TOMSK

21ST INTERNATIONAL CONFERENCE

SMMIB2019

SURFACE MODIFICATION OF MATERIALS BY ION BEAMS

21ST INTERNATIONAL CONFERENCE ON SURFACE MODIFICATION OF MATERIALS BY ION BEAMS

smmib.ru

25-30 August | 2019

TOMSK, RUSSIA

ELSEVIER

TOMSK POLYTECHNIC UNIVERSITY

25 YEARS RFBR

SMMIB-2019

21st International Conference on Surface Modification of Materials by Ion Beams
25-30 August 2019
Tomsk, Russia

Abstract Book

Welcome to SMMIB-2019 and to Tomsk

Dear colleagues,

It is our great pleasure and honor to extend a warm welcome to you to the 21st International Conference on Surface Modification of Materials by Ion Beams (SMMIB-2019).

Hosted by Tomsk Polytechnic University (TPU), SMMIB-2019 aims to achieve the primary goal of exchanging ideas, sharing new knowledge and future trends of ion beam technologies. SMMIB-2019 is held in order to provide a fundamental ground for a great number of scholars, experts and researchers within the industry around the world and to share the quality findings of the participants for gaining great insights and further information for their future research and careers. This year our conference is held in the Russian city of Tomsk, which is the oldest large scientific, educational and innovation center in Siberia. We hope that you will have a chance to convey the excellence of Science, Research and Technology Development in Russia and to enjoy the fascinating culture of the country.

This year's conference will focus on six topics that highlight ion beam processing of materials; ion-assisted coating deposition; mechanisms, theory and fundamentals of these processes; as well as new accelerator systems and tools; biomedical and industrial applications; and defect engineering, nano-science and technology. The number of submitted abstracts was about one hundred and eighty from over twenty countries. The conference program covers more than one hundred posters and seventy oral presentations in two parallel tracks, including four magnificent plenary talks and nineteen invited talks by worldwide-recognized scientists.

For their assistance in preparing for this conference over the last year, we would like to express our true appreciation to each of the SMMIB-2019 Committee members who provided continuous support and endorsement in organizing this conference. We believe each participant in the conference will be able to enjoy the results of this work.

We do hope the technical and social programs will assist you in gaining new friendships and great insights into your research work in the future. We wish you to enjoy the conference and experience a very pleasant stay in the beautiful city of Tomsk.

Warm regards,
SMMIB-2019 Conference Chairs:
Wolfgang Ensinger, Daryush Ila, and Gennady Remnev

Contents

Conference Chairperson....4
International Scientific Committee....4
International Program Committee....5
Organizer....6
Local Organizing Committee....6
Local Program Committee....6
Reminder to Conference Participants....7
Manuscripts....10
Acknowledgments....10
Map....11
SMMIB-2017. Memorable moments....12
Plenary Talks....13
Session 1: Ion Beam Processing of Materials....19
Session 1: Ion Beam Processing of Materials. Invited Talks....21
Session 1: Ion Beam Processing of Materials. Oral Presentation....26
Session 1: Ion Beam Processing of Materials. Poster Session....42
Session 2: Ion-Assisted Coating Deposition....83
Session 2: Ion-Assisted Coating Deposition. Invited Talks....85
Session 2: Ion-Assisted Coating Deposition. Oral Presentation....89
Session 2: Ion-Assisted Coating Deposition. Poster Session....100
Session 3: Basic Mechanisms, Theory and Fundamental....111
Session 3: Basic Mechanisms, Theory and Fundamental. Invited Talks....113
Session 3: Basic Mechanisms, Theory and Fundamental. Oral Presentation....115
Session 3: Basic Mechanisms, Theory and Fundamental. Poster Session....121
Session 4: Defect Engineering, Nano-Science and Technology....133
Session 4: Defect Engineering, Nano-Science and Technology. Invited Talks....135
Session 4: Defect Engineering, Nano-Science and Technology. Oral Presentation....138
Session 4: Defect Engineering, Nano-Science and Technology. Poster Session....143
Session 5: New Accelerator Systems and Tools for Materials Research....161
Session 5: New Accelerator Systems and Tools for Materials Research. Invited Talks....163
Session 5: New Accelerator Systems and Tools for Materials Research. Oral Presentation....165
Session 5: New Accelerator Systems and Tools for Materials Research. Poster Session....167
Session 6: Biomedical and Industrial Applications....173
Session 6: Biomedical and Industrial Applications. Invited Talks....175
Session 6: Biomedical and Industrial Applications. Oral Presentation....178
Session 6: Biomedical and Industrial Applications. Poster Session....186
Author Index....191

Conference Chairperson

Gennady Remnev (Russia)

Wolfgang Ensinger (Germany)

Daryush Ila (USA)

International Scientific Committee

Wolfgang Ensinger (Germany)
Daryush Ila (USA)
Koumei Baba (Japan)
Graham K. Hubler (USA)
Giovanni Marletta (Italy)
Cecilia Salvadori (Brasil)
Inigo Braceras (Spain)
Tomohiro Kobayashi (Japan)
Dushyant C. Kothari (India)
Nathalie Moncoffre (France)
Gennady Remnev (Russia)
Luc Pichon (France)
Christen A. Straede (Denmark)
Xiubo Tian (China)
Ronghua Wei (USA)
Bernd Rauschenbach (Germany)
Zbigniew Werner (Poland)

International Program Committee

Gennady Remnev (Russia)

Eduardo Alves (Portugal)

Katharina Lorenz (Portugal)

Paulo Fichtner (Brasil)

Takaaki Aoki (Japan)

Marcela Bilek (Australia)

John Baglin (USA)

Paul K. Chu (Hong Kong, China)

Wolfgang Ensinger (Germany)

Daryush Ila (USA)

Dushyant C. Kothari (India)

Giovanni Marletta (Italy)

Kai Nordlund (Finland)

Hiroshi Tsuji (Japan)

Jeroen Anton van Kan (Singapore)

Roger Webb (UK)

Yugang Wang (China)

Organizer

National Research Tomsk Polytechnic University (TPU)

Local Organizing Committee

Gennady Remnev, Chair (TPU)

Mikhail Yuzhakov, Secretary (TPU)

Olga Lapteva (TPU)

Lilia Kiryanova (TPU)

Alexandra Baranova (TPU)

Valery Krivobokov (TPU)

Sergey Pavlov (TPU)

Mikhail Slobodyan (TPU)

Local Program Committee

Vladislav Tarbokov (TPU)

Efim Oks (TUSUR)

Alexander Ryabchikov (TPU)

Sergey Zenkin (TPU)

Vladimir Uglov (BSU)

George Yushkov (HCEI)

Yuri Sharkeev (ISPMS SB RAS)

Alexander Potekaev (SPhTI, TSU)

Irina Kurzina (TSU)

Alexander Ligachev (GPI RAS)

Igor Stepanov (TPU)

Reminder to Conference Participants

- Registration at the Conference

The conference registration desk will be located in the hall on the first floor of Congress Center Rubin. All attendees must wear their name bage at all times to gain admission to all sessions, lunches and receptions.

- Oral

Acceptable presentation format is MS PowerPoint (2003).

Time for presentation (including 5 minutes for discussion):

Plenary: 45 minutes

Invited: 30 minutes

Oral: 20 minutes

An unload desk will be available in the registered location and venue on to manage and transfer presentation files to the specific presentation room. Speakers should go to the upload desk to upload the files at least half a day before the presentation starts.

- Poster

Presenting authors are required to be available for discussion about their work during the designated poster sessions. Each poster session is scheduled for 1.5 hour.

A poster board will be assigned to each poster presentation. A unique reference number is used to identify each contribution. Participants can find the reference numbers for their own contributions in the final Scientific Conference Program. The reference number will then be used for identifying the poster board on which the referred poster will be displayed.

All posters are required to conform to Portrait Orientation. Failure to follow this requirement will mean that the poster will not fit on the allotted board. Poster Board is made for A0 format sheet. If printing on a single page, use size A0 PORTRAIT ORIENTATION (0.84 x 1.19 m). It is better to use single sheet of A0 format. The organization will provide boards with special snap clips for your poster.

- Awards

In order to recognize the outstanding contributions made by young researchers on ion beams, SMMIB continues to sponsor the «SMMIB Young Researcher Award». The award committee of the conference representatives will consider scientific contributions in the form of poster presentations and oral presentations presented in the course of the conference.

The winners will receive a Certificate and a Cash Prize and will be awarded at the Closing Ceremony!

Eligibility: The nominee for this award must not have reached his/her 35th birthday and should be the presenter of his/her work at the conference.

Evaluation Process: The award committee of academic and industrial representatives will consider scientific contributions in the form of poster presentations and oral presentations presented in the course of the conference.

- Official Welcome, Lunch and Banquet

Official Welcome will take place in CC Rubin from 18:00 to 20:00 on 25 August 2019.

Lunches on the days of the conference will be held in two places:

1. Lunch A. CC Rubin (16 Akademicheskiy ave.);

2. Lunch B. Cafe «Scientist House» (5 Akademicheskiy ave.).

The location of your lunch will be indicated on your badge. Attendees must provide the cupon included in the conference kit.

The *Conference Banquet* will be held in the Da Vinchi Hall (24 Kuleva st.) from 18:00 to 21:00 on 29 August 2019.

- Transport

During the conference, there will be shuttle buses between hotels and venue. In case you miss the buses, you may take a taxi and show a business card with the address of the conference venue (CC Rubin) to your taxi driver. The business card is included in the conference kit.

- Language

The official language of the conference is English.

- City Tour

The city tour of SMMIB will be arranged from 09:00-16:00 in the afternoon of August 30, 2019. The weather is +18±3 ^{0}C at the end of August in Tomsk. There is a possibility of light rain.

- Currency

The currency of Russia is ruble. The ruble was also a national currency in the USSR and the Russian Empire. The code in the standard ISO 4217 - RUB, digital - 643. One ruble consists of 100 kopecks. The ruble is the oldest national currency in the world after the British pound. In Russia, the ruble has been used since the 13th century.

Credit cards such as Visa and Master are accepted at most establishments. You will find it very convenient with certain amount of Russian currency in hand if you would like to eat out or do other things in the Tomsk city. No currency exchange service will be provided at the conference.

- Insurance

The organizing committee will not be responsible for medical expenses, accidents, losses or other unexpected occurrences. Participants are advised to arrange their own insurance that they regard necessary.

- Emergency Phone Numbers

RESCUE SERVICE - 01, 101 (from a cell phone)

POLICE - 02, 102 (from a cell phone)

EMERGENCY ASSISTANCE - 03, 103 (from a cell phone)

Manuscripts

Peer-reviewed manuscripts will be published as a Special Issue of the Journal Surface and Coatings Technology. Submission of a manuscript implies that it represents original work not previously published and not considered for publication elsewhere.

Manuscripts would be uploaded in the Elsevier's Editorial System (EES) by the authors starting from September 20, 2019. The deadline for all manuscripts to be submitted to EES is November 18, 2019. All papers should be submitted before this date and the option to submit online via the submission system EES will be closed.

Late manuscripts will be considered as regular manuscripts for inclusion in a regular issue with an acknowledgement of the work of the Guest Editors.

Accepted manuscripts will be published no earlier than June 20, 2020.

On-line submission via (EES) at http://www.ees.elsevier.com/surfcoat/ is required (see Guide for Authors).

Acknowledgments

The Organizing Committee would like to express its sincere appreciation to the following organizations for their support in the International Conference on Surface Modification of Materials by Ion Beams (SMMIB-2019).

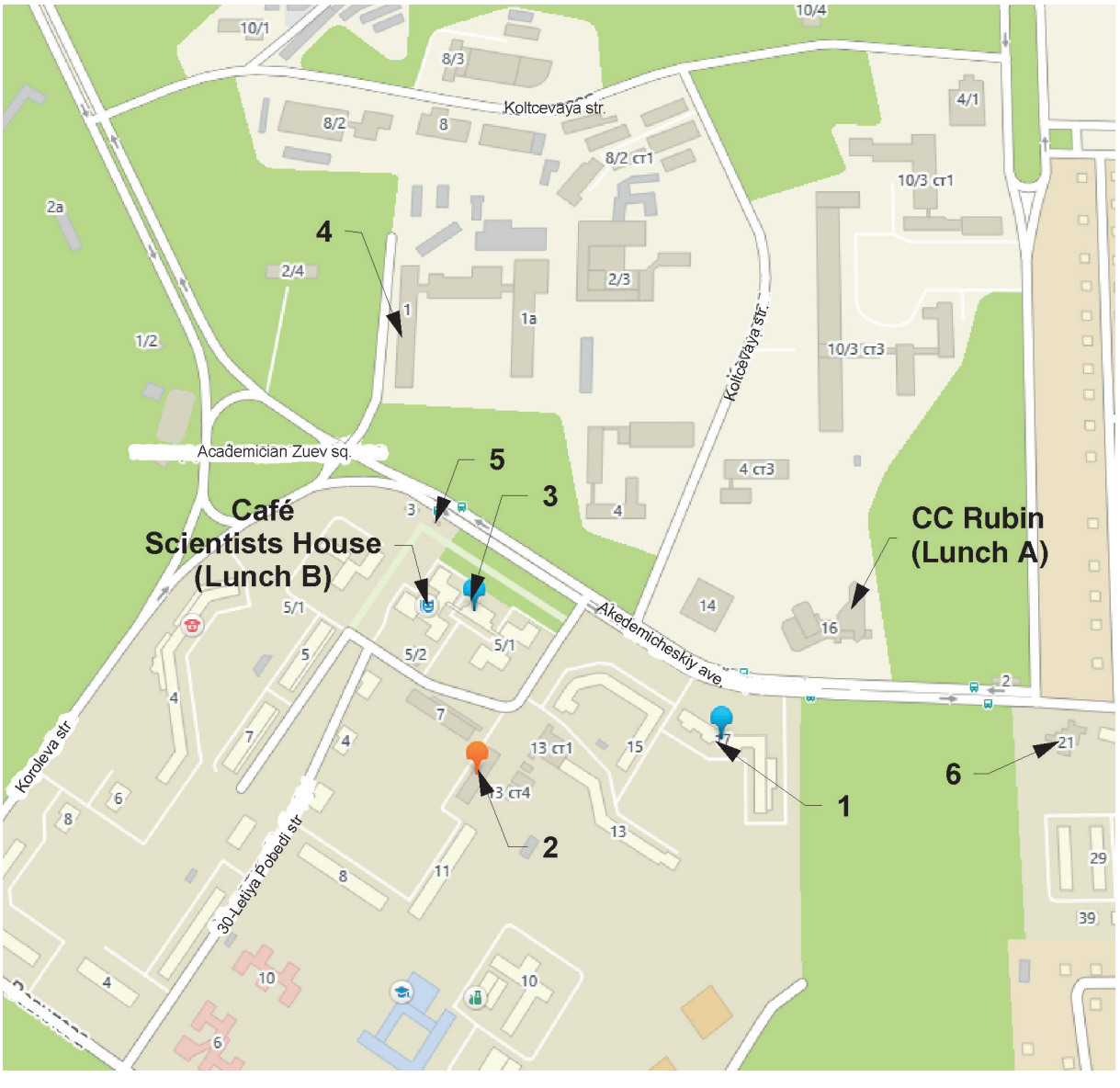
ELSEVIER

TOMSK POLYTECHNIC UNIVERSITY

25 YEARS RFBR

The conference was held with the financial support of the Russian Foundation for Basic Research, project No. 19-08-20114.

Map



1 - Sberbank (bank, ATM, currency exchange) – 17, Akademicheskiy ave.

2 - Pochtabank (bank, ATM) – 9, Akademicheskiy avenu

3 - Gazprombank (bank, ATM, currency exchange) – 5/1, Akademicheskiy ave.

4 - Gazprombank (ATM) – 1, Academician Zuev square

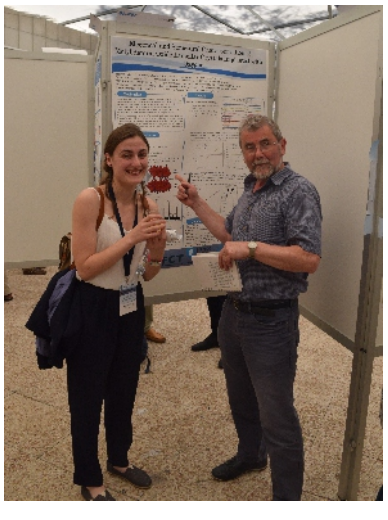
5 - Sberbank (ATM) – 3a, Akademicheskiy avenu, 24 hours

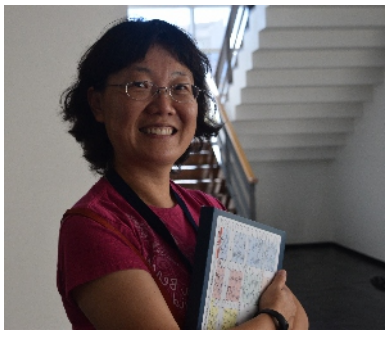
6 - Venskiy Dvor, restaurant – 21, Akademicheskiy ave.

CC Rubin (Lunch A) – 16, Akademicheskiy ave.

Cafe Scientist House, Dom Uchenih (Lunch B) – 5, Akademicheskiy ave.

20th INTERNATIONAL CONFERENCE ON SURFACE MODIFICATION OF MATERIALS BY ION BEAMS
Lisbon, 09-14 July 2017





SMMIB-2019

21ST INTERNATIONAL CONFERENCE
ON SURFACE MODIFICATION OF MATERIALS BY ION BEAMS
25-30 August 2019
Tomsk, Russia

Plenary Talks

Plenary Sessions

PL001
Interaction of Gas Cluster Ions with Solids: Experiment and Computer Simulations

Vladimir Chernysh[1]
A.E. Ieshkin[1], D.S. Kireev[1], A.V. Nazarov[2], A.D. Zavegilsky[1]

[1]Faculty of Physics, Lomonosov Moscow State University, Moscow, Russia
[2]Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia

Email: chernysh@phys.msu.ru

In recent years, the scope of application of gas cluster ion beams in various fields of science and technology has been actively expanding. The development of new technologies is inextricably connected with the study of the processes accompanying the irradiation of the solid surfaces by accelerated cluster ions.

Experimental study of the angular distributions of material sputtered under irradiation of various targets with cluster ions will be presented. The experiments were carried out using the first Russian accelerator of cluster ions [1]. Polycrystalline Cu, Mo etc. targets were irradiated with Ar and Xe cluster ions with energy of 10 keV. The mass composition of the cluster ion beam was controlled with time-of-flight (ToF) mass spectrometry. The surface topography of bombarded samples was studied using atomic force microscopy. A collector technique was used to measure the angular distributions of sputtered material. The analysis of the collectors was performed using Rutherford backscattering spectrometry (RBS).

Experiments have shown that for a number of targets the maximum yield of sputtered particles is observed along the surface normal, in contrast to the previously published results of other authors.

Computer simulations of spatial distributions of sputtered material were performed to understand the features revealed in the experiments. The molecular dynamics (MD) simulations of collisions of 10 keV clusters with the sizes from 50 to 1500 atoms per cluster with Cu (100) and Mo (100) single-crystalline targets at the temperature of 300 K were performed. The incident clusters were directed along the normal to the target surface. The simulations were performed with PARCAS code [2]. The research is carried out using the equipment of the shared research facilities of HPC computing resources at Lomonosov Moscow State University.

The experimental results and computer simulations reveal the mechanisms of the sputtered flux formation under cluster ion bombardment of the surface.

References
[1] A.A. Andreev, V.S. Chernysh,Yu.A. Ermakov and A.E. Ieshkin, Vaccum, 91(2013) 47.
[2] M. Ghaly, K. Nordlund, R.S. Averback, Phil. Mag. A, 79(1999)795.

PL002
Low Energy Heavy Ion Accelerator Facilities in IMP for Material Radiation Research

Liangting Sun
H.W. Zhao, J.Y. Li, Y. Yang, L. Lu, Y.H. Zhai, X.B. Xu, L.B. Shi, L.P. Sun, L. Jing, Y.H. Guo, J.Q. Li, Z.M. Zhang, Y. He

Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 730000, China

Email: sunlt@impcas.ac.cn

Material radiation research needs ion beams with the energies covering a wide range. For medium energy ion beams, users can apply to get the ion beams from the large scale facilities, such as SFC cyclotron that can cover the beam energies of several MeV/u to tens of MeV/u. For researches that need heavy ion beams of tens of keV/u up to hundred keV/u, it is usually hard to have wanted ion beams. Therefore, multi-discipline platforms and accelerator facilities have been developed at IMP, i.e. a 320 kV high voltage multi-discipline platform and a Low Energy high intensity heavy ion Accelerator Facility (LEAF). The 320 kV platform has been in operation since 2007 delivering ion beams of H~U for multi-discipline research activities with the ion beam energies from several keV/q to 320 keV/q. The recently developed LEAF facility is capable of providing the users with either CW or pulsed ion beams of He~U with the energies of several tens of keV up to 100 MeV. The typical features of LEAF are the high beam intensities in the range of emA, very high ion charge state, and a kind of so-called cock-tailed mixed ion beam, which will be a very powerful tool in material radiation researches. This talk will give a general introduction of IMP facilities, a status report on the 320 kV platform and its operation, and the development of LEAF facility.

PL003
Plasma Physics of Sputtering Magnetrons

Andre Anders

Leibniz Institute of Surface Engineering (IOM), Leipzig, Germany

Email: andre.anders@iom-leipzig.de

Sputtering is a mature deposition technology widely used since the 1970s due to the invention, improvement, and scaling of sputtering magnetrons. These devices utilize a closed drift of electrons in crossed electric and magnetic fields, thereby enhancing the probability of ionizing collisions at low process pressure. The basic operation, whether in continuous (dc), pulsed, radiofrequency (rf,) or high power impulse (HiPIMS) operation, is generally well understood although one finds «anomalous» transport of electrons across the magnetic field. Over the last years, it has become clear that the nature of this «anomalous» transport is related to a rich physics based on plasma instabilities [1-3]. They facilitate a disruption of the closed electron drift. There is now convincing evidence that plasma instabilities are also related to an important electron heating mechanism beyond the usual Thornton paradigm based on secondary hot electrons. Recent theoretical [4], spectroscopic [5], and probe data [6] prove that most of the electrons' energy comes from the presheath, and is provided by localized electric fields concentrated at the edge of «ionization zones» or «spokes» [7, 8]. This is closely related to self-organization and turbulence as visualized in interesting images of magnetron plasmas.

Most experimental work reported here was done at Lawrence Berkeley National Laboratory, Berkeley, CA, in collaboration with Yuchen Yang, Matjaz Panjan, and others, whose contributions are gratefully acknowledged.

References

[1] A. Kozyrev, N. Sochugov, K. Oskomov, A. Zakharov, A. Odivanova, Plasma Physics Reports 37 (2011) 621.
[2] A.P. Ehiasarian, A. Hecimovic, T. de los Arcos, R. New, V. Schulz-von der Gathen, M. Boke, J. Winter, Appl. Phys. Lett. 100 (2012) 114101.
[3] A. Anders, P. Ni, A. Rauch, J. Appl. Phys. 111 (2012) 053304.
[4] C. Huo, D. Lundin, M.A. Raadu, A. Anders, J.T. Gudmundsson, N. Brenning, Plasma Sources Sci. Technol. 22 (2013) 045005.
[5] J. Andersson, P. Ni, A. Anders, Appl. Phys. Lett. 103 (2013) 054104.
[6] M. Panjan, A. Anders, J. Appl. Phys. 121 (2017) 063302.
[7] A. Anders, Appl. Phys. Lett. 105 (2014) 244104.
[8] A. Anders, Y. Yang, J. Appl. Phys. 123 (2018) 043302.

PL004
Advanced Hard Nanocoatings Deposited by Magnetron Sputtering: Role of Energy

Jindrich Musil[1,2]

[1]Department of Physics and NTIS – European Centre of Excellence, University of West Bohemia, Univerzitni 22, CZ – 306 14 Plzen, Czech Republic
[2]Institute of Physics v.v.i., Academy of Sciences of the Czech Republic, Na Slovance 2, Praha 8, CZ – 18221, Czech Republic

Email: musil@kfy.zcu.cz

The lecture reports on magnetron sputtering of advanced hard nanocoating and is divided in three parts. The first part briefly reports on the enhanced hardness of nanocomposite coatings, the formation of the X-ray amorphous coatings with thermal stability and oxidation resistance above 1000 deg C and flexible hard coatings [1,2]. Reported results can be used in the development of the flexible ceramic coatings, the surface strengthening of brittle materials, the prevention of (i) cracking of the functional coatings and (ii) the cracks formation on the surface of bended materials. The second part is devoted to the energy vs. property relations in sputtered coating. It is shown that a key role in formation of the flexible hard coatings plays the energy delivered into growing coating by bombarding ions and fast neutrals. In part 3 two sputtering processes are described in detail (1) the low-temperature sputtering of coatings at low sputtering pressures p and (2) the new sputtering sputtering technology based on three strongly non-equilibrium processes at atomic level: (1) extremely fast heating of coating material to high temperatures up to its melting with low substrate heating, (2) high pressures ($\geq$1000 GPa) used in formation of coating from melted material and (3) extremely fast cooling ($\geq 10^{10}$ K/s) of created coating material. The principle of this technology is explained. The utilization of this technology for creation of advanced coatings with new unique properties is demonstrated in sputtering of the following coatings: (1) alloy coatings with high-temperature beta-phase sputtered at low substrate temperature T close to RT [3], (2) overstoichiometric nitrides which exhibit high hardness [4,5], and (3) superhard flexible Ti coatings with high hardness (up to 20 GPa) several times higher than that of the bulk Ti metal. Special attention is devoted also to the formation heterostructural coatings composed of elements or compounds with different crystal structure [3].

References
[1] J. Musil, Hard nanocomposite coatings: Thermal stabislity, oxidation resistance and toughness, Surf. Coat. Technol. 207 (2012), 50-65.
[2] J. Musil, Flexible hard nanocomposite coatings, RSC Advances 5 (2015), 60482-60496.
[3] J. Musil, S. Kos *et al*. Beta-(Me1, Me2) and MeNx films deposited by magnetron sputtering: Novel heterostructural alloy and compounds films, Surf. Coat. Technol. 337 (2018), 75-81.
[4] J. Musil, M. Jaros, S. Kos *et al*. Hard TiN2 dinitride films prepared by magnetron sputtering, J. Vac. Sci. Technol. A. 36 (2018) 040602.
[5] J. Musil, S. Kos *et al*. Coating of overstoichiometric transition metal nitrides (TMN_x ($x > 1$)) by magnetron sputtering, Jpn. J. Appl. Phys. 58 (2019) SAAD10.

SMMIB-2019

21ST INTERNATIONAL CONFERENCE
ON SURFACE MODIFICATION OF MATERIALS BY ION BEAMS
25-30 August 2019
Tomsk, Russia

Session 1
Ion Beam Processing of Materials

Invited Talk

I 1-1

Ion-Beam Modification of Si and SiO_2/Si Structures for the Development of Light-Emitting Silicon-Based Devices

David Tetelbaum[1]
Dmitriy Korolev[1,2], Alena Nikolskaya[1,2], Alexey Mikhaylov[1], Alexey Belov[1], Michael Marychev[2], Anton Konakov[2], Yuri Chigirinsky[1], Artem Sushkov[1,2], Dmitriy Pavlov[2], Alexey Tereshchenko[3], Vladimir Pavlenkov[4] and Sergey Nagornyh[5]

[1]Research Institute of Physics and Technology, Lobachevsky University, Nizhny Novgorod 603950, Russia
[2]Department of Physics, Lobachevsky University, Nizhny Novgorod 603950, Russia
[3]Institute of Solid State Physics, Russian Academy of Sciences, Chernogolovka 142432, Moscow region, Russia
[4]Faculty of Physics and Mathematics, Arzamas Branch of Lobachevsky University, Arzamas 607220, Nizhny Novgorod Region, Russia
[5]Institute of Radio Electronics and Information Technology, R.E. Alekseev State Technical University, Nizhny Novgorod 603950, Russia

Email: tetelbaum@phys.unn.ru

Key words: silicon, light-emitting structures, ion implantation, ion synthesis

The development of light-emitting silicon-based devices is a key challenge of modern electronics due to the exhaustion of opportunities for increasing the speed of ICs by scaling. The breakthrough in this area is associated with the transition to optoelectronic ICs. Herewith, it is very desirable to preserve silicon as the base material. For this aim, it is required to improve the light-emission efficiency of this indirect semiconductor.

One of the ways for the solution of this problem is the employment of light-emission property of silicon dislocations, namely the D1 line ($\lambda \approx 1.5$ μm) of dislocation luminescence (DL) [1], with simultaneously improving its temperature dependence. We have established that the decrease in temperature quenching of D1 line in the structures obtained by Si^+ implantation into Si can be achieved by additional implantation of boron ions with subsequent annealing at 800 °C for some fluence range. The model of this improvement is suggested and proved by calculations. Another way investigated by us is the irradiation of SiO_2/Si structure by Kr^+ ions with subsequent annealing. It is shown that, for certain conditions, the inclusions of hexagonal silicon phase 9R-Si are formed in silicon substrate at the SiO_2/Si interface, and the photoluminescence at $\lambda = 1242$ nm is observed which persists after etching off the implanted SiO_2 layer. The energy of emitted photons is very close to the ab initio calculated energy gap of 9R-Si [2].

Thus, the ion-beam technique can be used for the fabrication of silicon-based light-emitting devices after the optimization of ion implantation regimes.

The work was partially supported by Russian Ministry of Science and Higher Education (State Assignment #16.2737.2017/4.6) and RFBR (Grant #8-32-20168-mol_a_ved).

References

[1] Sobolev N.A, Semiconductors, 44(1), 1-23 (2010).
[2] Nikolskaya A.A., Korolev D.S., Mikhaylov A.N. *et al*., Appl. Phys. Lett., 113, 182103 (2018).

I 1-2
High-Power Pulsed Ion Accelerators and Their Practical Application

Gennady Remnev

National Research Tomsk Polytechnic University, 30 Lenin ave., Tomsk 634050, Russia

Email: remnev06@mail.ru

The report is devoted to the work of National Research Tomsk Polytechnic University in the field of development of high-power pulsed ion accelerators focused on practical use, as well as work on the modification of materials by high intensity pulsed ion beams. A distinctive feature of the accelerators under development is the use of a dense plasma in the diode formed by an additional nanosecond high-voltage pulse. In this case, the accelerator includes special designs of dual pulse generators. Two types of focusing magnetically insulated diodes with a Br magnetic field and with magnetic self-isolation for direct ion acceleration are used. The report presents the results of studies on the use of such beams for the modification of metal products and coatings formed by plants based on magnetron-sputtering systems. In this case, the ion beam density can provide three modes: short-pulse implantation - without changing the surface morphology, treatment with surface melting and rapid quenching of the surface layer, and the ablation plasma formation mode. The report also discusses work on the generation of high-energy light ion beams based on a modified scheme of the Luce diode. In this case, a group of ions is formed with a wide energy spectrum of ions: from energy corresponding to the applied voltage to energy which is several times higher than this value. In conclusion, we give a brief analysis of the directions of practical use of pulsed ion beams based on changes in the properties of the surface layer of materials.

I 1-3
Modifications of WNO_x Films by keV D and H Ions

Noriaki Matsunami[i1]
N. Ohno[1], M. Tokitani[2], B. Tsuchiya[3], M. Sataka[4]

[1]School of Engineering, Nagoya University, Nagoya 464-8603, Japan
[2]National Institute for Fusion Science, Toki 509-5292, Japan
[3]Faculty of Science and Technology, Meijo University, Nagoya 468-8502, Japan
[4]Japan Atomic Energy Agency (JAEA), Tokai 319-1195, Japan

Email: n-matsunami@nucl.nagoya-u.ac.jp

Key words: WNO_x polycrystalline film, low energy D and H ion, disordering of crystalline structure

We have investigated modifications of WNO_x films by D or H ions with energy of ~1 keV, where D and H ions are retained within the film and compared with those by high energy (~1 MeV/u) ions [1], where all ions are transmitted through the film. WNO_x films were prepared on C-plane-cut-sapphire (C-Al_2O_3) substrate. The composition x is determined to be ~0.4 and the film thickness ~50 nm by Rutherford backscattering spectroscopy (RBS) of He^+ ions. X-ray (Cu- K_α radiation) diffraction angle (2θ) $\approx 37^o$ and $\approx 78^o$ are observed and assigned as hexagonal-WN, and no peaks are observed other than WN and C-Al_2O_3 ($2\theta=41.7^o$). Similarly to the results of high energy ions, we find monotonic decrease of the XRD intensity with D ion fluence, and lattice expansion and compaction for low and high D fluence, respectively. Also, we have measured depth profile of D and H, using D(^{3}He, α)H nuclear reaction analysis (NRA), elastic recoil detection (ERD) and H(^{15}N, γ)O-NRA, resulting in H density (concentration ratio, H/W ~ 0.2) in as deposited film and nearly uniform distribution (D/W ~1) at saturation exposure of D. Considering these results, it will be discussed whether effects of energy deposition by ions can be separated from inclusion effects of D and H. Measurement of electrical resistivity modification is under way.

References
[1] N. Matsunami *et al*., Surf. Coat. Tech. 355(2018)84.

I 1-4

About Low Temperature Nitriding Mechanism of FCC-Nickel-Based Alloys by Plasma Immersion

Luc Pichon
J.B. Dubois, F. Larek, J. Cormier, M. Drouet

Institut P', UPR 3346 CNRS, Université de Poitiers, ISAE-ENSMA, France

Email: Luc.Pichon@univ-poitiers.fr

Based on the demonstrated interest of moderate (<450°C) temperature nitriding of several FCC alloys (like stainless steels or Co-based alloys) to improve wear or fatigue resistance [1–4], nitriding by plasma assisted gaseous diffusion or by plasma based ion implantation was investigated on Nickel based superalloys, especially for their applications at the lowest temperatures. Like in austenitic stainless steels, the fcc solid solution γ matrix was shown to incorporate a high content of nitrogen (up to 30 at.%), leading to the expanded nitrided γ_N phase or to a Ni_4N-like phase. However, these phases are metastable and decompose easily in nitrides compounds (CrN) even at moderate temperature. As shown by accurate TEM investigations, the nitrided material is constituted of nanometric and (semi)coherent γ_N, CrN and a third fcc phase resulting from the decomposition of γ_N. Controlling such decomposition of the γ_N phase was investigated versus the Cr content in the alloys (in Ni-Cr «model» alloys) and with various nitriding conditions.

In advanced Nickel-based superalloys, the γ matrix is usually strengthened by γ' ($L1_2$ structure, $Ni_3(Al,Ti,Ta)$ and/or γ'' (DO_{22} structure, Ni_3Nb) precipitates presenting a multimodal sizes dispersion. Interestingly the nitriding behavior of these precipitates is significantly varying from one alloy to the other: some are nitrided like the surrounding γ_N phase whereas others γ' incorporate almost no nitrogen. By choosing appropriate superalloys (MC2, René N4, Udimet 720Li, MarM200, bulk Ni_3Al…) including γ' precipitates with various characteristics (size, composition, γ'/γ coherency, rafting…), it was possible to determine the effective parameters controlling an efficient γ' nitriding [5–7]. Additional TEM and EDX-STEM investigations on nitrided γ' enable to identify the produced phases and to propose the mechanism of nitrogen incorporation in γ' in conjunction with the short range diffusion of metallic elements.

References

[1] L. Pichon, S. Okur, O. Ozturk, J.P. Riviere, M. Drouet, Surf. Coat. Technol. 204 (2010) 2913–2918.
[2] F. Noli, L. Pichon, O. Öztürk, Metall. Mater. Trans. A 49 (2018) 1383–1396.
[3] J.C. Stinville, C. Templier, P. Villechaise, L. Pichon, J. Mater. Sci. 46 (2011) 5503–5511.
[4] J.-C. Stinville, Thèse de Doctorat, Ecole nationale supérieure de mécanique et d'aérotechnique, 2010.
[5] L. Pichon, J. Cormier, A. Declemy, S. Chollet, P. Villechaise, J.B. Dubois, C. Templier, J. Mater. Sci. 48 (2013) 1585–1592.
[6] S. Chollet, L. Pichon, J. Cormier, J.B. Dubois, P. Villechaise, M. Drouet, A. Declemy, C. Templier, Surf. Coat. Technol. 235 (2013) 318–325.
[7] L. Pichon, J.-B. Dubois, S. Chollet, F. Larek, J. Cormier, C. Templier, J. Alloys Compd. (2018).

I 1-5

Progress in High Intensity, Low Ion Energy Implantation Method Development

Alexander Ryabchikov

National Research Tomsk Polytechnic University, 30 Lenin ave., Tomsk 634050, Russia

Email: ralex@tpu.ru

The report presents new results on the development of equipment and method of high-intensity implantation of metal ions, gases, and semiconductors of low energy providing a long-range effect of dopants penetration. The results of research and development of plasma-immersion systems for the ion beam formation with a current density of tens and hundreds of mA/cm^2, beam current exceeding 1 A with kilovolt accelerating voltages using different ion extraction and beam ballistic focusing systems are shown. A comparative analysis of various systems, their advantages, and disadvantages depending on the purpose are presented. The results of experimental studies of high-intensity implantation of aluminum, titanium and nitrogen ions into various structural materials are shown. The possibility of ion doping of materials at depths of several tens and hundreds of micrometers after 1 h of super high fluence ion implantation is demonstrated. Data on changes in the elemental composition, microstructure, and properties of various materials depending on the ion current density in the range from 10 to 500 mA/cm^2, ion energy, temperature implantation regime and irradiation fluence in the range from 10^{18} to 10^{22} ion/cm^2 are presented. Based on the obtained experimental data analysis and the numerical simulation results the directions of further studies within the framework of the development of the physical and technological fundamentals of high-intensity implantation method of low-energy metal, semiconductor and gas ions are discussed.

Oral Presentation

O 1-1

Surface Property Modification of Biocompatible Polymer Materials by Ion Implantation and Electron Beam Treatment

Irina Kurzina[1]
I.V. Vasenina*[,2], M.C. Salvadori[3], E.M. Oks[2], K.P. Savkin[2]

[1]StrAU Institute of Smart Materials and Technologies, Tomsk State University, Tomsk 634045, Russia
[2]Laboratory of Plasma Sources, Institute of High Current Electronics SB RAS, Tomsk 634055, Russia
[3]Institute of Physics, University of Sao Paulo, Sao Paulo 05508-090, Brazil

Email: ivpuhova@mail.ru*

Key words: biocompatible polymers, ion implantation, electron beam treatment, elemental compound, wettability, mechanical properties, degree of crystallinity

Surface is the interface between the substance and the environment; therefore, surface properties of solids usually differ from bulk ones and largely determine the functional characteristics of materials for use in various production areas. The aim of this work is to identify behavior of structural-phase state and surface physic-mechanical properties of polylactic acid (PLA), polyvinyl alcohol (PVA), polytetrafluoroethylene (PTFE) modified with silver, carbon, argon ion beams and electrons. Implantations were carried out using Mevva-5.Ru ion source [1] to exposure doses of 1×10^{14}, 1×10^{15} and 1×10^{16} ions/cm^2 at accelerating voltage of 20 kV. Electron beam irradiation was performed using a repetitively-pulsed, forevacuum-pressure, plasma-cathode electron beam source based [2] with a series of 10 pulses with pulse duration 100÷300 μs at accelerating voltage of 8 kV.

Under the ion and electron beam treatment conditions radiation-chemical processes occur, including the destruction of polymer macromolecules accompanied by the formation of free radicals; cross-linking of macromolecules; release of gaseous products (CO, CO_2, H_2); the formation of metallic nanoparticles. Metal nanoparticles with an average size up to 10 nm are formed in the subsurface layer of the polymers when silver ions are implanted. Surface energy is increased due to the oxidation processes of polymer materials, increasing the concentration of adsorption centers, structural defects and nanoscale inclusions of implanted atoms. The degree of crystallinity decrease of PLA and PVA surface layers after ion and electron beam treatment leads to decrease in microhardness and modulus of elasticity of the materials. The degree of crystallinity increase PTFE under the treatment conditions leads to improve its surface mechanical properties. The effect of long-range interaction in polymers under the conditions of surface treatment is due to changes in the structural phase state and physic-mechanical characteristics at depth of the surface layer (1200 ÷ 1900 nm) exceeding the magnitude of the projected run of ions (30 ÷ 100 nm) and electrons (315 ÷ 860 nm).

This work was supported by the Tomsk State University Competitiveness Improvement Program under Grant.

References

[1] Nikolaev A.G, Oks E.M., Savkin K.P. *et al*., Review of Scientific Instruments, 83, 02A501 (2012).
[2] Kazakov A.V., Burdovicin V.A., Medovnik A.V. *et. al*., Instruments and Experimental Techniques, 6, 50-53, (2013).

O 1-2

Investigation of the Nanomechanical Properties of Ion-Irradiated Ferritic-Martensitic Steels with Different Chemical Compositions Using Nanoindentation

Melanie Clozel[1]
L. Kurpaska[1], I. Jozwik[1,2], J. Jagielski[1,2], M. Turek[3], E. Wyszkowska[1]

[1]National Centre for Nuclear Research, st. A. Soltana 7, Otwock – Swierk 05-400, Poland
[2]Institute of Electronic Materials Technology, st. Wolczynska 133, Warsaw 01-919, Poland
[3]Institute of Physics, Maria Curie-Sklodowska University, pl. M. Curie-Sklodowsiej 1, Lublin 20-031, Poland

Email: melanie.clozel@ncbj.gov.pl

Faced with climate change, human societies need to turn to sustainable energy sources to provide for their needs. Though they have been in use for several decades, there is a constant drive to increase the efficiency of nuclear power plants leading to the developing of Generation IV fission as well as fusion reactors [1]. Ferritic-Martensitic steels are among prime candidates to make up structural parts of these new reactors [2]. In this study, nanomechanical investigations were conducted on 4 different materials (Fe-Cr steels: low activation Fe-9Cr-1WVTa (Eurofer97), Fe-9Cr (G385), Fe-9Cr-NiSiP (G389); model-iron: Fe (G379)) which were self-implanted at low energy (300 keV) with Fe ions at different temperatures (room-temperature, 300°C, 450°C). The irradiation campaign was performed with up to $3.1x10^{15}$ ions/cm^2 fluences, which resulted in damage levels from 0.1 to 10 dpa. After implantation, the samples were indented with a diamond Berkovitch tip at room-temperature with loads ranging from 0.05 to 50 mN to obtain depth profiles. The obtained results display varying softening and hardening effects depending on damage level and implantation temperature, which can be correlated with: dislocation loop type distribution, alpha' precipitates, Cr-content and the presence of other compositional elements. Obtained results were critically compared with the available data from the literature. Due to the surface preparation procedure, combined with shallow irradiation depth, surface effects like roughness and residual stress from mechanical polishing, were taken into account.

The work reported herein falls within the scope of the project entitled «Multiscale modelling for fusion and fission materials» (M4F), currently funded by H2020 programme, and is meant to help evaluate the microstructure evolution and plastic flow localisation due to alloying elements, thermal effects, and irradiation effects [3].

This project has received funding from the European research and training programme 2014 - 2018 under grant agreement #755039.

References

[1] S.J. Zinkle, G.S. Was, Acta Mater. 61 (2013) 735.
[2] C. Heintze, F. Bergner, S. Akhmadaliev, E. Alstadt, J. Nucl. Mater. 472 (2016) 196.
[3] http://www.h2020-m4f.eu.

O 1-3

The Structural Thermal Stability of the $Fe_{80}Si_7B_{13}$ Alloys Under the Irradiation of High-Intensity Pulsed Ion Beam

Xiaonan Zhang[1]
Tong Guan[1], Xianxiu Mei[1], Younian Wang[1], Gennady Remnev[2], Sergey Pavlov[2]

[1]Key Laboratory of Materials Modification by Laser, Ion and Electron Beams, Dalian University of Technology, Ministry of Education, Dalian 116024, China
[2]National Research Tomsk Polytechnic University, Tomsk 634050, Russia

Email: 15042445092@163.com

High-intensity pulsed ion beam (HIPIB) can simulate the thermal irradiation in the fusion irradiation environment due to its transient high thermal load. Fe-based amorphous alloys with high initial crystallization temperature have good resistance to ion irradiation. The atoms in the sub-surface layer of amorphous alloy $Fe_{80}Si_7B_{13}$ irradiated by HIPIB are arranged orderly, but the amorphous structure is still maintained. After 300 times of pulse irradiation, a large number of circular holes and a few convex spots appeared on the surface. After irradiation, the surface reflectance of amorphous alloy decreased slightly. Compared with metal W, the amorphous alloy $Fe_{80}Si_7B_{13}$ has better irradiation resistance due to its long-term disordered structure and large free volume. However, in order to further exclude the influence of elements on material properties, we studied and compared the irradiation resistance of amorphous and crystal $Fe_{80}Si_7B_{13}$ alloys of the same composition under different current densities and pulse times. After irradiation, Fe-based amorphous alloy retained amorphous as the main structure. Irradiation caused disordered rearrangement of atoms near the surface of the crystal alloy, and the crystallinity of crystal alloy decreased. HIPIB irradiation did not introduce significant irradiation damage to the surfaces of the two alloys. After irradiation, the roughness of $Fe_{80}Si_7B_{13}$ alloys increased, resulting in a slight decrease in the surface reflectivity of the two alloys. The decrease of reflectivity of the amorphous alloy was slightly smaller than that of crystal alloy. Fe-based amorphous alloy has better thermal irradiation resistance and structural thermal stability.

This work is financially supported by the National Science Foundation of China #11675035, #1181101276 and #11375037.

O 1-4

Structure and Optical Properties of ZnO-SiO_2 Nanocomposite Synthesized by High-Fluence Implantation and Subsequent Annealing

Jerzy Zuk[2]
Fadei Komarov[1], Maksim Makhavikou[1], Oleg Milchanin[1], Ludmila Vlasukova[3], Irina Parkhomenko[3], Elke Wendler[4]

[1]A.N.Sevchenko Institute of Applied Physics Problems, Minsk, Belarus
[2]Maria Curie-Skłodowska University, Lublin, Poland
[3]Belarusian State University, Minsk, Belarus
[4]Friedrich-Schiller University Jena, Jena, Germany

Email: jotzet@hektor.umcs.lublin.pl

In the present work, the high-fluence ion implantation of Zn ions in SiO_2/Si with subsequent annealing at 750°C in the air ambient during 120 min was performed. The temperatures of implantation were 25 and 500°C. The combination of elemental analysis (RBS), structural (TEM, XTEM, SAD) and optical (PL) techniques have been used to identify the phases formed and to correlate the optical behaviour of the ZnO-SiO_2 nanocomposite.

The dependence of elemental composition of system (SiO_2/Si:Zn↓) on the implantation and annealing regimes has been investigated. Analysis of TEM and XTEM images showed that the use of «hot» and room temperature implantation leads to the formation of small nanoclusters of size from 5 to 10 nm at the depth from 20 to 180 nm. Annealing of the implanted samples results in increase of nanocluster sizes (up to 35 nm) and creation of multilayer structure. The presence of the concentric rings on the electron diffraction patterns confirms the crystal nature of ZnO nanoclusters. It was shown, that the PL spectra are composed of two bands in blue (400-520 nm) and red-green (520-700 nm) spectral range before and after annealing. Besides, the relative intensity of PL bands depends on the implantation and annealing regimes. The nature of blue band can be explained by edge emission and the wide of red-green band emission can be explained by recombination at deep level defects.

O 1-5

Positron Annihilation Studies of Ultra-Fine Grain Ti Irradiated with 167 MeV Xe^{26+} Heavy Ions

Krzysztof Siemek[1,2]
V.A. Skuratov[2,3,4]

[1]Institute of Nuclear Physics, PAS, Krakow 31-342, Poland
[2]Joint Institute for Nuclear Research, Dubna 141980, Russia
[3]National Research Nuclear University MEPhI, Kashirskoye sh., 31, Moscow 115409, Russia
[4]Dubna State University, Universitetskaya st., 19, Dubna 141980, Moscow region, Russia

Email: siemek.krzysztof@gmail.com

Grain size refinement is proposed as a solution for enhanced radiation tolerance in materials under extreme irradiation conditions. Nanocrystalline (NC) and ultra-fine grain (UFG) metals with a relatively large volume of grain boundaries are expected to be more radiation resistant than conventional metals. During irradiation, point defects are produced as a result of displacement cascade. These defects can then cluster to form other types of defects that will alter the mechanical properties of irradiated materials. Formation of voids are the main cause of material failure under irradiation environment. High angle grain boundaries, twin boundaries, phase boundaries and free surfaces can effectively absorb the radiation-induced defect clusters. This can lead to a decrease in defect density and suppress hardening, swelling, embrittlement and creep. Many studies have confirmed the enhanced radiation resistance of nanosize grain metals and alloys [1,2,3].

One of the most promising method allowing to get knowledge about the type and defect concentration produced during irradiation is Positron Annihilation Spectroscopy (PAS). In current studies PAS techniques were applied to investigate of the influence of grain size refinement on radiation damages in pure Titanium. UFG surfaces were prepared through sandblasting and further annealing in 200 ^{o}C. Ti samples were then irradiated with 167 MeV Xe^{26+} ions with doses 10^{12}, 10^{13} and 10^{14} cm^{-2}. Two methods, i.e. energy variable positron beam and positron lifetime spectroscopy were employed. The reduction of defect concentration after grain refinement was noted.

References

[1] O. El-Atwani, J.A. Hinks, G. Greaves, J.P. Allain, S.A. Maloy, Materials Research Letters (2017) DOI: 10.1080/21663831.2017.1292326.
[2] A.R. Kilmametov, D.V. Gunderov, R.Z. Valiev, A.G. Balogh, H. Hahn, Scripta Materialia 59 (2008) 1027.
[3] G.M. Cheng, W.Z. Xu, Y.Q.Wang, A. Misra, Y.T. Zhu, Scripta Materialia 123 (2016) 90.

O 1-6

Modification of Graphene Oxide Films with Swift Heavy Ions: Changes in the Electrical and Structural Properties

Andrzej Olejniczak[1,2]
Aleksei V. Frolov[3], Željko Mravik[4], Nadezhda A. Nebogatikova[5], Mirosław Kulik[1,6], Ruslan Rymzhanov[1], Zoran Jovanović[4], Vladimir A. Skuratov[1]

[1]Joint Institute for Nuclear Research, Joliot-Curie 6, Dubna, 141980, Russia
[2]Faculty of Chemistry, Nicolaus Copernicus University, ul.Gagarina 7, Toruń 87-100, Poland
[3]Kotel'nikov Institute of Radio Engineering and Electronics RAS, Mokhovaya 11-7, Moscow 125009, Russia
[4]Laboratory of Physics, Vinča Institute of Nuclear Sciences, P.O. Box 522, Belgrade 11001, Serbia
[5]Rzhanov Institute of Semiconductor Physics, SB RAS, Lavrent'ev av. 13, Novosibirsk 630090, Russia
[6]Institute of Physics, Maria Curie-Sklodowska University, pl. M. Curie Skłodowskiej 1, Lublin 20-031, Poland

Email: aolejnic@chem.umk.pl

Key words: graphene oxide, reduced graphene oxide, swift heavy ions, quantum dots

Precise engineering of conductive and insulating regions in graphene oxide (GO) plays an important role in the fabrication of graphene-based structures and nanodevices. In this study, we intended to use swift heavy ion (SHI) irradiation to create nanometer-sized defunctionalized spots in GO thin films [1]. Such structures can be considered graphene quantum dots (QDs) embedded in a non-conducting GO matrix.

The virgin and SHI-irradiated specimens were characterized by atomic force microscopy (AFM), X-ray photoelectron spectroscopy, and infrared spectroscopy. The electrical properties of the films were investigated by current-voltage, capacitance-voltage, and temperature-dependent resistance measurements.

AFM images shown that the diameter of the created nanohillocks increased with increasing electronic stopping power. Ions with different energies led to a similar extent of GO defunctionalization with respect to the deposited electronic energy density. With increasing ion fluence the resistance of the samples decreased nonlinearly, and, at high fluences, was two orders of magnitude lower than that of the virgin GO. Temperature dependent resistance measurements point out that the conduction mechanism involves a combination of a thermally activated process and Efros-Shklarskii variable range hopping (ES-VRH). ES-VRH model highlights the localization of wavefunctions inside recovered graphene domains [2] and thus suits the expected QD nature of the fabricated structures. Capacitance-voltage characteristics of vertical metal-GO-semiconductor structures showed a large hysteresis (memory window) when a gate voltage was swept between the inversion and accumulation regions. This suggests the presence of charge trapping centers in the irradiated films.

O 1-7
Picosecond Surface Kinetics of Swift Heavy Ion Irradiated Insulators

Ruslan Rymzhanov[1,2,3]
J.H. O'Connell[4], A. Janse van Vuuren[4], V.A. Skuratov[1,5,6], N.A. Medvedev[7,8], A.E. Volkov[1,9,10]

[1]Joint Institute for Nuclear Research, Joliot-Curie st., 6, Dubna 141980, Moscow Region, Russia
[2]The Institute of Nuclear Physics, Ibragimov st., 1, Almaty 050032, Kazakhstan
[3]L.N. Gumilyov Eurasian National University, Satpayev st., 2, Nur-Sultan 010008, Kazakhstan
[4]Nelson Mandela Metropolitan University, University way, Summerstrand, Port Elizabeth 6001, South Africa
[5]National Research Nuclear University MEPhI, Kashirskoye sh., 31, Moscow 115409, Russia
[6]Dubna State University, Universitetskay 19, Dubna 141980, Moscow Region, Russia
[7]Institute of Physics, Czech Academy of Sciences, Na Slovance 2, 182 21 Prague 8, Czech Republic
[8]Institute of Plasma Physics, Czech Academy of Sciences, Za Slovankou 3, 182 00 Prague 8, Czech Republic
[9]National Research Centre 'Kurchatov Institute', Kurchatov sq., 1, Moscow 123182, Russia
[10]P.N. Lebedev Physical Institute of the Russian Academy of Sciences, Leninskij pr., 53, Moscow 119991, Russia

Email: rymzhanov@jinr.ru

We studied surface damage formation in four insulating materials: MgO, CaF_2, LiF and $Y_3Al_5O_{12}$ (YAG) irradiated with swift heavy ions (SHI, Xe 167 MeV, Bi 700 MeV, Au 200 MeV). Monte Carlo code TREKIS [1] was used to describe excitation of the electronic system and energy transfer into the lattice, followed by classical molecular dynamics (MD) simulations of lattice atoms motion [2,3]. The obtained results were compared with the TEM data on irradiated materials.

The simulations and experiments demonstrated noticeable differences in surface damages in these materials. The modeling revealed that the size and structure of SHI tracks, including hillock formation on the surface, are strongly affected by recrystallization of the initially disordered area.

Recrystallization in MgO almost completely recovers transient damage in the near surface region, forming a crystalline hillock, which is confirmed by TEM. The hillock morphology and formation kinetics in CaF_2 are similar to MgO, but production of a large hillock (~7 nm) requires formation of cavity-like structures in the under-surface region. TEM also shows a conical structure of the track at depth ~25 nm, but the hillock structure is crystalline in contrast to the results of modeling. YAG demonstrated almost no recovery of the transient disorder, forming a completely amorphous hillock and a track of a cylindrical shape, with an effect of surface pronounced only at depth down to 3 nm.

We also have considered sputtering yields from these targets due to ionizing radiation. It was demonstrated that the amorphizable dielectric has much lower sputtering yield than non-amorphizable ones. This difference is attributed to formation of nanojets from the surface of CaF_2 and MgO and possible emission of nano-sized clusters.

References
[1] N.A. Medvedev *et al*. J. Phys. D. 48 (2015) 355303.
[2] R. Rymzhanov *et al*. J. Phys. D. 50 (2017) 475301.
[3] R.A. Rymzhanov *et al*. Sci. Rep. 9 (2019) 3837.

O 1-8

Investigations of Elemental Depth Distribution and Chemical Compositions in the Multilayer Structures of $TiO_2/SiO_2/Si$ After Ion Irradiation

Tran Van Phuc[1,2]
M. Kulik[2,3] , D. Kolodynska[4], A. P. Kobzev[2], L.H. Khiem[1], J. Zuk[3], A. Drozdziel[2]

[1]Institute of Physics, 10 Dao Tan, Ba Dinh, Ha Noi, Viet Nam
[2]Frank Laboratory of Neutron Physics, Joint Institute for Nuclear Research, Dubna 141980, Russia
[3]Institute of Physics, Maria Curie-Skłodowska University, pl. M. Curie-Skłodowskiej 1, Lublin 20-031, Poland
[4]Chemical Department, Maria Curie-Skłodowska University, pl. M. Curie-Skłodowskiej 2, Lublin 20-031, Poland

Email: tvphuc@iop.vast.ac.vn

Key words: Rutherford backscattering spectrometry (RBS), X-ray photoelectron spectroscopy (XPS), multilayer structures

In this study we investigated depth distributions of elements in the multilayer structures of $TiO_2/SiO_2/Si$ before and after ion irradiation. There were two groups of studied samples of similar structures of $TiO_2/SiO_2/Si$, the thickness of TiO_2 and SiO_2 layers of the samples in the second group was smaller than that in the first group. Each group included 4 subgroups of samples implanted with four different noble ions Ne^+, Ar^+, Kr^+ and Xe^+. There were four samples in each subgroup that were irradiated by the same type of ion with different energy 100, 150, 200 and 250 keV. For each implantation, the fluency of the incident ion beam was the same 3×10^6 (ions/cm^2), the beams were perpendicular to the surface normal of samples. The ion implantation process was performed on the UNIMAS ion implanter being at the disposal of Maria Curie-Skłodowska University [1]. The depth distribution of the elements in the samples before and after irradiation was investigated using the RBS method [2]. The RBS experiments were carried out on the EG-5 accelerator at the Frank Laboratory of Neutron Physics, in JINR [3]. The He^+ ion beam with the energy 1.5 MeV was used. The beam was directed to the samples under the incident angle $\alpha = 60^o$ towards the normal of the sample surface. The RBS spectra were collected at the scattering angle = 170^o. The energy resolution of spectrometric measurements was 15 keV. The elemental composition, their content and depth distribution were calculated using the SIMNRA code [4]. In next step, the chemical composition of the near surface layers was investigated using XPS method [5]. The XPS spectra for all samples were registered in the energy range: 450 eV÷462 eV. This energy range was referred to the binding energy of Ti 2p electrons. After irradiation of $TiO_2/SiO_2/Si$ structures with the noble ions at different energies, it was founded that thickness of the TiO_2 and SiO_2 layers decreased while that of transition layers increased with the growing energy and atomic mass of the implanted ions. The similar situation was observed for the structures with different thicknesses, however, it was noticed that the degree changing thickness of the thin layers was greater than that of thick layers after irradiation process. In addition, under the influence of doping ions, the concentration of the Ti, TiO, Ti_2O_3 in the near surface layers were increased, accompanied by a decrease of TiO_2 concentration as a result of growing implanted ions energy.

References

[1] Chaves C., Regis R., Machado A., Souza R., 20, 127-131 (2009).
[2] Bragaglia L., Prates L., Calvo M., 20, 156-161 (2009).
[3] Nishigawa G., Maruo Y., Okamoto M. *et al*., 25, 75-80 (2006).

O 1-9

The Influence of Metal Surface Topography on Ablation Behavior During Intense Pulsed Ion Beam Irradiation

Xiaoyun Le[2,3,4]
Jie Zhang[1], Haowen Zhong[2,3,4], Jie Shen[1], Xiao Yu[2,5], Sha Yan[6], Gennady Remnev[2, 7]

[1]Nuclear and Radiation Safety Centre, Ministry of Ecology and Environment of China, Beijing 100082, China
[2]School of Physic and Nuclear Energy Engineering, Beihang University, Beijing 100191, China
[3]Beijing Advanced Innovation Center for Big Date-based Precision Medicine, Beihang University, Beijing 100191, China
[4]Beijing Key Laboratory of Advanced Nuclear Energy Materials and Physics, Beihang University, Beijing 100191, China
[5]School of Space and Environment, Beihang University, Beijing 100191, China
[6]Institute of Heavy Ion Physics, Peking University
[7]National Research Tomsk Polytechnic University, Tomsk 634050, Russia

Email: xyle@buaa.edu.cn

Key words: intense pulsed ion beam, ablation, surface topography, ablation mass

As a flash heat source, intense pulse ion beam (IPIB) has extensive applications in material surface modification. The ablation effect during IPIB irradiation on target can impact the results of material modification. Therefore, the understanding of ablation mechanism is of great significance for IPIB application. In this work, to investigate the mechanism of interaction between ablation behavior and surface morphology, pure zinc targets with different surface roughness were bombarded by IPIB of various energy densities at TEMP-4M accelerator. The ablation mass and the surface morphology after the irradiation were analyzed by the high precision balance and atomic force microscope. The experiments showed that the ablation mass increased with the surface roughness increasing. Combining Monte Carlo method and finite element method, a heat conduction model was constructed to describe the ablation process of zinc target with different surface roughness. The simulation results agreed with the experiments, and the mechanism of ablation influenced by the surface topography were proposed.

O 1-10
Damage Behaviour of Fe-Based Metallic Glass Under He and H Ions Irradiation

Xianxiu Me
Xiaonan Zhang, Tong Guan, Younian Wang

Key Laboratory of Materials Modification by Laser, Ion and Electron Beams, Dalian University of Technology, Ministry of Education, Dalian 116024, China

Email: xxmei@dlut.edu.cn

Due to the disordered structure, metallic glass are thought to be applied in the future fusion reactor irradiation environment. In this paper, the He ions with different energy and 250 keV H ions were used to irradiate the metallic glass $Fe_{80}Si_7B_{13}$ to investigated the evolution of the structural and superficial damage. Under 300 keV He ion irradiation, with the increase of the dose, nanocrystals appeared in the metallic glass in a sequence of that: β-Mn type phase→α-Fe phase and tetragonal Fe_2B phase→orthogonal Fe_3B phase, β-Mn type phase, α-Fe phase and tetragonal Fe_2B phase. And under the 2 MeV irradiation, a ordered arrangement of local atoms corresponding to the β-Mn type phase was firstly observed, which meant that in He ion irradiation with the energy range of hundreds keV to several MeV, the metastable β-Mn type crystallization phase would form firstly in Fe-based metallic glass. When the dose was up to 1.6×10^{18} ions/cm^2, cracks and spalling appear on the surfaces of the metallic glass caused by the bombardment of 300 keV He ions. while under the irradiation of He ions with low energy of 200 eV, a network of wavy fluctuation appeared on the surface of metallic glass when the dose upon 1×10^{21} ions/cm^2.The difference in surface damage was attributed to different mechanisms of ion energy loss. The viscous flow which caused the formation of fluctuation was more likely to form when nuclear energy loss accounts for a large proportion. Upon the successive irradiation of He and H ions irradiation, successive bombardment roughened the surface of the metallic glass, and the most interesting thing was we found that the subsequent H ion irradiation increased the number of bubbles while decreased the size, it indicated that main formation mechanism of bubbles transformed from merger of He atoms to migration and capture.

This work is financially supported by the National Science Foundation of China #11675035, #1181101276 and #11375037.

O 1-11
Critical Usage of Erbium for Radiation Shielding for Advanced Applications

Samit Kumar Mandal[1]
Akashrup Banerjee[1], Shyama Rath[1], G.R. Umapathy[2], Dinakar Kanjilal[2]

[1]Department of Physics and Astrophysics, University of Delhi, Delhi 110007, India
[2]Inter University Accelerator Center, Aruna Asaf Ali Marg, New Delhi 110067, India

Email: s.mandal.du@gmail.com

Key words: erbium, radiation hardness, ion beam bombardment

Research for development of an element that is stable and inert under the conditions of highly energetic and ionizing radiation bombardment is ongoing [1,2]. Towards this aim, the present work deals with a lanthanide element and tests its viability under aforementioned conditions. Highly pure and enriched films of the very rare ^{164}Er isotope were fabricated using the cold-rolling technique at the Target Laboratory of Inter University Accelerator Centre (IUAC- New Delhi, India). The raw material was obtained in the form of metal sheets from Oak Ridge National Laboratory (ORNL, USA), with an isotopic enrichment of 73.6%. Other components present in the sample included the more abundant isotopes of erbium ^{166}Er (14.97%), ^{167}Er (5.5%), ^{168}Er (4.42%) and ^{170}Er (1.51%). This quoted purity of the sample was verified using Rutherford Back-Scattering technique as well as by acquiring the elastic collision data for the ion-sample interaction using a silicon detector.

The 1 μm thick erbium film was irradiated with 180 MeV rapid-pulsed Silicon ion beam. The isotopic sample was fixed to a nickel alloy frame using silver paste to improve heat dissipation and loaded on a specially designed conductive holder. The holder arrangement was placed inside a chamber within which a constant circulation of pure helium gas at 1.5 Torr pressure was maintained. The 15 MV ion accelerator (tandem Pelletron) at IUAC was used for ion irradiation along with augmentation from a booster linear accelerator (LINAC, IUAC). ^{28}Si beam (with 11 electrons stripped away) was accelerated to 180 MeV voltage and a beam area of ~5×5 mm^2 on the sample was achieved.

Structural and compositional changes induced in the erbium film were studied using X-ray diffraction, Raman spectroscopy and Rutherford Backscattering Spectrometry. The morphology of the film before and after the irradiation was observed using Scanning Electron Microscopy. It has been observed that the erbium film remained stable with consistent physical properties after irradiation. Intra-matter defect mobility dynamics under radiation has been studied. The results obtained during this work indicate that erbium can be used as a suitable candidate for radiation shielding materials.

References

[1] M. Yue, J. Huang, W. Liu, D. Zhang, and J. Zhang, Structural and magnetic properties of bulk nanocrystalline Erbium metal, AIP Adv., Vol. 1, p. 022101, 2011.
[2] L.B. Bayu Aji, J.B. Wallace, L. Shao, and S.O. Kucheyev, Non-monotonic temperature dependence of radiation defect dynamics in silicon carbide, Sci. Rep., Vol. 6, p. 30931, Nov. 2016.

O 1-12
Ion Bombardment Effects on Polycarbonate

Sunmog Yeo
Maeng Jun Kim, Chan Young Lee, Won-Je Cho, Yong Seok Hwang, Chorong Kim

Korea Atomic Energy Research Institute, Korea Multi-purpose Accelerator Complex, Gyeongju 305-353, Korea

Email: sunmog@kaeri.re.com

Ion bombardment with energy of a few hundred keV can affect the properties of polycarbonate (PC), especially the surface properties. The surface properties examined by FT-IR show that the lighter ion mass causes the increase of C=O (1680÷1750 cm^{-1}) and C=C (1500÷1700 cm^{-1}) stretching vibration and the relative ratio of C-O-C peak near the wave number of 1200 cm^{-1} decreases with increasing dose and energy of H^+ ion. In addition, thermal gravimetric analysis (TGA) has been performed with flowing argon (Ar) gas for pristine PC and ion bombarded PC. We discuss the surface property changes based on these results.

O 1-13

Structural and Optical Properties of Si Hyperdoped with Teby Ion Implantation and Pulsed Laser Annealing

Elke Wendler[2]
I. Parkhomenko[1], N.S. Nechaev[1], L. Vlasukova[1], G.D. Ivlev[1], F. Komarov[3,4]

[1]Faculty of Radiophysics and Computer Technologies, Belarusian State University, Minsk, Belarus
[2]Institut für Festköperphysik, Friedrich-Schiller University Jena, Jena, Germany
[3]Laboratory of Elionics, A.N. Sevchenko Research Institute of Applied Physics Problems, Belarusian State University, Minsk, Belarus
[4]National University of Science and Technology MISIS, Moscow, Russia

Email: elke.wendler@uni-jena.de

During the last decade, hyperdoped Si has attracted special interest for its enhanced sub-band gap photoresponse. This property is of interest to fabricate Si-based optoelectronic devices operating in the infrared spectral range. In this report, Te-supersaturated silicon layers fabricated by ion implantation followed by pulsed laser annealing were studied. The p-Si (111) was implanted with Te ions (200 keV, 1×10^{16} cm^{-2}) at room temperature. Pulsed laser irradiation of the implanted layers was carried out by a ruby laser (λ = 694 nm, 70 ns). Pulse energy densities ranged at 1.5÷2.5 J/cm^2.

The impurity distribution and crystalline quality were studied by Rutherford backscattering spectroscopy (RBS). The substitutional fraction of Te atoms in the treated silicon layer was estimated by RBS-channelling method. Raman spectroscopy (RS) and electron microscopy revealed the peculiarities of restoration of crystal structure of the implanted layer via laser annealing. The optical absorption of the modified Si layers in the IR range (1000÷2500 nm) was estimated via transmission and reflectance spectra.

It is found that χ^{Si} (the ratio of the aligned to the random backscattering yields for Si atoms) decreases from 24% to 21% with increase of energy density in the laser pulse from 1.5 to 2.5 J/cm^2. Taking into account χ^{Si} for virgin Si wafer (<5%), this indicates a partial re-crystallization after laser treatment. It was proven by RS that laser annealing results in structural restoration. RS revealed an inhomogeneous residual stress distribution in the laser annealed layers. Based on the RBS data, the ratio of substitutional Te atoms at the Si lattice sites to the total amount of embedded Te atoms decreases from 91% to 74% with increase of energy density in the laser pulse from 1.5 to 2.5 J/cm^2. Laser treatment results in an increase of IR absorption up to 30÷60%. The role of dopant activation and degree of recrystallization is discussed.

O 1-14

Crater Evolution on Surface Morphology of Metallic Material Under Intense Pulsed Ion Beam Irradiation

Yu Xiao[1]
Shijian Zhang[1], Haowen Zhong[1], Xiaojun Cui[1], Guoying Liang[1], Mofei Xu[1], Nan Zhang[1], Shicheng Kuang[1], Jianhui Ren[1], Sha Yan[2], Xiaoyun Le[1,*]

[1]School of Physics, Beihang University, Beijing 100191, China
[2]Institute of Heavy Ion Physics, Peking University, Beijing 100871, China

Email: xyle@buaa.edu.cn*

IAs widely observed in previous studies, the surface morphology of metallic materials may exhibit significant change after irradiation of intense pulsed ion beams (IPIB), surface defects such as micro craters may also occur. These effects are crucial for surface treating applications and may limit the application of IPIB in some cases. In present work, taking stainless steel as an example, the evolution in microstructure near the surface region was studied. Combine with the observation of the evolution of single crater, a model of surface morphology change is proposed. The local uneven distribution of thermal resistivity formed by grain boundary may lead to local evaporation and crater is thus formed with a rise in surface roughness under irradiation of initial pulses. As grain refinement or metallic glass state may be formed after irradiation of succeeding pulses, the local evaporation by grain boundaries may be weaken and the surface is smoothened by the hydro effects of the molten surface.

O 1-15

Surface Modification of ZrO_2-$3Y_2O_3$ Ceramics with Continuous Ar^+ Ion Beams

Valeria Kostenko[1]
Sergei Ghyngazov[1], Vladimir Ovchinnikov[2], Natalya Gushchina[2], Fedor Makhinko[2]

[1]National Research Tomsk Polytechnic University, Tomsk, Russia
[2]Institute of Electrophysics UB RAS, Yekaterinburg, Russia

Email: kostenkova@tpu.ru

Key words: ZrO_2-$3Y_2O_3$ ceramics, continuous ion beams, argon ions, hardness, phase analysis

Currently, studies are underway to study the impact of intense ion beams on ceramic structures. Such an impact can provide the formation of the necessary gradient ceramic structures, strengthen instruments and modify the surface of ceramic bioimplants, which greatly expands the field of application of ceramic materials. In this connection, research aimed at studying the physical nature of the ion modification of ceramic materials are relevant. The purpose of this work was to research the effects of modification of partially stabilized zirconia ceramics under the impact with a continuous beam of argon ions with an energy of 30 keV.

Ultradisperse powder ZrO_2-$3Y_2O_3$, obtained by plasma chemistry, was used for the ceramic samples manufacture. The ceramics treatment was carried with a continuous beam of Ar^+ ions The current density was 300 and 500 μA/cm^2 in the ceramics irradiation area. The fluence varied in the range of 10^{16}÷10^{18} cm^{-2}.

According to the data of scanning electron microscopy, ion processing leads to the visualization of the granular structure of ceramics, and at an ion current density of 300 μA/cm^2 and a fluence of 2.4×10^{16} or 1.1×10^{17} cm^{-2}, the visualization occurs mainly in places with the greatest accumulation of pores. X-ray phase analysis showed that ion treatment changes the phase composition of the ceramics surface layers, namely, the monoclinic phase m-ZrO_2 appears, and its amount does not exceed 12%. Nano- and microindentation showed that there is a change in the mechanical properties of the near-surface layers of irradiated ceramics in comparison with the initial state. At an ion current density of 300 μA/cm^2 and a fluence of 1.1×10^{17} and 5×10^{17} cm^{-2}, the maximum increase in microhardness and nanohardness (by 14%) and modulus of elasticity by 20% is observed. It has been established that the ion treatment of ceramics with above used regimes leads to the modification of the surface of ceramics without melting, cracking and erosion processes characteristic of radiation processing with high-intensity ion beams.

O 1-16

Swift Heavy Ion Beam Induced Modifications in Structural, Optical, Chemical and Morphological Properties of SnO_2-TiO_2 Nanocomposite Thin Films

Vikas Kumar[1]
Vishnu Chauhan[1], P.K. Kuleriya[2], Rajesh Kumar[1]

[1]University School of Basic and Applied Sciences, Guru Gobind Singh Indraprastha University, New Delhi 110078, India
[2]Inter University Accelerator Center, New Delhi 110067, India

Email: kumarrrpi@gmail.com

Key words: SHI, thin films, AFM, SEM, XRD, UV-Vis, PL, Raman, RBS

Swift heavy ion beam induced dense electronic excitation in the solid material has unique way to introduce various modifications such as generate controlled defects, atomic transport and phase transformation etc. Ion passes through the target material cause the nuclear energy losses (S_n) and electronic energy losses (S_e). In this case S_e dominates over S_n. In this communication, we report the results, influence of 150 MeV Fe^{11+} ion beam modifications in structural, optical, chemical and morphological properties and various potential applications of SnO_2-TiO_2 nanocomposite thin films. Therefore, this work is based on the modification in the properties of Tin oxide and Titanium dioxide nanocomposite thin films prepared by RF sputtering deposition technique in the mol% 50:50 on Si and ITO coated glass substrates. The prepared nanocomposite thin films annealed at 500 ºC and irradiated with SHI of 150 MeV Fe^{11+} ions beam with varied ion fluences ranging from 5×10^{12} to 5×10^{13} ions/cm^{-2}. SHI beam irradiation facility was used at Inter University Accelerator Center (IUAC), New Delhi, India. The SRIM simulation was observed the electronic energy loss (S_e) as 1.038×10^2 eV/nm, nuclear energy loss (S_n) as 1.33×10^{-1} eV/nm and the projected range of the iron ion was found to be 17.18 um. The influence of ion irradiation on surface morphology of nanocomposite thin films was analyzed by Atomic Force Microscope (AFM). The sectional analysis of AFM images reveals that the grain size depends on the ion irradiation fluences. The optical properties were examined by UV-Vis and Photoluminescence (PL) spectroscopy. The Tauc's method was used to determine the optical band gap of the samples. Structural analysis and crystallization of pristine and irradiated thin films was studied by X-ray diffraction (XRD) technique. Changes observed in the peak intensity confirm the significant variation in grain size which was calculated by the Debye Scherrer equation. Raman spectroscopy measurements confirm that the structure is slightly affected by iron ion irradiation. Raman spectroscopy was used to identify the crystal phases and chemical structure of pristine and irradiated nanocomposite thin film samples. Rutherford Backscattering Spectrometry (RBS) was done to ensure depth profiling, elemental composition and absence of impurities in Tin oxide and Titanium dioxide nanocomposite thin films. Detailed results will be discussed during the presentation.

References

[1] Vikas Kumar, Rajesh Kumar, Optical Materials 91 (2019) 455-469.
[2] M. K. Jaiswal, Rajesh Kumar, Journal of Alloys and Compounds, 648 (2015)550-558.

Poster Session

P 1-1
Microstructure of Titanium Alloy Modified by High-Intensity Implantation of Low- and Medium-Energy Aluminum Ions

Alexey Shevelev
A.I. Ryabchikov, D.O. Sivin, I.A. Bozhko, I.B. Stepanov

National Research Tomsk Polytechnic University, 30 Lenin ave., Tomsk 634050, Russia

Email: shevelevae@tpu.ru

This work is devoted to the investigation of microstructure, elemental and phase composition of surface and near-surface layers of titanium after aluminum implantation. As the target material, a titanium alloy with a chemical composition close to CP-Ti (grade 2) was used. Ion implantation was conducted in two different modes of irradiation: using repetitively-pulsed ion beams with the mean ion energy of 35 keV and low-energy focused ion beams of very high intensity (mean ion energy of 2.6 keV). The irradiation fluence reached 1.1×10^{18} ion/cm^2 in the first mode and 1.6×10^{21} ion/cm^2 in the second mode, respectively. In both cases, the beam itself heated the targets.

The peak concentration of aluminum after implantation of medium-energy ions was about 60 at.% and the maximum depth of dopant penetration were equal to 2 μm. Contrariwise, in case of high-intensity low-energy ion implantation, the surface concentration of dopant was up to 20 at.% but the depth of penetration increased significantly and achieved 50 μm.

The results of XRD and TEM have shown the possibility to obtain the formation of fine-grained intermetallic phases Ti_3Al and TiAl and the solid solutions of a various composition through the depth after medium-energy ion implantation. It was shown that the mean grain size of intermetallic in these conditions was about 50 nm. XRD and TEM analysis in the case of low-energy high-intensity ion implantation have demonstrated the formation of the ion-alloyed layer which consists both of intermetallic phase Ti_3Al and solid solutions of aluminum in titanium. The grain size of Ti_3Al phase can reach 5 μm and more.

P 1-2
Studies of the Electrical Properties of Ion Irradiation Polymer Materials

Anna Kosińska[1]
J. Jagielski[1,2], D. Bielinski[3], M. Okraska[3], L. Kurpaska[1]

[1]National Centre for Nuclear Research, Otwock 05-400, Poland
[2]Institute for Electronic Materials Technology, Warszawa 01-919, Poland
[3]Technical University of Lodz, Institute of Polymer & Dye Technology, Lodz 90-924, Poland

Email: anna.kosinska@ncbj.gov.pl

The long-term exposure of the cable insulation, which are very often manufactured from polymers in nuclear power plant (NPP), to the standard operational environment conditions such as radiation, heat and humidity, can cause ageing and degradation of their functional properties. One can expect that elongation, embrittlement and their cracking can occur [1]. Polymers exposed to such factors as ionizing and gamma radiation, undergo significant phase and structural changes [2]. In order to simulate NPP conditions, one can perform ion irradiation of the samples.

It is known that the main effect of radiation is the hydrogen release from polymer. This phenomena leads to increase of hardness, shrinkage of the material and deterioration of material resistance. Polymers exposed to ionizing radiation become fragile, prone to fracture and tearing. In the case of cable insulation, a significant problem is the decrease of their electrical resistivity appears [3]. This phenomena and hydrogen release have influence on the electrical and mechanical properties of these materials [4-5].

The aim of recent works of this group was to investigate the correlation between ion irradiation and resistivity of different type of polymer insulation. In this study, structural properties of pristine and irradiated polymer insulation were assessed by Scanning Electron Microscopy. Chemical structure was obtained by Fourier-transform infrared spectroscopy. In the final stage of work, electrical properties such as insulation resistance of the cables were performed. It has been found out this these properties are strongly related to the ion irradiation and structure of the material. Reported findings suggest that current-voltage (I-V) characteristics depend from ion irradiation dose – their gradual increase with increasing dose has been recorded.

References
[1] H.M. Hashemian, (2013) Materials Ageing and Degradation in Light Water Reactors, (Chapter 6).
[2] T. Seguchi, K. Tamura, T. Ohshima, A. Shimada, H. Kudoh, Radiation Phys. Chem. 80 (2011) 268-273
[3] R.L. Clough, Nucl. Instrum. Methods B 185 (2001) 8.
[4] J. Jagielski, D. Grambole, I. Jozwik, D.M. Bielinski, U. Ostaszewska, D. Pieczynska, Mater. Chem. Phys. 127 (2011) 342.
[5] J. Jagielski, U. Ostaszewska, D.M. Bielinski, D. Grambole, M. Romaniec, I. Jozwik, R. Kozinski, A. Kosinska, Nucl. Instrum. Methods B 371 (2016) 216.

P 1-3

Effect of Ion Irradiation on the Structure of Inconel Made by 3D Printing Method

Monica Duchna[1,2]
I. Cieślik[1], P. Warzybok[1], E. Wyszkowska[1], Ł. Kurpaska[1], R. Sitek[2]

[1]National Centre for Nuclear Research, A. Sołtana 7, Otwock 05-400, Poland
[2]Warsaw University of Technology, Wołoska 141, Warsaw 02-507, Poland

Email: monika.duchna@ncbj.gov.pl

Key words: ion irradiation, Inconel alloy, 3D printing, nanoindentation

Materials used in high temperature applications such as aviation or power engineering require high temperature and corrosion resistance. Additionally, elements made of such materials exploited in a nuclear power plants must also be resistant to fast spectrum of neutron flux. Nickel-based superalloys like Inconel are extensively used at high temperature applications due to their temperature stability and high mechanical properties [1,2]. However, long term harsh conditions (radiation, high temperature, corrosion) during the service can cause a risk of damage of elements made of Inconel alloy. Therefore, it is necessary to understand changes in a structure of Inconel under the impact of radiation and high temperature. Understanding this behaviour is critical to evaluate its reliability to work in such conditions.

The aim of this work was to investigate effect of ion irradiation on the structural defects and diffusion of elements during 3D printing in the manufacturing process of Inconel alloy. Additionally, we reported comparison results with Inconel alloy made by conventional method. In order to understand structural and mechanical changes caused by fast spectrum of neutron flux, Inconel alloy have been irradiated with 650 keV Ni ions. Ion irradiation process have been performed over a wide range of fluences from 2.5×10^{13} to 8.7×10^{14} cm^{-2} at room temperature, which corresponds to 0.1 to 3 dpa of the material damage. Transmission Electron Microscopy has been used to investigate concentration of defects in the material. Reported studies revealed the number of defects such as dislocation loops and vacancies randomly distributed over the matrix. In order to study mechanical changes such as hardness and Young Modulus nanoindentaion technique has been used. The performed studies revealed hardening effect as a function of irradiation dose. It has been proven that irradiation-induced hardening effect is related to irradiation defects, mainly dislocation loops and its size.

References

[1] T. M. Pollock, S. Tin Nickel-Based Superalloys for Advanced Turbine Engines: Chemistry, Microstructure, and Properties, Journal of Propulsion and Power, Vol. 22, No. 2, 2006, 361-374.
[2] S.J. Patel, J.J. deBarbadillo, B.A. Baker, R.D. Gollihue, Nickel Base Superalloys for Next Generation Coal Fired AUSC Power Plants, Procedia Engineering, Vol. 55, 2013, 246-252.

P 1-4

Influence of Ion Irradiation on the Nanomechanical and Structural Properties of Thin Alumina Coatings

Agata Zaborowska[1]
M. Vanazzi[2,3], F. di Fonzo[2,3], M. Clozel[1], E. Wyszkowska[1], L. Kurpaska[1]

[1]National Center for Nuclear Research, st. A. Soltana 7/23, Otwock-Swierk, Poland
[2]Center for Nano Science and Technology @PoliMi, Istituto Italiano di Tecnologia, Via Giovanni Pascoli 70/3, Milano 20133, Italy
[3]Dipartimento di Energia, Politecnico di Milano, Via Ponzio 34/3, Milano 20133, Italy

Email: agata.zaborowska@ncbj.gov.pl

In Generation IV fission reactors, structural components will be exposed to significantly higher operating temperatures and radiation doses than LWRs. In addition to that, materials used for construction elements will be in contact with corrosive non-aqueous coolants. The lack of reliable materials (particularly for core elements) capable of withstanding these extremely harsh conditions is considered to be a key bottleneck in development of advanced nuclear power systems. Therefore, new materials must be considered, developed and comprehensively examined. Furthermore, the examination process should be performed in the conditions simulating reactor environment i.e. high temperature and radiation damage.

Ceramics are seen as particularly promising class of materials due to their chemical inertness and radiation resistance [1]. However, since ceramics exhibit brittleness at low homologous temperatures [1], application of monolithic ceramics is rather limited. On the other hand, deposition of ceramic coatings on metallic substrate may result in obtaining an excellent combination of mechanical, corrosion and radiation properties (especially at high temperature) [1-4]. In this work, Al_2O_3 coatings deposited by PLD (Pulsed Laser Deposition) on 316L SS substrate at room temperature were tested. In order to simulate the influence of neutrons, alumina samples were irradiated at the room temperature with 250 keV Au^+. The damage levels reached within the material were in the range of 0.5÷50 dpa. The influence of ion irradiation on nanomechanical and structural properties of studied material were investigated by means of Nanoindentation (Ni), Scanning Electron Microscopy (SEM) and Transmission Electron Microscopy (TEM). On the basis of performed studies, nanomechanical properties in the function of radiation damage level were determined and linked to the results of structural data. Previously published data [1,5] suggest that irradiation induces crystallization of the amorphous phase which is followed by grain growth. This effect results in initial hardness increase, while grain growth induces softening of the material. It has been postulated that this effect is related to the twinning phenomena. Reported findings were critically compared with our results. Presented studies are performed as one of the topics of the GEMMA project, which is financed by H2020.

References

[1] F.G. Ferré *et al*., Radiation endurance in Al_2O_3 nanoceramics. Scientific Reports. 6 (2016).
[2] F.G. Ferré *et al*., Advanced Al_2O_3 coatings for high temperature operation of steels in heavy liquid metals: A preliminary study. Corrosion Science. 77, 375–378 (2013).
[3] F.G. Ferré *et al*., Corrosion and radiation resistant nanoceramic coatings for lead fast reactors. Corrosion Science. 124, 80–92 (2017).
[4] F.G. Ferré *et al*., The mechanical properties of a nanocrystalline Al_2O_3/a-Al_2O_3 composite coating measured by nanoindentation and Brillouin spectroscopy. Acta Materialia. 61, 2662–2670 (2013).
[5] F.G. Ferré *et al*., Extreme ion irradiation of oxide nanoceramics: Influence of the irradiation spectrum. Acta Materialia. 143, 156–165 (2018).

P 1-5

Interaction of Plasma Jets and Ion Beams of a Plasma Focus Device with the Surface of Chromium Steel

Boris Lemeshko[1]
D.I. Yurkov[1,2], Yu.V. Mikhailov[1,*], I.A. Prokuratov[1], A.K. Dulatov[1], N.V. Boiko[2], S.G. Rydakov[2], M.D. Saveliev[2]

[1]The Federal State Unitary Enterprise «All-Russia Research Institute of Automatics named after N.L. Dukhov»
[2]National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Moscow, Russia

Email: mikhjur@gmail.com*

A study was made of the effect of plasma jets and ion beams of deuterium plasma on the surface of 12% of EC-181 type chromium steel. Plasma jets and ion beams were created using a Mather type plasma focus chamber of a plasma focus device operating at stored energy of 1.5 kJ, the deuterium pressure in the plasma chamber is 7÷10 Torr, the current amplitude is ~ 230 kA. In the course of the experiments, samples of steel located perpendicular to the axis of the chamber at a distance of ~ 50 mm from the plasma focus were irradiated. The study of changes in the surface of the steel when exposed to a different number of pulses of deuterium plasma was carried out using X-ray diffraction, optical and electron microscopy, X-ray spectral analysis, thermal analysis and Mössbauer spectroscopy.

It is shown that plasma exposure leads to the formation on the steel surface of a layer of uneven thickness with a modified structural-phase state. The modified surface layer is characterized by a high degree of imperfection of the structure, the emergence and stabilization of the paramagnetic austenitic phase (gamma-iron), the redistribution of the concentrations of chemical elements along the depth of the layer.

P 1-6

Structural-Phase State of Copper Substrate Under Surface Treatment by Intense Flux of Ti and Zr Ions

Alexey Podanev[1]
Fedorischeva M.V.[1,2,*], Kalashnikov M.P.[1,2], Sergeev V.P.[1,2], Bozhko I.A.[1,2]

[1]National Research Tomsk Polytechnic University, 30 Lenin ave., Tomsk 634050, Russia
[2]Institute of Strength Physics and Materials Science, SB RAS, 2/4 Academicheskii ave., Tomsk 634055 Russia

Email: Fed_mv@mail.ru*

The present requirements to the technical characteristics of aerospace engineering of 5th generation make actual the problem of developing of new technologies of hardening of constructional materials urgent, in particular, materials on the basis of ionic-plasma methods of deposition of the multilayered nanocomposite coatings and high-energy processing of the surface layers, which allow modifying their structurally-phase condition.

Among these methods the ion-beam modification is a promising trend to improve the performance properties of structural materials. The structure-phase state of the surface layer can be effectively modified using a high-current flow of heavy ions of low energy. Tribological, mechanical properties, including, the fatigue characteristics of the constructional materials can improve in this case.

The results of the surface modification of the copper alloy by an intense flux of Ti and Zr ions with energy of 2 keV and an ion current density of 3.5 mA/cm^2 were studied. The structural-phase state of the ion-modified surface layer of the copper samples was investigated by X-ray, TEM and SEM. The microhardness was investigated by the nanoindentation method.

It was experimentally shown that the bombardment of copper samples with high-current (2-20 mA/cm^2) ion fluxes of Ti and Zr with an energy of 1÷3 keV followed by ion-magnetron deposition on the modified surface of Zr-YO/Si-Al-N coatings can lead to an increase in its thermocyclic resistance and adhesion, respectively, by ~ 3.6 and ~ 2.2 times, as well as to an increase in the microhardness of the surface layer of the substrate.

By TEM, SEM and X-ray we have revealed that a two-level micro- and nanoporous nanocrystalline structure is formed in the surface layer of a metal substrate due to ion etching, heating, and radiation-induced diffusion. At treatment by the Ti ions, one can see a mixture of three phases: fcc-Cu and intermetallic compounds Cu_3Ti and Cu_4Ti_3 with a characteristic size of elements of the intermetallic «mesh» framework 1÷4 microns. At treatment by the Zr ions, there are α-Zr and intermetallic compound $CuZr_2$, $Cu_{51}Zr_{14}$ with the size of elements of the intermetallic frame 0.1÷0.6 microns. The average grain size of the phases in the surface layer decreases to ~ 50-100 nm.

Work was supported in the scope of basic scientific research of the RAS for 2013-2020.

P 1-7

Pulsed Ion Beam Induced Changes in a Topography of the Surface Layers of Titanium

Alexander Ligachev[1]
M.V. Zhidkov[2], Y.R. Kolobov[2,3], G.V. Potemkin[4]

[1]A. M. Prokhorov General Physics Institute RAS, Moscow 119991, Russia
[2]Belgorod State National Research University, Belgorod 308015, Russia
[3]The Institute of Problems of Chemical Physics RAS, Chernogolovka 142432, Russia
[4]National Research Tomsk Polytechnic University, Tomsk 634050, Russia

Email: carbin@yandex.ru

Key words: pulsed ion beam, titanium alloy

Samples were subjected to pulsed ion beams impact on the ion pulsed accelerator. Irradiation was carried out by beam pulses containing 70% of carbon ions and 30% of hydrogen ions. The beam energy was 250 keV, the pulse duration was ~100 ns, and the current density in a pulse was 150÷200 A/cm^2. The energy density on the sample surface under the impact of a single pulse varied from 0.5 to 3.0 J/cm^2.

The surface topography was checked by a Quanta 200 3D scanning electron microscope with thermal emission and a Quanta 600 FEG with field emission.

Traces of the ion beam impact in the form of a topographical feature, mainly concentric, were observed. Recesses of a crater form with more or less clear circular structure appear on the surface with the increase in the energy density to 1 and 3 J/cm^2.

The average size of craters at the energy density of 1 and 3 J/cm^2 is ~20±2 and 25±2 μm, the density of craters (on irradiated surface) has made the order of 5×10^4 cm^{-2}. Features of generated which structure (a drop phase, formation of crosspieces) are formed testify to course of processes of melting and fast crystallization. At an irradiation of VT6 by 1 pulse of beam (density of energy 1 J/cm^2) on a surface of the sample forms microcraters with the average diameter about 2÷3 μm and depth 2÷3 μm too.

The work was supported by RFBR (project #14-08-00632).

P 1-8

Modification of Microstructure and Properties of Martensitic Stainless Steel by High-Intensity Implantation of Nitrogen Ions

Olga Korneva
A.I. Ryabchikov*, D.O. Sivin, I.A. Bozhko, T.M. Koval, A.I. Ivanova, I.B. Stepanov

National Research Tomsk Polytechnic University, 30 Lenin ave., Tomsk 634050, Russia

*Email**: *ralex@tpu.ru*

In this work we report a study of the chemical and phase composition, structural modifications and mechanical properties of martensitic stainless steel surface layers modified by high-intensity nitrogen ion implantation using high current beam of low-energy nitrogen ions. The effect of ultrahigh-dose implantation of nitrogen ions into steel using a high-intensity repetitively pulsed beam of nitrogen ions with a current of 0.6 A (at an ion energy of 1.2 keV) and a sample temperature of 500 °C is investigated. The fluence of ion irradiation in the range from 2.4×10^{20} to 4.5×10^{21} ion/cm^2 varied by changing the current density and implantation time. The studies performed using transmission electron microscopy and X-Ray diffraction analysis of the microstructure and phase composition of the implanted samples showed that the surface-doped layer formed up to 90 μm thick and contains ferrite, iron nitride Fe_4N, and chromium nitride CrN. The obtained values of the coherent scattering region size of the formed chromium nitride and iron nitride indicate a very high dispersion of the elements in the ion-doped layer substructure. The results of experimental studies and numerical simulation of the spatial distribution of alloying atoms are discussed. The data on changes in the surface morphology and microhardness of the near-surface layers are presented.

The work was supported by the Ministry of Education and Science of the Russian Federation within the state assignment «Science», grant #3.2415.2017/4.6, grant #3.7245.2017/6.7

P 1-9

Temperature Gradients in the Irradiated Targets During High-Intensity Implantation and Their Influence on Ion-Modified Layer Properties

Georgy Modebadze
A.I. Ryabchikov*, G.A. Bleykher, A.I. Ivanova, T.V. Koval, P.S. Ananin, A.E. Shevelev

National Research Tomsk Polytechnic University, 30 Lenin ave., Tomsk 634050, Russia

*Email**: *ralex@tpu.ru*

The work is devoted to the study of the dynamics of the temperature gradient formation over the depth and on the surface of metal targets during the implantation process of high-intensity gas and metal ion beams. Repetitively pulsed ion irradiation regimes with ion current density from several tens of mA/cm^2 up to A/cm^2 were studied. The power of the ion beam was varied by changing the ion energy in the range from 0.6 to several keV and the pulse duty factor in the range of 0.2÷0.8. The integrated temperature of biased target was measured by an electrically isolated thermocouple. To measure the dynamic change in the local temperature on the target surface during irradiation, a high-temperature pulse pyrometer KLEIBER 740-LO was used. The problem of temperature evolution and melting of a metal sample under the exposure of a high-intensity repetitively pulsed ion beam was solved by numerical method using the equation of thermal conductivity recorded in cylindrical coordinates. Experimental data and numerical simulation results have revealed the presence of significant temperature gradient both on the surface and over the depth of the targets. Analysis of experiments and numerical simulation results of the diffusion of gas and metal atoms into various metal targets revealed some key features of mass transfer in materials during the high-intensity implantation of low-energy ions.

P 1-10
Pattern Formation on Metallic Surfaces Induced by Plasma Immersion Ion Implantation

Lubomir Gabriš[1]
Juraj Halanda[1], Milan Mikula[2], Ján Híveš[2], Pavol Noga[1]

[1]Slovak University of Technology in Bratislava, Faculty of Materials Science and Technology in Trnava, Advanced Technologies Research Institute, J. Bottu 25, Trnava 917 24, Slovakia
[2]Slovak University of Technology in Bratislava, Faculty of Chemical and Food Technology, Radlinského 9, Bratislava 812 37, Slovakia

Email: gabris.lubomir@gmail.com, xgabrisl@stuba.sk

We investigated usage of plasma immersion ion implantation (PIII) in process of surface morphology modification and possible pattern formation. Copper, aluminium, titanium and yttrium tin films were grown by magnetron sputtering deposition on silicon (100) substrates. The samples were irradiated with 5 to 30 keV Ar ions at normal incidence using the PIII technique with fluences of 10^{18} atoms/cm^{-2}. The surface morphology was analysed by Atomic force microscopy. First experimental results are presented and the influence of the non-monoenergetic nature of the PIII process on the morphology is discussed.

This work was supported by the European Regional Development Fund, Research and Development Operational Programme, project #ITMS: 26220220179, the Slovak Research and Development Agency under contract #APVV-15-0049, the Grant Agency VEGA under contract #1/0330/1.

P 1-11
Effect of He^+ Irradiation of Ti_2InC at Different Ion Beam Fluences

Giovanni Ceccio[1]
P. Horak[1] , J. Vacik[1], A. Cannavò[1], S. Bakardjieva[2], A. Michalcova[3], R. Klie[4], X. Rui[4], L. Calcagno[5], A. Torrisi[1]

[1]Nuclear Physics Institute of Czech Academy of Science, Rez 20568, Czech Republic
[2]Institute of Inorganic Chemistry of Czech Academy of Science, Rez 20568, Czech Republic
[3]Department of Metals and Corrosion Engineering, University of Chemistry and Technology, Technicka 5, Prague 6, 16628, Czech Republic
[4]University of Illinois at Chicago, Department of Physics, 845 W Taylor Str., Chicago 60607, USA
[5]University of Catania,Dipartimento di Fisica e Astronomia, Via S. Sofia 64, Catania 95135, Italy

Email: ceccio@ujf.cas.cz

MAX phases are a group of ternary carbide or nitride phases with a nano-layered microstructure. Their general formula is $M_{n+1}AX_n$ with n=1 to 3, where M is a transition metal, A is an A-group element (from IIIA to VIA), and X is either carbon or nitrogen. These carbides and nitride have unusual behavior combining the metal and ceramics in the sense of chemical, physical, electrical and mechanical properties. These properties can be explained with their anisotropic lamellar microstructures.

Here, we report on study of thin Ti_2InC (M_2AX) phases. The phases were synthetized by ion beam sputtering of single (M, A and X) elements at the Low Energy Ion Facility (LEIF). The ion beam sputtering was performed using the Ar^+ ion beam with energy of 25 keV and a current of 400 μA. The thickness of the Ti_2InC composite (measured by RBS/EELS) was found to be about 65 nm. After the deposition, the samples were annealed in vacuum at 120 °C for 24 hours in order to induce interphase chemical interaction and formation of the Ti_2InC material. In order to evaluate the radiation hardness and other effects induced by ion radiation (e.g., morphology alteration), the Ti_2InC samples were irradiated by 100 keV He^+ ion beam with different fluences between 1×10^{15} cm^{-2} and 1×10^{17} cm^{-2}. It was found that the low-level fluence of He^+ ions (1×10^{15} cm^{-2}) does not induce any significant change in surface roughness, and also the crystalline structure is preserved. At higher fluences, however, the formation of the concentrated point defects within the nanocrystalline Ti_2InC lattice, as well as a thin amorphous carbon shell can be seen. In view of these results, we can conclude that as obtained Ti_2InC (M_2AX) nanolaminates hold great promise for utilization in harsh environmental conditions and nuclear radiation.

P 1-12

Experimental and Numerical Simulations of Cracking Behaviors on Tungsten Under High Intense Pulsed Ion Beam Irradiation

Yan Sha[1]
Miao Qu[1], Jianming Xue[1], Yugang Wang[1], Xiaoyun Le[2]

[1]Institute of Heavy Ion Physics, State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing 100871, China
[2]School of Physics and Nuclear Energy Engineering, Beihang University, Beijing 100191, China

Email: syan@pku.edu.cn

Key words: tungsten, high intense pulsed ion beam, crack, thermal stress, J-integral, finite element method

Tungsten has been chosen as the main candidate of plasma facing materials (PFMs) in the tokamak divertor. Transient heat loads, such as Edge Localized Modes (ELMs), could induce plastic deformations, cracking, melting, even ablation of tungsten (W) surface. To investigate the cracking behaviors of tungsten under ELMs-like transient heat flux, rolled bar and plate tungsten samples have been tested by intense pulses ion beam using 1.0÷3.1 J/cm^2 with 1÷100 pulses. The effects of energy density and pulse number on crack characteristics, such as crack distance, width, and depth, were studied. Several pulse loading can induce discontinuous cracks and repetitive pulse loading can induce network cracks at the loaded surfaces. Repetitive pulse loading has lower energy density of crack thresholds than that of single shot and pulse number has almost no effect on crack distance. It was found that crack edge appeared to melt at high energy density ~3.1 J/cm^2 and a large number pulse loading could induce the bridging of partial cracks. Temperature and thermal stress distributions were calculated by thermal conduction model combining with the ideal elasto-plastic mechanics model considering the ductile-to-brittle transition temperature of tungsten to judge the crack initiation. Stress intensity factor was calculated by elasto-plastic fracture mechanics and J-Integral parameter to judge the crack propagation.

References

[1] Arshad K., Ding D., Wang J. *et al*., Nuclear Materials and Energy, 3: 32-36(2015).
[2] Wirtz M., Linke J., Loewenhoff T. *et al*., Physica Scripta, 2016, T167:014015.
[3] Ijaz S., Jie S., Xiao Y. *et al*., Journal of Fusion Energy, 2018.
[4] Li M., Werner E., You J. H., Nuclear Materials and Energy, 2:1-11(2015).

P 1-13
Ion Beam Synthesis of AuAg@Ag Core/Shell Bimetallic Nanoparticles in TiN

Pavol Noga[1]
Maja Popović[2], Mirjana Novaković[2], Dušan Vaňa[1], Zlatko Rakočević[2]

[1]Slovak University of Technology in Bratislava, Faculty of Materials Science and Technology in Trnava, Advanced Technologies Research Institute, Trnava, Slovakia
[2]University of Belgrade, Institute of Nuclear Sciences VINČA, 11351 Belgrade, Serbia

Email: pavol.noga@stuba.sk

We demonstrate the formation of a new type of AuAg@Ag core/shell nanoparticles in titanium nitride (TiN) thin films using sequential implantation of Au and Ag ions. The TiN films deposited by DC reactive sputtering were sequentially implanted with 200 keV Au ions with fluences of 0.5×10^{16} and 1×10^{16} ions/cm^2 and 150 keV Ag ions with fluences of 1×10^{16} to 4×10^{16} ions/cm^2. Formation of spherical particles with dimensions below 10 nm, homogeneously distributed along the ion track of implanted ions is verified by high resolution transmission electron microscopy. The specific nanostructure containing the Au-Ag alloy in the core of the particle and only silver in the shell was found in the TiN sample implanted with 1.0×10^{16} ions/cm^2 of Au and 4×10^{16} ions/cm^2 of Ag using high angle annular dark field scanning electron microscopy together with elemental mapping analysis. In samples implanted with the lower Au concentration only Au-Ag particles were observed.

This work was supported by the Ministry of Education and Science of the Republic of Serbia (Project #III 45005) and by the European Regional Development Fund under contract #ITMS:26220220179, and the Slovak Research and Development Agency under contract #APVV-15-0049.

P 1-14
Combined Method of Cutting Tool Treatment

Vladislav Tarbokov
Gennady Remnev

National Research Tomsk Polytechnic University, 30 Lenin ave., Tomsk 634050, Russia

Email: tarbokovv@tpu.ru

Key words: high-intensity pulsed ion beam, wear-resistant coating, adhesion increase

The method includes the wear-resistant coating deposition onto the tool surface treated by high-intense pulsed ion beam (HIPIB).

The influence of high-intense ion beam leads to the phase boundaries hardening due to the intersolution of tungsten carbide and cobalt matrix. The microhardness and surface layer elasticity increase both due to the high-velocity quenching at the surface cooling after pulse action ($10^7 \div 10^9$ K/s) and due to the WC crystalline structure improvement. As the result, the carrying capacity of the surface layer increases.

The change of the phase composition of the surface layer leads to the phase formation with lattice parameters similar to titanium nitride (cubic, a=4.24 Å). Together with the surface cleaning from contaminations and the developed microrelief formation with optimal roughness parameters (R_a=0.1÷0.3μm) it leads to the adhesion interconnection number increase between the coating and the substrate.

The combined influence of these facts causes the increase in the adhesion strength of titanium nitride coating deposited onto the hard-alloy tool treated by HIPIB and in the tool durability.

The combination of two technological processes in one vacuum volume enables to decrease the total cost of the equipment due to the exclusion of doubling systems and to reduce the treatment time.

The intensification of the surface cleaning effect of articles by HIPIB becomes possible due to the exclusion of contact with atmosphere between technological processes of treatment by ion beam and coating deposition.

The ion beam treatment in the coating deposition process makes it possible to carry out both coating with substrate material mixing that initiates the adhesion increase and the treatment of the growing coating layer to increase coating density and its cohesion strength.

The HIPIB treatment after coating deposition leads to partial amorphisation of coating surface layers, its microhardness growth. As a result, tribological tool qualities with wear-resistant coatings are improved.

P 1-15

Defects Formation and Evolution on Ceramics Irradiated by Intense Pulsed Ion Beams

Shijian Zhang[1,2,3]
Xiao Yu[1,2,3,4], Haowen Zhong[1,2,3], Mofei Xu[1,2,3], Guoying Liang[1,2,3], Xiaojun Cui[1,2,3], Nan Zhang[1,2,3], Jianhui Ren[1,2,3], Shicheng Kuang[1,2,3], Huaizhe Xu[1], Sha Yan[5], Xiaoyun Le[1,2,3,*]

[1]School of Physics and Nuclear Energy Engineering, Beihang University, Beijing 100191, China
[2]Beijing Advanced Innovation Center for Big Date-based Precision Medicine, Beihang University, Beijing 100191, China
[3]Beijing Key Laboratory of Advanced Nuclear Energy Materials and Physics, Beihang University, Beijing 100191, China
[4]School of Space and Environment, Beihang University, Beijing 100191, China
[5]Institute of Heavy Ion Physics, Peking University, Beijing 100871, China

Email: xyle@buaa.edu.cn*

Key words: intense pulsed ion beam, alumina ceramics, crater, crack

Featured by short-pulsed and high-power density, intense pulsed ion beams (IPIBs) are widely used in material processing for the enhancement of material performance, preparation of nano powder, etc. However, during the IPIB treatment, surface defects may be generated with deterioration of material properties. Thus, it is of great significance to investigate the formation and evolution of defects under the irradiation of IPIB. In this work, alumina ceramics (Al_2O_3) with different thickness were treated with IPIB with accelerating voltage of 400 kV, beam energy density of 3 J/cm^2. As demonstrated by the results, micro craters and cracks were generated It is revealed that the thickness of samples and the number of pluses play a predominant role in the formation and evolution of defect during the irradiation of IPIB. Numerical research based on Monte Carlo (MC) and finite element method (FEM) were carried out for the thermal and mechanical effects by the energy deposition of IPIB and it is demonstrated that the thermal shock induced by IPIB is the main reason for the defects generation during IPIB irradiation.

P 1-16
Zn, Mg, Ag Ion Implantation of Polylactic Acid

Olesya Laput[1]
D.A. Zuza[1], K.P. Savkin[2]

[1]Laboratory of Chemical Technologies, Tomsk State University, Tomsk 634045, Russia
[2]Laboratory of Plasma Sources, Institute of High Current Electronics SB RAS, Tomsk 634055, Russia

Email: olesyalaput@gmail.com

Key words: PLA, ion implantation, microhardness, TRIDYN, degree of crystallinity

Biopolymers are used in medicine to create immuno-tolerant prostheses, blood vessels, as well as in drug delivery systems and as protective films for skin damage. As one of the ways to solve the problem of compatibility of the implant surface with the organism, it was proposed to modify the surface of biopolymers by ion implantation. Therefore, in this study, we propose surface modification of biocompatible polylactic acid (PLA) using implantation of Mg, Zn, Ag ions. Moreover, besides the practical significance of this work, the irradiation of organic matrices with high-energy ions is of great interest in basic scientific research.

Surface treatment was performed using a Mevva-5.Ru ion source [1] based on a vacuum arc discharge. The ion energies for Zn^{1+}, $Mg^{1,5+}$, and Ag^{2+} were 20 keV, 30 keV, and 40 keV, respectively. The average ion charge was studied using a time-of-flight spectrometer. Exposure doses of ion implantation were 1×10^{15} and 1×10^{16} ions/cm^2. It was determined that the thickness of the modified layer (600÷1700 nm) is established to exceed the projective range of ions (4÷15 times) in PLA. The microhardness decrease with the exposure dose increasing for all ions was observed.

Irradiation with silver, magnesium and zinc ions leads to a decrease in the degree of crystallinity and, consequently, microhardness to a depth greater than projective that may be due to the effects of long-range action due to radiation-stimulated diffusion and rearrangement of the polymer matrix.

This work was supported by the Tomsk State University Competitiveness Improvement Program under Grant.

References
[1] Nikolaev A.G, Oks E.M., Savkin K.P. *et al.*, Review of scientific instruments, 83, 02A501 (2012).

P 1-17
Comprehensive Electron-Ion-Plasma Modification of Al-Si Alloy Surface

Yurii Ivanov
Ilya Lopatin, Elizaveta Petrikova, Anton Teresov, Maria Rygina

Institute of High-Current Electronics SB RAS, Tomsk 634055, Russia

Email: yufi55@mail.ru

Key words: metallic plasma, intense pulsed electron beam, surface alloy, structure, properties

Al-Si alloys (silumin), due to their low specific weight, good casting properties and corrosion resistance, have found wide application in mechanical engineering and instrument-making, aviation and astronautics [1,2]. A significant drawback of silumin is increased brittleness, the cause of which is the presence of plate-like (needle) shaped inclusions [3].

The aim of the research is to develop a method for creating gradient, nano- and submicrocrystalline, multi-element multiphase layers formed during controlled electron-ion-plasma treatment of silumin (Al-12% Si alloy), combining in a certain sequence irradiation with an intense pulsed electron beam and deposition of metallic films for fold increase in wear resistance, strength and ductility of the material. The essence of the developed method is the formation of surface layers with a thickness of at least 100 μm, characterized by a submicro-size aluminum structure, strengthened by nano-sized, uniformly distributed silicon particles and intermetallic compounds formed as a result of irradiating with an intense pulsed electron beam the silumin surface or the «film (titanium)/substrate (silumin)» system formed by an arc-plasma-assisted method.

Three groups of silumin samples were investigated: (1) in a cast state, (2) after irradiation with an electron beam and (3) after irradiation with an electron beam of the «film (Ti)/substrate (silumin)» system. It is established that the irradiation of silumin with an electron beam is accompanied by the formation of a surface layer, the wear resistance of which is 8.3 times higher than the wear resistance of the cast material. The formation of the surface alloy Al-Si-Ti is accompanied by an increase in the wear resistance of the material by more than 14 times. Studies of the elemental and phase composition, the state of the defective substructure revealed the formation in the modified layer of a submicrodimensional structure of a solid solution based on aluminum strengthened by nanoscale particles of aluminides and titanium silicides.

The work was supported by RSF (project #19-19-00183).

References

[1] Belov N.A., Savchenko S.V., Khvan A.V. Phase composition and structure of silumin: a reference book. - Moscow: MISiS, 2007. - 283 p. [in Russian].
[2] Modification of the structure and properties of eutectic silumin by electron-ion-plasma treatment / ed. by A.P. Laskovnev. - Minsk: Belarus. Navuka, 2013. - 287 p. [in Russian].
[3] Zolotorevsky V.S., Belov N.A. Metal science of cast aluminum alloys - Moscow: MISiS, 2005. - 376 p. [in Russian].

P 1-18

Restoration of Ductility of Cold-Deformed Aluminum Alloys by Short-Term Irradiation with Accelerated Ar^+ Ions

Vladimir Ovchinnikov[1]
Natalia Gushchina[1], Sergey Mozharovsky[1], Larisa Kaigorodova[2]

[1]Institute of Electrophysics, Ural Branch, Russian Academy of Sciences, Yekaterinburg 620016, Russia
[2]Institute of Metal Physics, Ural Branch, Russian Academy of Sciences, Yekaterinburg 620041, Russia

Email: viae05@rambler.ru

Key words: aluminum alloys, ion irradiation, electron microscopy, static uniaxial tension tests, radiation annealing, recrystallization, intermetallic phase formation, long-range effects

The use of beams of accelerated ions is one of the promising directions in the field of creating new technologies for processing materials. Nanoscale dynamic effects [1,2] make it possible to increase the depth of impact of accelerated ions on the structure and properties of materials by several orders of magnitude.

The work considers the processes of radiation-dynamic nature (unlike thermo-activated processes) during short-term irradiation with accelerated Ar^+ 20÷40 keV ions. The sheets of 1÷3 mm thick of the alloys of Al-Li and Al-Mg systems strengthened by cold plastic deformation were processed.

The samples were irradiated on an ILM-1 implanter equipped with an PULSAR-1M ion source based on a low-pressure glowing discharge with a cold hollow cathode [3]. Mechanical tests for uniaxial tension were carried out in accordance with Russian State Standart GOST 1497-84. The microstructure of the initial and irradiated samples was studied using a Neophot-21 optical microscope and a JEM-200 CX electron microscope.

The phenomenon of multiply accelerated bulk (throughout the thickness of the sheets) low-temperature radiation annealing of the alloy with a depth of penetration of Ar^+ ions into the metal, which is known not to exceed 0.1 μm, has been registered. Recrystallization processes, changes in the phase composition occurring within a few seconds, have common features and differences in comparison with the results of two-hour thermal annealing. The prospects for the use of radiation annealing are discussed.

References

[1] Ovchinnikov V.V., Physics Uspekhi, 51, 955-974 (2008).
[2] Ovchinnikov V.V., Surface and Coating Technology, 355, 65-83 (2018).
[3] Gavrilov N.V., Mesyats G.A., Nikulin S.P. *et al*., J. Vac. Sci. Technol, A14, 1050-1055 (1996).

P 1-19

Surface Modification of ZrO_2-$3Y_2O_3$ Ceramics with High-Intensity Pulsed N^{2+} Ion Beams

Valeria Kostenko[1]
Sergei Ghyngazov[1], Xiaopeng Zhu[2], Alexander Pushkarev[1], Yulia Egorova[1], Sergey Matrenin[1], C.C. Zhang[2], Mingkai Lei[2], Anatoliy Surzhikov[1]

[1]National Research Tomsk Polytechnic University, 30 Lenin ave., Tomsk 634050, Russia
[2]Dalian University of Technology, China

Email: kostenkova@tpu.ru

Key words: ZrO_2-$3Y_2O_3$ ceramics, high-intensity pulsed ion beams, hardness, electrical conductivity, phase analysis

Concentrated flows of accelerated charged particles, particularly pulsed electron and ion beams, are used for surface modification of various materials. They are most widely used for treatment of metals and alloys. Modification of dielectric materials, such as zirconia-based ceramics, is of scientific and practical interest. Due to low thermal conductivity of ceramics, its treatment with high-intensity pulsed ion beams (HIPIB) can lead to effects different from those obtained for metals and alloys. Literature results on zirconium and corundum ceramics treated with carbon ions suggest that due to local overheating of the near-surface layer, large thermal stresses are developed leading to changes in the near-surface layer of ceramics not obtainable for metals and alloys. This paper presents the results of a study on surface modification of partially stabilized zirconium dioxide ceramic with an intense beam of nitrogen ions.

The ZrO_2-Y_2O_3 ceramics samples were irradiated with a HIPIB of N^{2+} ions on the TEMP-6 accelerator at an accelerating voltage of 250÷300 kV, current density of 150÷200 A/cm^2, and energy density of 3.5÷5.0 J/cm^2. Nitrogen ions generation on the accelerator was achieved for the first time. Structural and phase changes of irradiated samples were studied using XRD and SEM analysis.

The analysis showed that HIPIB irradiation of zirconium ceramics leads to the recrystallization of the surface layers with the formation of a new microstructure. The effect of HIPIB irradiation on mechanical and electrical properties of the surface layers was analyzed. It was obtained that irradiation changes mechanical characteristics of the surface layers of ceramics, such as microhardness, nanohardness, Young's modulus, etc. Pulsed ion beam treatment of the studied samples also leads to the disruption of oxygen stoichiometry, which is accompanied by an increase in the electrical conductivity of ceramics.

P 1-20

XPS Characterization of Surface Layers of Stainless Steel Nitrided in Electron Beam Plasma

Ivan Zhidkov[1]
A.S. Kukharenko[1], A.V. Makarov[1,2,3], G.V. Samoilova[2], A.S. Mamaev[4], N.V. Gavrilov[4], S.O. Cholakh[1], E.Z. Kurmaev[1]

[1]Ural Federal University, 19 Mira st., Ekaterinburg 620002, Russia
[2]M.N. Miheev Institute of Metal Physics, Ural Branch of the Russian Academy of Sciences, 18 S. Kovalevskoy st., Ekaterinburg 620108, Russia
[3]Institute of Engineering Science, Ural Branch of the Russian Academy of Sciences, 34 Komsomolskaya st., Ekaterinburg 620049, Russia
[4]Institute of Electrophysics, Ural Branch of the Russian Academy of Sciences, 106 Amundsena st., Ekaterinburg 620016, Russia

Email: i.s.zhidkov@urfu.ru

The results of influence of plasma ion nitriding on the surface composition and phase formation of Cr-Ni austenitic steel are presented. Two initial states of austenitic steel were studied: quenched undeformed one and after nanostructuring frictional treatment. The full studies of XPS spectra were undertaken including the measurements of survey and high-energy resolved core level Fe 2p-, Cr 2p- and N 1s-spectra. All XPS measurements were carried out for the initial nitrided surfaces and after their etching with argon ions (V=2 keV, I=15 mA) for 30 min, which ensured the removal of the surface contaminated layer with a depth of ~10 nm. After such etching, the concentration of nitrogen in the near-surface layer increased from 2.6 to 12.0 at.%, and the content of carbon and oxygen, on the contrary, decreased 2 times. The measurements of XPS spectra of the core levels showed that nitriding of Cr-Ni steel leads to the formation of Fe and Cr nitrides in the surface layer which provides a significant increase in the strength properties.

P 1-21

Structure and Phase States Modification of Al-Si Alloy by the Ion-Plasma Jet and Pulsed Electron Beam Treated

Yulia Rubannikova[1]
Dmitrii Zaguliaev[1], Victor Gromov[1], Sergey Konovalov[2], Yurii Ivanov[3]

[1]Department ofNatural Sciences, Siberian State Industrial University, Novokuznetsk 654007,Russia
[2]Department of Metals Technology and Aviation Materials, Samara National Research University, Samara 443086, Russia
[3]Laboratory of Plasma Emission Electronics, Institute of High Current Electronics of the Siberian Branch of the RAS, Tomsk 654052, Russia

Email: rubannikova96@mail.ru

Key words: ion-plasma jet, pulse electron beam, electron microscopy, structure, surface, phase states

Ion-plasma jet obtained by the method of an electric explosion allows improving strength, durometer and tribological properties in the modified material. The coating properties are usually highly dependent on the microstructure, phase composition, porosity, and its distribution [1]. For elimination of coating defects formed by the ion-assisted deposition method, the subsequent treatment by an intense pulsed electron beam appears to be very promising [2]. This treatment causes remelting of surface layers of the material at superhigh heating and cooling rates, resulting in a homogeneous structure of submicro- and nanosized range [3].

Using methods of scanning and diffraction electron microscopy, X-ray diffraction analysis, it is study the structure, phase states, and morphology of the modified surface of Al-Si alloy subjected to a complex treatment (ion-plasma jet obtained by the method of an electric explosion with subsequent intense pulsed electron beam treatment). Electron scanning and diffraction microscopy is used to analyse the elemental and phase states, the defect substructure of the modified surface layer. It is established that a multiphase, morphologically diverse structure is formed, consisting mostly of aluminium and yttrium oxides and silicates. Treatment of Al-Si alloy samples by the intense pulsed electron beam with the diverse density results in release of the second phase submicro and nano-dimensional particles.

The work was financially supported by state contract of the Ministry of Science and Higher Education of the Russian Federation #3.1283.2017/4.6 and partially supported by the Russian Foundation for Basic Research (project #19-52-04009 Bel_mol_a).

References

[1] Osintsev K.A., Zagulyaev D.V., Konovalov S.V., Shlyarov V.V., AIP Conference Proceedings, 020159/1–020159/4 (2017).
[2] Wu Y., Liao W., Wang F., Wang M., Yu C., Wang Z., Guo Z., Liu Z., Cao Y., Huang J., Journal of Alloys and Compounds, 756, 33-39 (2018).
[3] Zhao L., Wang S., Jin Y., Chen Y., Aerospace Science and Technology, 82–83, 61-69 (2018).

P 1-22

Retardation of Corrosion Induced Hydrogen Embrittlement of Tantalum by Ion Beam Surface Alloying with Platinum

Wolfgang Ensinger[2]
Sevda Ayata[1]

[1]Dokuz Eylyl University, Department of Chemistry, Izmir 35160, Turkey
[2]Darmstadt University of Technology, Department of Materials Science, Darmstadt 64287, Germany

Email: ensinger@ma.tu-darmstadt.de

Due to its outstanding chemical stability, Tantalum is a suitable material for use in corrosive environments, such as vessels for handling concentrated mineral acids. However, under corrosion which leads to hydrogen formation it readily forms hydrides. When the metal is being dissolved in the acid, hydrogen is being formed at the metal surface at the same time. It diffuses into the metal lattice and reacts to the metal hydride. Since this compound is very brittle, the metal looses its ductility. The accompanying loss of mechanical strength can result in cracking.

Platinum catalyzes the recombination of hydrogen atoms to molecules and the desorption of the molecules from a surface. This favourable feature can be used to protect metals from detrimental hydrogen incorporation. In order to prevent hydrogen embrittlement, small amounts of platinum were implanted into the surface of tantalum foils or where alloyed by ion beam mixing a thin Pt layer which has been deposited by electron beam evaporation. Upon exposure to hot mineral acids, the untreated tantalum failed in mechanical tests due to embrittlement after short time, while the platinum surface-alloying considerably retarded the embrittlement.

In order to save precious noble metal, the treated surface area was reduced to 50% and eventually down to 10% of the total Ta area. The corrosion tests show that this treatment still resulted in a certain embrittlement inhibition with a long-range effect, i.e. even untreated parts of the Tantalum strips turned out to be protected.

P 1-23
Influence of the Formation Nickel Silicide on Resistivity of Silicon

Baltakhadja Umirzakov
Dilnoza Tashmukhamedova, Maxsuna Yusupjanova, Jahongir Sodikjanov, Mavluda Mirjalilova

Tashkent State Technical University, Tashkent 100095, Uzbekistan

Email: ftmet@rambler.ru

Key words: resistivity, impurity, nickel silicide, ion-implantation

In this work profiles of the distribution admixture atoms in ion-implanted by Si and their influences upon resistivity ρv of silicon were studied.

The depth distribution profiles of Ni, O, and B atoms obtained before and after processing at T=1000 K are studied. Note that near-surface Si layers are amorphized completely prior to heating and contain Ni_xSi_y compounds and free Ni and Si atoms. A single-crystal $NiSi_2$ film with a sharp boundary forms after heating. Oxygen atoms are accumulated primarily in the transition layer of the ion-implanted layer/silicon interface. The boron concentration increases somewhat near this interface and remains almost unchanged at d>200÷225 Å. An epitaxial NiSi2 film with thickness θ=130÷150 Å forms after processing at T=1000 K, and the width of the transition layer decreases sharply. The overall O concentration in the transition layer remains almost unchanged, but its maximum concentration increases by a factor of 1.5. As for B atoms, their concentration in the $NiSi_2$ film decreases to zero. The concentration of B in the transition layer increases considerably, reaches its peak value at d=200÷225 Å, and decreases to 0.2÷0.3 at.% at d>250 Å.

These data suggest that substantial migration of impurity atoms at the film–substrate interface occurs primarily after the crystallization of disordered layers and the formation of an epitaxial silicide–silicon system with a relatively sharp boundary. Apparently, this migration of B towards the silicide results in a reduction in the B concentration (and an increase in ρv of silicon) in layers below the transition ones.

P 1-24

Study of Fabrication and Characterization of Title: High Power 850 nm Vertical-Cavity Surface-Emitting Laser Arrays

Gwomei Wu
F.C. Kung, C.Y. Lee

Institute of Electro-Optical Engineering, Chang Gung University, Chang Gung Memorial Hospital, Taoyuan 333, Taiwan

Email: wu@mail.cgu.edu.tw

Key words: VCSEL, laser, high power

In this paper, we investigated the high power oxidation-confined AlGaAs 850 nm vertical-cavity surface-emitting laser (VCSEL) and fabricated two-dimensional arrays of VCSEL chips by the design of masks. Inductively coupled plasma (ICP) was employed to create the deep platform during the Mesa process. The number of illuminating lights has been 60, 85, 109, respectively. We further studied the influence of the number of illuminating lights on the characteristics of the VCSEL laser components. We introduced the development, advantages, and applications of the VCSEL lasers and compared with the traditional edge-emitting lasers. The current confinement methods included four basic structures: air-post type, ion-implanted type, epitaxial regrowth type and oxide confinement type. In addition, the basic principles of laser operation, epitaxial structure and the active layer, distributed Bragg reflector, wet oxidation process were discussed. The last part would analyze the measurement results, including current-voltage characteristics, power-current characteristics, luminescence spectrum, etc. The related photo-electronic characteristics would then be summarized and further discussed. This work was supported in part by the Ministry of Science and Technology under research grants MOST105-2221-E182-059-MY3/BMRP246 and CGMH CMRPD3G0062.

P 1-25
Interaction of Pulsed Plasma with the Surface of the Material and Dust Formation

Tazhen Aigerim
Dosbolayev Merlan, Rayimkhanov Zhanibek, Ramazanov Tilekkabul

Institute of Experimental and Theoretical Physics, al-Farabi Kazakh National University, Almaty 050040, Kazakhstan

Email: aigerim_tzh@mail.ru

Key words: pulsed plasma accelerator, pulsed plasma flow, plasma-dust cloud

Plasma with dust particles is found in the divertor zone of thermonuclear fusion reactors (TNER), and has strong influence on the basic parameters of the plasma pinch [1, 2]. Since carbon is one of the promising candidate materials for construction of the inner walls of TNER (e.g. in the International Thermonuclear Experimental Reactor, ITER), it is, therefore, of great scientific and technological value to study the interaction of plasma with bulk carbon material paper, we present the results of experimental investigation of the properties of dusty plasma formed in a pulsed plasma accelerator (IPU-30) through interaction of pulsed plasma beams with a carbon-based target [3].

In the experiments, the interaction of a beams of the pulsed plasma with the surface of the carbon plates afford instantaneous heating of the target substrate, and subsequent ejection of dust particles from the surface of the plates into the plasma bulk. These dust particles then dragged by the plasma beam creating a moving plasma-dust cloud. A high-speed camera (Phantom VEO710S) is used to obtain the velocity of the dust particles in a beam of the pulsed plasma. Ejection of dust particles is investigated at two different values of the discharge voltage (7 kV and 12 kV). The results of the particle trajectory analysis show that at relatively low voltages (7 kV) the particles' motion is predominantly opposite to the direction of the flow of the plasma beam, which is characteristic of a head-on collision. At high voltages (12 kV), on the other hand, the particles scatter in all directions. The velocities of the dust particles moving opposite to the plasma flow are smaller in magnitude in the 12 kV than in the 7 kV discharge. In addition, we observed dust particles with high relative velocities, enough to cause damage to the surface of the carbon plates. These particles are referred to as «projectile particles», due to large values of their speed, which are comparable to the ones of bullets fired from a handgun.

This work was supported by the Ministry of Education and Science of Kazakhstan under Grant IRN AP05134671.

References
[1] Flanagan J.C. *et al.*, Plasma Phys. Control. Fusion, 57, 014037. (2015).
[2] Krasheninnikov S.I., Smirnov R.D., Rudakov D.L., Plasma Phys. Control. Fusion, 53, 08300 (2011).
[3] Dosbolayev M.K., Utegenov A.U., Tazhen A.B., Ramazanov T.S., Laser and Particle Beams, 35, 741-749(2017).

P 1-26

Pulsed Ion Beam Irradiation of Silver Nanowire Networks for Use in Transparent Conductive Films

Marat Kaikanov[1]
Gulzat Demeuova[2], Gulnur Akhtanova[2], Bauyrzhan Amanzhulov[1], Alexander Tikhonov[1]

[1]Physics Department, School of Science and Technology, Nazarbayev University, Nur-Sultan 010000, Kazakhstan
[2]National Laboratory Astana, Nazarbayev University, Nur-Sultan 010000, Kazakhstan

Email: marat.kaikanov@nu.edu.kz

Key words: pulsed ion beam of nanosecond duration, silver nanowires, transparent conducting coatings, conductive thin layer, metal networks

Modern optoelectronic devices, such as touch panels, organic light emitting diodes (OLEDs), solar cells, transparent heaters, liquid crystal displays and more are fabricated on the basis of transparent conductive layer [1,2]. The characteristics of these devices are intensively developing, as a result enhancing the industrial demand. Therefore, extensive research has been conducted to investigate various fabrication methods of thin layers, which exhibit high optical transparency as well as conductivity. Indium-doped Tin Oxide (ITO) is widely used as a transparent material. However, the latter suffer from limitations associated with high cost of fabrication process and scarcity of ITO.

Metal networks based on silver nanowires (AgNW) were intensively researched as a promising replacement for ITO [1,7–9] due to their high electrical conductivity and high transparency [1,3,4]. High conductivity of the AgNW films is induced by large contact resistance of nanowire-nanowire junctions. The conductivity can be further enhanced by annealing post-treatment at about 200÷300 °C [5,6]. However, elevated temperatures are not applicable for polymer-based substrates. Therefore, the following work proposes the modification of AgNWs thin films using pulse ion beam to improve the structure, optical and electrical properties. Proton based pulse ion beam irradiation was performed using INURA pulse ion accelerator located in Nazarbayev University with the following parameters: accelerating voltage is up to 350÷400 kV, total beam current is 10 kA, the beam pulse duration is 80 ns (at half-height). A beam current density was changed from 10 to 100 A/cm^2 while keeping the accelerating voltage and composition of the ion beam the same. As a result, modification of structures using ion beam improved the optical and conductive properties of AgNW based coatings.

This work is supported by the grant AP05132270 «Pulsed ion beam modification of silver nanowires based transparent conducting film» from the Ministry of Education and Science of the Republic of Kazakhstan, and NU ORAU project «Neutralization of high-intensity pulsed ion beam by volumetric plasma».

References

[1] P. Kou, L. Yang, Ch. Chang, S. He. Scientific reports. (2017) 7, 42052.
[2] G. U. Kulkarni, S. Kiruthika, R. Gupta, K. Rao. Current Opinion in Chemical Engineering. (2015) 8, pp.60-68.
[3] Kan Zh. *et al*. Nanoscale. (2016) 8, pp.18121–18133.
[4] J. Q. Hu *et al*. Advanced Functional Materials. (2004)14(2), pp.183–189.
[5] Lee, P. *et al*. Advanced Materials. (2012) 24, p. 3326.
[6] Madaria, A. R., Kumar, A., Ishikawa, F. N., Zhou, C. Nano Research. (2010) 3, p.564.

P 1-27

High Energy Ionoluminescence of Al_2O_3 and LiF: Time Resolved Studies

Abdirash Akilbekov[1]
A. Seitbayev[1], V. Skuratov[2,3,4], Yu. Teterev[2], A. Krylov[2], M. Koloberdin[5], M. Zdorovets[5,6], A. Dauletbekova[1], M. Baizhumanov[1]

[1]L.N. Gumilyov Eurasian National University, Nur-Sultan (Astana), Kazakhstan
[2]Flerov Laboratory of Nuclear Reactions, Joint Institute for Nuclear Research, Dubna, Russia
[3]National Research Nuclear University MEPhI, Moscow, Russia
[3]Dubna State University, Dubna, Moscow Region, Russia
[4]Astana Branch of Institute of Nuclear Physics, Nur-Sultan (Astana), Kazakhstan
[5]Ural Federal University, Yekaterinburg, Russia

Email: akilbekov_at@enu.kz

Key words: ionoluminescence, swift heavy ions, radiation damage

The ionoluminescence (IL) technique is recognized as one of the most efficient tool for real-time characterization of irradiating insulating materials. Usually, in such works the evolution of the spectral content and emission intensities with ion fluence and the irradiation temperature is studied and much less experiments which concern on time-resolved IL measurements are known, especially for swift heavy ions. At the same time, the luminescence decay measured with picosecond resolution during high energy ion irradiation may provide very important information about energy dissipation processes and early stages of radiation damage formation [1-3]. For example, it was shown recently that the decay rate is increased with the linear energy transfer in α-Al_2O_3 irradiated with 2 MeV/amu N, Ar an Xe ions [3].

In this report we present the results on studies of «fast components» in luminescence decay curves measured in pure and pre-damaged by swift heavy ions Al_2O_3 and LiF single crystals during 1.2-1.6 MeV/amu C, Ar, V, Kr and Xe ion irradiation.

References

[1] Kazuie Kimura, Sumit Sharma, Anatoli Popov, Nucl. Instr. Meth. B 191, 48–53 (2002).
[2] Kazuie Kimura, Nucl. Instr. Meth. B 212, 123–134 (2003).
[3] M. Koshimizu *et al*., Nucl. Instr. Meth. B 365, 540–543(2015).

P 1-28
High Fluence Fe Implanted Polyethylene Surface Characterization

Juraj Halanda[2]
Danilo Kisić[1], Miloš Nenadović[1], Tanja Barudžija[1], Pavol Noga[2,*], Dušan Vaňa[2], Martin Muška[2], Zlatko Rakočević[1]

[1]University of Belgrade, Institute of Nuclear Sciences VINČA, Belgrade 11351, Serbia
[2]Slovak University of Technology in Bratislava, Faculty of Materials Science and Technology in Trnava, Advanced Technologies Research Institute, Trnava, Slovakia

Email: pavol.noga@stuba.sk*

We have investigated surface properties of Fe implanted high density polyethylene (HDPE). Polished HDPE plates were implanted with 95 keV Fe ions with fluences from 5×10^{16} to 5×10^{17} atoms/cm^2. Atomic force microscopy showed different structures forming on the surface depending on the applied fluence. Surface roughness increases significantly after the implantation, although it remains almost constant up to 2×10^{17} at/cm^2, and then increases about 3 times for 5×10^{17} atoms/cm^2. Sheet resistance shows an exponential decay like dependence and surface free energy first exhibits a significant increase, up to the fluence of 1×10^{17} atoms/cm^2, then decreases to initial value of the pristine HDPE in a wavy manner. X-ray photoelectron spectroscopy showed that significant fraction of the implanted Fe is in the metallic phase, and the rest is comprised of multiple iron oxides.

This work was supported by the Ministry of Education and Science of the Republic of Serbia (project III 45005), the European Regional Development Fund under contract #ITMS: 26220220179, the Slovak Grant Agency VEGA under contract 1/0330/18, and the Slovak Research and Development Agency under contract APVV-15-0049.

P 1-29
The Effect of Plasma Ar and Xe on Surface Roughness of Fuel Cladding Tube

Egor Korenevski
D.A. Safonov, A.S. Yashin, N.V. Volkov, P.S. Dzhumaev, B.A. Kalin, R.S. Isaev, Quoc Dat Dinh, D. P. Borisenko

Moscow Engineering and Physical Institute, Moscow 115409, Russia

Email: egor.korenevski@gmail.com

Key words: Ar/Xe plasma, surface roughness, zirconium alloys, ion polishing

Zirconium alloys are constructive and functional materials for VVER reactors. After the accident at Fukushima, methods for improving the safety of reactor facilities in the mode of loss of coolant accident (LOCA) were actively investigated. The creation of protective coatings for already existing zirconium alloys is one of the probable solutions for increasing the corrosion resistance. In connection with the search for effective solutions - methods of deposition and the formation of protective coatings [1] - preparation of the surface for coating has an important role. As a preparation, ultrasonic cleaning of various kinds of impurities and ion polishing can be used to improve surface roughness [2].

In this work we have studied the changes in the surface roughness of the E110 alloy after Ar^+, Xe^+ ion polishing and their combination in different ratios of gas concentrations, with different irradiation doses. The modes of ionic polishing were selected: 1 - Xe ions, 2 - Ar ions, 3 - Xe and Ar ions in the ratio of 1:1 applied pressure, 4 - Xe and Ar ions in the ratio of 2:1 applied pressure. The pressure of the residual gases before processing was 7.5×10^{-5} torr. Doses irradiation ranged from 6 to 40×10^{18} cm^{-2}. The pressure of the working gases, depending on the mode, ranged from 0.4÷0.8 Pa. As a result of processing in different modes, a decrease in surface roughness was recorded. According to the SEM data, smoothing of surface defects was observed.

References
[1] Brachet J., Idarraga-Trujillo I., Flem M. *et al*., Journal of Nuclear Materials 517, 268-285, (2019).
[2] Chkhalo N.I., Mikhailenko M.S., Mil'kov A.V. *et al*., Surface & Coatings Technology 311, 351-356, (2017).

P 1-30

Nanodiamond Luminescence in Hemispherical Fabry-Perot Microcavity Fabricated by FIB

Alexey Romshin[1,2]
O.S. Kudryavtsev[1], D.G. Pasternak[1,2], I.I. Vlasov[1]

[1]Prokhorov General Physics Institute Russian Academy of Science, 38 Vavilov Street, 119991 Moscow, Russia
[2]Faculty of Physics, Lomonosov Moscow State University, Leninskie Gory, 119991 Moscow, Russia

Email: alex_31r@mail.ru

Single-photon sources based on color centers in diamond, quantum dots, rare earth ions are intensively developed at present time. In order to localize their emission in a narrow spatial and spectral intervals, as well as to increase the speed of their spontaneous emission (the Purcell effect) , various types of microcavities are used.

This paper presents the results on the development of a hemispherical Fabry-Perot microcavity for amplifying and localizing silicon-vacancy (SiV) luminescence in diamond nanoparticles. The quality factor of a microcavity responsible for the amplification significantly depends on the surface roughness of the spherical mirror and the method of its manufacture, since the imperfection of the surface leads to additional scattering losses. For example, spherical dips created by isotropic etching in a mixture of acids [1] or using a CO_2 laser [2] demonstrate essential roughness (σ_{acid}=5 and σ_{CO2} =0.3 nm rms) decreasing Q-factor. The hemispherical dip formation by a focused beam of Xe ions used in this work allows to obtain the better mirror structure with minimal roughness σ_{Xe}=0.1 nm rms. The design of the resonator is a flat mirror rarely covered with diamond nanoparticles of 200÷500 nm in size, and located parallel to the mirror with an array of hemispherical dips (R=17 μm). The SiV centers in the diamond were excited by a laser at a wavelength of 532 nm. On a base of measured spectral characteristics the Purcell Factor(F_p=1.4) and Q-factor(Q=190) were calculated. The obtained values demonstrate an increase in the rate of spontaneous emission. Taking into account the inverse proportionality F_p to the mode volume, further fluorescence enhancement can be achieved by reducing the radius of curvature of the spherical dips. The Q-factor and F_p can also be increased by using smaller crystals.

References

[1] M. Trupke, J. Goldwin, B. Darquié, G. Dutier, S. Eriksson, J. Ashmore, E.A. Hinds. (2007). Phys. Rev. Lett. 99, 063601.10.1103/PhysRevLett.99.063601.
[2] Konstantin Ott, Sebastien Garcia, Ralf Kohlhaas, Klemens Schüppert, Peter Rosenbusch, Romain Long, and Jakob Reichel, Opt. Express 24, 9839-9853 (2016).

P 1-31
Craters on the Surface Metal After HPIB of Carbon Ions

Geliy Potemkin[1]
A.E. Ligachev[2], M.V. Zhidkov[3]

[1]National Research Tomsk Polytechnic University, Tomsk 634050, Russia
[2]A. M. Prokhorov General Physics Institute RAS, Moscow 119991, Russia
[3]Belgorod State National Research University, Belgorod 308015, Russia

Email: ep.gvp@yandex.ru

Key words: pulsed ion beam, metals alloy

Under the action of a high power ion beam (HPIB, $E \leq 1$MeV, power density $\geq 10^5$ W/cm^2), an avalanche of overlapping cascades of atomic collisions and radiation defects occurs in the surface layer of metals.

Most of the ions are stopping within the Bragg peak, and under the influence of HPIB the surface layer of the metal are melts. In the irradiated melt, radiation-induced segregation creates clusters of atoms that serve as nuclei of gas bubbles in the future. Initiated HPIB convective motion in the melt promotes their growth in boiling mode. After the termination of the HPIB on the moving crystallization front due to the decrease in solubility, gas emissions are also formed. Intense collisions of large and small bubbles due to convective motion in the melt and its subsequent crystallization lead to their fusion. Ruptures of the hardening surface of the melt leaving gas bubbles lead to the formation of craters. The shape and size of craters of different generations depend on the thickness of the liquid layer and the viscosity of the melt at the time of bubble release. The crater concentration is determined by the fluxes of atoms and ions of gases introduced into the surface of the sample during the pulse and the initial gas content in a particular metal.

References
[1] Kazuie Kimura, Sumit Sharma, Anatoli Popov, Nucl. Instr. Meth. B 191, 48–53 (2002).
[2] Kazuie Kimura, Nucl. Instr. Meth. B 212, 123–134 (2003).
[3] M. Koshimizu *et al*., Nucl. Instr. Meth. B 365, 540–543(2015).

P 1-32
Modification of Titanium Nickelide by Irradiation with Heavy Ions of Inert Gases

Valentina Poltavtseva

Institute of Nuclear Physics of Ministry of Energy, Almaty 050032, Republic of Kazakhstan

Email: vpoltav@list.ru

Key words: titanium nickelide, heavy ions, nanostructures, radiation hardening, martensite, austenite

Selection of heavy ions of inert gases for TiNi modification is determined by their features, such as exclusion of amorphization, the depth of the radiation-dynamic effects, formation of the nano-structured radiation defects. The performed studies [1-4] showed that a promising direction for creating a multilayer modified structure is the application of heavy ions of argon, krypton and xenon of MeV energy with maximum values of ion charge and beam current intensity.

The paper provides the features of changes in the structure and strength of TiNi depending on the phase composition and irradiation with Ar^{8+}, Kr^{15+}, Xe^{22+} ions at E=1.75 MeV/nuc., $F_{irr}=1\times10^{18}\pm5\times10^{19}$ ion/m^2, T_{irr}=100 and 250 ^{0}C. It has been established that, under the influence of heavy ions, a three-layer modifiable structure with varying degrees of hardening is formed in TiNi independently of the phase composition: the surface layer, the near-surface layer (the range of the projective range RP) and the out-range area.

The degree of the surface layer softening depends on the degree of sputtering processes (Ar^{8+}) or ion polishing (Kr^{15+}, Xe^{22+}), accumulation of the nano-structured defects, which type varies with the growth of F_{irr} and T_{irr}. The additional softening factor for TiNi in the martensitic-austenitic state is occurrence of the radiation-stimulated phase transformation «martensite→austenite». The increase in the strength of the TiNi surface layer at T_{irr}=100 ^{o}C by Xe^{22+} and Kr^{15+} ions is associated with the contribution of nano-tracks. Embrittlement of the surface layer at T_{irr}= 250 ^{0}C is caused by accumulation of xenon gas.

The degree of strength increase in the near-surface layer and in the out-range area is determined by the value of F_{irr} and T_{irr}, the phase composition and associated with accumulation of the radiation-induced nano-structured defects.

References

[1] Poltavtseva V., Kislitsin S., Satpaev D., Mylnikova T., Chernyavskii A., IOP Conf. Series: Materials and Engineering, 81, 01234 (2015).
[2] Poltavtseva V., Larionov A., Satpaev D., Gyngazova M., IOP Conf. Series: Materials and Engineering. 110, 012011 (2016).
[3] Poltavtseva V., Larionov A., Zheltova G., IOP Conf. Series: Materials and Engineering, 168, 012032 (2017).
[4] Poltavtseva V., Larionov A., Satpaev D., Proc. 12th Intern. Conf. Interaction of Radiation on with Solids, Minsk, Belarus, 274-276 (2017).

P 1-33

High-Intensity Implantation of Metal Ions in Conditions of Minimizing Ion Sputtering of the Material Surface

Denis Sivin
A.I. Ryabchikov, P.S. Ananin, I.B. Stepanov, G.S. Modebadze, T.V. Koval

National Research Tomsk Polytechnic University, 30 Lenin ave., Tomsk 634050, Russia

Email: sivin@tpu.ru

High-intensity implantation of low-energy ions into various materials demonstrates the possibility of formation of extended, ion-doped, layers with thicknesses reaching dozens and hundreds of microns. However, a significant ion sputtering due to ultrahigh-fluences of irradiation (10^{20}÷10^{22} ion/cm^2) results in a substantial surface erosion, changes in morphology as well as in properties of ion-modified layers. This work is devoted to the investigation of peculiarities of high-intensity ion beam formation with the ion current density up to several dozens to hundreds of mA/cm^2 and energies in the range of 0.1÷1.0 keV, and their interaction with the surface of solids. Various options of «accel-deccel concept» implementation to the beam formation system were investigated, including the use of additional grid electrode near the main extractor grid either near the irradiated target itself. The dynamic of space charge neutralization and the efficiency of the focusing beam transportation after decreasing in the beam kinetic energy were investigated as well. The special attention was given to the long pulse high current beams (beam duration of several dozens of microseconds), which transportation was previously characterized by space charge associated instabilities. The influence of additional electron emitter, which was installed in the beam drift section, on the space charge compensation and ion current density distribution in a beam crossover was also examined and discussed. The results on high-intensity titanium implantation into aluminum with the ion energy providing minimal surface sputtering are demonstrated.

P 1-34

Modification of Sputter Deposited Silver Nanostructures with Thermal Annealing vs Pulsed Ion Beam Irradiation

Alshyn Abduvalov
Marat Kaikanov, Alexander Tikhonov

Department of Physics, School of Science and Technology, Nazarbayev University, Kazakhstan

Email: alshyn.abduvalov@nu.edu.kz

Key words: magnetron, silver, glancing angle deposition, ion beam

Developing new and modified materials is of high demand in various sectors of industry and science. Ion beam irradiation and thermal annealing gives unique opportunity to change and enhance properties of many materials. Thermal annealing may change and enhance properties of many materials. Irradiation with pulsed ion beam may fast heat surface of materials with subsequent fast cooling, providing additional opportunities for control of annealing process.

In this work, we fabricate and characterize Ag nanoparticles and nanostructures produced by magnetron sputtering using glancing angle deposition technique. We studied structural dependences of Ag nanostructures on magnetron deposition parameters. Magnetron sputtered Ag nanostructures were then modified with thermal annealing and then compared with the same structures irradiated with high current pulsed ion beams.

We observed that materials modified with thermal annealing and beam irradiation turn into two different microstructures. Annealed samples have shown hemispherical shapes, while irradiated samples have ideal spherical shape with average diameters up to ~110 nm. Results of experiments show crystalline structures with increased average crystallite size and average nanoparticle size proportional to the beam current density or annealing temperatures. The largest average crystallite size was observed at highest irradiated ion dose of 120 A/cm^2.

Finally, ion beam treated nanoparticles has ideal spherical shape, which makes them suitable for absorption enhancement of solar panels.

P 1-35
Study of the Effect of Various Types of Irradiation on Ceramic Materials

Artem Kozlovskiy[1,2]
K. Dukenbayev[3], M. Zdorovets[1,2,4]

[1]Kazakh-Russian International University, Aktobe, Kazakhstan
[2]The Institute of Nuclear Physics of Republic of Kazakhstan, Astana, Kazakhstan
[3]School of Engineering, Nazarbayev University, Astana, Kazakhstan
[4]Ural Federal University, Yekaterinburg, Russia

Email: kozlovskiy.a@inp.kz

In recent years, great attention has been paid to the development and use of new structural materials for nuclear and hydrogen energy, as the first wall materials of GenIV reactors. The basic concept of creating a new generation of nuclear reactors is to increase the level of safety, durability of work, as well as increase the burning of nuclear fuel and the power of nuclear facilities [1-3]. The main problem with increasing power and duration of use is with radiation swelling and degradation of structural materials with prolonged exposure to ionizing radiation. In this connection, great hopes are pinned on the development of new structural materials such as ferritic/martensitic steels, carbide and nitride ceramics. One of the promising materials is AlN-based ceramics. The potential of their use is due to the low vacancy swelling and creep, a small amount of induced activity, a high rate of radiation resistance to various types of external influences. Also, this class of materials is able to withstand temperatures above 1200÷1400°C, which makes them promising materials for GenIV reactors. When using ceramics as structural materials, the most important condition for their applicability is not only resistance to high temperatures and aggressive media, but also the effects of light charged particles, such as protons, helium ions, and carbon on structural and heat-conducting properties.

The paper presents the results of a study of the effect of proton and ion radiation on structural changes in nitride ceramics, which have a high potential for using as a structural material for GenIV nuclear reactors. Proton beams with an energy of 1.5 MeV and low-energy helium (He^{2+}) and carbon (C^{2+}) ions with an energy of 40 keV were used, to simulate defect formation and to estimate ceramics radiation resistance. According to the data obtained, it has been established that AlN nitride ceramics have high radiation resistance to the effects of proton radiation. While under irradiation with C^{2+} ions, the observed degradation of the surface layer is due to the accumulation of carbon in the structure with the subsequent formation of impurity carbide inclusions. It is established that the accumulation of slightly soluble ions of helium and carbon in the structure of the surface layer leads to an increase in the strain and distortion of crystal lattice due to introducing ions into the interstitial lattice and breaking chemical and crystalline bonds. As a result of studying the optical characteristics of irradiated samples, it was found that the decrease in absorption spectra intensity for samples irradiated with helium and carbon ions is due to a change in the interplanar distances as a result of the migration of defects along the structure with the subsequent formation of impurity inclusions. The formation of impurity phases and a high concentration of defects in the structure of ceramics leads to a sharp decrease in performance.

References
[1] A.L. Kozlovskiy *et al*. Ceramic International (2019) 1-6.
[2] A.L. Kozlovskiy *et al.* Vacuum 153 (2018) 254-261.
[3] K. Dukenbayev *et.al.* Vacuum 159 (2019) 144-151.

P 1-36

The Use of Pulsed Beams for Increasing Radiation Resistance of AlN Ceramics

Artem Kozlovskiy[2,3]
M. Kaikanov[1], A. Abduvalov[1], K. Dukenbayev[4], M.V. Zdorovets[2,3,5], A. Tikhonov[1]

[1]Nazarbayev University, School of Science and Technology, Astana, Kazakhstan
[2]The Institute of Nuclear Physics of Republic of Kazakhstan, Astana, Kazakhstan
[3]L.N. Gumilyov Eurasian National University, Astana, Kazakhstan
[4]School of Engineering, Nazarbayev University, Astana, Kazakhstan
[5]Ural Federal University, Yekaterinburg, Russia

Email: kozlovskiy.a@inp.kz

One of the ways to protect against swelling and degradation of the surface layer as a result of irradiation is the technology of layered systems with different density of materials and a large number of grain boundaries, as well as the creation of a large number of dislocation and vacancy defects in the surface layer. The presence of a large number of grain boundaries, which are drains of defects, and dislocations in the structure, reduces the probability of helium ions migration with their subsequent agglomeration. The most effective method of creating a high dislocation density at a shallow depth is the method of applying pulsed beams with a high current density [1,2]. Under irradiation with pulsed beams, the main processes of recrystallization and the creation of dislocation defects arise in a small surface layer, the thickness of which does not exceed 0.5 μm. This technology has proven itself to modify various refractory materials in order to increase the microhardness of the surface layer and change their structural characteristics [3]. However, the application of this technique for modifying the surface layer for nitride ceramics has been studied rather poorly. Also, the possibility of modifying the near-surface layer of small thickness, corresponding to the depth of helium accumulation in materials under irradiation, in order to increase the radiation resistance to helium swelling is quite promising and relevant.

The paper presents the results of studying the use of pulsed beams of high current density to modify the radiation resistance to helium swelling of AlN nitride ceramics. It has been established that for unmodified ceramics irradiated with helium ions, helium bubbles form on the surface, the average size of which varies from 70 to 150÷200 nm. It is shown that when irradiated with a pulsed beam of a mixture of C^+/H^+ (85/15) leads to the formation of a large concentration of dislocation and vacancy defects in the surface layer, which prevent the helium swelling of nitride ceramics. The effect of modification on the change in the structural characteristics of investigated samples has been established. It should be noted that these changes occur in a small surface layer with a thickness of not more than 0.5 μm, which is most susceptible to degradation under irradiation and influence of corrosive media during practical use.

References

[1] V.V. Uglov *et al*. Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms 435 (2018): 228-235.
[2] A.L. Kozlovskiy *et al*. Vacuum 153 (2018) 254-261.
[3] M.V. Zhidkov *et al*. Inorganic Materials: Applied Research 9.3 (2018) 376-378.

P 1-37
Diffusion Behaviour of Selenium Implanted into Polycrystalline SiC

Zaki Adam Yousif Abdalla[1]
T.T. Hlatshwayo[1], E.G. Njoroge[1], M. Mlambo[1], M.Y.A. Ismail[1], E. Wendler[2], J.B. Malherbe[1]

[1]Department of Physics, University of Pretoria, Pretoria 0002, South Africa
[2]Institut für Festkörperphysik, Friedrich-Schiller Universität, Ch07743 Jena, Germany

Email: zaki.abdalla@up.ac.za

Key words: diffusion, ion implantation, polycrystalline SiC, recrystallization

Diffusion of selenium (Se) implanted into polycrystalline SiC was investigated using Rutherford backscattering spectrometry (RBS), scanning electron microscopy (SEM) and Raman spectroscopy. Se ions of 200 keV were implanted into polycrystalline SiC wafers to a fluence of 1×10^{16} cm^{-2} at three different temperatures, room temperature. The implanted samples were annealed at temperatures ranging from 1000 to 1500 °C in steps of 100 °C for 10 hours. Implantation of Se at room temperature amorphized the near surface region of both the SiC substrates, while at high temperatures (350 °C and 600 °C) the crystal structure is retained, albeit with a high degree of distortions at 350 °C. Annealing at 1000 °C resulted in the recrystallization of the amorphized SiC layer. In the case of room temperature, diffusion was observed to occur after annealing at 1300 °C and became significant with an increase in annealing temperature. The diffusion was accompanied by a peak shift towards the surface and loss of implanted Se. In either 350 °C or 600 °C, no diffusion of selenium was observed, but the peak shift towards the surface and slight loss of ions began after annealing at 1200 °C. Diffusion was estimated from the peaks broadening of the implantation profiles after isochronal annealing using RBS analysis. Retained damage and annealing of radiation damage were investigated by Raman spectroscopy and SEM.

References
[1] E. Friedland, T. Hlatshwayo, and N. van der Berg, Phys. Status Solidi, 10, 208–215 (2013).
[2] J.B. Malherbe, P.A. Selyshchev, O.S. Odutemowo, C.C. Theron, E.G. Njoroge, D.F. Langa and T.T. Hlatshwayo, Nucl. Instruments Methods Phys. Res. Sect. B Beam Interact. with Mater. Atoms, 406, 708–713 (2017).
[3] J.B. Malherbe, N.G. Van Der Berg, R.J. Kuhudzai, T.T. Hlatshwayo, I. Festkörperphysik, and F. Jena, Nucl. Inst. Methods Phys. Res. B. 354, 23-27 (2015).
[4] S. Nakashima and H. Harima, Phys. Stat. Sol., 162, 39–64 (1997).
[5] E. Wendler *et al*., Nucl. Inst. Methods Phys. Res. B. 286, 97–101 (2012).

P 1-38

Comparison of the Optical Properties Degradation of Oxide Micro- and Nanopowders Irradiated by 100 keV Protons

Victoria Iurina[2]
Mikhail Mikhailov[1], Vitaly Neshchimenko[2], Chundong Li[3]

[1]Radiation and Space Materials Laboratory, Tomsk State University of Control Systems and Radio-Electronics, Tomsk 634050, Russia
[2]Space Materials Laboratory, Amur State University, Blagoveshchensk 675027, Russia
[3]Key Laboratory of Science and Technology on Material Performance Evaluating in Space Environment, Harbin Institute of Technology, Harbin, Heilongjiang Province 150001, China

Email: viktoriay-09@mail.ru

Key words: nanopowders, metal oxide, irradiation, proton

White oxide powders are components of ceramic and enamel coatings, which are often used in aggressive conditions, including ionizing radiation exposure. The search radiation resistant pigments for paints are an urgent problem. It was previously established that the particle size and surface morphology affects to radiation resistance of particles [1-3]. The purpose of this paper is a comparative analysis of diffuse reflectance spectra of micro- and nanopowders of the Al_2O_3, CeO_2, TiO_2, Y_2O_3, ZrO_2, ZnO and their changes after irradiation by protons. Herein, the concentration of induced absorption centers in various oxide powders is analyzed and compared with each other by the solar absorptance. It has been established that, in addition to particle size and surface morphology, the degree of optical properties degradation is affected by the symmetry of the crystal lattice and the position of defect levels in the band gap.

References

[1] Li Chundong, Mikhailov M.M., Neshchimenko V.V., Nuclear Instruments and Methods in Physics Research Section B, 319, 123-127 (2014).
[2] Mikhailov M.M., Li Chundong, Neshchimenko V.V., Nuclear Instruments and Methods in Physics Research Section B, 333, 52-57 (2014).
[3] Neshchimenko V.V., Li Chundong, Mikhailov M.M., Lv Jinpeng, Nanoscale, 10(47). 22335-22347 (2018).

P 1-39

Effect of Proton Irradiation on the Optical Properties of Coating Based On ZnO Powder and Liquid K_2SiO_3

Vadim Karanskiy
Alexey Lapin, Semyon Yuryev, Mikhail Mikhailov

Radiation and Space Materials Laboratory, Tomsk State University of Control Systems and Radio-Electronics, Tomsk 634050, Russia

Email: membrana2010@mail.ru

Key words: zinc oxide, potassium silicate, optical properties, irradiation, proton

In outer space, the spectra of protons and electrons affect the materials of external surfaces. To determine the degradation of the performance properties of materials, it is necessary to know their dependence on the particle energy. The paper presents the results of the study of diffuse reflectance spectra ($\rho\lambda$) in the range of 0.3–2.2 μm and integral absorption coefficient of solar radiation (a_S) of the coating consisting of zinc oxide powder and K_2SiO_3 liquid glass after irradiation with protons.

Irradiation was carried out at proton energies of 1-3 keV, corresponding to the proton energy in the solar wind plasma. Proton flux was $\varphi = 1\times10^{11}$ cm^{-2}/s in the range of fluences (F) $10^{13}\div10^{15}$ cm^{-2} in vacuum 1×10^{-5} Pa at a hydrogen pressure of 4×10^{-3} Pa at a temperature of 300 K. The following features of changes in the spectra of diffuse reflectance ($\Delta\rho\lambda$) and absorption coefficient (Δa_S) are established:

1. In the spectra of $\Delta\rho\lambda$, the absorption band is recorded with a maximum at 420 nm, which is determined by the formed displacement and ionization defects. The band is not symmetrical, with a prolonged long-wave front, which indicates its non-elementary character, determined by several components [1].

2. Depending on F of protons, the values of Δa_S increase with saturation.

3. An explanation is given of the obtained dependences of the degradation of optical properties based on the concepts of the theory of defect formation in the interaction of protons with a solid.

References

[1] Vitaly Neshchimenko, Chundong Li, Mikhail Mikhailov and Jinpeng Lv, Optical radiation stability of ZnO hollow particles, Nanoscale, 10, 22335-22347 (2018).

P 1-40
Influence of High-Intense Ion Pulses on Tungsten Surface Erosion

Vitaliy Shymanski[1]
V.V. Uglov[1,2], V.S. Pigasova[1], V.M. Astashynski[3], A.M. Kuzmitski[3], H.W. Zhong[4], S.J. Zhang[4], X.Y. Le[4]

[1]Belarusian State University, Nezavisimosty ave. 4, Minsk 220030, Belarus
[2]Tomsk Polytechnic University, Lenina ave. 30, Tomsk 634050, Russia
[3]A.V. Luikov Heat and Mass Transfer Institute of National Academy of Science of Belarus, P.Brovki str. 15, Minsk 220072, Belarus
[4]Beihang University, Xueyuan rd. 37, Beijing 100191, China

Email: shymanskiv@mail.ru

Tungsten is considered as a main plasma facing material for ITER and DEMO because of its low sputtering yield, high melting point and high thermal conductivity. During the operation of a fusion reactor the tungsten-contained parts will be subjected to high thermal influences and mechanical loads during the plasma disruptions and the plasma direct interaction with the first-wall material. Besides, the tungsten will be irradiated with neutrons or different ions, like helium, deuterium, tritium, that are produced in the thermonuclear reactions. A lot of radiation effects like blistering, flecking or bubbles formation take place during the irradiation.

In the present work the tungsten surface erosion is investigated by means of high-intense pulsed ion beams generated in the BIPPAB-450 accelerator. Every pulse with duration of 100 ns and absorbed energy density about 3 J/cm^2 changes the structure of the surface layer. The considered changes deal with grain size modification, defect density increase and carbon accumulation in the sub-surface layer. So, the mechanisms of surface erosion will be changed after every pulse.

The samples investigated in the work were tungsten plates with sizes 10 per 10 mm and thickness of 3 mm. Every sample was treated by high-intense ion beam with the absorbed energy density of 3 J/cm^2. The pulse number was changed from 1 to 15. Another series of the samples was preliminary treated by compression plasma flows with the absorbed energy density of 50÷70 J/cm^2 and pulse duration of 100 μs. Such type of the treatment provides surface melting and solidification that, in turn, modifies the structure and mechanisms of surface erosion after ion beam impact.

P 1-41

Effect of Ni ion irradiation on mechanical properties of Ni-Fe single crystal alloys

Edyta Wyszkowska[1]
Ryszard Diduszko[2], Łukasz Kurpaska[1], Piotr Dłużewski[3], Iwona Cieślik[1], Jacek Jagielski[1,2]

[1]Material Physics Department, National Centre for Nuclear Research, st. Andrzeja Soltana 7, Otwock-Swierk 05-400, Poland
[2]Institute of Electronic Materials Technology, Wolczynska 133, Warsaw 01-919, Poland
[3]Institute of Physics Polish Academy of Sciences, Al. Lotnikow 32/46, Warsaw 02-668, Poland

Email: edyta.wyszkowska@ncbj.gov.pl

Understanding impact of radiation effects on structural materials designated to be used as components in Generation IV nuclear reactors is essential in order to assess their reliability to operate in harsh conditions [1]. Therefore, materials resistant to high temperature and fast spectrum of neutron flux are highly desired for such applications [1-3]. Single crystal Ni-Fe based alloys seem to be promising candidates due to exceptional mechanical properties and very high radiation tolerance [2].

In this study, face-centered cubic Ni-xFe single crystalline alloys with different additions of Fe (from 12 ÷ 62 at.%) and pure Ni single crystal have been irradiated with 1 MeV Ni ions. Ion irradiation campaign have been performed over a wide range of fluences from 3×10^{13} to 1.45×10^{15} cm^{-2} at room temperature. Afterwards, Transmission Electron Microscopy has been utilized to study the types of defects and their concentration in the function of ion fluences. Reported studies revealed decrease in the number of defects such as dislocation loops and vacancies with increasing Fe addition. This phenomenon is related to their efficient recombination in the chemically disordered alloys. It has been postulated that this phenomenon is related to the interstitials mobility and their tendency to form clusters. Finally, in order to prove structural data, nanoindentation technique has been applied in order to record mechanical changes such as hardness and Young Modulus as a function of irradiation fluence. Conducted studies show irradiation-induced hardening effect, which was related to the amount of radiation defects, their mobility and size.

References

[1] Mohammad W. Ullah, Dilpuneet S. Aidhy, Yanwen Zhang, William J. Weber. Acta Mater. 109 (2016) 17-22.
[2] Ke Jin, Wei Guo, Chenyang Lu, Mohammad W. Ullah, Yanwen Zhang, William J. Weber, Lumin Wang, Jonathan D. Poplawsky, Hongbin Bei. Acta Mater. 121 (2016) 365-373.
[3] K. Jin, H. Bei, Y. Zhang. J. Nucl. Mater 471 (2016) 193-199.

SMMIB-2019

21ST INTERNATIONAL CONFERENCE
ON SURFACE MODIFICATION OF MATERIALS BY ION BEAMS
25-30 August 2019
Tomsk, Russia

Session 2
Ion-Assisted Coating Deposition

Invited Talk

I 2-1
Plasma Source Ion Implantation: from Research Setups to Large-Scale Industrial Applications

Koumei Baba[1,2]
R. Hatada[3], S. Flege[3], E. Furuta[2], W. Ensinger[3]

[1]SANNO Co., Ltd., Yokohama, Japan
[2]Fine Coating Co., Ltd., Omura, Japan
[3]Technische Universität Darmstadt, Germany

Email: babakoumei@gmail.com

The presentation will give an overview of our research on plasma source ion implantation (PSII) and the subsequent applications to 3D coating of industrial samples.

Initial setups with extra plasma sources (RF, ICP) were suitable for tasks such as implantation of nitrogen. When the focus shifted to deposition of diamond-like carbon (DLC) films, the setup was simplified, i.e. the voltage applied to the sample generated the plasma. The lower deposition rate could be compensated by superposing a high voltage pulse and a DC voltage. Additional advantages were an improved film adhesion and a higher hardness of the films.

For some applications, special approaches were developed. This includes the combination with magnetron sputtering to deposit metal-DLC films. Samples with peculiar geometries, e.g. tubes (1300 mm length or diameter of 0.5 mm), were successfully treated on their interior using a microwave plasma of 2.45 GHz. Anatase TiO_2 films were prepared using a liquid type precursor, titanium tetraisopropoxide, and by conversion of a titanium surface by the implantation of carbon and subsequent annealing in air.

The experience with the PSII process was transferred to a company. At first, a vacuum chamber with 1.3 m diameter and 1.8 m length was put into service. To accommodate bigger samples and to be able to treat many samples simultaneously, a larger chamber of 1.9 m diameter and 3.5 m length was commissioned recently. Applications include coatings of blades used for meat cutting, of drills, solar cells, touch panels, wafer polishing carriers and of transport guide parts for cans. The deposition conditions were optimized to ensure a homogeneous coating of the samples.

I 2-2
Metal Coatings Deposition Using Hot Target Magnetrons

Valery Krivobokov
Galina A. Bleykher, Alena V. Yuryeva, Dmitrii V. Sidelev

National Research Tomsk Polytechnic University, 30 Lenin ave., Tomsk 634050, Russia

Key words: hot target, magnetron sputtering, metal coatings

Email: krivobokov@tpu.ru

Magnetron sputtering is a widely used tool for deposition of thin films. Apart from advantages, there is a strong drawback - low productivity, even for metal coating deposition [1,2]. This is caused by use of sputtering as a single mechanism of erosion of the target material. For modern coating technologies higher range of deposition rates is needed. So, evaporation (sublimation) of target material can be used as additional erosion mechanism for magnetron sputtering systems and sputtered target should be heated up to elevated temperature or melting point [3-5]. To heat target material, gas discharge plasma of magnetron diode can be used in the case of thermal insulation of the target from cooled magnetron body and magnetic system. The change of power density of discharge plasma delivered to the target and the construction of magnetron diode allow to vary a target temperature and the deposition rates.

In present work, we will describe the design of a magnetron sputtering system with a hot target, which is enable to operate with 2 times and higher productivity than classical magnetrons (with cooled target). Both calculated and experimental data of deposition rates and energy fluxes to the substrate for the deposition of metal coatings will be presented and discussed in detail for such coatings as copper, tin, aluminum, chromium and nickel. Application and future prospects of magnetron sputtering with hot target will be considered.

References:

[1] Bräuer G., Szyszka B., Vergöhl M., Bandorf R., Vacuum, 84, 1354-1359 (2010).
[2] Sidelev D.V., Bleykher G.A., Krivobokov V.P., Koishybayeva Z., Surface & Coatings Technology, 308, 168-173 (2016).
[3] Bleykher G.A., Borduleva A.O., Krivobokov V.P., Sidelev D.V., Vacuum, 132, 62-69 (2016).
[4] Bleykher G.A., Krivobokov V.P., Yurjeva A.V., Sadykova I., Vacuum, 124, 11-17 (2016).
[5] Bleykher G.A., Krivobokov V.P., Yuryeva A.V., Technical Physics, 60, 1790-1795 (2015).

I 2-3
Pulsed High-Power Discharge and Arc for Deposition of Carbon Based Films

Xiubo Tian[1]
Chunzhi Gong[1], Bing Chen[1], Houpu Wu[1], Ronghua Wei[2]

[1]State Key Laboratory of Advanced Welding & Joining, Harbin Institute of Technology, Harbin 150001, China
[2]Southwest Research Institute, San Antonio, Texas 78238, USA

Email: xiubotian@163.com

Key words: pulsed discharge/arc, power supply, Si-DLC, ta-C

High-power pulsed discharge or high-current pulsed arc has been utilized to fabricate carbon-based films (including Si-DLC, ta-C, etc.). High power discharge or arc is featured by high density plasma, elevated ion-energy, high deposition rate and good adhesion between film and substrate. Many studies have confirmed that higher plasma density is very critical for optimal microstructure and surface properties. The high-density plasma may be achieved by larger target current, however it may easily give rise to more macroparticles and the contamination of the films. A hybrid power supply (combining DC and pulse) has been developed with peak current from 200 A to 1200 A. A Ta-C films has been deposited. In addition, a high-current pulser (5 kV, 200 A) has also been manufactured to fabricated Si-DLC with a higher deposition rate and decreased internal stress of the films. The OES analysis has shown that spectral intensity is greatly enhanced with pulsed arc mode. The substrate current has been substantially increased by pusled arc mode with the same average target current. It means much higher plasma density near the substrate, which produces the denser microstructure. A thicker (>40 μm) DLC film has also been deposited using high-current pulsed discharge. The pulsed discharge/arc has proven to be a versatile tool to fabricate the films with denser structure, good adhesion and higher resistance of wear resistance, etc. In this presentation, we will describe the design conceptions of our power supply and practical coatings using specially designed pulse configuration.

I 2-4

Generation of «Unusual» Ion Beams Based on Discharge Systems of Vacuum Arc and Hollow Cathode Glow

Efim Oks[1,2]

[1]Department of Plasma Sources, High Current Electronics Institute (HCEI), Tomsk 634055, Russia
[2]Department of Physics, Tomsk State University of Control Systems and Radioelectronics (TUSUR), 634050, Russia

Email: oks@opee.hcei.tsc.ru, oks@fet.tusur.ru

Key words: vacuum arc, hollow cathode glow, ion beam, multiply charged ions, boron ions, deuterium ions

The report provides a review of recent results on the development and improvement of some ion sources for the modification of materials. Works are carried out in the joint research team of two Tomsk research organizations: HCEI and TUSUR. Research attention is focused to the generation of «unusual» ion beams in traditional ion sources based on vacuum arc and discharge with a hollow cathode. Presented results are the following:

- the processes of multiple ionization in an arc plasma and the generation of intense beams of multiply charged metal ions;
- generation of boron ions in the discharge systems of the arc discharge and planar magnetron in the self-sputtering mode;
- generation of deuterium ions in arc discharge with a gas-saturated cathode, as well as in a glow discharge with a hollow cathode;
- generation of tri-atomic ions of hydrogen, deuterium and formation of ion beams on the basis of a hollow-cathode discharge.

We will also present the parameters and characteristics of the ion beams obtained, as well as some examples of the possible applications of such ions.

Oral Presentation

O 2-1
Magnetic Field Induced Ion Motion in Vacuum Arc Deposition for Interior Surfaces

Tiancheng Wang
Hongfei Shang, Tianmin Shao*

State Key Laboratory of Tribology, Department of Mechanical Engineering, Lee Shau Kee building, Tsinghua University, Haidian District, Beijing 100084, China

Email: shaotm@tsinghua.edu.cn*

Key words: inner surface, vacuum arc depositing ion, magnetic field, spatial trajectory simulation

In multiple industrial application areas, the interior surfaces of tubular work pieces are usually exposed to failure due to wear, corrosion and oxidation, where modification to improve surface quality is urgently needed [1,2]. Vacuum cathodic arc deposition (VAD) is a widely applied coating technology for fabricating hard, wear-resistant and anti-corrosion coatings because of low deposition temperature and high ionization degree (60÷80%) as well as plasma density (10^{10}÷10^{12}/cm^3) [3]. However, the deposited coatings become thinner along inner tube surface and even hardly found while the depth exceeding the tube diameter [4]. Researches showed magnetic field could influence the transmission of cathodic plasma [5-7]. The ratio of coating depth to diameter for deposited TiN improved to 3:1÷6:1 with 50%÷80% decline of coating thickness under coil magnet field enhancement [6,7]. But the mechanism of improving coating depth and uniformity still remains to be further discovered.

Numerical simulation of magnetic field induced motion of Titanium ions generated by vacuum arc depositing into tubular work piece was conducted. First, magnetic field generated by an adjustable coil around a tube piece coaxial with arc target was simulated. Second, the spatial trajectories of Titanium ions under magnetic field were then obtained. The effect of magnetic field intensity on ion movement was discussed. Meanwhile the role which coil spatial location played was evaluated. Besides, the influence of work piece size was investigated as well. The rate and depth of deposited ions were calculated as criteria to optimize the parameters mentioned above.

Within the limit of this research, it is revealed that ion deposition rate and depth increases when the coil is closer to the arc target than the tube, and a range of magnetic field intensity providing better deposition results was found.

References
[1] Vyskocil J., Musil J. Journal of Vacuum Science & Technology A, 10(4), 1740-1748 (1992).
[2] Boxman R.L., Zhitomirsky V.N. Review of Scientific Instruments, 77(2), 49-27 (2006).
[3] Anders A., Anders S., Jüttner B. *et al*., IEEE Transactions on Plasma Science, 20(4), 466–472 (1992).
[4] Shi C.L., Zhang M., Lin G.Q. Vacuum Science and Technology, 27, 517 (2007).
[5] Boxman R.L., Beilis I.I. *et al*., IEEE Transactions on Plasma Science, 33(5), 1618-1625 (2005).
[6] Lang W.C. *et al*., Applied Mechanics and Materials, 152-154, 1705-1710 (2012).
[7] Zhao Y., Guo C. *et al*., Vacuum, 112, 46-54 (2015).

O 2-2

Study of Specifics in Nanolayer Composite Coating Formation Using Filtered Cathodic Vacuum Arc Deposition (FCVAD) Technology

Alexey Vereschaka[1]
Sergey Grigoriev[1], Nikolay Sitnikov[2], Filipp Milovich[3]

[1]Moscow State Technological University STANKIN, 1 Vadkovsky lane, Moscow 127994, Russia
[2]National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), 31 Kashirskoe shosse, Moscow 115409, Russia
[3]National University of Science and Technology MISIS, 4 Leninsky ave., Moscow 119049, Russia

Email: dr.a.veres@yandex.ru

The paper discusses the methods of forming coatings with nanolayer structures, including nanolayers (with thicknesses of 20÷100 nm), that, in turn, contain subnanolayers (with thicknesses of 2÷20 nm). In particular, Ti-TiN-(Ti,Al,Si)N and Zr-ZrN-(Zr,Cr,Al,Si)N coatings were considered. The SEM and TEM methods were used to investigate the structures of the coatings. The study revealed the relationship between nanolayer and subnanolayer thicknesses, as well as the pattern of the homogenization in the coating structure, and the planetary rotation speed of the turntable. The mechanism of the coating destruction in scratch testing was considered, depending on the thicknesses of nanolayers and subnanolayers. The investigation included cutting tests for carbide tools with the coatings under study in turning C45 steel at f = 0.25 mm/rev, a_p =1.0 mm, v_c =300 and 350 m/min. The patterns of wear and destruction of the coated tools and the oxidation and diffusion processes were investigated. As a result of the conducted investigations, a range of optimal nanolayer thicknesses has been determined, which makes it possible to increase cutting speed while maintaining the tool life period and high quality of the machined surface.

O 2-3

Microstructures and Optoelectronic Properties of NiO Films Deposited by High Power Impulse Magnetron Sputtering

Hui Sun[1,2]
Wei-Tao Zheng[1], Sheng-Chi Chen[3,4], Tsung-Yen Kuo[5], Kun-Lun Wang[2], Shu-Mei Song[2]

[1]Department of Materials Science, Jilin University, Changchun 130012, China
[2]School of Space Science and Physics, Shandong University at Weihai, Weihai 264209, P. R. China
[3]Department of Materials Engineering and Center for Plasma and Thin Film Technologies, Ming Chi University of Technology, Taipei 243, Taiwan
[4]College of Engineering, Chang Gung University, Taoyuan 333, Taiwan
[5]Institute of Materials Science and Engineering, National Taiwan University, Taipei 106, Taiwan

Email: huisun@sdu.edu.cn

Key words: NiO films, p-type conductivity, HiPIMS

Within a few intrinsic p-type transparent conductive oxides (TCOs), NiO with wide bandgap is a promising candidate. Due to its resource availability, low production cost and non-toxicity, NiO film can be employed in various fields. In order to clarify the p-type conductivity mechanism of NiO, a series of work has been reported. Nandy *et al*. reported that the p-type conductivity of NiO maybe derive from the conversion of Ni^{2+} to Ni^{3+} under oxygen-rich conditions [1]. In this process, Ni vacancies and holes are associated, resulting in an increment in carrier concentration and film's conductivity.

Recently, the high power impulse magnetron sputtering (HiPIMS) technology developed on the basis of conventional magnetron sputtering has attracted people's attention because of its extremely high target ionization rate [2]. The high target ionization rate of this technology is beneficial to increase Ni^{3+} content level during the film's formation, thereby improving the probability of the generation of Ni vacancies, which in turn enhances the film's p-type conductivity. In the current work, the influence of oxygen flow ratio on the microstructural and optoelectronic properties of NiO films deposited by HiPIMS technology was studied. The results show that, compared with DC magnetron sputtering, NiO films deposited by HiPIMS technology possess better electrical properties. In addition, the films resistivity significantly reduces with increasing the oxygen flow ratio.

References

[1] Nandy S., Saha B., Mitra M.K., Chattopadhyay K.K., Journal of Materials Science 42, 5766-5772 (2007).
[2] Kouznetsov V., Macak K., Schneider J.M., Helmersson U., Petrov I., Surface and Coating Technology 122, 290-293 (1999).

O 2-4
Nickel and Chromium Deposition by Hot Target Magnetron Sputtering

Dmitry Sidelev[1]
Galina A. Bleykher[1], Vladislav A. Grudinin[1], Valery P. Krivobokov[1], Massimiliano Bestetti[2]

[1]National Research Tomsk Polytechnic University, Tomsk 634050, Russia
[2]Politecnico di Milano, Milano 20133, Italy

Email: sidelevdv@tpu.ru

Key words: hot target, magnetron sputtering, Cr and Ni coatings

Magnetron sputtering is a well-known technique for surface modification [1]. This is applied for deposition of metal (including magnetic), oxide, nitrides coatings and many other. Apart from high reproducibility, thickness uniformity, good adhesion, wide variety of deposition parameters, some drawbacks of magnetron sputtering systems are significantly limited their technological capabilities and application. Mainly, the weaknesses are low deposition rate (concerning to evaporation) and low efficiency of magnetic materials sputtering. These problems can be eliminated by using of magnetron sputtering system with hot target. In this case, magnetron target significantly heats by bombarding ions and sublimation particle flux additional to sputtering can be formed [2]. For magnetic materials, this approach provides the transition of target material from to paramagnetic state, if the target temperature will be higher the Curie point [3].

Now, the main interest is devoted to study of target type (hot or cooled) of magnetron sputtering system on properties of deposited coatings. On the one hand, the deposition rate (from 1÷5 to 10÷50 nm/s) and distribution of particle flux over pulse period significantly change. On the other hand, additional heat flux due to target radiation results in higher energy per one deposited atom on substrate (increase from 3÷7 to 20÷40 eV/atom). Thus, the crystal structure, microstructure, mechanical properties (hardness, adhesion), corrosion resistance of coatings were studied in these conditions and depending on target type and deposition parameters.

References
[1] Bräuer G., Szyszka B., Vergöhl M., Bandorf R., Vacuum, 84, 1354-1359 (2010).
[2] Sidelev D.V., Bleykher G.A., Krivobokov V.P., Koishybayeva Z., Surface & Coatings Technology, 308, 168-173 (2016).
[3] Sidelev D.V., Bleykher G.A., Grudinin V.A., Krivobokov V.P., Bestetti M., Syrtanov M.S., Erofeev E.V., Surface & Coatings Technology, 334, 61-70 (2018).

O 2-5

Influence of Ion-Plasma Assistance on the Composition, Structure and Properties of Wear-Resistance Nitride Coatings

Olga Krysina
V.V. Shugurov, N.A. Prokopenko, S.S. Kovalsky, N.N. Koval

Institute of High-Current Electronics SB RAS, 2/3 Akademichesky ave., Tomsk, Russia

Email: krysina_82@mail.ru

Vacuum arc deposition of wear-resistant nitride coatings was carried out in the mode of ion-plasma assistance by an original source of gas-discharge plasma (IHCE SB RAS, Tomsk, Russia) [1]. It is shown that changing a share of nitrogen ions in generated gas-metal plasma by the simultaneous work of a gas plasma source and arc evaporator at constant operating pressure leads to change the concentration of nitrogen in synthesized nitride coatings. It, in turn, leads to change of elemental and phase composition, structure of the coatings and their main properties. The varied parameter is the relation of ion current density on a substrate of gas and metal components of the plasma, i.e. current of gas plasma source. Change of discharge current is a quick-response (<1 ms) process therefore this effect can be used at deposition of multilayered coatings of metal/nitride system with high repeatability of thickness and composition of layers. On the example of single-layer nitride coatings, such as ZrN and ZrNbN, the possibility of their elemental composition and characteristics control by change of a share of nitrogen ions in gas-metal plasma is shown. The dependences of nitrogen concentration, phase structure, physical, mechanical and tribotechnical properties of these coatings on composition and parameters of gas-metal plasma are revealed. On the example of Zr/ZrN and Zr/ZrNbN systems the possibility of formation of multilayered metal/nitride system coatings by a new quick-response method with the use of the ion-plasma assistance modes is shown.

The work was supported by the Russian Science Foundation (project #18-79-10111).

References

[1] Vintizenko L.G. *et al*. 2001 Russ. Phys. J. 44 927.

O 2-6

Generation of Beam Plasma Formations in a Non-Self-Sustained Glow Discharge with a Hollow Cathode for Ion Nitriding of Steels

Vladimir Denisov[1]
Nikolay Koval[2], Evgeny Ostroverkhov[1], Ilya Lopatin[2], Yulia Denisova[1]

[1]Laboratory of Beam-Plasma Surface Engineering, Institute of High Current Electronics, Tomsk 634055, Russia
[2]Laboratory of Plasma Emission Electronics, Institute of High Current Electronics, Tomsk 634055, Russia

Email: denisov@opee.hcei.tsc.ru

Key words: non-self-sustained discharge, ion nitriding, plasma inhomogeneity, low pressure plasma

Ion nitriding is mostly realized in the plasma of anomalous glow discharges at a pressure of 50÷1000 Pa [1]. However, it was shown that the plasma of arc and glow discharges [2] and beam plasma at ≈1 Pa [3] provide faster nitriding. The problem is to generate plasma at low pressure in sufficiently large volumes. The generation of a homogeneous plasma in large vacuum volumes can be provided in a hollow-cathode glow discharge [4] and in its non-self-sustained mode with external electron injection [5]. The plasma synthesized in hollow cathode glow discharge with external electron injection by the method of its generation can be attributed to beam-plasma formations. In this study we analyze how the operating parameters of a steady and a quasi-steady low-pressure hollow-cathode glow discharge with a current of up to several hundred amperes influence on the plasma inhomogeneity.

Investigations were conducted in a vacuum chamber in which the inner walls formed a hollow cathode with a volume of 0.2 m^3 and surface area of 2.3 m^2 for the main glow discharge. The operating pressure was controlled in the range 0.4÷1.0 Pa through gas supply. The glow discharge was ignited between the hollow cathode and plane anode. The ratio of the anode and cathode areas was $S_a/S_c = 1/74$.

It was concluded that for pulsed operation in nitrogen at a pressure of 1 Pa, discharge current of 50÷130 A, and voltage of 100÷250 V the electron temperature is about 1 eV and the plasma potential is up to 1 V. At a current of 100 A, the plasma density at the chamber center is 10^{18} m^{-3} and ion current density is up to 10 mA/cm^2.

The plasma of this type of discharge becomes more homogeneous at lower pressure, higher discharge voltage, higher discharge current and hence higher plasma density, and smaller anode-to-cathode area ratio with its optimum value $S_a/S_c \approx (2m_e/M)^{1/2}$, all other thing being equal. In argon, the azimuthal distribution is more round compared to its form in pure nitrogen.

The plasma of non-self-sustained discharge was used for investigation of ion nitriding process parameters influence (ion current density, electrical bias voltage) on the regularities of structure and phase composition formation in the surface layer of die steels. Studies of the influence of the structure and phase composition of the surface layer on the physico-mechanical characteristics (wear resistance, microhardness) of steels were carried out.

The work was supported by the Russian Foundation of Basic Research (project #19-08-00370).

References

[1] Rie K-T., Surf. Coat. Technol., 112, 56-62 (1999).
[2] Schanin P. M., Koval N. N., Goncharenko I. M. and Grigoriev S. V., Physics and Chemistry of Materials Treatment, 3, 16–19 (2001).
[3] Walton S.G., Muratore C., Leonhardt D., *et al.*, Surf. Coat. Technol., 186, 40–46 (2004).
[4] Metel A.S., Sov. Phys. Tech. Phys., 29(2), 141–144 (1984).
[5] Oks E.M., Vizir A.V., and Yushkov G.Yu., Rev. Sci. Instrum., 69, 853 (1998).

O 2-7
RF-Magnetron Sputtering of Calcium Phosphates for Medical Implants: Structure and Properties

Yury Sharkeev[1,2]
K. Prosolov[1,2], A. Bolat-ool[1,2], O. Belyavskaya[1]

[1]Institute of Strength Physics and Materials Science of SB RAS, 2/4 Akademichesky ave., Tomsk 634055, Russia
[2]National Research Tomsk Polytechnic University, 30 Lenin ave., Tomsk 634050, Russia

Email: sharkeev@ispms.tsc.ru

A significant part of the medical devices market is comprised of bone fixation devices. Multidisciplinary groups are focused on the increase in bone fixation implants service life and enhance in performance. In order to address those challenges, bioinert metals and alloys that are used in implantology undergo surface modifications by a coating deposition stage. Hydroxyapatite (HA) is the main constituent of the bone tissue and calcium phosphates (CaPs) in general were recognized to be effective as a coating material for devices used in implantology. The physical vapor deposition is gaining more attention as a method for bioactive coatings manufacturing. Radio frequency (RF) magnetron sputtering is one of the methods that allows deposition of bioactive CaPs coatings in a highly controllable manner. In a plasma environment, it is possible to synthesize nanostructures of various sizes and shapes, with a controlled surface density, with the desired geometric parameters and a deterministic distribution function of structures in size. Moreover, RF magnetron sputtering allows to preserve or manipulate the phase and elemental composition of coatings by variation of process parameters. We are aiming to deposit coatings with different crystallinity state in order to be able to manipulate the bioresorption rate for on-demand application in various clinical cases. Moreover, deposition of biphasic calcium phosphates could not only allow the manipulation of bioresorption rate but also change physicomechanical properties of the coatings. Recently, significant efforts were made to deposit Zn substituted HA coatings with an antibacterial effect.

O 2-8

Microstructure, Fatigue Strength and Erosion Resistance of MAX-Phase Embedded Ti-Si-B Nanostructured Coatings on Ti-6Al-4V

Oksana Bytsenko[1]
I.G. Steshenko[1], V.A. Shulov[2,*], A. I. Raybchikov[3], D.A. Teryaev[2]

[1]Chernyshev Machine Building Enterprise, 7 Vishnevaya st., Moscow 123362, Russia
[2]Moscow Aviation Institute (National Research University), 4 Volokolamskoye Shosse, GSP-3, A-80, Moscow 125993, Russia
[3]National Research Tomsk Polytechnical University, 30 Lenin ave., Tomsk, 634050 Russia

Email: shulovva@mail.ru*

Key words: MAX-phase, fatigue strength, nanostructured coatings

Ti-Si-B nanostructured coatings were deposited on Ti-6Al-4V substrates by vacuum plasma processing with droplet separation and ion implantation in the Raduga-6 accelarator. A composite Ti-Si-B cathode fabricated by self-propagating high temperature synthesis with subsequent hot pressing was used. The microstructure and mechanical properties of the obtained coatings were analysed by applying Auger-electron spectroscopy, X-ray diffraction and scanning electron microscopy methods accompanied by hardness measurements, fatigue strength and erosion resistance testing. It was established that Ti-Si-B nanostructured coating deposition leads to significant improvement of fatigue strength and erosion resistance of Ti-6Al-4V. A noticeable raise of the fatigue strength is attributed to presence of low dispersed Ti_3SiB_2 MAX-phase inclusions that suppress fatigue crack propagation.

O 2-9

Influence of Combined Nitrogen Implantation on Adhesion Strength of TiAlN Film on TiAl Alloy

Yulei Yang
Tianmin Shao*

State Key Laboratory of Tribology, Tsinghua University, Beijing 100089, China

Email: shaotm@tsinghua.edu.cn*

Key words: ion implantation, adhesion strength, TiAlN film, γ-TiAl alloy

γ-TiAl alloys are attractive for high temperature applications in view of their high specific strength and oxidation resistance. However, poor tribological behavior and inadequate oxidation resistance at temperature above 850 °C are still challenging factors for their application [1,2]. A variety of films has been developed to combat wear and oxidation of γ-TiAl alloys [3,4]. Spalling of films may occur due to adhesion problem induced by film-substrate mismatch in thermal expansion and mechanical properties under various service condition [2,5].

Nanometer TiAlN films was deposited on γ-TiAl alloy followed by nitrogen implantation, to create a mixed transition zone and form chemical bonding between the film and substrate, and the ultimate TiAlN film deposition of 1μm thickness. TiAlN film was deposited via Ion Bea Assisted Deposition (IBAD) at a sputtering voltage of 2.5 kV. Nitrogen implantation was carried out by a Kaufman ion source at accelerating voltage of 10÷40 kV with the dose of 1×10^{17} atoms/cm^2. All the mentioned implantation and deposition process were finished in one chamber without breaking the vacuum. Adhesion strength of the TiAlN film produced was evaluated by scratch test and compared with that of TiAlN film deposited by direct IBAD.

The combination of nitrogen implantation improves adhesion strength of TiAlN film deposited on γ-TiAl alloy, as a result of the mixed transition zone and film-substrate chemical bonding formed by the nitrogen implantation process.

References

[1] Dong H., Surface Engineering of Light Alloys, 58-80 (2010).
[2] Pflumm R., Friedle S., Schutze M., Intermetallics, 56, 1–14 (2015).
[3] Chu M.S., Wu S.K., Acta Materialia, 51, 3109-3120 (2003).
[4] Walker J.C., Ross I.M., Reinhard C., Wear, 267, 965-975 (2009).
[5] Sarkar S., Datta S., Das S., Surface & Coatings Technology, 203, 1797-1805 (2009).

O 2-10
Effect of Glancing Angle Deposition to the Morphology of Calcium Phosphate Thin Coatings

Konstantin Prosolov[1,2]
O. Belyavskaya[1], J. Rau[3], Yu. Sharkeev[1,2]

[1]Institute of Strength Physics and Materials Science of SB RAS, 2/4 Akademichesky ave., Tomsk, 634055, Russia
[2]National Research Tomsk Polytechnic University, 30 Lenin ave., Tomsk 634050, Russia
[3]Istituto di Struttura della Materia, Consiglio Nazionale delle Ricerche (ISM-CNR), via del Fosso del Cavaliere 100, Roma 00133, Italy

Email: konstprosolov@gmail.com

It has been widely accepted that the surface morphology, chemical composition, wettability, and surface potential play an important role in cell adhesion and proliferation. Surface modification by deposition of calcium phosphate coatings is recognized to increase the overall performance of the implants. In order to enhance cell adhesion and osteointegration, a significant effort was paid to develop the coatings with the complex morphology in macroscale level. Commercially used methods for manufacturing of such coatings are thermal spraying or micro-arc oxidation. On the other hand, it has been recently shown that nano-scale morphology in some cases is equally important. Moreover, a significant drawback of these methods is in the problem of cohesion and poor coating to substrate adhesion that lead to delamination and debris that in turn could cause a cytotoxic effect. The glancing angle deposition configuration has emerged as a promising tool for the deposition of porous and/or columnar-like nanostructured with variations at the nano-roughness level thin films. Due to that, physical vapor deposition of calcium phosphate coatings is the method of choice for implants' surface modification. When GLAD geometry is used with methods as pulsed laser deposition and RF magnetron sputtering it allows to deposit homogeneous, crack-free coatings with a high level of coating to substrate adhesion and possibility to vary nano-roughness and overall shape of the coating's surface features.

O 2-11
Preparation, Properties and Application of Composite Microparticles

Hongfei Shang
Tianmin Shao*

State Key Laboratory of Tribology, Department of Mechanical Engineering, Lee Shau Kee building,Tsinghua University, Haidian District, Beijing 100084, China

Email: shaotm@tsinghua.edu.cn*

Key words: composite microparticles, multi-arc ion plating, thermal spraying

Particle is a kind of material form widely existing in nature and engineering field. In recent years, more and more attention has been paid to the study of particles, especially microparticles. Surface modification of microparticles can further develop their excellent properties. There are many methods for surface modification of particles, which can be roughly summarized into the following two categories. One is to use high-energy radiation (gamma rays, X-rays, etc.), and the other is to prepare composite particles by coating or plating on the surface of particles.

In this work, multi-arc ion plating was used to prepare composite microparticles. Surface morphology, composition and microstructure of the composite powders were analyzed by optical microscopy, scanning electron microscopy, X-ray photoelectron spectroscopy and X-ray diffraction. Ultimately, the composite powders were used in preparation of thermal spraying coatings.

Poster Session

P 2-1
The Deposition of Cu-Films in a Planar Magnetron Sputtering System at Ultra-Low Operating Pressure

Efim Oks[1,2]
M.V. Shandrikov[1,*], K.V. Oskomov[1], A.V. Vizir[1], G.Yu. Yushkov[1], I.D. Artamonov[2]

[2]Institute of High Current Electronics SB RAS, 2/3 Akademichesky ave., Tomsk 634055, Russia
[2]Tomsk State University of Control Systems and Radioelectronics, 40 Lenin ave., Tomsk 634050, Russia

Email: shandrikov@opee.hcei.tsc.ru, maxshandrikov@gmail.com*

The effect of operating pressure in the range of ultra-low values (down to 5×10^{-4} Torr) on a film deposition process using a planar magnetron has been studied. The copper target has a diameter of 125 mm. The magnetron discharge power was 500 W (discharge current 1.3 A) in DC mode. The distance from the target to the substrate was varied from 25 to 55 cm. Using moveable flat Langmuir probe the axial distribution of the ion current density was measured under the same conditions. It was shown that at a distance of more than 30 cm from the target the deposition rate increases by 1.5÷2.0 times and the roughness of the Cu-films decreases by 3 times as the operating pressure decreases. The ion current on the substrate does not change substantially with pressure.

P 2-2

Direct Current Arc Plasma Synthesis of Superdisperced Powder Materials in «Tungsten-Carbon» System

Alexander Pak
Yuliya Vassilyeva

Department of Arc Plasma Phenomenon Application, School of Computers Science and Robotics, National Research Tomsk Polytechnic University, Tomsk 634050, Russia

Email: ayapak@tpu.ru

Key words: non-vacuum method, arc plasma, direct current, superdisperced powder

Nowadays, carbon nanostructures and metal carbides are widely spread and considered as useful materials. Some powder materials, such as carbon nanotubes, graphene, carbon onions, metal and non-metal carbides and other materials, can be synthesized by the direct current arc plasma [1]. However, the particles size distribution, phase composition and morphology of the objects are quite difficult to control, moreover, the process realization is not cost-effective. In this case, the arc discharge method needs to develop. One of the promising trend is applying a non-vacuum atmospheric method [2-3].

The experimental study was conducted by the direct current arc plasma reactor, designed and constructed by the team of our Laboratory [3]. Graphite electrodes connected to the direct current source were used to generate the arc plasma. The tungsten was set into the hole drilled in the cathode. The principle of the non-vacuum synthesis was applied for non-vacuum arc plasma synthesis process realization [1-3].

The synthesis process was realized using the plasma consist of carbon and tungsten. According to the XRD data and PDF4+ database the typical powder product consists of tungsten, graphite-like structures, tungsten carbide WC, tungsten carbide W_2C. Phase composition can be varied by the arc energy level of the direct current arc. According to the HRTEM there are several nanosized types of objects in the product: carbon nanotubes, tungsten carbide and tungsten.

In summary, it should be noted that novel direct current atmospheric arc plasma method has been developed for the «tungsten-carbon» system superdisperced powder materials synthesis.

References

[1] Neha A., Sharma N.N., Diamond and Related Materials, 50, 135-150 (2014).
[2] Yanjie Su, Hao Wei, Tongtong Li et al.,Materials Research Bulletin, 50, 23-25 (2014).
[3] Pak A.Ya. Technical Physics Letters, 44/12, 1192-1194 (2018).

P 2-3

Modification with an Intense Pulsed Electron Beam of the Structure and Properties of a Powder Coating of the Ni-Cr-B-Si System, Plasma-Sprayed on Steel

Anatolii Klopotov[1,2]
Yurii Ivanov[3], Alecsandr Potekaev[2], Yurii Abzaev[1], Mark Kalashnikov[4], Gennadii Volokitin[1], Andrey Chumaevskii[4], Anton Teresov[3], Vladimir Klopotov[5] , Yurii Vlasov[1]

[1]Tomsk State University of Architecture and Building, 2 Solyanaya sq., Tomsk 634003, Russia
[2] Siberian Physical-Technical Institute, National Research Tomsk State University, 1 Novo-Sobornaya sq., Tomsk 634050, Russia
[3]Instituteof High CurrentElectronics SB RAS, Tomsk 634055, Russia
[4]Institute of Strength Physics and Materials Science SB RAS, 2/4 Akademicheskii ave., Tomsk 634055, Russia
[5]National Research Tomsk State University, 36 Lenin ave., Tomsk 634050, Russia

Email: klopotovaa@tsuab.ru

Key words: low-energy high-current electron beams, structure, microhardness, plasma spraying

The use of a combined electron-ion-plasma action on modified surface layers of metals and alloys allows forming specific structural-phase states on the surface [1-3]. As a result, the modified surface layers and coatings in many cases exhibit higher physicomechanical and tribological properties with respect to the hardened part or product.

The paper presents the results of studies on structural and mechanical properties of surface layers of the coating on industrial steel after an integralaction combining plasma spraying of a powder coating and irradiation with an intense pulsed electron beam.

The phase and elemental composition, the state of the defective substructure of the powder coating of the Ni-Cr-B-Si system formed on 35L steel by plasma spraying and subsequent irradiation with an intense pulsed electron beam of asubmillisecond duration have been determinedusing methods of electron diffraction microscopy and X-ray diffraction analysis. It has been established that the effect of a low-energy high-current electron beam on the surface formed by plasma spraying of the Ni-Cr-B-Si powder leads to healing of micro- and macro-pores, smoothing of the surface coating, and formation of high-speed dendritic crystallization cells of submicron sizes.

It has been shown that the combined electron-plasma action is accompanied by a multiple increase in hardness and wear resistance of the powder coating with respect to the initial steel.

The work was supported by RSF (project #19-19-00183).

References

[1] Potekaev A., Klopotov A., Ivanov Yu., Volokitin O., Russian Physics Journal, 56, 914-919 (2013).
[2] Klopotov A., Ivanov Yu., Abzaev Yu. *et al*., IOP Conf. Series: Journal of Physics: Conf. Series, 1115, 032038 (2018).
[3] The evolution of the structure of the surface layer of steel subjected to electron-ion-plasma treatment methods. Ed. N.N. Koval, Yu.F. Ivanov. Tomsk: Publishing house NTL, 2016. 304 p.

P 2-4

Features of Multilayer Coatings on the Basis of Zr-Y-O/Si-Al-N System

Alisa Nikonenko[1,2]
M.V. Fedorischeva[2,3,*], I.A. Bozko[2,3], V.P. Sergeev[2,3], M.P. Kalashnikov[2,3]

[1]Tomsk State University of Control and Radioelectronics, 40 Lenina ave., Tomsk 634050, Russia
[2]Institute of Strength Physics and Materials Science, SB RAS, 2/4 Academicheskii ave., Tomsk 634055, Russia
[3]National Research Tomsk Polytechnic University, 30 Lenin ave., Tomsk 634050, Russia

Email: Fed_mv@mail.ru*

Now it is possible to obtain coatings with a combination of high functional properties such as thermocyclic durability (TCD) and the adhesion to the metal substrate. Heat-shielding coatings on the basis of Zr-Y-O are applied in the production of gas turbine engines to protect from heat units: combustion chambers, impellers, blades and nozzle turbines, etc.

Nanostructured multilayer coatings are of special interest. They provide minimum amplitude of modulation of normal and tangent stresses on all interfaces of multilayered coatings. This fact improves operational characteristics cardinally. The intermediate layer is the layers basic bearing mechanical loads. Amplitude stresses appearing during thermal cycling in a multi-coating relaxed.

The paper deals with the results of TEM, SEM and X-ray study of the thin structure of multilayer coatings of the Zr-Y-O/Si-Al-N.

The deposition of the coating was carried out using the «KVANT» UVN05MD equipment with two magnetrons using mosaic zirconium-yttrium and aluminum-silicon targets. The fine structure of the multilayer coatings was investigated by TEM, SEM and X-ray analysis.

It was found by X-ray that there are the ZrO_2 phases in two different structural modifications in multilayer coating: tetragonal (t) and monoclinic (m). Other phases are not found in this layer of the coating. It was established, the layers on the basis of Zr-Y-O in the Zr-Y-O/Si-Al-N multilayer coatings have a columnar crystalline structure whereas the layers on the basis of Si-Al-N are amorphous. The grain size of Zr-Y-O column cross-section is 80 nm, the height of the column is about 1000 nm. In this case, its value corresponds to the thickness of the deposited layer. The structure of all the Zr-Y-O layers in the multilayer coating is not dependent on the position of the coating layer.

At heating the layer in the TEM column in the «in-situ» mode one can observe a) martensitic transition of the tetragonal phase to the monoclinic one in temperature interval of 400÷500 °C, b) the grain size decreases compared with the initial grain size in the coating, c) the modification of the grain boundaries, i.e. their total length increases, the form of the grains changes, in initial column grains there are cross boundaries, which suggest the fragmentation of grains.

P 2-5

Development of Nitrogen Ion Beam Sputtering and Mixing Deposition Method for Nitride Film Formation

Takaomi Matsutani
Yuki Tai

Graduate School of Science & Engineering, Kindai University, 3-4-1 Kowakae, Higashi-Osaka, Osaka 577-8052, Japan

Email: matsutani@ele.kindai.ac.jp

Key words: nitrogen ion, ion beam sputtering, ion beam mixing, nitride film

Inorganic nitrides are well known as attractive material for wide bandgap semiconductor, hard protective coating and biocompatible material. A reactive sputtering and an ion beam mixing are representative of nitride coating methods, particularly in physical vapor deposition. The reactive sputtering is capable of formation a very flat film due to the deposition particles with the atomic size level [1]. On the other hand, the ion beam mixing can be formed the film with excellent adhesion due to form a mixing layer at the interface between the substrate and the film [2]. In order to obtain advantages of both methods, a nitrogen ion beam sputtering and mixing method has been developed for nitride film formation. Here, this method was applied to AlN film formations.

An aluminum mesh (99.6% purity) was placed coaxially between the ion gun and the substrate of *p*-type Si (100). The substrate was treated by HF solution before the depositions. The nitrogen ions that collided with the mesh induced sputtering of aluminum, and the ions that have passed through the mesh induced an ion mixing effect. The distances between the mesh and the substrate were varied 0.6 and 1.2 cm. Nitrogen ions irradiation were performed with acceleration voltages varied between 0.8 and 1.5 kV and with the ion doses varied between 4.0×10^{16} and 2.4×10^{17} ions/cm^2. The ion density was fixed at 1.8 μA/cm^2. The meshes were used with varied between #20 to #100 mesh. The deposition films were characterized by X-ray photoelectron spectroscopy (XPS) and the surface morphology was measured by atomic force microscopy (AFM). Al 2p and N 1s XPS spectra of the films indicated peaks of 74.5 eV and 397.7 eV meaning Al-N bonding, respectively [3]. The coverage of AlN on the substrate strongly depended on the increase of mesh number. AFM measurements indicated that the films had very flat surface with root mean square of roughness less than 17.3 nm at 10×10 μm2 measurement area.

References

[1] Zhoua F., Yuea B., Wanga X., Wub X., Zhugeb L., Journal of Alloys and Compounds 492, 269–276 (2010).
[2] Laverentiev V., Adeeva V., Kotko A., Tolopab A., Surface and Coatings Technology 106, 145–149 (1998).
[3] Motamedi K., Cadien P., Applied Surface Science 315, 104-109 (2014).

P 2-6

Deposition of Gradient Zr-Nb-N Coatings by Vacuum-Arc Method with Ion-Plasma Assistance

Nikita Prokopenko
O.V. Krysina, Yu.F. Ivanov, V.V. Shugurov, E.A. Petrikova, O.S. Tolkachev, Yu.A. Denisova

Institute of High-Current Electronics SB RAS, 2/3 Akademichesky ave., Tomsk 634055, Russia

Email: nick08_phantom@mail.ru

Key words: Zr-Nb-N coating, gradient coating, vacuum-arc deposition, ion-plasma assistance

To improve the service life and properties of the cutting tool, it is sufficient to form a thin layer of hard or superhard material on the surface of the product. At present, nitrides of transition metals, such as TiN, MoN, ZrN, etc., are used as hard materials. As well as complex systems such as TiAlN, TiCuN, etc. The design of protective coatings can be single-layer (the same elemental composition of the whole of coating thickness, thickness is 1÷5 μm), multilayer (alternating layers of different elemental composition, one layer thickness is ~1÷100 nm, the total thickness of the coating is 1÷5 μm), as well as gradient (varying the coating composition on the thickness). The aim of the present work are synthesis and investigation of gradient coatings with variable niobium (Nb) concentration and with constant zirconium (Zr) concentration.

There are many methods of coating deposition. Vacuum arc method is approached to industrial use. This method allows to obtain the coatings with a wide range of characteristics including high mechanical and tribological properties.

As an experimental installation QUINTA setup for complex ion-plasma treatment of materials was used. An extended gas plasma PINK-04P source based on non-self-sustained arc discharge with a combined thermionic and hollow cathode was used for heating, finishing cleaning and activation of products surface, and ion-plasma assistance during coating deposition [1]. To reduce the number of droplets in the obtaining coating, the zirconium plasma flow was passed through a curvilinear plasmaguide with a rotation angle of 120° [2]. In the work niobium was evaporated by an arc DI-100 evaporator. Since niobium is a refractory metal, the droplets number and size in the synthesized coatings was minimal under selected deposition conditions.

The set of experiments were carried out to obtain Zr-Nb-N coatings with niobium concentration gradient on the coating thickness. In the obtained coatings the tribological and mechanical properties, the elemental and phase composition were investigated.

The work was supported by the Russian Science Foundation (project #18-79-10111).

References

[1] L.G. Vintizenko, S.V. Grigoryev, N.N. Koval, *et al*., Russian Physics Journal, Vol. 44, No. 9, 927-936, (2001).
[2] V.M. Bashkov, A.I. Dodonov. Patent CA2284368A1, (2001).

P 2-7

Controlling the Properties of Metal Films Deposited Using Magnetron Sputtering Systems with Evaporative Targets

Galina Bleykher
Alena Yuryeva, Dmitriy Sidelev, Artem Shabunin, Yuri Yuryev

National Research Tomsk Polytechnic University, 2a Lenin ave., Tomsk 634028, Russia

Email: bga@tpu.ru

Key words: magnetron sputtering systems, metal films and coatings, sputtering, evaporation, film growth

The results of our research show that the operation of magnetron sputtering systems (MSS) with highly heated and evaporative metal targets gives possibility significantly (by one or two orders of magnitude) increase the deposition rate of films coatings in comparison with conventional magnetrons. In this case, the characteristics of the energy and particle fluxes entering the substrate during the growth of the film change significantly. Consequently, the structural and functional properties of the films should also have their own characteristics as compared to deposition using traditional magnetrons, in which the erosion flux on the target is created only by collision sputtering.

We developed mathematical and numerical models of thermal and erosion processes in cathodes with thermally insulated targets, calculated the particle flux densities and energy entering the substrate, depending on various operating parameters of the magnetrons (type of power source, its power, pressure in the chamber, configuration of the heat exchange of the target with the environment, etc.). The experiments on the deposition of metal films (copper, chromium, aluminum) were carried out, their structural and functional properties were investigated. Comparison of calculations and experimental results allowed us to identify the factors that most significantly affect the properties of the films. The ranges of operating parameters for different types of films in which not only high deposition rates occur, but also good functional characteristics of the films are determined.

This study was supported by the Russian Foundation for Basic Research (Project #18-08-00454).

P 2-8

Study of Magnetron-Sputtered Coatings on Ion-Modified Surface of Alloy E110

Dmitry Safonov
A.S. Yashin, N.V. Volkov, B.A. Kalin, E.L. Korenevski, R.Sh. Isayev, Dinh Quoc Dat

Department of Materials Science, National Research Nuclear University «MEPhI», Moscow 115409, Russia

Email: weggstar@mail.ru

Key words: protective coatings, magnetron sputtering, ion-beam surface treatment, roughness of the surface

One of the methods for increasing the resistance of zirconium to oxidation in a steam-water medium is the use of protective metallic coatings [1]. In this case, protective coatings must have the necessary adhesion to the substrate, provide resistance to oxidation of zirconium, etc. [2]. Therefore, the purpose of this work was to study the effect of ion-beam surface treatment of materials from alloy E110 on the deposition and structure of magnetron-sprayed metal films.

Tubes of alloy E110 with a diameter of 9.15 mm and a length of up to 500 mm were used as samples. Ion modification of the surface of the samples followed by coating was carried out on the ILUR-03 installation [3], which consists of a discharge chamber allowing irradiating cylindrical samples with a radial ion beam with a wide energy spectrum (discharge voltage 1÷6 kV, discharge current 1÷500 mA) and chambers with three magnetrons, which allow deposition of thin coatings in an inert gas atmosphere at a working gas pressure above 10^{-4} Pa.

In the state of delivery, the surface of the samples has a developed relief, on the surface technological circular scratches and separate «flows» of metal are observed, apparently caused by rolling and mechanical grinding of tubes at the manufacturing stage. To evaluate the results of ionic surface cleaning, the elemental composition of the samples before and after ion treatment was obtained by X-ray fluorescence analysis. Measurement of the roughness Ra before and after the ion treatment of the samples in the ion polishing mode showed a decrease in the roughness from 2.0±0.2 μm to 0.6±0.2 μm. The coatings are homogeneous in thickness and microstructure, have good adhesion to the substrate - no cracks and peeling of the coating is observed.

Analysis of the surface showed that the structure of the coatings in all cases inherits the original macropattern of the substrate surface. Therefore, as a result of ion processing of the samples, the adhesive properties and continuity of the applied coating are improved. The value of the roughness of the coatings is noticeably less than the roughness of tubes in the state of delivery and is in the range of 0.3 to 0.5 μm.

References

[1] Hyun-Gil Kim, Il-Hyun Kim, Yang-Il Jung *et al*., Top Fuel 2016, 1157-1163, (2016).
[2] Kurata Masaki, Jrnl. Nuclear Engineering and Technology, 4826-4832, (2016).
[3] Safonov D.A., Yashin A.S., Volkov N.V. Bulletin of the Russian Academy of Sciences: Physics. 82, 193–196, (2017).

P 2-9

Properties of Intermetallic-Based Ti-Al Coatings Deposited on the Ultrafine Grained Martensitic Steel

Rustem Nagimov
Almaz Nazarov, Kamil Ramazanov, Eduard Vardanyan*

Ufa State Aviation Technical University, Ufa 450008, Russia

*Email**: *vardanyaned@gmail.com*

Key words: ultrafine grained, ion nitriding, physical vapor deposition, intermetallic Ti-Al

Recently the ultrafine grained (UFG) metals and alloys attracted great interest due to their unique structure and enhanced strength and fatigue [1]. Special severe plastic deformation (SPD) techniques, based on large strains under the conditions of high pressure and relatively low homologous temperatures, were developed to produce UFG materials [2]. Despite enhanced mechanical properties of UFG materials [3], their protection in aggressive environment is still an open question. Defects of crystal lattice and numerous grain boundaries, appearing during SPD, contribute to local increase of dissolution rate in the UFG material. In this connection the development of new approaches to increase the corrosion resistance of the UFG materials is a topical task. Up to date there are known surface treatment techniques which contribute to increase of corrosion resistance of metals and alloys, such as ion nitriding, physical vapor deposition (PVD) of corrosion resistance coatings [4] et al. It is known, that intermetallic-based coatings possess unique properties and preserve their structure and strength at high temperatures. They have good anticorrosion and antifriction properties, thus leaving behind other metallic coatings. In particular papers [5] present the results of investigations of corrosion properties of coatings, containing intermetallic phases (TiAl, $TiAl_3$), which demonstrated that they possess good corrosion resistance and can be considered for protection of materials in aggressive environment under the condition of their high adhesion to the substrate material.

This work considers several approaches to protect martensitic steels with ultrafine-grain (UFG) structure in aggressive environments. Scanning electron microscopy was used to study the microstructure and composition of steel substrates and coatings. The samples were also subjected to corrosion tests. Regularities of corrosion behavior were specified for the UFG steels. The samples were subjected to ion nitriding in a glow discharge and deposition of protective TiAl/TiAlN coatings in vacuum arc discharge plasma. Adhesion of the coatings was examined with CSM ScratchTEST for samples with different structures critical load was defined at which microcracks are formed in the coatings The structural and phase composition of the coatings and their physicochemical properties were studied by X-ray diffraction analysis on a Shimadzu XRD-7000 diffractometer. Corrosion tests were made in artificial conditions, imitating influence of climatic atmosphere factors, composition of the corrosion environment was 3% NaCl. Evaluation of the corrosion resistance was made via weight technique.

References

[1] R.Z. Valiev, R.K. Islamgaliev, I.V. Alexandrov, Progress in Materials Science 45 (2000) 103-189.
[2] A.P. Zhilyaev, T.G. Langdon, Progress in Materials Science 53 (2008) 893–979.
[3] G. Yang, C.X. Huang, C.Wang, L.Y. Zhang, C. Hu, Z.F. Zhang, S.D. Wu, Materials Science and Engineering A 515 (2009) 199–206.
[4] Sonia P. Brühl, Raúl Charadia, Silvia Simison, Diego G. Lamas, Amado Cabo, Surface and Coatings Technology 204(20) (2010) 3280-3286.
[5] Vardanyan E.L., Budilov V.V., J. Synch. Investig. 10 (2016) 728-732.

P 2-10
Surface Modification of E110 Alloy by High-Intensity Low Ion Energy Cr Implantation

Alexey Shevelev[1]
E.B. Kashkarov[1], A.I. Ryabchikov[1], M.S. Syrtanov[1], A. Obrosov[2]

[1]National Research Tomsk Polytechnic University, 30 Lenin ave., Tomsk 634050, Russia
[2]Brandenburg Technical University, Germany

Email: shevelevae@tpu.ru

The Fukushima disaster has strongly effected on nuclear energetics and their progress [1]. It pointed to a crucial oxidation and subsequent destruction of nuclear fuel claddings in light-water reactors in the case of loss of coolant accident conditions. Surface modification is one of the promising approaches to protect Zr alloys in normal operation and accident conditions of nuclear reactors [2]. Surface modified layers or coatings forming chromia during oxidation is of greatest interest since it meets the basic requirements for accident tolerant fuel materials [3]. The aim of this research is to study the possibility of deep surface modification of zirconium alloy E110 by high intensity ion implantation using low energy metal ion beam. The formation of the metal ion beams is provided by the application of negatively pulsed bias (1.5 kV) to the system immersed in the chromium vacuum arc plasma. The structure and composition of Cr-implanted zirconium alloy were studied by X-ray diffraction, scanning electron microscopy and energy dispersive spectroscopy. The mechanical properties and wear resistance were measured by nanoindentation and «ball on disk» testing, respectively. The influence of implantation temperature on the phase composition, microstructure, and mechanical properties as well as on the corrosion behavior of Cr-implanted zirconium alloy under high-temperature oxidation (up to 1100÷1200 °C) have been described.

References
[1] N. Minin, T. Vlček. Energy Strategy Rev. 21 (2018) 98–110.
[2] Z. Duan, H. Yang, Y. Satoh, K. *et al*. Nuclear Engineering and Design 316 (2017) 131–150.
[3] K.A. Terrani. Journal of Nuclear Materials 501 (2018) 13-30.

P 2-11

Hard and Wear-Resistant Niobium Carbide Layered Coatings on Tools by Niobium Ion Bombardment and Cathodic Vacuum Arc Deposition

Vladimir Uglov[1,2]
Andrey Kuleshov[1], D.P. Rusalsky[1]

[1]Belarusian State University, Nezavisimosti ave., 4, Minsk 220030, Belarus
[2]South Ural State University, Lenin ave., 76, Chelyabinsk 454080, Russia

Email: uglov@bsu.by

A perspective approach is considered for creating a multi-level architecture coatings with high hardness, adhesion and wear resistance by bombarding with niobium ions and subsequent cathodic vacuum arc deposition (CAVD) of NbC in an atmosphere of methane on a carbide tool. Using XRD, GXRD, SEM, EDX methods the investigations of hardness, adhesion, wear, microstructure, phase and elemental composition over the depth of the cross section of hard alloy samples with the formed surface layers and coatings depending on the time of bombardment by niobium ions with energy of 1 keV were carried out. The temperature fields on the surface of the samples during niobium ion bombardment were monitored with a high-temperature thermograph in the temperature range of 700÷1700 °C. It was established that during ion bombardment with niobium for ~ 1 minute, a layer of $(Nb,W)C_{0.7}$ is formed on the surface of hard alloy. The temperature fields on the surface of the hard alloy are 1200-1400 °C. The thickness of the synthesized layer obtained in the process of ion bombardment $(Nb,W)C_{0.7}$ is 0.5÷0.7 μm, the hardness is ~ 50 GPa. After that, a NbC coating with a thickness of 2 microns is formed on the $(Nb,W)C_{0.7}$ surface layer using CAVD of niobium in a methane atmosphere. The hardness of the layered coating $(Nb,W)C_{0.7}$ + NbC increases to 60÷70 GPa. Using Halder-Wagner GXRD method, it was found that the macrostresses in these coatings do not exceed 1 GPa. It is established that layered coatings have high adhesive resistance. They have a critical exfoliation load of at least 140 N, which is 1.5÷2.0 times greater than the exfoliation load of NbC coatings deposited without intensive niobium ions bombardment. Layered coatings on carbide cutting tools allow to reduce the specific volume wear during dry friction on the tool surface by 6÷8 times (indenter load 20 N) compared with the tool without such a $(Nb,W)C_{0.7}$ + NbC layered coating.

SMMIB-2019

21ST INTERNATIONAL CONFERENCE
ON SURFACE MODIFICATION OF MATERIALS BY ION BEAMS
25-30 August 2019
Tomsk, Russia

Session 3
Basic Mechanisms, Theory and Fundamental

Invited Talk

I 3-1
Intense Pulsed Ion Beam Applications on Metals Modification and Test

Yan Sha[1,2]
Xiaoyun Le [3,4]

[1]State Key Laboratory of Nuclear Physics & Technology, Peking University, Beijing 100871, China
[2]Institute of Heavy Ion Physics, School of Physics, Peking University, Beijing 100871, China
[3]School of Physics and Nuclear Energy Engineering, Beihang University, Beijing 100191, China
[4]Beijing Key Laboratory of Advanced Nuclear Energy Materials and Physics, Beihang University, Beijing 100191, China

Email: syan@pku.edu.cn

Key words: intense pulsed ion beams, IPIB-materials interaction, metals modification

Intense pulsed ion beams (IPIBs) have been applied world widely to metals modification for many years, especially in USA, Russia, Japan, and China [1,2]. The feature of shock destines that IPIBs interaction with materials has more violent form than normal ion beams. IPIB irradiation may drive intense energy, momentum, and mass transport processes in materials, and induce widely diverse changes of materials morphology and microstructure.

A joint group of Peking University and Beihang University involved in IPIB-materials interaction research for 20 years. We would like to present a part of our research results on both basic physical processes and effects of modifications, such as surface hardening, surface amorphization, corrosion resistance improvement, interface mixing, and so on. Recently we also tried to use IPIB as a tool to test the materials tolerance to high heat and ion flux. We attempt combine the experimental measurement and the thermodynamic calculation to diagnose beam energy deposition, correct the difference brought from material ablation.

IPIB have shown its great advantages in many application fields. However, unstable repeatability and the difficulty on accurate diagnosis of beam parameters limited its applications. Facing the challenge, it need more efforts to win the better prospect of IPIB application.

References

[1] D.J. Rej, H.A. Davis, and J.C. Olson, G.E. Remnev, A.N. Zakoutaev, V.A. Ryzhkov, V.K. Struts, I.F. Isakov, V.A. Shulov, N.A. Nochevnaya, R.W. Stinnett, E.L. Neau, K. Yatsui and W. Jiang, J. Vac. Sci. Technol. A 15, 1089 (1997).
[2] W.J. Zhao, G.E. Remnev, S. Yan, M.S. Opekounov, X.Y. Le, V.M. Matvienko, B.X. Han, J.M. Xue, and Y.G. Wang, Review of Scientific Instruments 71, 1045 (2000).

I 3-2

Computer Modeling of PKA Energy Spectra and Concentration of Vacancy Clusters Irradiated by Light Ions

Anatoliy A. Kupchishin[1]
N.A. Voronova[1], A.I. Kupchishin[1,2], T.A. Shmygaleva[2], S.A.Shafii[2]

[1]Kazakh National Pedagogical University named after Abai, Almaty, Kazakhstan
[2]Kazakh National University named after al-Farabi, Almaty, Kazakhstan

Email: ankupchishin@mail.ru

As is known, the main cause of changes in the structure and physicochemical properties during radiation exposure is the formation of defects [1,2].

In this paper, we simulated the energy spectra of primary-knocked-out atoms (PKA) and the concentration of vacancy clusters irradiated with light ions.

The PKA spectra, depending on the energy, decrease, and depending on the depth of penetration, increase, reaching a maximum, then decreasing. Using the expression for the PKA spectrum, we calculated the concentration of vacancy clusters for various particles irradiated with light ions (hydrogen, nitrogen, carbon, aluminum). As the results of calculations show, the concentration values have the following behavior: for light incident particles, the curves increase, reaching a maximum, then decrease to zero. With an increase in the initial energy of the particles, the curves shift to the right. With an increase in the threshold energy E_C, the concentration values decrease and the curves pass much lower, the transition through the maximum is smoother. At energies of E_0 = 100 keV, the curve decreases. With an increase in the atomic weight of the incident particle, the value of the function at the maximum point increases and, consequently, the curves pass higher, while the depth values decrease.

References

[1] V.M. Agranovich, V.V. Kirsanov, Simulation problems of radiation defects in crystals, Uspekhi Fizicheskikh Nauk 118 (1) (1976) 3–51.
[2] N.A. Voronova, A.I. Kupchishin, A.A. Kupchishin, A.A. Kuatbayeva, T.A. Shmygaleva, Computer modeling of depth distribution of vacancy nanoclusters in ion-irradiated materials, Key Engineering Materials 769 (2018) 358–363, doi: 10.4028/www.scientific.net/KEM.769.358.

Oral Presentation

O 3-1
Simulation Studies on Secondary Electron Emission Characteristics of Metal Materials Radiated by Ions of the Order of 100 keV

Wei Zhao
Jialong He

Institute of Fluid Physics, CAEP, No. 64, Mianshan Road, Mianyang, China

Email: hailang921@foxmail.com

Key words: ion beam material modification, metal material, secondary electron emission characteristics, radiation effects, Monte-Carlo simulation

In many scientific fields such as particle accelerators, spacecraft and high power microwave devices, the secondary electron emission (SEE) characteristics of the surface of metal materials and its modification research are of great significance. It is a promising method to modify the SEE characteristics of the surface of metal materials by ion irradiation of the order of 100 keV, for the escape distance of the SEE of the metal material is in the range of 10 nm, which is equivalent to the depth of incidence of the ions of the order of 100 keV. According to the theoretical analysis, the SEE characteristics of the surface of materials are affected by many factors such as the surface work function, the surface geometry, the kind of defects and their distributions. As complicated changes in the microscopic and mesoscopic structure of materials produced by ion bombardment with various irradiation parameters, the mentioned factors will undergo various changes, leading to complex effects on the SEE characteristics.

To study the influence factors of the SEE characteristics of the surface of the metal materials by ion irradiation, a program on the basis of Monte-Carlo method was established to simulate the generation, transportation and emission of the secondary electrons. The program adopted the simplified Mott elastic cross sections which had been proved to be suitable for the low energy electrons, and inelastic energy losses with full dispersion. The subsequent cascading processes and charge carrier multiplication by SEE were as well as taken into account. Besides, the surface effects and the quantum mechanical surface transmittance were also included in the simulation model. To clarify the sensitivities of each influence factor, the control variable method was applied. Results were obtained for the material Cu, Ti, Ta and Au. It was concluded that the surface geometries, radiation defects and distributions gave rise to decrease of the generation and escape probability of the secondary electron, due to decrease of the energy loss linear density and increase of multi-scattering of electrons respectively, resulting in obvious decrease of the secondary electron yield of metal materials comparing with that without ion irradiations.

O 3-2

The Law of Independence of the Emission Spectra of Metal Targets from Energy and the Mass of Implanted Ions

Vladimir Ovchinnikov[1,2]
Konstantin Shalomov[1,2], Vladimir Dremov[3], Sergey Samarin[3], Aleksey Karavaev[3]

[1]Institute of Electrophysics UB RAS, Yekaterinburg 620000, Russia
[2]Ural Federal University named after the first President of Russia B.N. Yeltsin, Yekaterinburg 620000, Russia
[3]Russian Federal Nuclear Center, All-Russian Scientific Research Institute of Technical Physics (RFNC VNIITF), Snezhinsk 456770, Russia

Email: viae05@rambler.ru

Key words: ion bombardment, thermal spikes, targets glow spectra, final stage of the cascade model

Spectral analysis of the optical emission of targets from pure metals (Fe, W, Zr, Ta) in the course of ion bombardment with Ar^+, Kr^+, Xe^+ ions showed that the emission spectra of different metals are significantly different. At the same time, the spectra of each of these metals are almost unchanged, regardless of the type of bombarding ion (whether Ar^+, Kr^+ or Xe^+) and its energy, which varies in the range of 5-20 keV. This applies both to the nonequilibrium radiation lines (with the exception of some nuances) and to the continuous strips of the Planck thermal radiation, corresponding to thermal spikes according to [1,2] (i.e. areas of passage of dense cascades of atomic displacements, heated for 10^{-12} s to 3000÷6000 K and above).

Irradiation with accelerated ions was carried out on an ILM-1 ion implanter. The emission spectra of the targets were measured using an OS-12 diffraction spectrometer on base of a CCD array in the range from 360 to 850 nm. Supercomputer calculations using Monte Carlo + molecular dynamics methods [3] have shown that the effect of constancy of the spectrum of thermal glow when changing the energy of the bombarding ions corresponds to the condition of proportionality of the averaged radius of the of almost spherical thermal spike area $R = 4/3\pi(\Delta R_{\perp}\Delta R_{||})^{1/3}$ to the square root of the implanted ion energy E: $R \sim E^{1/2}$. A model of the final stage of the cascade, describing the results of the experiment, is proposed.

References

[1] Ovchinnikov V.V., Makhinko F.F., Solomonov V.I., Gushchina N.V., Kaigorodova O.A., Technical Physics Letters, 38, 1, 42-46 (2012).
[2] Ovchinnikov V.V., Surface & Coating Technology, 355, 65-83 (2018).
[3] Dremov V.V., Sapozhnikova F.A., Samarina S.I. *et al*., Journal of Alloys and Compounds, 444-445, 197-2001 (2007).

O 3-3
Molecular Dynamics of Free-Standing Graphene Bombarded with keV Ar_n Clusters

Mikołaj Gołuński
Zbigniew Postawa

Institute of Physics, Jagiellonian University, Łojasiewicza 11, 30-348 Kraków, Poland

Email: mikolaj.golunski@gmail.com

Key words: graphene, argon clusters, SIMS, MD simulations

Researchers around the globe are constantly looking to perform more sensitive and accurate chemical analysis of ultra-small organic structures. One of the methods that could be used for this purpose is a Secondary Ion Mass Spectrometry (SIMS). A type of the projectile and substrate applied in SIMS is essential. Recently, a novel «transmission» SIMS geometry using free-standing graphene substrate and cluster projectiles was proposed. [1] It provides the possibility of detecting such small amounts of the analyte as atto or zeptomoles. Molecular Dynamics (MD) simulations of projectile impacts at free-standing graphene have been already performed with C_{60} projectile. [1] However, other studies have shown that gas cluster projectiles, such as argon clusters, are more suitable for analysis of organic molecules. A gentler interaction between cluster atoms and the analysed molecules results in lower rates of molecules' fragmentation. [2] So far, there is no study investigating the particle ejection during bombardment of free-standing graphene with such projectiles.

MD simulations are employed to investigate the effect of the projectile size and its kinetic energy. The target is bombarded by Ar_n projectiles (n=60÷1000) with kinetic energy between 5 and 40 keV. The sample damage, the sputtering yields, kinetic energies, and ejection directions of atoms are monitored. It has been observed that during bombardment with Ar_{60} clusters, the hole in the graphene keeps the size comparable to the projectile's diameter. However, the use of an Ar_{1000} cluster projectile results in the creation of a much bigger hole in graphene than the size of the projectile. In this case, graphene breaks and unfolds in petal-like shapes. The implications of the observed phenomena for the analysis of ultra-thin organic coatings deposited on free-standing graphene will be discussed.

This work was supported by NCN, grant #2016/23/N/ST4/00971 and NCN, grant #2015/19/B/ST4/01892.

References
[1] S.V. Verkhoturov et al., J. Chem. Phys., 16, 160901 (2019).
[2] N. Winograd, Ann. Rev. of Anal. Chem., 11, 29 (2018).

O 3-4
Fragmentation of Carbon on Elemental Targets at 290 A MeV

Dong-Hai Zhang[1]
Tian-Li Ma[1,2], Jun-Sheng Li[1], Hui-Ling Li[1], Ming-Ming Xu[1], Rui-Xia Yang[1], Zhi Zhang[1,2], Qi Wang[3], S. Kodaira[4]

[1]Institute of Modern Physics, Shanxi Normal University, Linfen 041004, China
[2]China Institute of Atomic Energy, P. O. Box 275 (96), Beijing 102413, China
[3]Linfen Occupational Technology College, Linfen 041000, Shanxi, China
[4]Radiation Measurement Research Section, National Institute of Radiological Sciences, 4-9-1 Anagawa, Inage, Chiba 263-8555, Japan

Email: zhangdh@sxnu.edu.cn

Key words: heavy ion collision, total charge-changing cross section, partial cross-section, emission angle

The total charge-changing reaction cross-sections and the partial cross-sections of projectile fragments(PFs) production for the fragmentation of ^{12}C on C, Al, Cu, Pb and CH_2 targets at the highest energy of 290 A MeV are investigated. It is found that the total charge-changing cross-sections and the partial cross-sections of PFs production for the fragmentation are independent of the beam energy, and increase with increase of mass of target for the same of beam energy. The total charge-changing reaction cross section is the same as the prediction of Bradt-Peters semi-empirical formula, PHITS and NUCFRG2 models. The partial cross section of PFs production increases with the increase of the mass of target, and it is the same as the prediction of NUCFRG2 models. The average scattering angle of beam particle is lesser than the mean emission angle of PF, and the width of scattering angle distribution of beam particle is less than that of emission angle distribution of PF. The mean emission angle of PF increases with the mass of target for the same beam energy and charge of PF.

O 3-5

Effect of the Impact Angle on the Angular Distributions of β-Carotene Sputtered by 15 keV Ar_{2000}

Michał Kański
Zbigniew Postawa

Institute of Physics, Jagiellonian University, Łojasiewicza 11, 30-348 Kraków, Poland

Email: michal.kanski@doctoral.uj.edu.pl

Key words: SNMS, sputtering, depth profiling, MD simulations

Depth profiling of complex, organic multilayered materials and biological samples with nanometric resolution requires an efficient method of detecting the sputtered particles and a gentle way of material removal, without introducing damage to the structures. The second requirement is satisfied by the utilization of cluster beams such as Ar_n projectiles. Their disadvantage, however, is the low ionization probability of ejected material, which can be overcome by introducing a laser post-ionization step. Thanks to this method, most of the ejected material can be analyzed with mass spectrometers.

In order to access a large number of sputtered neutral particles, the overlap of the laser beam and the ejected plume must be optimized. This requirement also applies to the timing of sputtering and arrival of the laser pulse for schemes utilizing pulsed light sources. Knowledge of the kinetic energy and angular distributions is thus critical for a proper design of the experiment.

We performed molecular dynamics computer simulations to investigate the effect of the projectile impact angle on the kinetic energy and angular distributions of particles emitted from β-carotene, bombarded by 15 keV Ar_{2000} clusters. We found that even a slight change of the incident angle has a significant impact on the directions of ejected molecules and their ejection mechanism. Two temporally-separated ejection channels have been identified. Their importance, as well as the effect of surface topography on the processes of particles ejection, will be discussed.

This work is supported by NCN, grant #2016/23/N/ST4/01013.

O 3-6

Post-Cascade Waves Instead of Temperature. Low Atomic Ordering Temperatures at Depth far Beyond Ion Range

Efrem Makarov[1]
V.V. Ovchinnikov[1,2], V.A. Semyonkin[1,2]

[1]Institute of Electrophysics UB RAS, Yekaterinburg 620000, Russia
[2]Ural Federal University named after the first President of Russia B.N. Yeltsin, Yekaterinburg 620000, Russia

Email: efre-m@yandex.ru

Key words: FeMn, FeSi, ion bombardment, electrical resistance, Mössbauer effect, dynamic shock-wave effects

In the IEP UB RAS studies [1] nanoscale dynamic effects were found in condensed media under cascade-forming types of irradiation. They are associated with the processes of explosive energy release in areas of dense cascades of atomic displacements with the formation for trillionths of a second of nanoscale zones (thermal spikes) heated to 3000-6000 K and higher with thermal pressures of 5÷40 GPa, which in some cases exceed the theoretical yield point of materials. This leads to the formation of post-cascade shock waves capable of provide liquid type flow of condensed media at their front, initiating structural phase transformations. In this case, radiation shaking can play the role of temperature.

Were investigated by quenching and plastic deformation of iron alloys with 6.25 at.% Si and 6.25 at.% Mn. To prove the radiation-dynamic nature of the processes, all temperature regimes of heating the targets (to temperatures below the threshold of active diffusion: ≤ 350 °C) with ion beams were exactly reproduced by heating the same targets in the vacuum chamber of the implanter using special heaters. In the absence of ion irradiation, no structural rearrangements were observed. Using the methods of resistometry and Mössbauer spectroscopy, structural states of the alloys that do not arise in thermal processes were detected. Small exposures ($\tau < 1 \div 10$ s, $F < 10^{14} \div 10^{15}$ cm^{-2}) made it possible to reveal a high rate of initiated atomic rearrangements, which is several orders of magnitude higher than the rate of thermal processes, over the entire depth of foils 20÷30 μm thick when projected ranges of ions not exceeding several tens of nanometer.

This work was supported by the Russian Scientific Foundation, project #19-79-20173.

References

[1] Ovchinnikov V.V., Surface and Coating Technology, 355, 65-83 (2018).

Poster Session

P 3-1

Radiation Tolerance of La-Doped Nanocrystalline Steel Under Heavy-Ion Irradiation at Different Temperatures

Haocheng Liu[1]
Yuan Fang[1], Wei Ge[1], Tengfei Yang[2], Congcong Du[3], Chenxu Wang[4], Shaoshuai Liu[1], Youping Lu[1], Zhanfeng Yan[1], Feng Liu[1], Gen Yang[1], Tongde Shen[3], Yugang Wang[1]

[1]State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing 100871, People's Republic of China
[2]Department of Nuclear Engineering, University of Tennessee, Knoxville, Tennessee 37996, United States of America
[3]State Key Laboratory of Metastable Materials Technology and Science, Yanshan University, Qinhuangdao 066004, People's Republic of China
[4]Department of Geological Sciences, Stanford University, Stanford, California 94305, United States of America

Email: liuhaocheng@pku.edu.cn

Key words: radiation tolerance, heavy-ion irradiation, La-doped, nanocrystalline steel

Nanostructured materials have great potential for use as structural materials in advanced nuclear reactors due to the high density of grain boundaries that can serve as sinks to absorb irradiationinduced defects. In the present study, the irradiation tolerance of a La-doped nanocrystalline 304 austenitic stainless steel (NC-La) with a grain size of about 40 nm was investigated under an irradiation of 6 MeV Au ions to 1.5×10^{16} ions cm^{-2} at 600 °C and room temperature. Compared to its coarse-grained counterpart, in La-doped nanocrystalline steel no visible voids were observed at high-temperature irradiation, and no significant difference in extended defects, such as irradiation-induced dislocation loops or clusters, were found between irradiated and unirradiated areas at room temperature irradiation. Furthermore, the nano grain remains stable under irradiation, and no significant grain growth occurs at both irradiation temperatures. The excellent irradiation tolerance of the La-doped nanocrystalline alloys is attributed to the abundant grain boundaries and enhanced stability of nano grains induced by the Zener pinning effect and La segregation on grain boundaries. This study therefore demonstrates the superior irradiation tolerance of the La-doped nanocrystalline steel.

P 3-2

The Influence to Crater Formation by Inclusions on Metal Surface During IPIB Irradiation Process

Haowen Zhong[1,2,3]
Jie Zhang[4], Jie Shen[4], Guoying Liang[1,2,3], Shijian Zhang[1,2,3], Mofei Xu[1,2,3], Xiao Yu[1,5], Sha Yan[6], Xiaoyun Le[1,2,3,*]

[1]School of Physic and Nuclear Energy Engineering, Beihang University, Beijing 100191, China
[2]Beijing Advanced Innovation Center for Big Date-based Precision Medicine, Beihang University, Beijing 100191, China
[3]Beijing Key Laboratory of Advanced Nuclear Energy Materials and Physics, Beihang University, Beijing 100191, China
[4]Nuclear and Radiation Safety Centre, Ministry of Environrnental Protection of China, Beijing 100082, China
[5]School of Space and Environment, Beihang University, Beijing 100191, China
[6]Institute of Heavy Ion Physics, Peking University, China

Email: xyle@buaa.edu.cn

Key words: intense pulsed ion beam, crater, inclusions, ablation

The crater, as a characteristic defect appeared on metal surface after intense pulsed ion beam (IPIB) irradiation, restricts the application of this surface treatment technology due to the potential risks brought about by craters on corrosion resistance, wear resistance and other properties. Hence, the understanding of crater formation mechanism is obviously significant to the development of IPIB. In previous studies, it is found that the inclusions on metal surface, which is unavoidable in industrial material, can result in craters during IPIB irradiation. In this work, a thermodynamic model was established by means of finite element method to study the temperature evolution on target surface during IPIB irradiation. Different combination of inclusions and matrixes, including Al_2O_3/Al, FeS/Fe, SiO_2/Fe and TiN/Ti, were investigated. It is found that inclusions on target surface would be ablated more preferentially than matrix even though melting point of some inclusions is higher than that of matrix. It is reveal that the ablation of inclusion was decided collaboratively by the melting point, the thermal conductivity and the thermal capacity of inclusions under IPIB irradiation of a specific energy density. Besides, the effect of inclusion dimension and position relative to the matrix on temperature evolution was investigated.

P 3-3

The Odd-Even Effect of Fragmentation Cross Sections for ^{36}Ar and ^{40}Ar

Jin-Xia Cheng[1]
Jun-Long Tian[2], Dong-Hai Zhang[3]

[1]College of Electrical and Information Engineering, North Minzu University, Yinchuan 750021, China
[2]College of Physics and Electrical Engineering, Anyang Normal University, Anyang 455000, China
[3]Institute of Modern Physics, Shanxi Normal University, Linfen 041004, China

Email: lfcjxlyl@163.com

Today, one of the hot topics is the nuclear fragmentation in heavy-ion collisions at intermediate energies, both in experiment and theory. The nuclear fragmentation can help us to understand nuclear structure effects by interactions of heavy ions. The study of nuclear fragmentation has been applied to astrophysics and medical treatment.

Previously, we have analyzed the fragmentation of the ^{20}Ne projectile on different targets[1, 2]. The study showed that the odd-even effect of partial cross sections is observed both in experiment and in theory, and the odd-even effect mainly from the fragments with T_z =0±0.5. Now, the odd-even effect is investigated for stable isotopes of ^{36}Ar and ^{40}Ar on C, Al, Cu, and Pb targets at 400 A MeV by the ImQMD model [3] together with the GEMINI statistical decay model[4]. The isotopic distributions and isospin distributions suggest that the odd-even effect is dependent on the projectile nuclei. For a 36Ar projectile with T_z = 0, the partial cross sections appear an obvious odd-even effect, and the isotopic distributions show that the maximal cross sections for the even-Z isotope are larger than that for the neighboring odd-Z isotope. However, the fragmentation cross sections and the isotopic distributions for the ^{40}Ar projectile have not shown these characteristics. The isospin distributions show that the odd-even effect of fragments from the T_z = 0 projectile is stronger than that from the T_z = −2 projectile.

References

[1] Cheng J.X., Zhang D.H., Yan S.W., Li J.S., Wang L.C., Li Y.J. and Yasuda N, Chin. Phys. C 2012, 36, pp. 37-42.
[2] Cheng J.X., Jiang X, Yan S.W. and Zhang D.H., J. Phys. G: Nucl. Part.Phys. 2012, 39, 055104.
[3] Wang N, Li Z.X., Wu X.Z., Tian J.L., Zhang Y.X. and Liu M, Phys. Rev. C 2004, 69, 034608.
[4] Charity R.J., Jing K.X., Bowman D.R., McMahan M.A., Wozniak G.J. and Moretto L.G., Nucl. Phys. A 1990, 511, 59.

P 3-4
Deposition of Diamond-Like Carbon Films on Insulating Substrates

Koumei Baba[2,3]
R. Hatada[1,*], S. Flege[1], W. Ensinger[1]

[1]Technische Universität Darmstadt, Germany
[2]SANNO Co., Ltd., Yokohama, Japan
[3]Fine Coating, Co., Ltd., Omura, Japan

Email: hatada@ma.tu-darmstadt.de

Plasma source ion implantation (PSII) is a technique that is suitable for implantation as well as film deposition, also on three-dimensional substrates. Since it involves a high voltage that is applied to the sample holder to attract ions from the plasma to the sample, an influence can be expected in case that the substrate or part of it is nonconductive.

Diamond-like carbon (DLC) films were deposited by PSII, using C_2H_2 as precursor. Silicon samples were placed on a horizontally oriented conductive sample holder in three different ways: 1) directly on the holder, 2) with an alumina block of 5 mm height between holder and sample, 3) with an alumina block of 12 mm height between holder and sample. The high voltage (pulsed or DC) was applied directly to the sample holder. The plasma was generated either by this voltage or, in some experiments, by an additional RF signal that was applied to a plate, which was oriented parallel to the sample holder, in a distance of 100 mm.

The effect of the insulating alumina block on the film properties was investigated. Without RF, the thickness of the films on the insulator (cases 2 and 3) was reduced to values as low as 30% of the film thickness of the sample placed directly on the holder (case 1). With RF, the film thickness was higher in cases 2 and 3 as compared to case 1 for some experimental conditions. The films in cases 2 and 3 possess a higher hydrogen content (as measured by SIMS) and also a higher amount of sp^3 bonding (as indicated by a lower I_D/I_G ratio in Raman spectra) as in case 1. The surface roughness was generally higher in cases 2 and 3. The influence on the hardness of the samples was investigated as well.

P 3-5

Influence of Implantation by Ions of Aluminium on Change of Size of Grain of UFG-Titanium

Alisa Nikonenko[1]
N.A. Popova[2], E.L. Nikonenko[2], I.A. Kurzina[3]

[1]Tomsk State University of Control Systems and Radioelectronics, 40 Lenin ave., Tomsk 634050 Russia
[2]Tomsk State University of Architecture and Building, 2 Solyanaya sq., Tomsk 634003, Russia
[3]Tomsk State University, 36 Lenin ave., Tomsk 634050, Russia

Email: aliska-nik@mail.ru

Key words: ion implantation, Ti, Al, grain size

Titanium as a structural material in ultra-fine grained (UFG) state possesses such properties as high mechanical strength, corrosion resistance, low density and heat resistance. Performance properties of titanium in UFG state can be enhanced by means of surface modification.

The present work is aimed at comparative analysis of research results of UFG titanium grain structure with various grain size before and after implantation by aluminium ions at the dosage of 1×10^{18} ion/cm^2.

The object of study is specimens of VT1-0 titanium with the average grain size of ~0.2 and ~0.3 μm. Ion implantation was carried out on MEVVA-V ion source [1], ion implantation dosage of 1×10^{18} ion/cm^2 was reached by the exposure time of 5.25 hours. The grain structure was investigated by transmission electron microscope (TEM) EM-125K at 120 kV accelerating voltage.

TEM investigations were carried out to study the grain structure of initial titanium specimens before and after radiation. The studies showed that before implantation strongly elongated grains with well-defined texture were present. The shape of grains is anisotropic due to sample preparation method: multiple uniaxial compacting with further multipass rolling in grooved rolls.

It is also crucial to highlight that for titanium with the average grain size of 0.2 μm, as well as of 0.3 μm, distribution functions of longitudinal and lateral sizes remain unimodal. The maximums of distribution functions are still within the range of their average values. As a result of ion implantation decrease in anisotropy coefficient is also observed. It means that after implantation grains are becoming more isotropic. A significant change in the structure is primarily attributed to energy deposition in implantation conditions.

The work is carried out with the financial support of Russian Foundation for Basic Research #19-08-01041.

References

[1] Savkin K.P., Nikolaev A.G., Oks E.M., Yushkov G.Yu. Ion beam Mass and Charge Composition for the Vacuum Arc Mevva-V.RU Metal Ion Source with Compound Cathodes, Prock. 9th Int. Conf. on Modification of Materials with Particle Beams and Plasma Flows. – Tomsk: Tomsk Polytechnic University, 2008. – pp.68-71.

P 3-6
The Ablation of Metals and Plastics by Intense Pulsed Ion Beam

Yu Xiao[1]
Shijian Zhang[1], Haowen Zhong[1], Xiaojun Cui[1], Guoying Liang[1], Mofei Xu[1], Nan Zhang[1], Shicheng Kuang[1], Jianhui Ren[1], Sha Yan[2], Xiaoyun Le[1,*]

[1]School of Physics, Beihang University, Beijing 100191, China
[2]Institute of Heavy Ion Physics, Peking University, Beijing 100871, China

Email: xyle@buaa.edu.cn*

Key words: magnetron sputtering systems, metal films and coatings, sputtering, evaporation, film growth

With strong flash thermal effects, intense pulsed ion beam (IPIB) may induce ablation on target surface and it is the basics of applications such as surface cleaning, nanopowder and thin films synthesis with IPIB. In this study, a comparative study on the ablation effects of IPIB on solid materials was made on stainless steel and plastics. Ablation mass measurement demonstrated that under irradiation of IPIB with pulse length of 120 ns, ion energy up to 400 keV, energy density up to 3 J/cm^2, the mass loss of metal general increases with the rise up of IPIB energy density. However, on plastics, with increase IPIB energy density, the trend in mass loss increases much slower. Combined with calorimetric measurement and thermal field numerical research, it is revealed that when energy reaches certain threshold, the ablation plume generated on the target surface may impose shield to the ion beam energy deposition in the target. For the low evaporation temperature and high thermal resistance, intense ablation plume may be generated on the surface of plastics under low IPIB energy density. And the principals for this energy shielding on other material, such as metals was discussed reasonably.

P 3-7

Effect of Vacancy on Thermal Conduction During Energetic Ions Irradiation: a Molecular Dynamics Study

Guoying Liang[1,2,3,4]
Jie Shen[5], Haowen Zhong[1,2,3], Jie Zhang[5], Xiaojun Cui[1,2,3], Shijian Zhang[1,2,3], Mofei Xu[1,2,3], Sha Yan[6], Xiao Yu[1,7], Xiaoyun Le[1,2,3,*]

[1]School of Physics, Beihang University, Beijing 100191, P.R. China
[2]Beijing Key Laboratory of Advanced Nuclear Energy Materials and Physics, Beihang University, Beijing 100191, P. R. China
[3]Beijing Advanced Innovation Center for Big Date-based Precision Medicine, Beihang University, Beijing 100191, P. R. China
[4]Institute of Biophysics, Dezhou University, Dezhou 253023, P.R. China
[5]Nuclear and Radiation Safety Center, Ministry of Environmental Protection, Beijing 100082, P.R. China
[6]Institute of Heavy Ion Physics, Peking University, Beijing 100871, P.R. China
[7]School of Space and Environment, Beihang University, Beijing 100191, P.R. China

Email: xyle@buaa.edu.cn*

Structural integrity of crystalline silicon significantly affects performance and life of electronic devices [1]. Intense pulsed ion beam (IPIB) technique, which is an effective tool in the field of material modification [2], can be used in regulation and utilization defects in crystalline silicon. This paper investigates the effect of vacancy on thermal conduction during energetic ions irradiation by using molecular dynamics simulations. The size and direction of vacancy are two major factors of impact on thermal conduction in crystalline silicon under energetic ions irradiation.

References

[1] W. Heywang, K.H. Zaininger, Springer Verlag, Berlin Heideberg, 2004, pp. 25-42.
[2] G.E. Remnev, V.A. Shulov, Laser Part. Beams, 11 (1993) 707-731.

P 3-8
Thermal-Diffusion Model of Ion Implantation with Soret and Dufour Effects

Maria Chepak-Gisbrecht[1,2]
Anna Knyazeva [1,2]

[1]Institute of Strength Physics and Materials Science SB RAS, 2/1 Akademicheskii ave., Tomsk 634055, Russia
[2]National Research Tomsk Polytechnic University, Tomsk 634050, Russia

Email: mv2016@mail.ru

Key words: modeling, Soret effect, Dufour effect, thermal diffusion

Ion implantations of material surface lead to such processes as heating, impurity transfer and stress appearance. It is known that the modified zone exceeds the track length of the implanted particles. The cause consists of interrelation between processes of various physical nature, that leads to special transfer mechanisms. To investigate this interrelation it is suggested non-isothermal model based on irreversible processes thermodynamics. The model includes non-stationary equations of heat conduction and diffusion taking into account of Soret and Dufour effects. Additionally, the equations include terms connecting with internal sources due to the impurity penetrate into the target material. When the coefficients of thermal conductivity, diffusion, Soret and Dufour do not change, the problem has analytical solution [1]. In other case, the problem could be solved numerically. The calculation show that Soret and Dufour effects lead to displace of maximum of concentration and temperature from surface to the depth of target material. The temperature gradient influence on mass transfer a more intensively then impurity concentration gradient on heat transfer. These results indicate on the influence of the effects of Soret and Dufour on the formation of the modified zone depth of treated material.

This work was performed within the frame of the Fundamental Research Program of the State Academies of Sciences for 2013-2020, line of research III.23.2.

References

[1] Knyazeva A.G., Gizbrekht M.V. Russian Physics Journal, 11/3, 39-46 (2011).

P 3-9
Electrical Resistivity Modification of Graphene Layers by Low Energy Ion Irradiation

Noriaki Matsunami[1]
B. Tsuchiya[2], S. Bandow[2]

[1]School of Engineering, Nagoya University, Nagoya 464-8603, Japan
[2]Materials Science & Engineering, Meijo University, Nagoya 468-8502, Japan

Email: matsunami.noriaki@a.mbox.nagoya-u.ac.jp

Key words: graphene layers, low energy N ion implantation, electrical resistivity

Graphene has been extensively investigated for both fundamental aspects and applications such as electric devices. For such applications, electrical property modification of graphene layers by ion irradiation is of interest. In this study, modification of the electrical resistivity of graphene layers has been investigated under low energy N ion irradiation. Graphene layers were prepared on SiO_2-glass substrate by a mist-chemical-vapor-deposition method [1]. Thickness of graphene layers were evaluated by 1.8 MeV He^+ Rutherford backscattering spectroscopy and it reasonably agrees with layer thickness derived from the optical transmission. The number of graphene layers used in this study is ~10 (3.5 nm). Samples were exposed to 1 keV N^{2+} and N^+ ions using a hot-filament type plasma ion source (fractions of N^{2+} and N^+ ions are 2:1). Electrical resistivity was measured by four-terminal method. It is found that the electrical resistivity of 10^{-3} Ωcm increased by more than two order of magnitude at 4×10^{16} cm^{-2} and steeply increased for further ion irradiation, meaning graphene layer loss due to ion-induced sputtering. A similar increase of the electrical resistivity was observed for 30 keV N^+ ion irradiation. In this case, the ion projected range (60 nm) is much larger than the graphene layer thickness and N's are scarcely remained in graphene layers. Hence, the resistivity increase is more likely due to defects generated by energy deposition during the ion irradiation.

References
[1] B. Tsuchiya *et al*., Diamond & Related Materials 65(2016)1.

P 3-10
Nonideality Factor in Entropy-Multifractal Analysis of Surfaces

Nikolay Makarevich[1,2]

[1]Northern (Arctic) Federal University named after M.V. Lomonosov, Arkhangelsk, Russia
[2]Military Academy of the Republic of Belarus, Minsk, Belarus

Email: nikma@tut.by

The generalized factor of nonideality of systems is introduced into the mathematical entropy-multifractal apparatus for the analysis of real systems. Entropy-fractal approach is one of the universal tools for analyzing complex systems of the most diverse nature [1], which operates with mutually complementary concepts:

- entropy (S) as a measure of randomness and as a measure of missing information on the state of the system (L. Boltzman, J. Hybbs, C. Shannon, N. Kolmogorov, A. Renyi, K. Tsalles, etc.);
- fractal with its key characteristic (d-fractal dimension) - extremely ordered, self-similar and scale invariant structure (Cantor, Hausdorf, M. Mandelbrot, etc.) [1].

The important criterion of real systems GNF the generalized factor of non-ideality of systems (g as a thermodynamic characteristic [2] connecting the ideal and real models of systems logically fits in the entropy-fractal mathematical apparatus. Two competitive (opposite in sign and action) processes: order and chaos; attraction and repulsion; compression and expansion etc. always act in real systems.

GNF (g) is introduced into classical equations (models) suitable for studying ideal systems, processes, etc. in order to use them to describe real systems. For example, it can be introduced in the equations that correspond to the laws of Henry, Raoul, Vant-Hoff, Gibbs, Coulomb, Hooke and many other equations (mathematical models) to describe the behavior of real physical systems in natural-science fields of knowledge. At the same time, g itself can also be in the form of constant or equations of any complexity. But with the obligatory condition that, besides the unit, g includes mathematically and physically sound, different in sign and action, relative characteristics of the processes: $\beta_{ord}=1/n\sum^{n}_{i}\beta_i$ and $\alpha_{nord}=1/n\sum^{n}\alpha_i$.
In general, g can be defined by β_{ord} and α_{nord} [2].

$$g=1-\beta_{ord}+\alpha_{nord}, \quad (1)$$

or through the probabilities $p_i(\alpha,\beta)$ of random variables α, β of opposite events $p_i(\alpha-\beta)$.

$$g=1+(-\beta_{ord}+\alpha_{nord})=p_i(\alpha-\beta), \quad (2)$$

GNF clearly fixes any deviations in the system under study from ideality when comparing the experimental and theoretical (obtained by the classical equation) dependence. The author [2] proposes to introduce the factor g into the equations describing self-organized structures of essentially nonequilibrium systems, i.e. fractal structures. To substantiate the connection between S, d and g, we need to refer to some of the accepted provisions of the modern entropy-fractal theory, such as the Hausdorff-Besikovich dimension, the mass one, etc. with the transition to an ensemble having a whole continuum of fractal dimensions – a fractal.

$$\lim_{\varepsilon\to 0}(\sum^{N}_{i=1}p^{q}_{i}\varepsilon^{\tau}_{i})^{n}=c, \quad (3),$$

where $p_i(\varepsilon_i)$ is the probability of creating a fractal by the generator ε at the n-th level of a self-similar set with the number of elements (a) equal N^{n}_{i} and the set of indicators $\tau = \tau(q)$ forming the scaling size distribution of clusters, q - Renyi order.

A fractal object can be any surface. Relationships of fractal dimensions with entropies (L. Boltzmann, J. Gibbs, C. Shannon, A.N. Kolmogorov, A. Renyi, K. Tsallis, at all) are established when considering the limit

$$d=\lim_{\varepsilon\to 0} S(a)/\ln(1/\varepsilon), \quad (4),$$

where the entropy S(a) can be: $S^{(B)}$ – Boltzmann, $S^{(K)}$ – Kolmogorov, $S^{(R)}$ –Renyi, etc.

The establishment of a functional relationship between q, S and d is important for the entropy-multifractal analysis of self-organized structures of simple and complex systems and processes, including technological ones. This concerns surface modification with directed energy effects, such as ionic, electron and laser beams, thermochemical treatment, sol-gel coating, plasma electrolytic oxidation, etc. [3].The report will present universal equations for the entropy-fractal analysis of real surfaces using the generalized nonideality factor of real systems (GNF) and analyze some experimental data on energy and thermo-chemically modified natural objects.

REFERENCES

[1] J. Feder. Fractals, Plenum, New York (1988).
[2] Makarevich N.A. The nonideality factor in classical equations for gases and condensed systems. DAN Belarus 60(1), (2016), 94-101.
[3] Surface modification of materials by ion implantations for industrial and medical applications, VIENNA, 2000. IAEA-TECDOC-1165. IAEA, Austria.2000.

P 3-11

Interfacial Reactions in Al_2O_3/Cr_2O_3 Interfaces Obtained by Pulsed Magnetron Sputtering

Ivan Zhidkov[1]
M.A. Korotin[2], A.I. Kukharenko[1], N.V. Gavrilov[3], S.O. Cholakh[1], E.Z. Kurmaev[1,2]

[1]Insitute of Physics and Technology, Ural Federal University, Yekaterinburg, Russia
[2]Insitute of Metal Physics, Ural Branch of Rassian Academi of Science, Yekaterinburg, Russia
[3]Institute of Electrophysics, Ural Branch of Rassian Academi of Science, Yekaterinburg, Russia

Email: i.s.zhidkov@urfu.ru

Interfacial reactions were found in Al_2O_3/Cr_2O_3 layers obtained by high-power pulsed magnetron sputtering of Al_2O_3 on a Cr_2O_3 substrate. Measurements of X-ray photoelectron (XPS) survey spectra revealed the presence of Cr atoms on the surface of the Al_2O_3/Cr_2O_3 interface, while XPS Cr $2p_{3/2}$ and Cr $2p_{1/2}$ spectra with high energy resolution showed that the chromium ions are in the trivalent state. This made it possible to conclude that the Cr^{3+} ions from the Cr_2O_3 substrate diffuse onto the Al_2O_3 surface, partially replacing the Al nodes. This conclusion is confirmed by the calculation of the electronic structure of $Al_{1.95}Cr_{0.05}O_3$, carried out within the framework of the density functional theory (DFT) in the coherent potential approximation, which, in full agreement with the XPS data of the valence spectra, shows the arrangement of Cr 3d states in the band gap of pure Al_2O_3 with the level Fermi crossing the 3d-zone of the Cr effective cationic atom.

P 3-12
Electronic Structure of Ion-Implanted 3D Impurities in a Topological Insulator Bi_2Te_3

Ivan Zhidkov[1]
M.A. Korotin[2], D.W. Boukhvalov[1,2], A.I. Kukharenko[1], N.V. Gavrilov[3], S.O. Cholakh[1], E.Z. Kurmaev[1,4]

[1]Institute of Physics and Technology, Ural Federal University, Yekaterinburg, Russia
[2]College of Science, Institute of Materials Physics and Chemistry, Nanjing Forestry University, Nanjing, China
[3]Institute of Electrophysics of Ural Branch of Russian Academy of Sciences, Yekaterinburg, Russia
[4]M.N.Mikheev Institute of Metal Physics of Ural Branch of Russian Academy of Sciences, Yekaterinburg, Russia

Email: i.s.zhidkov@urfu.ru

The results of measurements of the X-ray photoelectron spectra of 3d impurities (Cr, Mn, Fe, Co, Ni, and Cu) in Bi_2Te_3 thin films are presented. Bi_2Te_3 thin films (560 nm thick) were grown on Al_2O_3 (0001) substrates by pulsed laser deposition using the original target with a stoichiometric composition of 99.99% purity. The implantation of ions into thin-film Bi_2Te_3 samples was carried out in a vacuum chamber, which was evacuated to a residual pressure of 3×10^{-3} Pa. An ion beam with an energy of 30 keV was created at the initial cathode by evaporating the metal with an electric arc. The ions were then used to irradiate the sample in a pulsed mode (25 Hz). After 38 minutes of exposure, the sample had an ion density (integrated flux over time) of 1×10^{17} cm^{-2}. To study the local atomic and electronic structure of the impurity atoms of 3d-elements in Bi_2Te_3:3d systems the high-resolution XPS 2p spectra of 3d-dopants were measured. The XPS Mn 2p spectra in Bi_2Te_3:Mn were found to be close in energy to the spectrum of Mn_2O_3. This indicates the replacement of bismuth atoms with trivalent manganese atoms. On the other hand, in the XPS 2p spectra of Fe, Co, Ni, and Cu in Bi_2Te_3:3d in addition to the lines corresponding to the cationic substitution new lines are clearly recorded that coincide in energy with the spectra of pure metals. This indicates the formation of more complex structural configurations of impurity atoms in these systems, in which not only «pure» cationic substitution can be traced, but also the introduction of impurity atoms into interstitials and the formation of metal clusters. The results of numerical first-principle calculations of the formation energies of various configurations of impurity atoms in Bi_2Te_3:3d systems showed that the formation energy of single impurities of substitution for manganese atoms (S) turned out to be lower than the formation energies of mixed configurations, including both substitution impurities and interstitial impurities (S+I, 2S+I, 2S+3I). For impurities of other 3d-elements the opposite situation is observed and the formation of mixed configurations of substituted and implanted atoms is energetically favorable. This difference can be explained by the fact that the ionic radius of the trivalent manganese ion (0.65 Å) of bismuth is closer to the ionic radius of the trivalent bismuth ion (1.03 Å) than the analogous radii of trivalent ions of Fe, Co, Ni, Cu (0.56-0.61 Å). Therefore, the calculations performed are in good agreement with the experimental XPS spectra, which makes it possible to draw unambiguous conclusions about the character of doping of Bi_2Te_3 with impurities of 3d elements.

SMMIB-2019

21ST INTERNATIONAL CONFERENCE
ON SURFACE MODIFICATION OF MATERIALS BY ION BEAMS
25-30 August 2019
Tomsk, Russia

Session 4
Defect Engineering, Nano-Science and Technology

Invited Talk

I 4-1

Damage Tracks of High Energy Ions in Polymers and Their Use for Fabricating 1-Dimensional Nanostructures

Wolfgang Ensinger[1,2]

[1]Darmstadt University of Technology Department of Materials Science, Darmstadt, Germany
[2]Helmholtz-Center of Heavy Ion Research, 64287 Darmstadt, Germany

ensinger@ma.tu-darmstadt.de

When ions of heavy elements with large kinetic energy and a high charge state cross a polymer foil, they set energetic electrons free (delta-electrons) which are able to break covalent chemical bonds. Along the ion trajectories, the polymers show both a reduced density and a lower chemical stability. Here, the polymers can chemically be etched with a large track-to-bulk etch ratio, thus forming high-aspect-ratio nanochannels (ion track etching method). An example is the formation of a 10 nm diameter nanochannel in a 10 micrometer thick polyester foil by irradiation with 2 GeV Au-ions. Polymer films with such nanochannels can act on one hand as a filter or a sensing device and on the other hand they can be used as a template for fabricating 1-dimensional nanostructures such as nanowires and nanotubes. For this purpose, the channels are homogeneously filled with metals, either galvanically or redox-chemically. The electrochemical deposition yields solid nanowires, the electroless deposition nanotubes that are obtained by depositing a thin film onto the nanochannel walls. When the template is removed by chemical dissolution, the nanostructures are set free.

In the present contribution, the ion damage track formation in the polymer is described and the template technique and its parameters for etching nanochannels are explained.

From the wide range of applications of the obtained 1-D nanostructures several will be shown:

- Examples of the application of nanochannels as (bio)chemical sensors after chemically modification by attaching biorecognition molecules will be presented.
- In case of the metallic nanowires and nanotubes, such as Pt, Au, Ag and Ni, applications in (electro) catalysis in microreactors, as fuel cell electrodes and for force/acceleration sensing will be shown.

I 4-2

Atomic-Scale Tuning of Quantum Dot Site Nucleation and Si Based Nanostructures Growth on Ion Beam Modified Surface

Anatoly Dvurechenskii[1,2]
Zhanna Smagina[1], Vladimir Zinoviev[1], Pavel Novikov[1], Sergei Rudin[1]

[1]Rzhanov Institute of Semiconductor Physics, Siberian Branch of Russian Academy of Science, Novosibirsk 630090, Russia
[2]Novosibirsk State University, Physics Department, Novosibirsk 630090, Russia

Email: dvurech@isp.nsc.ru

Key words: quantum dot, molecular beam epitaxy, Si, Ge, ion beam surface modification

Quantum dots (QDs) nanostructures are promising candidates to be implemented in next generation CMOS-compatible optoelectronic and nanoelectronic devices if they can be formed in regular and uniform arrays with controlled size, shape, chemical composition, and the properties of their surrounding like choice of matrix material. For realistic integration of QD into Si-technology devices, the QDs have to be site-controlled to ensure their large scale addressability. Besides, ordered QDs provide several more benefits as compared to their randomly nucleated counterparts: a more homogeneous chemical composition and energy spectrum. In this report, we will focus on self-assembled, group-IV, Ge-on-Si epitaxial QDs, formed with dislocation-free growth [1].

The size homogeneity and density of the arrays of quantum dots was found to be tuned with low-energy ion-beam actions during molecular beam epitaxy (MBE). Nucleation of QDs due to a pulsed low-energy (100 eV) beam action of intrinsic ions (Ge^+) resulted in the increasing of QDs density and improving of homogeneity in QDs sizes.

The linear ordered chains of quantum dots were formed on Si groove patterned Si(001) substrate formed by using combination of nanoimprint lithography and Ge ion irradiation through mask. Ordered structures with grooves and ridges were prepared by the selective etching of regions amorphized by ion irradiation. Laterally ordered chains of Ge nanoislands were grown by MBE of Ge on the prepatterned Si substrates. It was shown that temperature during ion irradiation affects the location of subsequently grown Ge nanoislands at MBE: inside grooves or on ridges. It was shown also, that the location of subsequently grown Ge nanoislands depends upon the sidewall inclination in grooves and grooves shape: in the case of the V-shaped pits, 3D Ge islands nucleate inside the pits. For U-shaped pits the 3D Ge island nucleation takes place around the pit periphery. This effect is attributed to the strain relaxation depending not only on the initial pit shape, but also on its evolution during the Ge wetting layer deposition.

Monte Carlo simulations was shown that in the case of a V-shaped pits with a pointed bottom, the strain relaxation is most effective inside the pit, while for a U-shaped pits with a wide bottom, the most relaxed area migrates during Ge deposition from the pit bottom to its edges, where 3D Ge islands nucleate. The interpretation is consistent with the general approach, considering the strain as a driving force for the island positioning. In addition, a specific mechanism, associated with a shift of the relaxed area from a pit bottom to its top during Ge deposition, was identified. The mechanism is pronounced in the case of a pit with a wide flat bottom.

The work was funded by Russian Scientific Foundation (grant 19-12-00070).

References:

[1] A.V. Dvurechenskii, A.I. Yakimov. Silicon-Based Nanoheterostructures with Quantum Dots. In: Advances in Semiconductor Nanostructures: Growth, Characterization, Properties and Applications, Ed. by A.V. Latyshev, A.V. Dvurechenskii, A.L. Aseev. Elsevier, Amsterdam, 2017, pp. 59–99.

I 4-3

Tolerance of Multilayered Systems MeN/Si_3N_4 (Me=Cr, Zr, Al) to Radiation Erosion

Vladimir Uglov[1,2]
G. Abadias[3], S.V. Zlotski[1], A.A. Malashevich[1], I.A. Saladukhin[1], A.L. Kozlovskiy[4], M.V. Zdorovets[4], V.A. Skuratov[5], A. Janse van Vuuren[6], J. O'Connell[6]

[1]Belarusian State University, 4 Nezavisimosti ave., Minsk 220030, Belarus
[2]National Research Tomsk Polytechnic University, 30 Lenin ave., Tomsk 634050, Russia
[3]Institut Pprime, Université de Poitiers-CNRS-ENSMA, Dpt. Physique et Mécanique des Matériaux, SP2MI, Teleport 2, F86962 Chasseneuil-Futuroscope cedex, France
[4]L.N. Gumilyov Eurasian National University, Astana, Kazakhstan
[5]Joint Institute for Nuclear Research, Dubna 141980, Russia
[6]Centre for HRTEM, Nelson Mandela Metropolitan University, Port Elizabeth, South Africa

Email: uglov@bsu.by

The deposition of multilayered systems can improve radiation resistance that depends on the layer structure and composition, as well as on the presence of interfaces. Crystalline/amorphous nanostructured multilayers exhibit a high radiation tolerance along with crystalline/crystalline systems, due to amorphous nanolayers associated with excellent defects absorption capability.

Nanoscaled n-CrN/a-Si_3N_4, n-ZrN/a-Si_3N_4 and n-AlN/a-Si_3N_4 multilayers with different thickness of elementary layers grown by reactive magnetron sputter-deposition from Cr(Zr, Al) and Si3N4 targets at RM was performed. SEM, AFM and HRTEM investigations of the multilayer's surface structure after He (40 keV and a dose up to 1×10^{18} cm^{-2}) ions implantation at RM were carried out.

HRTEM studies have shown that at doses of 1×10^{16} cm^{-2}, the appearance of chains of pores in amorphous layers was detected. In CrN/S_3N_4 and ZrN/S_3N_4 multilayer systems, the pore chains are located in the center of the amorphous layer, and in the AlN/Si_3N_4 system, closer to the boundary with the crystalline layer (from the surface). It was revealed that He bubbles form chains in amorphous layers, and the dependence of the diameter of bubbles on the concentration of implanted He is established.

Microscopic studies of the multilayered films irradiated with He ions showed the formation of the multilayered structure leads to an increase in the critical dose of blister formation compared to mononitride crystalline films. It was found that multilayered systems with the amorphous layer thickness large then crystalline are most resistant to radiation erosion. The critical dose of blistering is greater than 1E18 cm^{-2}. In contrast to mononitride systems (CrN, ZrN and AlN), the feature of multilayer films is the absence of dependence of the size and density of blisters on the radiation dose.

The influence of the structure of crystalline layers and internal stresses on the processes of radiation erosion in multilayer systems is discussed.

Oral Presentation

O 4-1
Positron Annihilation Studies of Irradiation Induced Defects in Gold and Niobium

Pawel Horodek[1,2]
A.G. Kobets[2,3], K. Siemek[1,2], V.A. Skuratov[2]

[1]Institute of Nuclear Physics, Polish Academy of Science, Krakow 31-342, Poland
[2]Joint Institute for Nuclear Research, Dubna 141980, Russia
[3]Institute of Electrophysics and Radiation Technologies NAS of Ukraine, Chernyshevsky str. 28, Kharkov 61002, Ukraine

Email: pawel.horodek@ifj.edu.pl

Key words: positron beam, gold, niobium, swift heavy ion irradiation, defects

Within this presentation we report experimental studies of pure Gold and Niobium exposed to Xe^{26+} irradiation. Implantation using 167 MeV ions and fluencies 10^{12}, 10^{13}, 5×10^{13}, 10^{14} ions/cm^2 were performed at IC-100 cyclotron at FLNR, JINR. Radiation damages were investigated with variable energy positron beam (VEP) in the near surface region. Doppler broadening spectroscopy (DB) was applied and the line shape S parameter of annihilation line was extracted. The analysis of S parameter profiles gives information about the presence of open volume defects in irradiated samples. The positron diffusion lengths extracted from the profile decreases with the dose increase and energy decrease in the investigated depth. It points out the increase of defects concentration.

On the other hand conventional positron lifetime measurements in the etching experiment were also performed. They allowed us to find the kind of introduced defects (stacking fault tetrahedras in the case of Au and dislocations in the case of Nb). Moreover, the defects depth profiles were reproduced. The thickness of damaged layer was much deeper than implanted one in the case of Nb samples.

O 4-2
Studies of InAs Formation in Indium Implanted GaAs Exposed to Annealing

Miroslaw Kulik[1,2]
D. Kołodyńska[3], J. Żuk[2], P. Horodek[1,4]

[1]Joint Institute for Nuclear Research, Dubna 141980, Russia
[2]Institute of Physics, Maria Curie-Skłodowska University, M. Curie Skłodowska sq. 1, 20-031 Lublin, Poland
[3]Faculty of Chemistry, Maria Curie-Skłodowska University, M. Curie Skłodowska sq. 2, 20-031 Lublin, Poland
[4]Institute of Nuclear Physics, Polish Academy of Science, Krakow 31-342, Poland

Email: mkulik@hektor.umcs.lublin.pl

Key words: ellipsometry, GaAs, ion implantation

GaAs is used in the production of electronic and optoelectronic systems. This semiconductor has found a wide application due to its physical properties. The results presented in this report point out formation of InAs in GaAs implanted with indium ions and subjected to the thermal annealing. The samples were measured by the nuclear reaction (NR) and Rutherford backscattering spectrometry (RBS). The optical properties of the GaAs region enriched with indium atoms were measured using chemical etching and ellipsometric spectrometry (SE). The effective medium approximation (EMA) was used to describe the samples before the thermal treatment. It was found that the depth profile of the degree of amorphization estimated by the SE method in the near-surface GaAs layer before the thermal annealing is consistent with the profiles theoretically calculated by the SRIM code. The collected spectra of Ψ and Δ ellipsometric angles for the samples after the thermal treatment are similar to those obtained for the virgin GaAs. This result indicates that the crystallographic structure of implanted semiconductor samples has been rebuilt during irradiation process. Based on this fact, approximation with the parametric model of the dielectric function was used to describe the samples after thermal treatment. As follows the shape of the dielectric function spectra varies with the depth for the irradiated samples and depends on the amount of the surface atomic concentration of indium atoms. In order to clarify these effects, the additional chemical composition tests were carried out. In_2O_3, Ga_2O_3 and the traces of As_2O_5 were observed in the layer of 40 nm below the surface before thermal treatment. In turn, InAs was found after annealing next to mentioned components. The concentration of InAs and metallic Ga decreases while the concentration of GaAs increases with depth.

O 4-3
Fabrication of Metal-Dielectric Nanocomposites Using a Table-Top Ion Implanter

Victor Paperny
O.I. Shipilova, S.P. Gorbunov, V.L. Paperny, A.A. Chernih

Department of Space Physics, Faculty of Physics, Irkutsk State University, K. Marx st.,1, Irkutsk 664003, Russia

Email: paperny@math.isu.runnet.ru

Key words: low-voltage vacuum spark, molecular silver clusters, nano-scaled Ag crystals

The optical and X-ray characteristics of the layers formed in the dielectric matrixes as a result of irradiation by ions emitted by a small-sized low-voltage vacuum spark with a voltage < 2 kV and a pulse duration of about 1 μs were studied. The photoluminescence technique showed that as a result of the irradiation, layers of molecular silver clusters Agn are formed in the matrixes. The luminescence characteristics of these layers are close to those of layers formed in the matrixes owing to irradiating by a metallic ion beam with energy up to 150 keV emitted by a high-voltage ion implanter. The absorption spectra of the samples showed that the annealing of the samples resulted in coalescence of the molecular clusters resulting to formation of nano-scaled Ag crystals, exhibited the characteristic extinction bands. Using the X-ray fluorescent technique it was shown that the fluence of the silver ions in the matrix approached 4×10^{12} ion/cm^2 per a single pulse. The results show that this «table-top» source of beams of metallic ions accelerated by a collective mechanism can be used to create modified nano-scaled layers in dielectric matrix for optical applications.

O 4-4

Preliminary Experimental Study on the Effects of Low-Energy Titanium Ion Beam Irradiation on Secondary Electron Emission Characteristics of Metal Materials

Jialong He
Jie Yang, Wei Zhao

Institute of Fluid Physics, CAEP, No. 64, Mianshan Road, Mianyang, China

Email: hejl2003@qq.com

Electrons will be emitted from the surface of the solid material when the material was bombarded by photons, electrons and ions. This phenomenon is called secondary electron emission (SEE) phenomenon of solid materials. The secondary electron emission and multiplication problems on the surface of solid materials will lead to various serious consequences of device or product performance degradation or even failure in many fields like particle accelerators, spacecraft, electric vacuum devices, high-power microwaves, electrical insulation, pulse power technology, and so on. Therefore, in the fields of scientific research and engineering application related to SEE of materials, effective measures should be taken to modify the SEE characteristics of the materials in order to improve the performance of devices or products. Based on the demand of application, many methods and technologies for modifying SEE properties of materials have been developed in the related fields, including surface coating based on TiN, graphite and diamond-like carbon films, surface etching based on photolithography, laser, plasma, mechanical groove, and so on. In addition to these methods, ion beam irradiation is also a kind of effective method to modify the SEE characteristic of materials.

Different from the ion irradiation of inert gas elements with the highest energy of several keV, which mainly changes the SEE characteristics by surface sputtering to change the surface morphology of the material, the defects caused by the ion beam irradiation with energy of tens of keV to hundreds of keV on the surface of the material also have an important impact on the SEE characteristics of the material. Further research on the law and mechanism needs to be carried out. The samples of oxygen-free copper and stainless steel were irradiated by titanium ion beam with energy ranging from 40 keV to 160 keV. The ion implantation dose ranged from 10^{15} ions/cm^2 to 10^{18} ions/cm^2. The secondary electron yield (SEY) and energy spectra of the samples before and after ion irradiation were measured under electron beam incidence. It was found that the SEY of the samples decreased significantly after ion beam irradiation. Vacancies and other defects caused by ion irradiation increase the probability of low-energy secondary electrons being trapped by defects during the diffusion process of secondary electrons inside the material, thus reducing the yield of secondary electrons.

O 4-5
Morphological Effects on the Dopant Activation of Gasb Films Implanted with Si Ions

Shyama Rath[2]
Rakesh Kumar Pandey[1,2], Puspashree Mishra[1]

[1]Solid State Physics Laboratory, DRDO, Delhi 110054, India
[2]Dept. of` Physics & Astrophysics, University of Delhi, Delhi 110007, India

Email: srath@physics.du.ac.in

Antimonide-based compound semiconductors have been found to be suitable for various applications such as IR detectors, lasers, LEDs, high-speed transistors, and thermo-photovoltaic cells. In this work, GaSb epitaxial layers were grown by molecular beam epitaxy (MBE) on semi-insulating GaAs substrates. Doping was done by ion-implantation with Si ions using an energy of 50 keV and a fluence varying between 1×10^{12} and 1×10^{15} ions/cm^2 for both ions. Van der Pauw four-probe Hall measurement was performed to evaluate the sheet and bulk carrier concentration, mobility, and type of carriers. From this data, the donor nature of the amphoteric dopant Si and with a significant dopant activation is obtained. From temperature vs conductivity measurements, hopping conduction due to implantation induced defects is ruled out in post-implanted annealed GaSb. Field-emission scanning electron microscopy (FESEM), atomic force microscopy (AFM) and Raman spectroscopy measurements are used to monitor the fluence-dependent structural and morphological changes on implantation. Sb out-diffusion is also determined from Raman spectroscopy. The results suggest the scope of Si as an-type dopant in GaSb.

Poster Session

P 4-1
Structure of Austenitic Steel Surface Layer Subjected to Compression Plasma Flows Impact

Nikolay Cherenda[1,2]
V.V. Uglov[1,2], V.M. Astashynski[3], A.M. Kuzmitski[3]

[1]Belarusian State University, Nezavisimosti ave., 4, Minsk 220030, Belarus
[2]National Research Tomsk Polytechnic University, 2a Lenin ave., Tomsk 634028, Russia
[3]A.V. Luikov Heat and Mass Transfer Institute, National Academy of Sciences of Belarus, P. Brovki str., 15, Minsk 220072, Belarus

Email: cherenda@bsu.by

Compression plasma flows (CPF) treatment is a promising technology of materials' properties modification. Its main advantages are a short treatment time (~ $1e^{-4}$ s), a possibility of surface layer formation with predetermined element and phase composition. CPF can be effectively used for formation of metastable phases and alloys containing immiscible elements. Earlier conducted investigations showed that alloying of austenitic steel surface layer with Zr atoms by means of Zr/steel system CPF treatment allowed increasing steel microhardness by a factor of 2 [1]. At the same time formation of cracks at the surface and appearance of bcc Fe phase in the alloyed layer was found that could worsen corrosion resistance. In order to separate the effects of Zr alloying and effects of high-temperature plasma impact the investigation of the austenitic steel surface layer structure, phase and element composition after CPF treatment were carried out in this work.

Samples of austenitic steel (~0.12 C, 18 Cr, 10 Ni, 0.2 Mn, 0.8 Si, 0.8 Ti, 0.3 Cu, in wt.%, and balance Fe) were investigated. Compression plasma flows were obtained using a gas-discharge magneto-plasma compressor of compact geometry. Number of plasma pulses was varied in the range of 1÷7. The energy absorbed by the surface was ~ 25 J/cm^2 per pulse. The experiments were performed in a «residual gas» mode at which the vacuum chamber was filled with a nitrogen. X-ray diffraction, scanning electron microscopy, energy-dispersion X-ray microanalysis, Vickers microhardness measurements were used for samples characterization.

The findings showed that fcc Fe was the main phase constituent in the analyzed layer after plasma impact though small amount of iron nitride was detected. The decrease of the plasma pulses number resulted in the growth of the fcc Fe (200) diffraction line that can be explained by formation of columnar-like grains in the re-melted layer grown in <100> direction. Variation of the element composition with plasma treatment parameters change occurred. The microhardness value was not depended on the plasma pulses number.

References
[1] A.H. Sari *et al*. Alloying of austenitic steel surface with zirconium using nitrogen compression plasma flowVacuum 115 (2015) 39-45.

P 4-2

Effect of Hydrogen Content on Water Wettability of Diamond-Like Carbon Films Prepared by Plasma-Based Ion Implantation and Deposition

Setsuo Nakao[1]
Kohtaku Suzuki[2], Atsushi Kinomura[3], Yoshihiro Kuzuya[3], Tsutomu Sonoda[1], Koumei Baba[4]

[1]National Institute of Advanced Industrial Science and Technology (AIST), Nagoya 463-8560, Japan
[2]The Wakasa Wan Energy Research Center (WERC), Fukui 914-0192, Japan
[3]Institute for Integrated Radiation and Nuclear Science, Kyoto University, Osaka 590-0494, Japan
[4]SANNO Co., Ltd., Yokohama 223-0052, Japan

Email: nakao.s@aist.go.jp

Key words: diamond-like carbon, bipolar, plasma-based ion implantation and deposition, elastic recoil detection analysis, hydrogen content, contact angle

Diamond-like carbon (DLC) films have attracted much attention because of their excellent mechanical properties. In addition, high biocompatibility of DLC films is also reported and DLC coatings of biomaterials have attracted much interest in recent years. The water wettability is one of the important factors for the application of biomaterials. DLC films, thus, has been studied to obtain suitable wettability by adjusting deposition parameters to control the microstructure. Hydrogen content apparently affects the microstructure of the films and it is likely to relate to the wettability of the films. However, the relationship between hydrogen content and wettability is not always clarified. Plasma-based ion implantation and deposition (PBIID) is a chemical vapor deposition method using hydrocarbon source gases, which involves an ion bombardment process and may adjust the hydrogen content of the deposited films by changing applying negative pulse voltage. In this study, DLC films are prepared on silicon substrates by a bipolar-type PBIID system developed at AIST. A positive pulse voltage is kept +1.2 kV and negative pulse voltages are changed in the range of -0.3 to -5.2 kV. The hydrogen content is examined by elastic recoil detection analysis (ERDA) and the wettability is evaluated by water contact angle measurement. The results of ERDA show that the hydrogen content varied in the range of 1.8 to 7.0×10^{22} H/cm^3, while the contact angles range from 77.1 to 91.4 degree. The current results comparing all the sample types, however, suggest that there is little relationship between hydrogen content and contact angles. To make clear the trends, careful classification of the samples and further analysis of the data is necessary.

P 4-3

Investigations of Chemical Composition and Thickness of Oxide Layers Deposited on Si GaAs Implanted with Xe Ions

Phan Luong Tuan[1,2]
M. Kulik[1,3], J. Nowicka-Scheibe[4,1], A.P. Kobzev[1], J. Żuk[3], P. Horodek[1,5], L.H. Khiem[6,7], M. Turek[3], K. Pyszniak[3], A. Drozdziel[3]

[1]Joint Institute for Nuclear Research, Dubna 141980, Russia
[2]Vietnam Atomic Energy Institute, 59 Ly Thuong Kiet, Hoan Kiem, Hanoi, Vietnam
[3]Institute of Physics, Maria Curie-Skłodowska University, pl. Marii Curie-Skłodowskiej 1, 20-031 Lublin, Poland
[4]Department of Organic Chemistry and Physical Chemistry, Faculty of Chemical Technology and Engineering, West Pomeranian University of Technology, Piastów Ave. 42, 71-065 Szczecin, Poland
[5]Institute of Nuclear Physics, Polish Academy of Science, Krakow 31-342, Poland
[6]Institute of Physics, Vietnam Academy of Science and Technology,10 Dao Tan, Ba Dinh, Hanoi, Vietnam
[7]Graduate University for Science and Technology, Vietnam Academy of Science and Technology, Vietnam

Email: phanluongtuan@gmail.com

Key words: chemical composition, ion implantation, oxide layer, GaAs, nuclear methods

Surfaces of (100) SI GaAs irradiated with 250 keV Xe beam at room temperature with different fluencies were the objects of studies. The implantation doses for individual sample varied from 1×10^{12} cm^{-2} to 3×10^{16} cm^{-2}. After implantations the samples were kept in air for 5 hours. The characterization of native oxide layers and their thicknesses were performed using the nuclear reaction (NR) method. The depth profiles of As, Ga and Xe atoms were measured by the Rutherford backscattering spectrometry (RBS).

Smaller contraction of As in comparison to Ga atoms has been observed in the near surface layer of samples irradiated with doses from 3×10^{15} cm^{-2} to 3×10^{16} cm^{-2}. It is caused by selective sputtering of the As atoms from the irradiated surface. The NR results show that the surface oxygen concentration and the thickness of the oxidized layers increase with the dose. The surface concentration of oxygen is a linear function of the implanted dose in the range from 3×10^{13} cm^{-2} to 8×10^{14} cm^{-2}. The chemical composition of studied oxides layers was determined by the X-ray photoelectron spectroscopy (XPS) technique. These results indicate faster increasing of Ga_2O_3 in comparison to As_2O_3. It was also found that the amount of As_2O_5 in the oxidized region decreases linearly with applied dose. The mentioned effects can be attributed to a faster increase of the number of gallium vacancies than of arsenic.

P 4-4

Radiation Tolerance of Nanostructured TiAlN Coatings Under Ar^+ Ion Irradiation

Elke Wendler[2]
S.V. Konstantinov[1], V.A. Zaikov[3], F.F. Komarov[1,4]

[1]Institute of Applied Physics Problems of Belarusian State University, Minsk, Belarus
[2]Friedrich Schiller University, Jena, Germany
[3]Belarusian State University, Minsk, Belarus
[4]National University of Science and Technology MISIS, Moscow, Russia

Email: elke.wendler@uni-jena.de

TiAlN coatings show unique strength and tribomechanical characteristics. Additionally, they can effectively withstand the accumulation of an inert gas. High integral length of grain boundaries of these nanostructured coatings serve as an effective sink for radiation-induced defects. Because of these properties, TiAlN coatings are potentially useful for nuclear reactors including reactors of the IV Generation. For successful application, the radiation resistance of corresponding layers is of essential importance. The effect of He^+ ion irradiation was already investigated in our previous papers. In this presentation, the radiation resistance of TiAlN coatings under irradiation with 200 keV Ar^+ ions is examined at room temperature. The ion fluence varied in the range of $1\times10^{16}\div2\times10^{17}$ Ar/cm^2. The TiAlN coatings were deposited by reactive magnetron sputtering. Single crystalline silicon wafers as well as AISI 304 stainless steel bars were used as substrates for investigating Ar ion concentration, composition of the layers and mechanical properties after irradiation. Rutherford backscattering spectrometry (RBS) with He ions of 4.5 MeV energy results in an enhanced non-Rutherford backscattering yield on N atoms, which proved to be useful for determination of the nitrogen content. Up to the ion fluence of 2×10^{17} Ar/cm^2 not any change in the composition of the coating is observed and most of the Ar ions are retained within the layer. X-ray diffraction method (XRD) was used to define the phase composition and structure of as-deposited and irradiated TiAlN coatings. Further, depth dependent studies by scanning electron microscopy and energy dispersive X-ray spectroscopy were performed in order to measure the local distribution and blisters formation in the implanted layers. Mechanical properties were investigated by nanoindentation with CSM Instruments NHT2 Nanoindenter equipment using the Berkovich diamond indenter.

It is shown that nanostructured TiAlN coatings are perspective as radiation-resistant ones in different applications of nuclear and space technologies.

P 4-5

Admittance Studies of Modification of HgCdTe Surface Properties with Ion Implantation and Thermal Annealing

Alexander Korotaev[1]
A.V. Voitsekhovskii[1], I.I. Izhnin[1,2], K.D. Mynbaev[3,4,] S.N. Nesmelov[1], S.M. Dzyadukh[1], V.S. Varavin[5], S.A. Dvoretsky[1,5], N.N. Mikhailov[5], M.V. Yakushev[5], G.Yu. Sidorov[5]

[1]National Research Tomsk State University, 36 Lenin ave.,Tomsk 634050, Russia
[2]Scientific Research Company «Electron-Carat», 202 Stryjska str., Lviv 79031, Ukraine
[3]Ioffe Institute, 26 Polytechnicheskaya str., Saint-Petersburg 194021, Russia
[4]ITMO University, 49 Kronverkskiy ave., Saint-Petersburg 197101, Russia
[5]A.V. Rzhanov Institute of Semiconductor Physics of SB RAS, 13 Lavrent'ev ave., Novosibirsk 630090, Russia

Email: kor@mail.tsu.ru

Key words: MBE-grown HgCdTe, ion implantation, MIS structures

Recently, much effort has been put in the development of HgCdTe-based photodiodes with p-n junction formed with implantation of arsenic. Despite numerous studies, there is still no complete understanding of the processes occurring in the surface layer of HgCdTe when exposed to irradiation with ion beams and annealing, especially for material with graded-gap surface layers. Up to now, the properties of such material have been studied with the use of the Hall effect. Admittance studies, in their turn, allow, within the space charge region (SCR), for studying profiles of electrically active defects and dopants. We report on the results of experimental studies of the admittance of MIS structures based on molecular beam epitaxy (MBE)-grown HgCdTe films. The measurements were performed at different stages of the fabrication of p-n junction with ion implantation.

We have studied two similar n-$Hg_{1-x}Cd_xTe$ ($x\approx0.22$) films grown on Si substrates. The films were subjected to activation annealing and implantation with As^+ ions (200 keV energy, 10^{14} cm^{-2} fluence) with subsequent two-stage arsenic activation annealing. MIS structures were fabricated after each processing step, and their admittance was studied in a wide condition range.

The surface layers of initial films were found to have donor concentration $\sim5\times10^{15}$ cm^{-3}, and this concentration changed only slightly after activation annealing. Ion implantation did not change the conductivity type, yet the donor concentration increased up to $\sim10^{17}$ cm^{-3}, while differential resistance of SCR under strong inversion increased tenfold. Post-implantation activation annealing converted conductivity type with acceptor concentration reaching $\sim2\times10^{18}$ cm^{-3} (which would be difficult to establish with the Hall-effect measurements). The resistance of SCR after this annealing decreased. The concentration profiles in the film surface layer are determined.

The study was supported by the Russian Science Foundation (grant N 19-12-00135).

P 4-6

Hall Effect Studies of Modification of Hgcdte Surface Properties with Ion Implantation and Thermal Annealing

Alexander Korotaev[1]
I.I. Izhnin[1,2], K.D. Mynbaev[3,4], A.V. Voitsekhovskii[1], S.N. Nesmelov[1], S.M. Dzyadukh[1], O. Fitsych[1,2], V.S. Varavin[5], S.A. Dvoretsky[1,5], N.N. Mikhailov[5], M.V. Yakushev[5], O.Yu. Bonchyk[6], H.V. Savytskyy[6], Z. Swiatek[7], J. Morgiel[7]

[1]National Research Tomsk State University, 36 Lenin ave.,Tomsk 634050, Russia
[2]Scientific Research Company «Electron-Carat», 202 Stryjska str., Lviv 79031, Ukraine
[3]Ioffe Institute, 26 Polytechnicheskaya str., Saint-Petersburg 194021, Russia
[4]ITMO University, 49 Kronverkskiy ave., Saint-Petersburg 197101, Russia
[5]A.V. Rzhanov Institute of Semiconductor Physics of SB RAS, 13 Lavrent'ev ave., Novosibirsk 630090, Russia
[6]Ya.S. Pidstryhach Institute for Applied Problems of Mechanics and Mathematics NASU, 3b Naukowa str, Lviv 79060, Ukraine
[7]Institute of Metallurgy and Material Science PAN, 25 Reymonta Str., Krakow 30-059, Poland

Email: kor@mail.tsu.ru

Key words: MBE-grown HgCdTe, ion implantation, radiation defects

Fabrication of p^+-n-type $Cd_xHg_{1-x}Te$-based high-operating-temperature photodiodes with ion implantation of arsenic appears to be more challenging than traditional n^+-p technology, which uses implantation of boron. Implantation produces both extended (dislocation loops) and quasi-point radiation defects in the surface layer of the material. Interstitial mercury released as a result of ion damage interacts with these defects and form two types of donor centers responsible for electrons with low and middle mobility, respectively. Fabrication of p^+-n structure requires an annealing, which would activate implanted arsenic, annihilate radiation defects and restore original electrical properties of the n-region of the photodiode. To get a deeper understanding of these processes, we studied the effect of various types of annealings on the properties of arsenic-implanted $Cd_{0.22}Hg_{0.78}Te$ grown by molecular-beam epitaxy on GaAs and Si substrates.

Implantation was performed with As^+ ions with 190 or 350 keV energy and 10^{14} cm^{-2} fluence. The implanted structures were studied with transmission electron microscopy, optical reflection in the VIS range, and the Hall-effect and electrical conductivity measurements. Studied were the effects of 'conventional' two-stage activation annealing (~360 ^{0}C, 2 h/~220 ^{0}C, 24 h) under saturated mercury pressure (AO), annealing under low mercury pressure (PO) and annealing in helium atmosphere (~230 ^{o}C, 22 h).

It was revealed that AO lead to the formation of thin (~ 300 nm) p-type surface layer with high electrical activity of arsenic. As a possible mechanism of activation we consider the decomposition of glass-like As_2Te_3 phase, which was formed under the implantation. However, under PO we did not observe arsenic activation. After AO we also observed annihilation donor defects related to dislocation loops and to quasi-point defects. In some cases, AO modified the properties of the n-base, possibly via activation of uncontrolled acceptor defects.

P 4-7

Kinetics of Formation of Nanostructures by Frank-Van Der Merwe, Volmer-Weber and Stranski-Krastanow Growth Modes

Alexander Korotaev
Kirill A. Lozovoy, Andrey P. Kokhanenko, Alexander V. Voitsekhovskii

Tomsk State University, 36 Lenin ave., Tomsk 634050, Russia

Email: kor@mail.tsu.ru

Key words: two-dimensional crystals, quantum dots, molecular beam epitaxy

Nowadays, two-dimensional crystals (2D materials) and structures with quantum dots (0D materials) are considered as one of the most promising materials for electronics and photonics of the next generation of semiconductor technology development. Unique properties of 2D materials make it possible to create on their basis devices of a new generation: topological transistors, high-sensitive gas sensors, energy-intensive sources of power, thermoelectric generators, and quantum computers. Meanwhile, nanoheterostructures with quantum dots can be used to create highly efficient photodetectors, solar cells and light-emitting devices.

The basic method of synthesis of heterostructures with 2D and 0D structures nowadays is their self-induced formation during the molecular beam epitaxy. For various applications in modern industries it is essential to create heterostructures with 2D layers and 0D quantum dots with different properties that are defined by such parameters as thickness and roughness of 2D layers, elastic strain distribution, presence or absence of defects, average size and surface density of quantum dots.

Three epitaxial growth modes are distinguished: Frank-van der Merwe, Volmer-Weber, and Stranski-Krastanow, that allow one to obtain multi-layered structures with 2D materials, quantum wells and quantum dots. In this work generalized kinetic model of epitaxial growth of nanostructures by all three mechanisms is presented. Comparison of various growth modes is conducted and their peculiarities are pointed out. Ways to control the properties of obtained 2D and 0D nanostructures are proposed with the help of the established model.

P 4-8

The Relaxation of Electrophysical Properties HgCdTe Epitaxial Films Affected by Plasma of High Frequency Nanosecond Volume Discharge in Atmospheric-Pressure Air

Alexander Korotaev[1]
D.V. Grigoryev[1], A.V. Voitsekhovskii[1], K.A. Lozovoy[1], V.F. Tarasenko[2], V.S. Ripenko[2], M.A. Shulepov[2], M.V. Erofeev[2], M.V. Yakushev[3], S.A. Dvoretskii[3], N.N. Mikhailov[3]

[1]Tomsk State University, 36 Lenin ave., Tomsk 634050, Russia
[2]Institute of High Current Electronics, 2/3 Akademichesky ave., Tomsk 634055, Russia
[3]Semiconductor Physics SB RAS, 13 Lavrentyeva str., Novosibirsk 630090, Russia

Email: kor@mail.tsu.ru

Key words: MBE-grown HgCdTe, plasma treatment, electrophysical properties

HgCdTe semiconductor compounds are one of the main materials used for manufacturing IR photodetectors. Along with study of initial properties of HgCdTe epitaxial films a very urgent task is controlled changing of electrophysical parameters of the material. At the present time plasmas generated by nanosecond pulses have gained wide adoption for using in order to modify near-surface properties of materials. Characteristics of such discharges represent the complex influence of dense nanosecond discharge plasma ions with the specific power of heat input of the order of hundreds of megawatts per cubic centimeter, of an ultrashort electron beam with a wide energy spectrum and of optical radiation of different spectral ranges.

In the present report the investigation of electrophysical parameters of HgCdTe specimens upon irradiation shows that the action of volume discharge plasma leads to changes in the electrophysical properties of MCT epitaxial films due to the formation of a near-surface high-conductivity layer of the n-type conductivity. It should also be noted that, over time, the relaxation of the electrophysical properties to the initial values is observed. A detailed study of the relaxation process showed that the maximum change of the electrophysical parameters of epitaxial films was observed in the first 24 hours.

P 4-9

Effect of 28 MeV He^{2+} Ion Beam and Short-Pulsed 200 keV C^{+} Ion Beam Irradiation on Optical Properties of Multilayer Al-Si-N Coatings

Sergey Pavlov[1]
Fedor Konusov[1,*], Alexander Lauk[1], Valentina Sokhoreva[1], Ruslan Gadirov[2], Vladislav Tarbokov[1]

[1]National Research Tomsk Polytechnic University, 30 Lenin ave., Tomsk 634050, Russia
[2]Siberian Physical-Technical Institute, Tomsk State University, 1 Novo-Sobornaya sq., Tomsk 634050, Russia

Email: konusov@tpu.ru*

Key words: ion beam, Al-Si-N coatings, radiation defects, absorption

This presentation reports on radiation defect formation and radiation resistance of multilayer coatings consisting of thin layers of aluminum and silicon nitrides deposited on sodium–calcium–silicate glass and monocrystalline silicon substrates by reactive magnetron sputtering. 28 MeV He^{2+} ion beam generated by a cyclotron accelerator and short-pulsed (110 ns) 200÷220 keV C^{+} ion beam were used for the irradiation. The characteristics of local absorption and luminescence centers before and after irradiation are determined. The optical centers had been identified as a point intrinsic defects having growth and radiation nature. The accumulation of radiation defects in the layers of amorphous Si_3N_4 prevailed over that in the layers of crystalline AlN due to the processes of diffusion of defects in the amorphous layers and secondary defect formation in them. Changes in optical properties allowed us to conclude about high radiation resistance of coatings. The main reasons for the resistance of coatings to ion irradiation were the high concentration of growth defects, their strong interaction and the wide band gap of nitrides. Coatings on a silicon substrate had a higher resistance compared to the same coatings on glass.

P 4-10

Effect of Short-Pulsed 200 keV C+ Ion Beam and 350 keV He^{2+} Ion Beam Irradiation on Optical Properties of Al-Si-N Coatings with a Various Si Content

Sergey Pavlov[1]
Fedor Konusov[1], Alexander Lauk[1], Maxim Syrtanov[1], Semen Karpov[1], Valeriy Karpov[1], Ruslan Gadirov[2], Egor Kashkarov[1], Vladislav Tarbokov[1], Jindrich Musil[1,3], Gennady Remnev[1]

[1]National Research Tomsk Polytechnic University, 30 Lenin ave., Tomsk 634050, Russia
[2]Siberian Physical-Technical Institute, Tomsk State University, 1 Novo-Sobornaya sq., Tomsk 634050, Russia
[3]Department of Physics and NTIS-European Centre of Excellence, University of West Bohemia, Univerzitní 22, CZ-306 14, Plzeň, Czech Republic

Email: lab.sergey@gmail.com

Key words: ion beam, Al-Si-N coatings, radiation defects, absorption

This presentation reports on the effect of short-pulsed carbon ion beam and helium ion beam irradiation on optical properties and structure of aluminum nitride coatings and Al-Si-N coatings with a various Si content. The coatings were deposited on a steel substrate by a reactive magnetron sputtering. Irradiation was carried out by a short-pulsed (110 ns) 200÷220 keV C^+ ion beam and by 350 keV He^{2+} ion beam to an absorbed dose up to 600 MGy. The structure of coatings before and after irradiation was researched by X-ray diffraction analysis. Optical properties were researched by diffuse reflectance spectroscopy. The energy and kinetic characteristics of the absorption spectra due to radiation defects and their simplest complexes have been determined. Irradiation was accompanied by intense radiation and thermal annealing of unstable radiation and growth defects and their complexes and the formation of thermostable complexes of defects. The influence of the interaction between the states of defects of growth and/or radiation nature localized in the forbidden zone on the degree of change in properties is established. Dose dependencies of optical characteristics indicate high radiation resistance of the coatings. Based on the obtained results, we concluded that the radiation resistance of coatings is due to the limiting effect on the radiation defect accumulation of the high concentration of growth defects, a wide band gap of nitrides and interaction of defects through the exchange of charge carriers between their levels.

P 4-11

Doping and the Band Gap Engineering in Group IV Alloys Using Ion Implantation and Flash Lamp Annealing

Jerzy Zuk[1]
S. Prucnal[1,2], M. Wang[2], J. Grenzer[2], R. Hübner[2], A. Drozdziel[1], K. Pyszniak[1], M. Turek[1], S. Zhou[2]

[1]Maria Curie-Skłodowska University, Pl. M. Curie-Skłodowskiej 1, Lublin 20-035, Poland
[2]Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf, Germany

Email: jotzet@hektor.umcs.lublin.pl

Key words: Ge, GeSn, ion implantation, flash lamp annealing, band gap engineering

Ge is an indirect band gap semiconductor with carrier mobility much higher than in Si. Using ultra-high n-type doping and strain engineering or alloying Ge with Sn or Pb, Ge can be converted from indirect to direct band gap semiconductor. Here we present the formation of heavily doped *n*-type Ge [1] and GeSn [2] alloys using ion implantation followed by millisecond range flash lamp annealing. The strain engineering and the composition of heavily doped *n*-type Ge and GeSn films is confirmed by X-ray diffraction and Rutherford backscattering spectrometry, respectively. The change of the band gap as a function of carrier density and Sn concentration is theoretically predicted using density functional theory and experimentally verified by near-infrared spectroscopic ellipsometry. It is shown that for the electron concentration higher than 1×10^{20} cm^{-3} the band gap renormalization in *n*-type alloys is partially compensated by the Burstein-Moss effect. These results indicate that Ge-based materials have a large potential for the engineering of near-infrared optoelectronic and plasmonic devices fully compatible with CMOS technology.

References

[1] Prucnal S. *et al*., Semicond. Sci. Technol. 32, 115006 (2017).
[2] Prucnal S. *et al*., Semicond. Sci. Technol. 33, 065008 (2018).

P 4-12

Crystallographic Orientation Dependence of Blistering Kinetics and Defect Evolution in Silicon Implanted by Hydrogen Ions

Der-Sheng Chao[1]
Yu-Cheng Hsiao[2], Jenq-Horng Liang[2,3], Chih-Ming Lin[4]

[1]Nuclear Science and Technology Development Center, National Tsing Hua University, Hsinchu 30013, Taiwan, R.O.C.
[2]Department of Engineering and System Science, National Tsing Hua University, Hsinchu 30013, Taiwan, R.O.C.
[3]Institute of Nuclear Engineering and Science, National Tsing Hua University, Hsinchu 30013, Taiwan, R.O.C.
[4]Department of Physics, National Tsing Hua University, Hsinchu 30013, Taiwan, R.O.C.

Email: dschao@mx.nthu.edu.tw

Key words: ion-cut, layer splitting, blistering, defect, microcrack

The ion-cut technology is currently a mainstream method for the fabrication of Silicon-On-Insulator (SOI) substrates. This method involves a thermally activated layer splitting process with the evolution of hydrogenated defect complexes into microcracks in hydrogen-implanted Si, ultimately enabling a Si thin layer transfer onto another oxidized Si substrate. Since the effectiveness of layer splitting process is highly correlated to the interaction of hydrogen atoms with defects, it is expected that the blistering kinetics arising from hydrogen implantation would vary with the crystallographic orientation of substrate. That is, Si substrate with specific crystallographic orientation should correspond to exclusive layer splitting process conditions. Therefore, the purpose of this study is to thoroughly investigate the influence of Si crystallographic orientation on the blistering kinetics and defect evolution induced by hydrogen implantation.

4-inch Si substrates with orientations of (100), (111), and (110) were used in this study. The Si substrates were implanted with H^{2+} ions at an accelerated energy of 40 keV to a fluence of 2.5×10^{16} cm^{-2}. After ion implantation, the blistering characteristics, defect complexes, and microstructure of the samples were examined by OM, Raman spectra, and XTEM. The results revealed that the number density, mean diameter, and areal fraction of blisters and craters on Si surface are correlated with Si crystallographic orientation. The nucleation of H-terminated platelets is controlled by the atomic planar density of Si substrate, while the growth of them is dominated by the interplanar spacing and surface free energy of Si atoms. This can be further evidenced by the ratio of the VH_3 (or V_2H_6) defect complexes to the Si:H surface states from the Raman spectra. Moreover, the number density and the orientation of platelets also varied with Si crystallographic orientation, which could affect the combination and extension of microcraks in Si.

P 4-13
Ion Beam Stimulated Defects in Transparent $MgAl_2O_4$ Ceramic

Arseny Kiryakov[1]
Anatoly Zatsepin[1], Dmitry Zatsepin[2], Nikolay Gavrilov[3], Julia Shchapova[1,4]

[1]Institute of Physics and Technology, Ural Federal University, Yekaterinburg 620002, Russia
[2]Institute of Metal Physics of Ural Branch of Russian Academy of Sciences, Yekaterinburg 620108, Russia
[3]Institute of Electrophysics of Ural Branch of Russian Academy of Sciences, Yekaterinburg 620016, Russia
[4]Institute of Geology and Geochemistry of Ural Branch of Russian Academy of Sciences, Yekaterinburg 620016, Russia

Email: arseny.kiriakov@urfu.ru

Key words: transparent $MgAl_2O_4$ ceramic, ion beam modification, XPS

Ion-beam processing of optical materials provides a controlled modification of the structure and properties not characteristic of such materials in nature [1], but this method is associated with a radiation load, which not all compounds can withstand. Optical ceramics based on $MgAl_2O_4$ are of interest because they have high radiation resistance and can act as a matrix for its activation by various impurities. [2]. The goal of our work was to study ion-stimulated defects in transparent $MgAl_2O_4$ ceramics with irradiated Cu^{2+}.

Transparent $MgAl_2O_4$ ceramics synthesized by a thermobaric method from a nanopowder was used as a starting material. The modification was performed on a pulsed ion beam with an energy of Cu^{2+} 30 keV ions, a discharge current of 60 A and a pulse duration of 0.4 ms. The fluences ranged from 5×10^{15} cm^{-2} to $1\times10^{17}cm^{-2}$. The study of irradiated ceramics by X-ray photoelectron spectroscopy shows that the valence band is modified by copper 3d states. A detailed study of the Cu $2p_{3/2}$ core level with Voigt decomposition suggests that with an increase in the implantation dose, there is a redistribute of maxima associated with Cu^{2+}, Cu^{+}, and Cu^{0}. We also observed changes in the position of the O 1s band under increase in the implantation dose, associated with the radiation effect on the anion sublattice, at which both annealing of defects and their stimulation are observed. The induced optical absorption spectra (IAS) recorded bands associated with defects in the anion and cation sublattices. Observed changes in the induced optical spectrum from fluences are consistent with the XPS data. IAS 2 eV peak in samples irradiated with a fluence of 5×10^{16} cm^{-2} and higher is associated with resonant absorption of the surface plasmon in copper nanoparticles. In the photoluminescence spectra recorded under laser excitation with the focusing of a laser beam in the near-surface layer of modified ceramics, new Cu-related luminescence bands are observed.

Thus, during ion-beam implantation of Cu^{2+} transparent ceramics, the optical characteristics are modified by defects that are sensitive to external electromagnetic radiation. The features of the core levels of the impurity copper ion are determined for different fluence. Collectively, these data indicate that $MgAl_2O_4$ transparent ceramics may be used as the optical matrix for alloying elements 3d, and as ion implantation dose indicators.

References:
[1] Toulemonde M., Bouffard S., Studer F., Nucl. Instr. and Meth. in Phys. Res. Sec. B, 91, 108-123 (1994).
[2] Mlcak R., Kitai A. H., Journal of luminescence, 46, 391-396 (1990).

P 4-14
Focused-Ion-Beam Controlled Nucleation and Growth of ZnO Nanorods

Hana Faitová[1,2]
Š. Kučerová[1,2], N. Bašinová[1], O. Černohorský[1], J. Grym[1], J. Vaniš[1], J. Veselý[2]

[1]Institute of Photonics and Electronics of the CAS, Chaberská 57, Prague, Czech Republic
[2]Faculty of Mathematics and Physics, Charles University, Ke Karlovu 3, Prague, Czech Republic

Email: faitova@ufe.cz

Key words: ZnO nanorods, GaN, FIB, TEM

Zinc oxide is a wide band gap semiconductor, which has been recently deeply investigated for its beneficial properties such as piezoelectricity, absorption and emission in the UV region, optical transparency in the visible region or surface sensitivity. The applications of ZnO nanostructures include electronic devices, light emitters, chemical or biological sensors and other devices in the field of photovoltaics or medicine. Most of these applications require well-defined periodically distributed ZnO nanostructures. Moreover, the periodic distribution of ZnO nanostructures allows for the in-depth investigation of the growth mechanisms and for advanced characterization of the physical properties.

We fabricate highly ordered arrays of uniform ZnO nanorods with the help of focused ion beam lithography (FIBL) and chemical bath deposition. Thanks to FIB processing, we can control the nucleation and positioning of the nanorods. This method enables the nucleation to be uniform even on substrates whose morphology is originally non-uniform. Representative examples of substrates with non-uniform morphology are GaN epitaxial templates, which are commercially widely used as an alternative of very expensive GaN monocrystals.

We study the impact of several parameters of FIB (e.g. the ion dose, the current, the beam profile) on the geometry and physical properties of the nanorods. Detailed observation of the interface between the zinc-oxide nanorod and ion-treated GaN surface in transmission electron microscopy (TEM) is employed to understand the fundamental growth mechanisms.

P 4-15

Magnetron Deposition of Multilayer Coatings on the E110 Zirconium Alloy Cladding Tube Segments

Pavel Dzhumaev
Boris Kalin, Nikolay Volkov, Alexander Yashin, Dmitriy Safonov, Egor Korenevsky, Vladimir Yakushin, Maksim Staltsov

Department of materials science, Institute of Nuclear Physics and Engineering, National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Moscow 115409, Russian Federation

Email: PSDzhumaev@mephi.ru

Key words: magnetron coating, zirconium alloy, corrosion resistance, LOCA accident

Fukushima Daiichi nuclear disaster raised an interest in development of accident tolerant nuclear fuel (ATF). ATF should avoid reaction of zirconium alloy with water steam at elevated temperatures in case of lossof coolant accident (LOCA) which leads to the rapid oxidation of cladding tube accompanied with the hydrogen gas production. Different ways to improve accidentfuel tolerant properties are being considered [1-3]: development of the alternative cladding materials, optimization of existing zirconium alloy compositions and processing regimes, and deposition of the protective coating on the currently used zirconium alloy cladding tubes. One of the promising coating materials are chromium or chromium-based alloys.

The advantages of chromium coatings include the relatively equal values of thermal expansion coefficient with the zirconium-based alloys, high melting point, corrosion resistance in superheated water and steam, high thermal conductivity and heat capacity. This work presents results of experimental investigations of various multilayer coatings on E110 fuel cladding tube segments made by magnetron deposition. Coatings of pure chromium (Cr), Fe-16Cr-20Ni-2Mo-2Si-B (16Cr), 06X18H10T (18Cr), Fe-21Cr-5Al-3Mo (21Cr) and specially melted alloys 33Cr-33Fe-32Ni-2Mo (33Cr) and nichrome (38Cr) and their multilayer combinations were investigated. Significant part of this investigation was the selection of the diffusion barrier layer in order to prevent formation of eutectics or intermetallic compounds between coating elements and Zr-alloy substrate. Results of high-temperature water steam oxidation tests at 1200 °C and exposure time 400 s showed a positive effect of magnetron deposition of multilayer chromium-based coatings on the oxidation process of zirconium alloy fuel cladding tubes.

References:
[1] B.A. Pint, K.A. Terrani, M.P. Brady, T. Cheng, J.R. Keiser, High temperatureoxidation of fuel cladding candidate materials in steam-hydrogen environments,J. Nucl. Mater. 440 (1) (2013), pp.420-427.
[2] S.J. Zinkle, K.A. Terrani, J.C. Gehin, L.J. Ott, L.L. Snead, Accident tolerant fuels for LWRs: a perspective, J. Nucl. Mater. 448 (1) (2014), pp. 374-379.
[3] D.J. Park, H.G. Kim, Y.I. Jung, J.H. Park, J.H. Yang, Y.H. Koo, Behavior of animproved Zr fuel cladding with oxidation resistant coating under loss-of-coolant accident conditions, J. Nucl. Mater. 482 (2016), pp.75-82.

P 4-16

Synthesis of $ZnSe_2O_5$ Nanocrystals in a-SiO_2/Si-n Track Template: Experimental Studies and Theoretical Calculations

Alma Dauletbekova[1]
Zein Baimukhanov[1], Artem Kozlovskii[2], Lyudmila Vlasukova[3], Sholpan Giniyatova[1], Abai Usseinov[1], Aiman Akylbekova[1], Zhakyp Karipbayev[1], Maxim Zdorovets[2,4]

[1]L.N. Gumilyov Eurasian National University, Nur-Sultan 01008, Kazakhstan
[2]Institute of Nuclear Physics, Nur-Sultan 010008, Kazakhstan
[3]Scientific Research Laboratory of Materials and Device Structures, Belarus State University, Minsk 220064, Belarus
[4]Ural Federal University, Yekaterinburg 620002, Russia

Email: alma_dauletbek@mail.ru

Key words: SiO_2/Si track template, template synthesis, electrochemical deposition, zinc diselenide

This research presents the results on the synthesis of $ZnSe_2O_5$ nanocrystals in a-SiO_2/Si-n track template. The structure of a-SiO_2/Si was prepared by thermal oxidation of Si substrate (*n*-type). The thickness of SiO_2 layer was 700 nm. The structures were irradiated at a DC-60 accelerator (Nur-Sultan, Kazakhstan) with 200-MeV Xe ions, Φ=108 ions/cm^2. Chemical etching of irradiated samples was produced in HF solution. For electrochemical deposition (ECD), the following electrolyte composition was used: Zn - 7.2 g/l, SeO_2 - 0.2 g/l. Also, the standard electrolytic cell was used, with zinc electrodes, the voltage across the electrodes was 1.25 V and deposition time was 15 minutes.

The surface of the precipitated samples was examined using SEM JSM 7500F. XRD patterns were obtained using the X-ray diffractometer D8 ADVANCE ECO. As result, we shown that $ZnSe_2O_5$ nanocrystals is created after ECD and they have an orthorhombic crystal structure, the space group — Pbcn (60). Our observed unit cell parameters: a = 6.80307 Å; b = 10.35266 Å; c = 6.14842 Å, which gave good agreement in comparison with experimental data [1]. The main phase for all samples is crystalline, it dominates over amorphous and the degree of crystallinity varies within 58.6-76%. Thus, $ZnSe_2O_5$ nanocrystals were first obtained by synthesis into a-SiO_2/Si-n track templates.

To confirm the experimental data and the basic properties of $ZnSe_2O_5$ nanostructures, we also performed *ab-initio* calculations within the approximation of linear combinations of atomic orbitals (LCAO) and using the density functional theory-exchange-correlation functional LDA-PZ [2,3]. The calculations are performed in the program CRYSTAL [4]. The calculated lattice parameters, material density, and band structure well consistent with experimental data obtained from our experiments and literature. It was shown that $ZnSe_2O_5$ have a direct bandgap at Γ-point; the calculated effective charges indicate considerable covalency of chemical bonds.

References:
[1] Meunier G., Bertaud M., Acta crystallographica. Section B, Structural science 30, (12):2840-2843 (1974).
[2] Dirac P.A.M., Proc. Cambridge Phil. Soc., 26:376, (1930.
[3] Perdew J.P. and Zunger A., Self-interaction correction to density functional approximations for many-electron systems. Phys. Rev. B,23:5048-5079, 1981.
[4] Dovesi R., Saunders V.R., Roetti R.O., Civalleri B., Doll K., Harrison N.M., Bush I.J. 2014 CRYSTAL14 User's Manual University of Torino, Torino.

P 4-17

Structure and Properties of CdTe Nanocrystals Created in SiO_2/Si Track Templates

Alma Dauletbekova[1]
Rakhima Balakhayeva[1], Zein Baimukhanov[1], Artem Kozlovskii[2], Lyudmila Vlasukova[3], Abdirash Akilbekov[1], Sholpan Giniyatova[1], Maxim Zdorovets[2,4]

[1]Faculty of Physics and Technical Sciences, L.N. Gumilyov Eurasian National University, Nur-Sultan 010008, Kazakhstan
[2]Nur-Sultan Branch of Institute of Nuclear Physics, Nur-Sultan 010008, Kazakhstan
[3]Scientific Research Laboratory of Materials and Device Structures, Belarus State University, Minsk 220064, Belarus
[4]Ural Federal University, Yekaterinburg 620002, Russia

Email: alma_dauletbek@mail.ru

Key words: cadmium telluride, CdTe nanocrystals, SiO_2/Si track template, electrochemical deposition, sulphate electrolyte, chloride electrolyte

Cadmium telluride is a direct-gap semiconductor with a band gap of E_g=1.49 eV at 300 K [1]. It is known that cadmium telluride is one of the materials most suitable for creating solar cells [2]. This is due to the width of the forbidden band, close to the optimal value, as well as a large coefficient of light absorption in the entire spectral range of photosensitivity [3].

The purpose of this research is to obtain CdTe nanocrystals by electrochemical deposition ina-SiO_2/Si -n track template. The structure of a-SiO_2/Si -n was obtained by thermal oxidation of Si substrate at 900 °C. The thickness of SiO_2 layer was 600 nm. The a-SiO_2/Si -n was irradiated on a DC-60 accelerator (Astana) with Xe ions 200 MeV, $\Phi = 10^8$ ion/cm^2, the subsequent etching in HF solution led to the creation of nanopores. A conventional electrolytic cell was used for electrochemical deposition. The voltage on the electrodes was 1.5V, t = 5 min. electrochemical deposition of CdTE was carried out on two different solutions: 1) 1M $CdSO_4$ + 1mM TeO_2, pH =2; 2) 1M $CdCl_2$ + 1mM TeO_2, pH =2.

The surface of the samples was examined before and after electrochemical deposition by SEM JSM 7500F. To identify the crystal structure of CdTe nanoclusters, an X-ray structural analysis was carried out to form cadmium telluride nanocrystals of the hexagonal phase (wurtzite) together with the amorphous phase. The use of chloride and sulphate electrolyte leads to the formation of the dominant amorphous phase of CdTe over the crystalline hexagonal phase. Subsequent annealing leads to the dominance of CdTe nanocrystals.

References:

[1] Bovina L.A. *et al*., Physics of AIIBVI Compounds, edited by Georgobiani A. N., Sheinkman M. K., Science, Moscow, 319 (1986).
[2] Bonnet D., Meyers P.V., Cadmium-telluride – Material for thin film solar cells, Mater. Res. 13, 2740 (1998).
[3] Kosyachenko L.A., Maslyanchuk O.L., Sklyarchuk V.M., Grushko E.V. Electrical characteristics of Schottky diodes based on semi-insulating CdTe single crystals, Appl. Phys. Letters 101, 013704 (2007).

P 4-18
Spectral and X-ray Studies of In_2O_3 Films on Al_2O_3 Substrates

Alexander Tikhii[1,2]
Yu.M. Nikolaenko[2], A.S. Kornievets[2], I.V. Zhikharev[2]

[1]Lugansk Taras Shevchenko National University, 2 Oboronnaya str., Lugansk 91011, Ukraine
[2]Donetsk Institute for Physics and Engineering named after A.A. Galkin, 72 Rozy Lyuksemburg str., Donetsk 83114, Ukraine

Email: ea0000ffff@mail.ru

The studies of X-ray diffraction and optical transmission spectra of thin In_2O_3 films on Al_2O_3 (012) substrates are presented. The films deposited by magnetron sputtering with an alternating current of 50 mA and 300 V of voltage. The deposition time varied from 15 to 180 minutes. The temperature of the substrates during deposition was 600 °C.

The band gap of the films is determined using the optical transmittance spectra. It was found to be significantly lower than the typical value of 3.6 eV [1] and decreases from 1.4 eV to 3.45 eV by an increase in the deposition time from 15 to 180 minutes.

The obtained diffractograms contain a reflex, which decreases in intensity and shifts from 30.3 to 30.6° with decreasing film deposition time. This reflex can be associated with the (222) plane of the cubic In_2O_3 (space group Ia-3) [2]. Rotation of the sample in the plane of its surface does not affect the intensity of the reflex near 30.6°. This indicates the polycrystalline structure of the film. The decrease in the half-width of this reflex by a decrease in the deposition time may indicate an increase in the crystallite size of the film, which explains the nature of the variation in the band gap of the films. The shift of the (222) reflex, as well as the low values of the band gap are presumably related to the influence of the substrate on the structure of film.

References
[1] Z. M. Jarzebski. Preparation and Physical Properties of Transparent Conducting Oxide Films. Phys. Stat. Sol. (a), 1982, V. 71, pp. 13-41.
[2] Howard E. Swanson, Nancy T. Gilfrich, and George M. Ugrinic, National Bureau of Standards (US), Circular 539, 1955, V. 5, pp. 26-27.

SMMIB-2019

21ST INTERNATIONAL CONFERENCE
ON SURFACE MODIFICATION OF MATERIALS BY ION BEAMS
25-30 August 2019
Tomsk, Russia

Session 5
New Accelerator Systems and Tools for Materials Research

Invited Talk

I 5-1
Small Accelerator-Driven Neutron Source for Material Analysis

Tomohiro Kobayashi[1]
Yoshie Otake[1], Yujiro Ikeda[1], Shota Ikeda[1], Noriyosu Hayashizaki[2]

[1]RIKEN, Japan
[2]Tokyo Institute of Technology, Tokyo, Japan

Email: t-koba@riken.jp

A compact neutron source by using a particle accelerator is a promising tool for material analysis, infrastructural diagnostics, nuclear detection, and medical treatment. We have been operating the neutron source RANS (RIKEN Accelerator-driven compact Neutron Source) with 7 MV proton LINAC with beryllium target for 6 years and performed a lot of measurements such as imaging, diffraction and activation analysis. The specifications of RANS are as follows.

RANS: 7 MeV, 100 μA H^+ with ^9Be (p, n) ^9B reaction, 10^{12} neutrons/sec, weight > 30 ton.

The weight of the accelerator and the neutron target station of RANS are 5 tons and 25 tons, respectively, so it is not «transportable». Due to the fast neutrons (~5 MeV) from Be target, the shielding around the target became thicker. For quick and flexible use of neutrons such as non-destructive inspection of old concrete constructs, developing of smaller and lighter system is required. We started research and development of a mobile neutron source «RANS-II» with a newly designed proton LINAC. Based on the experimental results at RANS facility, we chose lithium for neutron generation target material and the energy of the new accelerator was set at 2.49 MV. The specification of RANS-II are as follows.

RANS-II: 2.49 MeV, 100 uA H^+ with ^7Li (p, n) ^7Be reaction, 10^{11} neutrons/sec, weight < 7.5 ton.

The neutron energy distribution of RANS-II is mainly between 300 and 700 keV. Fast neutrons of several hundreds keV are suitable for transmission and reflection imaging of concretes around 30 cm thick. The shield surrounding the target can lose much weight because there are no MeV neutrons. The present status of R&D is as follows. The pulsed 2.45 GHz microwave ECR ion source and the 2.49 MeV RFQ-LINAC are in operation tests for confirmation of parameters. So far, 3 mA at a short pulse peak was measured at the end of the RFQ with a low duty (0.09%) operation. If it is operated at the rated duty of 3.3%, a time averaged current will be 100 μA. Whole system was relocated to radiation controlled area in early 2019 and high-duty (~3%) operation with Li target will start soon.

I 5-2
Some Reflections on Very Large Scale Ion Beam Surface Modification

Ian Brown

Lawrence Berkeley National Laboratory, Berkeley, California, USA

Email: igbrown@comcast.net

It is commonly the case in ion beam surface modification that the processing rate is limited by the beam current that can be delivered by the ion source. Although in many cases surface modification is carried out in a laboratory environment and limitation of the processing rate is not a concern, nevertheless it is interesting to consider possibilities that might allow substantial (orders of magnitude) increase in processing rate, possibly for industrial application. Here we consider two possible approaches to very large scale ion beam surface modification -- the use of very broad beam vacuum arc ion sources, and the use of ion sources that have been developed to provide intense neutral beams as part of the world controlled fusion research effort. These sources can provide beam intensities in the tens of amperes range, and quasi-dc operation has been demonstrated. A third consideration is the possibility of scale-up of the PI3 (Plasma Immersion Ion Implantation) approach, and some relevant work has been done along these lines.

Another part of the concern involves the practicality of the electrical system to drive these large ion beam generators, especially the concern of isolating high power electronics at very high voltage. An alternative to the conventional approach is provided by a set-up in which the plasma and its electronics are held at ground potential and the ion beam is formed and injected energetically into a space maintained at high negative potential. This configuration is called an «inverted ion source», and offers substantial savings both technologically and economically, providing substantial simplification of the electrical system requirements for driving very large scale ion beam facilities.

These approaches to giant ion beam surface modification systems, and the implied parameters and features of such systems, are considered here.

Oral Presentation

O 5-1
The Test of Silicon Strip Detector for Heavy-Ion Nuclear Reaction

Gaolong Zhang[1,2]
Lin Chengjian[3], Yang Feng[3], Zhang Huanqiao[3], Zhang Chunlei[3], An Guangpeng[3], Jia Huiming[3], Wu Zhendong[3]

[1]School of Physics and Nuclear Energy Engineering, Beihang University, Beijing 100191, China
[2]Beijing Advanced Innovation Center for Big Data-Based Precision Medicine, Beihang University, Beijing 100083, China
[3]China Institute of Atomic Energy, Beijing 102413, China

Email: zgl@buaa.edu.cn

To avoid the amplitude loss in silicon strip detectors by Frenkel defects in heavy-ion reactions, the response of the detector to heavy ions is described. The experiment was performed on HI-13 tandem of China Institute of Atomic Energy. 5 MeV/u ^{16}O and 4.7 MeV/u ^{32}S beams were selected respectively to impinge on the self-supported ^{197}Au target. The scattered products were measured by two one-side silicon strip detectors which were made by Institute of Microelectronics, Peking University. The detectors were mounted symmetrically along the incident beam line. The thickness of each detector is 300 μm with 24 1.3 mm-wide strips and the span between two strips is 0.1 mm. First, the scattering peak was determined in the experiment, then the peak was monitored at different fluence condition and one observed if the peak position was moved and the energy resolution changed to be bad as well as the many peaks appeared. When using 5 MeV/u ^{16}O beam and the detectors were laid at 25 degree, the fluence on detectors was arrived at 2.0×10^6 mm^{-2}. The peak position basically kept stable. It is shown that the silicon strip detectors can keep a stable energy response well for the same energy ^{16}O. When the detectors were moved to 35 degree, the peak positions moved to low channels at 2.7×10^5 mm^{-2} and 5.8×10^5 mm^{-2}, then the characteristics trended to be stable after 6.0×10^5 mm^{-2}. It is indicated that for the same types of particles, the radiation damage is also related to the particle fluence and injection depth. When using 4.7 MeV/u ^{32}S beam in the same experimental conditions, it was found that particle types also gave a large influence on radiation damage, the radiation damage produced by ^{32}S ions with larger mass number and nuclear charge number are more distinct for silicon strip detectors. The properties of the detector are deteriorated as it is easy to produce lattice defect for ^{32}S ions when interact with atoms.

This work pointed that the effect of different kinds of ions dose on the silicon strip detector is distinct. The property of the present silicon strip detectors is stable until the dose approaches 10^6 mm^{-2}.Their properties are fit for the experimental request, especially for measuring ^{16}O and the other heavy ions with the mass numbers less than that of ^{16}O. This measurement can provide the reliable guarantee for the future regular experiments.

O 5-2

Radioactivation Control of Energy and Number of Protons and Deuterons Collectively Accelerated in Luce Diodes

Vladislav Ryzhkov
M.V. Zhuravlev, I.N. Pyatkov, V.S. Lopatin

Research School of High-Energy Physics, National Research Tomsk Polytechnic University, Tomsk 634050, Russia

Email: slavar@fibrtec.com

Plates of boron carbide B_4C were used as refractory targets for determination of energy and fluencies of protons collectively accelerated in a Luce diode accelerator by control of ^{7}Be and ^{13}N gamma-radioactivities induced by nuclear reactions $^{10}B(p,\alpha)^{7}Be$ and $^{12}C(p,\gamma)^{13}N$, respectively. The Luce diode exploited a cylindrical tungsten rod as a cathode and polyethylene washer as an anode, producing pulsed electron beams with durations and currents of up to 100 ns and 30 kA at voltages of 250÷350 kV. The technique allows controlling proton energies within the range of 500÷1500 keV and fluencies of up to 5×10^{13} protons per cm^2 per pulse. Numerous varieties of Luce diode geometries were examined to elucidate possible mechanism of the collective acceleration and find optimal regimes for radionuclide production.

Poster Session

P 5-1
Ring-Shaped Ion Sources Based on Closed Drift Anode Layer Thruster

Vasily Gushenets[1]
A.S. Bugaev[1], Efim Oks[1,2]

[1]Institute of High Current Electronics, 2/3 Akademichesky ave., Tomsk 634055, Russia
[2]State University of Control Systems and Radioelectronics, 40 Lenin ave., Tomsk 634050, Russia

Email: gvi@opee.hcei.tsc.ru

Two newest conceptual designs of ion sources for materials modification are investigated. The sources presented in this publication are based on plasma thruster's technology, that were developed by Prof. Goncharov group in Institute of Physics (Kiev, Ukraine). One of the ion sources is based on ring-shaped closed drift anode layer thruster with hollow cathode. It is known that the anode-layer thruster has two operating modes. The first mode is low current with narrow anode layer and clear-cut plasma flow, whereas the second mode operates with high current and plasma fills the entire volume of the hollow cathode. The transition to the high-current mode occurs under variation of worked gas pressure and applied voltage. In high-current quasi-neutral plasma mode of operation, plasma jet is observed along system axis. This mode of the anode-layer ion source was used in a wide-aperture plasma optical system for producing and transporting intense electron beams. In low current mode of the ion source operation, the axially converged ion beam are formed and, as follow from experiment, the energy of the ions could reach some kV. This operational mode will be used for argon or oxygen plasma cleaning as well as coating of outer wall pipe and cylindrical pieces.

Another ion source design uses a geometry of circular anode layer plasma thruster in which ion beam is extracted through 360 degrees toward the full circumference. The device is simple in design and is suitable for use in the technological processes for the treatment of the inner wall surface of pipes and tubes.

For effective operation of devices, it is important to know their usage parameters, therefore the electrical characteristics of the discharge in the ion sources operated in different modes were studied in the feed rate of operating gasses (argon and nitrogen) range up to 20 sccm as well as the spatial distributions of plasma parameters and ion beam characteristics.

This work was supported by the grants of Russian Foundation for Basic Research 18-08-00113-a in an ion source development and 19-08-00315-a in a ring-shaped plasma source investigations.

P 5-2

Source of High-Intensity Ultra-Low-Energy Ion Flow and Bulk Gaseous Plasma for Large-Area Surface Modification

Maxim Shandrikov[1]
Efim Oks[1,2], A.V. Vizir[1], G.Yu. Yushkov[1], I.D. Artamonov[2]

[1]Institute of High Current Electronics SB RAS, 2/3 Akademichesky ave., Tomsk 634055, Russia
[2]Tomsk State University of Control System and Radioelectronics, 40 Lenina ave., Tomsk 634050, Russia

Email: shandrikov@opee.hcei.tsc.ru, maxshandrikov@gmail.com

A new unified plasma source for generation of large volume (up to 1m^3) gaseous plasma or high intensity (up to 10 mA/cm^2) ultra-low energy (less than 20 eV) gaseous ion flow are designed and investigated. The operating pressure range is ($3\times10^{-4}\div3\times10^{-3}$) Torr. The source is based on DC high-current (up to 30 A) two-stage discharge. As electron emitter, an arc discharge with two-component cold hollow cathode is used. The use of two metals with very different arc current threshold does not require replacing the cathode during the entire service life. The possibility of independent control of the current of injected electrons, and their energy, makes it possible to choose the optimal parameters to ensure high energy efficiency of plasma generation (up to 150 eV/ion). Using Hughes-Rojansky electrostatic analyzer, electron and ion energy spectra in plasma were measured. The source operates with noble gases, nitrogen, oxygen and hydrocarbons, and can be used for plasma immersion ion implantation and other ion technologies.

P 5-3

Investigation of Magnetically Insulated Diode for Intense Pulsed Ion Beam Generation for Materials Research

Xiao Yu[1]
Shijian Zhang[1], Andrey Stepanov[2], Vitaly Shamanin[2], Haowen Zhong[1], Xiaojun Cui[1], Guoying Liang[1], Mofei Xu[1], Nan Zhang[1], Shicheng Kuang[1], Jianhui Ren[1], Sha Yan[3], Xiaofu Zhang[1], Xiaoyun Le[1,*]

[1]School of Physics, Beihang University, Beijing 100191, China
[2]National Research Tomsk Polytechnic University, Tomsk 634050, Russia
[3]Institute of Heavy Ion Physics, Peking University, Beijing 100871, China

Email: xyle@buaa.edu.cn*

The output characteristic and possible optimization of a Br type magnetically insulated diode for intense pulsed ion beam generation and its possible usage in material research was reported. The diode with surface flash-over of polymers as the ion source, insulated by external magnetic field can generated intense pulsed ion beam with pulse length of 120 ns, ion energy up to 400 keV, energy density of over 3 J/cm^2 The pulsed ion beam can induce strong thermal effects on the surface of materials and the irradiation effects on metals, ceramic and plastics proved that the flash heating effects of generated pulsed ion beam can be used for the surface treatment and ablation related application. The beam component was studied with time-of-flight method and the generation stability, cross-sectional distribution of the ion beam was diagnosed by infrared imaging method. The results on the focusing of the diode revealed the non-uniformity in the plasma generation on the anode and it is revealed that the electric field intensity in the diode gap plays a predominant role in the beam emission and possible optimization of the diode system was carried out based on better electric field distribution with finite element analysis.

P 5-4

Application of Silicone Based Polymer Modified by Low Energy Nitrogen Ion Beam to Diaphragm for Environmental-Cell Transmission Electron Microscope

Yuki Tai[1]
Takaomi Matsutani[1,*], Tadahiro Kawasaki[2]

[1]Graduate School of Science & Engineering, Kindai University, 3-4-1 Kowakae, Higashi-Osaka, Osaka 577-8052, Japan
[2]Japan Fine Ceramics Center, 2-4-1 Mutsuno, Atsuta, Nagoya 456-8587, Japan

Email: matsutani@ele.kindai.ac.jp*

Key words: nitrogen ion beam, surface modification, silicone,a-SiCN, E-TEM, XPS

An environmental-cell transmission electron microscope (E-TEM) systemcan be observed under atmospheric pressure because it has aspecimen holderwith small chamber that is sandwiched by the diaphragm on an electro-optical axis. Hence, catalytic behavior between catalyst and reaction gas and biologicalbehavior of living specimens without dehydration are beinginvestigatedby using E-TEM [1]. In our previous study, a tryacetylcellulose (TAC) film was modified by nitrogen ion beam to apply a diaphragm for E-TEM. However, the pressure resistance was maintained at only around 0.1 MPa [2]. In this study, to obtain higher pressure resistance, an amorphous silicon carbonitride (a-SiCN) film with high hardness, chemical inertness and a wide bandgap [3] was focused onit. Asurface modification layer of silicone based polymer film by nitrogen ion beam was applied to form an a-SiCN diaphragm.

Conditions of nitrogen ion irradiation for surface modification of siliconewere the accelerating voltages of 0.8÷1.5 kV, the ion current densities of 0.70÷2.10 μA/cm^2 and the ion doses of (3.2÷8.0)×10^{16} ions/cm^2. The irradiated samples were etched with acetone to leave only the modified layer.The conditions of high ion energyled to increasing thickness of the surface modified layerdue to enhance the increasing penetration depth of ion and pyrolysis. In these conditions,thethickness of surface modified layer was lowest with14.6 nm when ion irradiation was carried out at the acceleration voltage of 0.8 kV andthe dose of 4.8×10^{16} ions/cm^2 at the ion current density of 0.7 μA/cm^2. A 300 kV TEM observation of the layer indicatedfewcontrast difference between the layer and vacuum, this means that it has high permeability at 300 kV electrons. X-ray photoelectron spectroscopy analysis of modified layer indicated the increasing ion energy led to the decreasing a nitrogen concentration in the layer. It is considered to enhance a dissociation of nitrogendue to sputtering.

Within this study, very thinsilicone modified layer with 14.6 nm could be developed. This layer has potential for high resolution observation of E-TEM because of a high permeability of an electron beam.

References

[1] Yamasaki K., Matsutani T., Kawasaki T., Vacuum, 122, 332-336 (2015).
[2] Matsutani T., Murano M., Kawasaki T., Surface & Coatings Technology, 344, 58-61 (2018).
[3] Murano M., Matsutani T., Kawasaki T., Vacuum, 158, 60-64 (2018).

P 5-5
Aluminum HIPIB Production in Ion Diode with Self-Magnetic Isolation

Vitaly Shamanin
Gennady Remnev

National Research Tomsk Polytechnic University, Tomsk 634050, Russia

Email: shamanin@tpu.ru

The report presents investigation results on generation of aluminum high-intensity pulsed ion beam (HIPIB) in the ion diode with self-magnetic isolation from a dense explosive-emmition plasma produced by an additional high-voltage pulse that precedes to a primary pulse. Such approach was used before for generation of carbon and proton HIPIB [1].

The magnitude of a high-voltage primary pulse was up to 200 kV at 100 ns pulse duration with various timing ranged within 200 to 600 ns relatively to an additional pulse. The Thomson spectrometer, with a CR-39 track detector, and the Faraday cup were used to investigate an ion beam. The plasma produced by an advanced pulse, which precedes to a primary pulse, included gas ions adsorbed on the aluminum anode surface. With an increase of a pause between a primary and additional pulses, the proportion of an aluminum, carbon and proton ion species was changed.

References
[1] Remnev G.E., Isakov I.F., Opekounov M.S., Kotlyarevsky G.I., Kutuzov V.L., Lopatin V.S., Matvienko V.M., Ovsyannikov M.Yu., Potyomkin A.V., Tarbokov V.A.. High Power Ion Beam Sources for Industrial Application. Surface and Coatings Technology, 1997, Vol. 96, № 1, P.103-109.

P 5-6

High-Current Pulsed Induction Plasma Source for Generation of High Intensity Ion Beams of Various Gases

Pavlov Sergey
Anatoly Petrov, Vladislav Tarbokov, Danil Chernopenev

National Research Tomsk Polytechnic University, 30 Lenin ave., Tomsk 634050, Russia

Email: lab.sergey@gmail.com

Key words: inductively coupled plasma, diverging laval nozzle, ion diode, intense ion beams

Conventional configurations of inductively coupled plasma sources, which are used to provide ion emission to generate high-intensity pulsed ion beams, have noticeable problems associated with insufficient time and amplitude stability of plasma parameters and its radial irregularity on the emission surface. In this paper, an integrated approach is used to overcome these shortcomings, and namely an inductive source of conical geometry with a pulsed gas inlet. The source has a two-turn shock coil (inductor) with bipolar power supply up to ± 25 kV to increase the transformed current with a half-period T/2 = 1.6 μs and the vortex electric field in the discharge zone with the ability to concentrate this current in a thin gas layer near the inductor. To form a gas flow, a high-speed gas valve on the axis and a diverging Laval nozzle are used. The results of the calculation of the nozzle and its gas-dynamic functions are given. The main observed characteristics of gas and plasma flows and the parameters of the plasma source are presented. The high reproducibility of plasma parameters on the emission surface of the ion diode with an insulated B-field was demonstrated when it was operated in the standby mode. With a voltage of 120 kV on the diode, the protons current density was obtained up to 25 A/cm^2 on a 250 cm^2 square with a pulse duration of up to 600 ns.

P 5-7

Generation of Beams of Multiply Charged Heavy Metal Ions of Bismuth up to 19^+ in a Pulsed High Current Vacuum Arc Ion Source

Efim Oks[1,2]
Valeria Frolova[1,2,*], George Yushkov[1], Aleksey Nikolaev[1]

[1]Institute of High Current Electronics, Russian Academy of Sciences, 2/3 Akademichesky ave., Tomsk 634055, Russia
[2]State University of Control Systems and Radioelectronics, 40 Lenin ave., Tomsk 634050, Russia

Email: Frolova_Valeria_90@mail.ru*

Key words: plasma, vacuum arc, high charge state

The vacuum arc source generates beams of ions of various metals, which can be used both for the injection of ions into the accelerator and for modifying the properties of the surface. Typically, such a source generates beams of metal ions with a charge from 1^+ for carbon or lithium to 5^+ for refractory metals such as molybdenum and tantalum, and the average charge of the ion beam is usually in the range from 1^+ to 3^+ [1]. Increasing the charge of metal ions in a beam of a vacuum arc ion source makes it possible to increase the energy of the extracted ions without increasing the accelerating voltage. Previously, ion charges in vacuum arc ion sources were increased by various methods, including using a strong magnetic field in the cathode region [1], additional plasma heating by a powerful microwave flux [2] or electron beam [3]. In the present studies, the charge rate of a bismuth ion beam was increased due to the use of a high current vacuum arc discharge current in a discharge system of an ion source with a unit length of microseconds and an amplitude of several kiloamperes. This paper presents the results of experimental studies on the increase in the charge of heavy metal ions in a source with a short pulse high current discharge using the example of bismuth ion beams.

At optimal values of the arc current level of 3.5 kA and a pulse duration of about 1 μs, beams of bismuth ions with charge states up to 19^+ were obtained, which exceeds the value obtained in previous works (17^+) [4]. A relatively small increase in ion charge rates is important, since the ionization potentials increase, with an increase in the multiplicity of charge states of ions, nonlinearly, and the charges obtained in this work for bismuth ions are a record for this class of ion sources.

This work was supported by the Russian Foundation for Basic Research, project no. 17-08-00133.

References:

[1] Nikolaev A., Oks E., Yushkov G., JTF, 68, 39-43 (1998.).
[2] Vodopyanov A., Golubev S., Khizhnyak V., Mansfeld D., Nikolaev A., Oks E., Savkin K., Vizir A., Yushkov G., RSI, 2008, 79,02B304 (2008).
[3] Yushkov G., Oks E., Anders A., Brown I., J. Appl. Phys, 87, P. 8345-8550 (2000).
[4] Yushkov G., Nikolaev A., Physics of Plasmas, 24, 123501 (2017).

SMMIB-2019

21ST INTERNATIONAL CONFERENCE
ON SURFACE MODIFICATION OF MATERIALS BY ION BEAMS
25-30 August 2019
Tomsk, Russia

Session 6
Biomedical and Industrial Applications

Invited Talk

I 6-1

New High-Current Pulsed Ion Accelerator Facility INURA at Nazarbayev University: First Results and New Opportunities for Advanced Materials and Nanoscience

Alexander Tikhonov[1,2]
Marat Kaikanov[1,2], Kanat Baigarin[1], Artem Kozlovskiy[2], Gulnur Akhtanova[2], Will Waldron[3], Joe Kwan[3], Gennadiy Remnev[4], Mikhail Zhuravlev[4]

[1]Nazarbayev University, Astana, Kazakhstan
[2]National Laboratory Astana, Astana, Kazakhstan
[3]Lawrence Berkeley National Laboratory, Berkeley, USA
[4]Tomsk Polytechnic University, Tomsk, Russia

Email: atikhonov@nu.edu.kz

Key words: pulsed ion beam accelerator, radiation material science

Recently a new high-current pulsed ion accelerator facility INURA (Nazarbayev University Research Accelerator) was commissioned at Nur-Sultan, Kazakhstan, as a collaboration effort between a team from Nazarbayev University, Lawrence Berkeley National Laboratory and Tomsk Polytechnic University.

INURA is a single gap pulsed ion accelerator based on pulsed-power technology to generate a high current ion beam with the following parameters: accelerating voltage is up to 400 kV, ion beam current is up to 10 kA, pulse duration of less than 100 ns. Ion beam reach a high current density of 150 A/cm^2 at focal spot ˜5 cm diameter, enabling experiments in plasma and beam physics as well as in irradiation induced materials modification [1,2]. Electron and X-ray pulsed beam capability is currently been developed at INURA facility.

We present our recent results on ion-beam induced modifications of surface layer of Nb refractory alloys, high-temperature ceramics and semiconducting ferroelectric thin films. With electron beam, we achieve useful modification of Cu and Ni-nanotubes, improving conductivity properties and corrosion resistance. We modify with ion-beam conductive transparent thin films coatings based on silver nanowires networks to optimize mechanical and electric properties.

This work is supported by the grant AP05135686 «Pulsed plasma-chemical synthesis of new generation TiO_2 photo catalysts» from the Ministry of Education and Science of the Republic of Kazakhstan, and NU ORAU project «Neutralization of high-intensity pulsed ion beam by volumetric plasma»

References

[1] A. Kozlovskiy, *et al*., Mater. Res. Express 5, 075010 (2018).
[2] M.I. Kaikanov, *et al*., Journal of Physics: Conference Series 717, 012099 (2016).

I 6-2
Nanoscale Pattern Formation at Surfaces in Unconventional Formats

Jae-Sung Kim[1]
J. Kim[1,2,] M. Joe[3] , S. M. Yun[1], S. Jo[1], J. Seo[4]

[1]Department of Physics, Sook-Myung Women's University, Seoul, Korea
[2]Department of Chemistry, Universität Ulm, Ulm, Germany
[3]Department of Physics and Astronomy, Seoul National University, Seoul, Korea
[4]Institute of Advanced Materials and Systems, Sook-Myung Women's University, Seoul, Korea

Email: jskim@sookmyung.ac.kr

Key words: ion beam sputtering, nano patterning, physical self-assembly

For the nanopatterning by ion-beam-sputtering (IBS), the conventional format is employing single ion beam in a fixed ion-incident geometry with respect to a stationary substrate. That limits the variety of the patterns, and thus the information to examine the models proposed to elucidate the mechanisms behind the pattern formation. There have been sporadic efforts to pattern the surface in the other formats such as the substrate rotation during IBS [1], and offered insights to deepen our understanding of the mechanism for the pattern formation by IBS.

In the present talk, I will review our long-term researches on the pattern formation by IBS under unconventional formats; dual ion beam sputtering [2], sequential ion beam sputtering [3-5], and substrate swing [6] and rocking [7]. There are found patterns with the motifs other than dots and ripples, which well served in the elaboration of the models for the pattern formation by IBS.

References
[1] F. Frost, A. Schindler, and F. Bigl, Phys. Rev. Lett. 85, 4116 (2000).
[2] M. Joe, C. Choi, and B. Kahng, Appl. Phys. Lett. 91, 233115 (2007).
[3] J.-H. Kim, M. Joe, S.-P. Kim, N.-B. Ha, K.-R. Lee, B. Kahng, and J.-S. Kim Phys. Rev. B 79, 205403 (2009).
[4] J.-H. Kim, N.-B. Ha, J.-S. Kim, M. Joe, K.-R. Lee, and R. Cuerno, Nanotechnology 22, 285301(2011).
[5] J.-H. Kim, J.-S. Kim, J. Munoz-Garcia, and R. Cuerno, Phys. Rev. B 87, 085438 (2013).
[6] S. M. Yoon and J.-S. Kim, J. Appl. Phys. 119, 205301 (2016).
[7] S. Cho and J.-S. Kim (Unpublished).

I 6-3

Ultra-High Selective and Permeable Ion Sieve Fabricated with Irradiated Polymer Membranes

Feng Liu[1]
Q. Wen[1], P.F. Wang[1], M. Wang[1], D.X. Yan[1], S.Y. Ding[1], X. Wang[1], W.H. Sheng[1], J. Liu[2], P. Kluth[3], P. Apel[4], C. Trautmann[5], Y.G. Wang[1]

[1]State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing 100871, People's Republic of China
[2]Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 730000, People's Republic of China
[3]Department of Electronic Materials Engineering, Research School of Physics and Engineering, Australian National University, Canberra ACT 2601, Australia
[4]Flerov Laboratory of Nuclear Reactions, Joint Institute for Nuclear Research, 141980 Dubna, Russia
[5]GSI Helmholtzzentrum and Technische Universität Darmstadt, Darmstadt, Germany

Email: liufeng-phy@pku.edu.cn

Track-etching technique has been established for over 60 years to fabricate ion-track membranes. Although these ion-track membranes have found broad applications, their capability is rather limited in ion sieving, an emerging demand in nanotechnology for applications such as water filtration, ion separation and battery construction. This is because it has been very challenging to utilize chemical etching to produce a high density of uniformly sized channels with the diameters of ~ 1 nm for fast ion sieving, which is the key to overcome the general tradeoff between selectivity and permeability of nanoporous membranes. To achieve this long-standing goal, we have recently developed a highly controllable nanofabrication method without any chemical etching, namely track-UV technique. The key procedures are swift heavy ion irradiation with energy loss above a certain threshold followed by subsequent sufficient UV illumination. By optimizing experimental conditions, we successfully produce nanoporous polymer ion-track membranes outperforming all the other reported membranes in ion sieving: 12-μm-thick polyethylene terephthalate (PET) Hostaphan® films show unprecedented ionic selectivity, e.g., a selectivity of up to 108 for cations over anions, and 106 for alkali metal ions over heavy metal ions [1]; and 2-μm-thick PET Lumirror® films show an excellent balance between selectivity and permeability, e.g., a transport rate of K^+ ions of ~14 mol/(h×m^2) as well as a selectivity of 103 for alkali metal ions over heavy metal ions [2]. With small X-ray scattering (SAXS) and a series of molecular transport experiments, we determine that the diameters of the nanopores in these ion-track membranes are indeed about 0.6-1 nm. Using molecular dynamics (MD) simulations with a polymeric nanopore model, we further reveal the excellent performance of these membranes is attributed to the electrostatic interaction between the charged pore walls and ions, coupled with the partial dehydration effect [1,2]. Finally, in light of the fine structure of these ion-track nanopores, we have been developing MD simulations to investigate the formation mechanism of the latent track of swift heavy ions in polymers. These studies will help us to design and fabricate new types of ion-track membranes, and deepen our understanding of the irradiation effect on polymers.

References

[1] Wen Q., Yan D., Liu F. *et al.* Highly Selective Ionic Transport through Subnanometer Pores in Polymer Films [J]. Advanced Functional Materials, 2016, 26(32): 5796–5803.
[2] Wang P.F., Wang M., Liu F. *et al*. Ultrafast ion sieving using nanoporous polymeric membranes [J]. Nature Communications, 2018, 9: 568.
[3] Liu F. *et al*., Fabrication and application of nanoporous polymer ion-track membranes [J]. Nanotechnology, 2019, 30:052001.

Oral Presentation

O 6-1
A Promising New Class of Nuclear Materials: Reduced Activation FeCrV Medium-Entropy Alloy

Songqin Xia
Yugang Wang

State Key Laboratory of Nuclear Physics and Technology, Center for Applied Physics and Technology, Peking University, Beijing 100871, China

Email: songqin@pku.edu.cn, sqxia@pku.edu.cn

Key words: ion beam material modification, metal material, secondary electron emission characteristics, radiation effects, Monte-Carlo simulation

Recently, the multi-principal-element alloys have been considered as candidate materials used in advanced reactors due to their reduced defect mobility under irradiation. Yet, the strength and the swelling resistance values of medium- and high-entropy alloys investigated so far do not substantially reach to the best with increasing the number of elements. Meanwhile, the most of existing high-entropy alloys are composed of highly activated elements, e.g., Co and Ni. Here, we report a new single-phase body-centered cubic structured FeCrV medium-entropy alloy composed of the reduced activation elements. The FeCrV medium-entropy alloy exhibits a high fracture strength of 2.7 GPa and a strain of 33% at room temperature. Meanwhile, at 500 ^{0}C and above, the FeCrV medium-entropy alloy shows extensive compressive plastic strain. These strong resistances to high-temperature softening make it to be a potential candidate material in the next-generation nuclear reactors.

O 6-2
Chemical and Physical Aspects of Ion Beam Sharpening of Medical Needle

Alexey Remnev

ShinMaywa Industries, Ltd., 1-1, Shinmeiwa-cho, Takarazuka, Hyogo 665-0052, Japan

Email: remnev.a@shinmaywa.co.jp

The sharpness of cutting edges and apexes is crucial in the performance of various medical devices. A method of medical needle finishing, consisting of large area ion beam sputtering, is introduced and studied. Significant deburring, edge sharpening and surface modification of the needles is demonstrated by an experiment. The influences of working gas composition and total ion fluence on the resulting needle properties are emphasized. It was shown that the utilization of an Ar/dry air mixture (37/6) resulted in a significant improvement in surface morphology, compared to pure Ar sputtering. The effect of gas composition is discussed in terms of concurrent material sputtering and chemisorption of reactive species. Needle sharpening aspects studied using microscopy techniques were confirmed by measuring the force required to push a needle through a plastic film. The puncture force of an as-grinded needle was reduced by ~50% by means of the reported method.

O 6-3
Reactive Dual Deep Oscillation Magnetron Sputtering of Al_2O_3 Films

Andrey Solovyev
V.O. Oskirko, A.N. Zakharov, A.P. Pavlov, V.A. Semenov

Institute of High Current Electronics, 2/3 Akademichesky ave., Tomsk 634055, Russia

Email: andrewsol@mail.ru

The report presents the results of a study of a new magnetron sputtering system with high-power modulated pulses operating in the dual deep oscillation magnetron sputtering (DU DOMS) mode. A distinctive feature of the DOMS technology is the use of long pulses (1÷3 ms), consisting of a set of short micropulses (a few μs) and repeating with a low frequency (10÷500 Hz) [1,2]. In the developed system, bipolar pulse packets are applied to the dual magnetron sputtering system for the first time. Compare to traditional dual magnetron sputtering and high power magnetron sputtering (HIPIMS) technologies, DU DOMS could be expected to improve process stability in reactive mode, deposition rate and at the same time retain the high ionization rate of sputtered material.

Al_2O_3 films are synthesized by the new reactive DU DOMS technique. The regimes of arc-less sputtering are found, the hysteresis effect occurring in reactive sputtering is studied in these regimes. The possibility of stabilizing the DU DOMS processes by monitoring the electrical parameters of the discharge has been demonstrated. The deposition rate of oxide films was measured. The microstructure and optical properties of Al_2O_3 films obtained in the transition region between the «metallic» and «oxide» sputtering regimes were studied. The results obtained are compared with traditional magnetron sputtering modes (direct current and middle-frequency).

The work is supported by the Russian Foundation for Basic Research and the government of the Tomsk region of the Russian Federation, grant #18-42-703005.

References
[1] Ferreira F. *et al*. Surf Coat Tech 258 (2014) 249-256.
[2] Lin J. Surf Coat Tech 357 (2019) 402-411.

O 6-4

Surface Chemistry and Electronic Structure of Passive Film on N18 Zircaloy with Krypton Irradiation

Yunhan Ling[1]
Yunfei Fu[2], Yakui Bai[1], Qingyun Zhou[1], Zhengjun Zhang[1]

[1]School of Materials Science and Engineering, Tsinghua University, Beijing 100084 China
[2]School of physics and information engineering, Jianghan University, Wuhan 430056 China

Email: yhling@mail.tsinghua.edu.cn

Key words: N18 zircaloy, passive film, krypton irradiation, electrochemical impedance spectroscopy

As the first wall for reactor safety, zirconium alloy (Zircaloy) cladding material is subjected to harsh environment with high temperature and high pressure water chemistry during active service as well as high dose and high-energy particle bombardments such as fission fragments, fast and thermal neutrons, gamma, alpha and beta rays. Irradiation corrosion of Zircaloy, which always brings a 2-4 folds increase in corrosion rate, is an important scientific issue related to the nuclear security and economic operation of the reactors. However, it remains unclear how irradiated particles manage to degrade the protectiveness of passive film on the alloys from the viewpoint of electrochemistry. Herein, we perform surface chemistry and electronic structure investigation of N18 Zircaloy hydrothermally treated in 300 ^{o}C, 10 MPa Li-H_3BO_3 water chemistry before and after Kr irradiation. It was found that a significant increase in complex impedance but a relatively loose structure was obtained with the increase of irradiation fluence due to the point-defect accumulation; therefore an obvious enhancement of the oxygen diffusion at the surface was detected by depth profile. Calculations by density functional theory (DFT) indicated that the dislocation of oxygen atoms in the passive film would change the charge distribution and subsequently alter the absorption of hydroxyl groups, which accelerated the corrosion of zirconium. We believed that the improvement in ionic and electronic transportation properties of the passive film should be ascribed to this change and our findings have implications for understanding irradiation corrosion on different zircaloys.

O 6-5

Effect of Surface Modification of Zr-1%Nb Alloy on Corrosion Resistance and High-Temperature Oxidation

Mikhail Slobodyan
Sergey Pavlov

National Research Tomsk Polytechnic University, 30 Lenin ave., Tomsk 634050, Russia

Email: s.m.s@ngs.ru

Zirconium alloy E110 (Zr-1%Nb) is one of the main structural materials of fuel assemblies for nuclear reactors. We investigated [1] the effect of modification of the surface layer of the E110 alloy sheets as well as its laser butt welds by a high-power pulsed ion beam. The beam was composed of ions of carbon (70%) and protons (30%) with the energy of particles ~ 250 keV, the current density of a pulse was 80 A/cm^2, the number of pulses: 5. The irradiation was carried out in a vacuum chamber at room temperature and pressure of 10^{-4} Torr.

In terms of resistance to corrosion and high temperature steam oxidation three main problems arose during welding: optimal energy parameters determination of which minimally change properties of weld metal; a welding zone protection from the environment; surface microcracks formation on the welds. As a result, corrosion resistance of the welds is worse than the base metal. Surface irradiation using a pulsed ion accelerator did not cause a noticeable change in its corrosion resistance. However, corrosion test in water at a temperature of 360±6 °C and a pressure of 19.6±1.96 MPa, which correspond to operating conditions of fuel claddings, for 200 hours led to complete relaxation of the modified layer as well as reduction residual stresses in the welds.

After high-temperature steam oxidation at a temperature of 1200 °C for 60 s, surface of the non-irradiated samples is covered with a light gray oxide film and blisters. However, the black oxide layer and absence of blisters are on the surfaces of heat-affected zone and welds which have a large amount of contamination as well as surface microcracks. Black oxide layers of pre-irradiated samples have only a small amount of light color nodules. Thickness of the oxide layer on the irradiated samples is much larger despite the smaller number of nodules as well as the weight gain is also greater than that of the non-irradiated ones.

Based on these facts, the main conclusion is that the investigated technology of surface modification by ion irradiation is not effective for improving of zirconium alloys resistance against corrosion and high-temperature steam oxidation. However, additional studies are required to confirm or refuse this hypothesis.

References

[1] M.S. Slobodyan, S.K. Pavlov, G.E. Remnev, Corrosion Science 152 (2019), 60-74. doi:10.1016/j.corsci.2019.02.031.

O 6-6
Medical Polyurethane Modified by Ion Beam

Vyacheslav Chudinov[1]
Igor Shardakov[1], Alexey Kondyurin[2]

[1]Institute of Continuous Media Mechanics, Ural Branch of the Russian Academy of Sciences, 1 Akademika Koroleva st., Perm 614013, Russia
[2]School of Physics, University of Sydney, Sydney, Australia

Email: Chudinovsl@mail.ru

Key words: ion beam, polyurethane, biocompatibility, foreign body reaction

Modern problem of surgery with artificial implant is an immune reaction of the host organism following inflammatory reaction, foreign body reaction, fibrotic encapsulation and in worse case calcification of the capsule [1]. First stage of these reactions is attachment of host proteins on the implant surface and change their conformation and activity [2]. It was found that ion beam treatment of polymer implants can provide the strong protein attachment with saving of their conformation and activity [3].

In present study, medical grade polyurethane was treated by high energy nitrogen ions. The surface energy, chemical structure changes, covalent protein attachment and cells proliferation in the surface layer were investigated. The polyurethane was implanted to rats. The histology analysis showed that the foreign body reaction is significantly weaker for treated polyurethane.

Therefore the foreign body reaction can be avoided for medical implants treated by ion beams.

The investigation is supported by Russian Academy of Science (State task of the ICMM UB RAS).

References

[1] Z. Sheikh, P.J. Brooks, O. Barzilay *et al*. Macrophages, foreign body giant cells and their response to implantable biomaterials, Materials, 8, 2015, 5671–5701.
[2] J.M. Anderson, A. Rodriguez, D.T. Chang. Foreign body reaction to biomaterials, Semin Immunol. 20, 2008, 86–100.
[3] A. Kondyurin, N.J. Nosworthy, M.M.M. Bilek, Attachment of horseradish peroxidase to polytetrafluorethylene (teflon) after plasma immersion ion implantation, Acta Biomaterialia, 4, 2008, 1218–1225.

O 6-7

Blood Platelets Adhesion to an Intermetallic Coating Made by SHS Using Magnetron Sputtering Ti-Ni-Ti Nano-Laminate

Gulsharat Baigonakova[1]
Yuriy Yasenchuk[1], Ekaterina Marchenko[1], Sergey Gunther[1], Oleg Kokorev[1], Sergey Zenkin[2], Mikhail Yuzhakov[3,*]

[1]Research Institute of Medical Shape Memory Materials and Implants, National Research Tomsk State University, Tomsk 634050, Russia
[2]Research School of High-Energy Physics, National Research Tomsk Polytechnic University, Tomsk 634050, Russia
[3]R&D Laboratory for Medical Engineering, National Research Tomsk Polytechnic University, Tomsk 634050, Russia

Email: libra2000@yandex.ru, libra@tpu.ru

Plasma treatment methods are widely used to increase the corrosion resistance of titanium alloys through the creation of oxynitride surface layers and increase in their bioinertness. For example, plasma treatment of Ti-Ni in gas atmosphere with nitrogen implantation improves the adhesion of osteoblasts on the implant surface.

Self-propagating high-temperature synthesis (SHS) is a method commonly used to create intermetallic coatings, since it forms a good bond between the coating and the substrate. In addition, the method enables using argon, nitrogen, gases of complex composition and air as a technological medium, and various techniques to apply metal components of the exothermic reaction. Synthesis can be initiated either by a point heat pulse or by heating the entire sample. All this makes the surface modification process flexible.

The proposed method of producing coating by SHS using Magnetron Sputtering Ti-Ni-Ti Nano-laminate (SHS-MSNL) involves a reaction synthesis of the intermetallic coating on TiNi alloy using a three-layer Ti-Ni-Ti coating produced by magnetron sputtering.

Before applying the layers by the magnetron sputtering method, the surface of the TiNi sample was preliminarily etched with argon plasma to remove the oxidized surface layers and to level the surface.
The deposition of the layers of Ti-Ni-Ti nano-laminate was ceased after complete coverage of the underlying surface to achieve the minimum thickness of the deposited layers.

The Ti-Ni-Ti layers exhibit the uniform thickness to ensure the Ti/Ni ratio close to the Ti_2Ni stoichiometry in the synthesized intermetallic coating.

To prevent spontaneous synthesis during deposition of the layers, especially the last two layers, the temperature of the sample was monitored.

Uncontrolled heating of the nano-laminate leads to premature and nonuniform synthesis of the intermetallic coating and to the formation of Ti_xNi_y phases of undefined composition.

The reaction synthesis initiated by heating the sample to 200 °C was performed in the thermal explosion mode. The synthesis was controlled visually through a viewing window. The synthesis of the intermetallic layer took place in the liquid phase since it was accompanied by self-heating and luminescence of the Ti-Ni-Ti nano-laminate. The synthesized coating is of dark brown color, while the TiNi substrate retains the original metallic luster.

The phase and elemental composition of the synthesized coating were investigated by STEM and HRTEM methods using the JEM-156 2100F (JEOL) after cutting the lamella using the QUANTA 200 3D.

Optical microscopy and atomic force microscopy were used to study the surface and biological characteristics of the TiNi alloy treated using the SHS-MSNL method to compare them with the surfaces subjected to sandblasting and acid treatment, and oxidized in air.

The effect of different surface treatment of TiNi samples was investigated: fine grinding, sandblasting, etching, oxidation, SHS-MSNL for contact angle, microrelief, polarization, and adhesion of platelets. The sample processed using the SHS-MSNL method showed successful platelet adhesion to the surface due to satisfactory wettability and corrosion resistance.

O 6-8

Time-Stable Wetting Effect of Plasma-Treated Biodegradable Scaffolds Covered with Graphene Oxide

Pavel Maryin
R. Rodriguez*, E. Bolbasov, S. Tverdokhlebov**, E. Sheremet

National Research Tomsk Polytechnic University, Tomsk 634050, Russia

Email: rodriguez@tpu.ru*
*Email**: tverd@tpu.ru*

Key words: reactive magnetron sputtering, bioresorbable polymeric scaffolds, graphene oxide (GO)

Tissue engineering as an alternative to transplantation for the damaged tissues and organs used artificial three-dimensional structures (scaffolds) based on polycaprolactone (PCL), polylactic acid (PLA), polyglycolic acid (PGA) and their copolymers formed by electrospinning method [1]. Main disadvantages of these materials are poor hydrophilicity and low surface energy. The non-thermal plasma treatment is one of the promising methods for modification scaffolds surface without adversely affecting its structure. However, well known that the hygroscopic effect is not stable over time. Graphene oxide (GO) is a promising candidate to prolong the plasma treatment effect as its flakes are highly hydrophilic and stable. However, it is not yet clear if GO can fasten the plasma hydrophilic effect providing time stability. Knowing this would be highly helpful especially for long-term applications involving binding drugs or cells to implants.

The scaffolds were produced using a NANON-01A (MECC Co., Japan) electro-spinning setup. A 200 mm length metal cylinder with a diameter of 100 mm rotating at 200 rpm was used as the collector. Fabrication parameters: 4 ml/h spinning solution consumption, 25 kV voltage, 18G needle, the distance between needle and collector 19 cm. To prepare the PCL spinning solutions, hexofluoroisopropanol ($C_3H_2F_6O$) (Sigma Aldrich, UK) was used. The polymer concentration in the spinning solution was equal to 5 mass %. The other polymers were (with the polymer concentration, mass %): copolymer of polylactic acid and polycapralactone (PLC) Purasorb PLC 7015 (Corbion, Netherlands) - 8%, poly-L-lactide (PLLA) Purasorb PL 38 (Corbion, Netherlands) - 4%, and copolymer of lactic and glycolic acids (PLGA) Purasorb PLG (Corbion, Netherlands) - 2.5%. For plasma treatment used the magnetron sputtering system described earlier [2]. Plasma treatment was carried out by reactive magnetron sputtering of a titanium (99.999%) target in a nitrogen atmosphere (99.999%). The treatment was performed for 60 seconds at a discharge power of 40 W. The GO functionalization was performed at room conditions by drop coating 100 µl of the GO dispersion over 3 cm^2 of the scaffolds' surface. The samples were dried overnight before the contact angle monitoring.

During the systematic study of four polymer types during the 30 days period the long-term hydrophilic nature of GO-functionalized scaffolds was observed. This was contrary to plasma-treated surfaces that already started to turn back hydrophobic within the first days. The GO-functionalized scaffolds display contact angle values after one month that did not exceed 41° among all samples. The enhanced long-term wettability can be attributed to the hydroxyl groups from GO, resulting in a significant increase of polar groups.

References

[1] J. Wu, Y. Hong, Bioact Mater. 1 (2016) 56–64.
[2] E.N. Bolbasov, L.V. Antonova, K.S. Stankevich *et al.*, Appl. Surf. Sci. 398 (2017) 63–72.

Poster Session

P 6-1
Atmospheric Pressure Plasma Jet Application for Magnesium and Zinc Oxides Generation

Konstantin Savkin[1]
E.M. Oks[1,2], A.S. Bugaev[1], V.I. Gushenets[1], A.G. Nikolaev[1], M.V. Shandrikov[1], G.Yu. Yushkov[1]

[1]Institute of High Current Electronics SB RAS, 2/3 Akademichesky ave., Tomsk 634055, Russia
[2]Tomsk State University of Control Systems and Radioelectronics, 40 Lenin ave., Tomsk 634050, Russia

Email: savkin@opee.hcei.tsc.ru, savkinkp@mail2000.ru

The plasma source based on atmospheric pressure discharge in an argon flow was investigated in the mode of generation of a plasma jet containing atomic particles of magnesium and zinc - the materials from which the discharge system electrodes are made. The optical emission spectrums of plasma are investigated depending on the discharge modes (DC or pulsed) and the average power dissipated in the discharge gap. It was shown, that when a discharge is operated in a pulsed mode with a pulse duration of several microseconds with a frequency of 100 kHz, a stable plasma jet is realized. In such a discharge, with an average power of about 50 W, local liquid metal formation on the cathode surface stabilizes. It causes to the emission of excited vapors of the cathode material, as can be seen from the structure and features of the optical radiation of the jet behind the anode nozzle of the plasma generator. With these jets the coatings were deposited and investigated by scanning electron microscopy and energy dispersive X-ray microanalysis. It was found that they consist of submicron-sized particles containing magnesium or zinc atoms, as well as a significant proportion (up to 70 at.%) of oxygen atoms. The results can be useful in the processes of generating magnesium oxide nanopowders at atmospheric pressure.

P 6-2

A Theoretical Model for Predicting and Optimizing in Vitro Screening of Potential Targeted Alpha-Particle Therapy Drugs

Wenzong Ma[1]
Xudong Wang[1], Weihao Liu[2], Huan Ma[2], Yue Su[1], Ning Liu[2], Yugang Wang[1], Gen Yang[1]

[1]State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing 100871, People's Republic of China
[2]Key Laboratory of Radiation Physics and Technology, Ministry of Education, Institute of Nuclear Science and Technology, Sichuan University, Chengdu 610064, People's Republic of China

Email: wzma7@pku.edu.cn

Key words: targeted alpha-particle therapy, microdosimetry, linear-quadratic equation

One highly promising approach to cancer treatment, especially for tumors that have undergone micrometastasis, is targeted alpha-particle therapy (TAT). However, the development of a TAT drug has not been possible due to numerous unsuccessful attempts to establish effective in vitro screening methods. The goal of this study was to construct a model to predict and optimize in vitro screening of potential TAT drugs. Based on mean field hypothesis, microdosimetry and the classic linear-quadratic equation, a novel model was built, which can predict our own in vitro experiments and replicate published data from others. Interestingly, this model can also be used to quickly optimize several key parameters in in vitro screening of potential TAT drugs, instructing the optimal combinations of the expression level of antigen, the binding affinity of antibody and drug antibody ratio, as well as others. In addition, to conveniently evaluate the therapeutic benefit of different drugs, a simple but universal parameter, the death ratio, is proposed. To our knowledge, this is the first model that can predict and guide the optimization of in vitro potential targeted alpha-particle therapy drug screening, which may then accelerate the development of potential targeted alpha-particle therapy drugs dramatically.

P 6-3
Diamond Film Etching by Low Energy Large Aperture Ion Beams for Cutting Tools Reconditioning

Alexey Remnev

ShinMaywa Industries, Ltd., 1-1, Shinmeiwa-cho, Takarazuka, Hyogo 665-0052, Japan

Email: remnev.a@shinmaywa.co.jp

In the metalworking industry wear resistant thin film coated tools, such as cemented carbide drills and end mills are often re-used, after their re-conditioning, thus decreasing the tooling cost. The re-conditioning consists in stripping of the partially worn hard coating, re-grinding and re-application of a new protective hard coating. Traditionally, the film stripping is carried out through electro-chemical etching (ECE) process, primarily focusing the ceramic coatings such as TiN, AlCrN, TiAlN, etc.. The ECE method is not applicable for carbon based coatings (diamond like carbon and CVD diamond), due to the chemical stability of the later. As an alternative to the ECE, we have recently developed a method of ion beam stripping via ion beam irradiation – ion beam stripping (IBS) [1]. The method have showed sufficient etching rates and homogeneity of stripping off of various ceramic coatings [2]. In this work we present and study a chemically enhanced IBS - reactive ion beam stripping process (RIBS) consisting in diamond film irradiation by energetic ions and reactive radicals resulting in rapid erosion of the coating.

Anode layer ion sources were utilized in order to obtain ion beams with ~100 mm aperture, ~100 mA total current and 4kV accelerating voltage. Ar, O_2 and their combination were utilized as a working gas. Erosion rates of morphologically different diamond films (microcrystalline and nanocrystalline) were studied and the mechanism of the diamond decomposition was discussed in terms of combination of physical and chemical processes. Raman spectrometry was utilized in order to reveal the structural changes of the diamond films as a result of RIBS and facilitated the discussion on the mechanism of the erosion.

References

[1] Alexey Remnev and Kensuke Uemura, US Patent 9824858(2017), Covering material stripping method and stripping device using ion irradiation.
[2] Alexey Remnev and Kensuke Uemura, 2019, Jpn. J. Appl. Phys. 58 SAAB04, Geometrical aspects of ion beam and plasma-based stripping processes for refurbishing cutting tools.

P 6-4

Ion Beam Assisted Deposition of Rare Earth Metals and Platinum for Obtaining of Catalytic Layers

Vasily Poplavsky[1]
Alexandr Dorozhko[1], Fadei Komarov[2], Vladimir Matys[1]

[1]Belarusian State Technological University, Minsk, Belarus
[2]Belarusian State University, Minsk, Belarus

Email: vasily.poplav@tut.by

Catalytic layers were formed by ion beam assisted deposition (IBAD) of platinum as basic active metal and one of rare earth metal (Ce, Gd, Dy, Ho, Yb) as an activating additive on Toray Carbon Fiber Paper TGP-H-060 T and AVCarb® Carbon Fiber Paper P50 carbon fiber catalyst carriers with the aim of electrocatalysts production for direct methanol and ethanol fuel cells. We carried out IBAD mode in which the deposition of the metal and the mixing of deposited layer with the substrate are carried out by accelerated (U = 5 kV) ions of the same metal. Deposition of the metal and mixing of the deposited layer with substrate by accelerated ions of the same metal were performed in an experimental unit, respectively, from a neutral fraction of metal vapor and the vacuum (~10^{-2} Pa) arc discharge plasma of a pulse arc ion source, respectively.

Investigation of the microstructure and composition of layers was carried out by SEM, EDX, WD XRF and RBS methods. Multicomponent layers with a thickness of ~30 nm were obtained, including atoms of precipitated metals and elements that make up the surface of the substrate, as well as oxygen impurities. According to RBS data the content of atoms of each of the deposited metals in the formed layers is approximately $(1.2 \div 2.4) \times 10^{16}$ cm^{-2}. The concentration of deposited metals at the maximum of the distribution near the surface depends on the layer content of the metal and amounts to several atomic percent.

It was established that the prepared electrocatalysts show activity in the processes of electrochemical oxidation of methanol and ethanol. The inclusion of the rare earth metal in the composition of formed layers enhances the activity of electrocatalysts in a multistage process of oxidation of alcohols. Activity of prepared electrocatalysts in the oxidation of more complex molecules of ethanol is higher than the activity in oxidation reaction of methanol. The advantages of proposed IBAD method are as follows: possibility of forming a cohesive catalytically active layer at low platinum consumption; one stage of deposition of each metal a comparison against multistage traditional chemical methods of catalysts preparation.

P 6-5
Titanium Surface Roughness Modification Using Ion Beam and Mechanical Method

Vladislav Tarbokov[1]
G.E. Remnev[1], S.K. Pavlov[1], N.A. Nochovnaya[2], V.E. Eshkulov[3]

[1]National Research Tomsk Polytechnic University, Tomsk, Russia
[2]All-Russian Scientific Research Institute of Aviation Materials, Moscow, Russia
[3]RUDN University, Moscow, Russia

Email: tarbokovv@tpu.ru

Key words: titanium alloys, high-intense ion beam, surface modification, microrelief

Biocompatibility of dental implants is largely determined by the state of the surface, in particular its topography. In this case, the role of surface roughness at the micro- and nanometer level is different. Surface modification and treatment of titanium alloys are an urgent problem, since, due to their tribological characteristics, titanium alloys are difficult to process.

The purpose of this work is to study the possibility of modifying the surface of titanium samples with a high-intense pulsed ion beams, and also in combination with blasting with ceramic (SiO_2) particles in order to increase the biocompatibility of dental implants.

Our work presents the results of a study of the influence of the treatment on the parameters of the relief of samples made of commercially pure titanium alloy. The possibility of changing the roughness and surface area in a wide range is shown. This treatment also reduces the chemical activity of the surface of titanium alloys. These results will expand the field of application of titanium alloys, in particular, in medicine, by creating the optimum surface topography for titanium samples for osseointegration.

SMMIB-2019

21ST INTERNATIONAL CONFERENCE
ON SURFACE MODIFICATION OF MATERIALS BY ION BEAMS
25-30 August 2019
Tomsk, Russia

Author Index

A

Abadias G. 137
Abdalla Zaki Adam Yousif 78
Abduvalov Alshyn....75, 77
Abzaev Yurii....102
Aigerim Tazhen....66
Akhtanova Gulnur....67, 175
Akilbekov Abdirash....68, 159
Akylbekova Aiman....158
Amanzhulov Bauyrzhan....67
Ananin P.S. 50, 74
Anders Andre....17
Apel P. 177
Artamonov I.D....100, 168
Astashynski V.M. 81, 143
Ayata Sevda....63

B

Baba Koumei....85, 124, 144
Bai Yakui....181
Baigarin Kanat....175
Baigonakova Gulsharat....184
Baimukhanov Zein....158, 159
Baizhumanov M. 68
Bakardjieva S. 52
Balakhayeva Rakhima....159
Bandow S. 129
Banerjee Akashrup....36
Barudžija Tanja....69
Basinova N. 156
Belov Alexey....21
Belyavskaya O. 95, 98
Bestetti Massimiliano....92
Bielinski D. 43
Bleykher Galina A. 50, 86, 92, 106
Boiko N.V. 46
Bolat-ool A. 95
Bolbasov E. 185
Bonchyk O.Yu. 148
Borisenko D. P. 70
Boukhvalov D.W. 132
Bozhko I.A. 42, 47, 49
Bozko I.A. 103
Brown Ian 164
Bugaev A.S. 167, 186
Bytsenko Oksana 96

C

Calcagno L. 52
Cannavò A. 52
Ceccio Giovanni....52
Cernohorsky O. 156
Chao Der-Sheng....154
Chauhan Vishnu....41
Chen Bing.... 87
Chen Sheng-Chi....91
Cheng Jin-Xia....123
Chengjian Lin.... 165
Chepak-Gisbrecht Maria....28
Cherenda Nikolay....143
Chernih A.A. 140
Chernopenev Danil....172
Chernysh Vladimir....15
Chigirinsky Yuri....21
Cho Won-Je 37
Cholakh S.O. 61, 131, 132
Chudinov Vyacheslav 183
Chumaevskii Andrey 102
Chunlei Zhang....165
Cieślik Iwona....44,82
Clozel Melanie....27, 45
Cormier J. 24
Cui Xiaojun 39, 56, 126, 127, 169

D

Dat Dinh Quoc....107
Dauletbekova Alma....68, 158, 159
Demeuova Gulzat....67
Denisov Vladimir....94
Denisova Yulia A. 94, 105
di Fonzo F. 45
Diduszko Ryszard....82
Ding S.Y. 177
Dinh Quoc Dat 70
Dłużewski Piotr 82
Dorozhko Alexandr 189
Dremov Vladimir 116
Drouet M. 24
Drozdziel A. 33, 145, 153
Du Congcong 121
Dubois J.B. 24
Duchna Monica 44
Dukenbayev K. 76, 77
Dulatov A.K. 46
Dvoretsky S.A. 147, 148, 150
Dvurechenskii Anatoly 136
Dzhumaev Pavel S. 70, 157
Dzyadukh S.M. 147, 148

E

Egorova Yulia 60

Ensinger Wolfgang.....63, 85, 124, 135
Erofeev M.V. 150
Eshkulov V.E. 190

F

Faitova Hana.....156
Fang Yuan.....121
Fedorischeva M.V. 47, 103
Feng Yang.....165
Fitsych O. 148
Flege S. 85, 124
Frolov Aleksei V. 31
Frolova Valeria.....173
Fu Yunfei 181
Furuta E. 85

G

Gabris Lubomir.....51
Gadirov Ruslan.....151, 152
Gavrilov Nikolay V. 61, 131, 132, 155
Ge Wei 121
Ghyngazov Sergei.....40, 60
Giniyatova Sholpan.....158, 159
Gołuński Mikołaj 117
Gong Chunzhi.....87
Gorbunov S.P. 140
Grenzer J. 153
Grigoriev Sergey 90
Grigoryev D.V. 150
Gromov Victor 62
Grudinin Vladislav A. 92
Grym J. 156
Guan Tong 28, 35
Guangpeng An 165
Gunther Sergey 184
Guo Y.H. 16
Gushchina Natalya 40, 59
Gushenets Vasily I. 167, 186

H

Halanda Juraj.....51, 69
Hatada R. 85, 124
Hayashizaki Noriyosu.....163
He Y. 16
He Jialong.....115, 141
Híveš Ján.....51
Hlatshwayo T.T. 78
Horak P. 52
Horodek Pawel.....138, 139, 145
Hsiao Yu-Cheng.....154
Hübner R. 153
Huiming Jia 165
Hwang Yong Seok.....37

I

Ieshkin A.E. 15
Ikeda Yujiro.....163
Ikeda Shota.....163
Isaev R.S. 70
Isayev R.Sh. 107
Ismail M.Y.A. 78
Iurina Victoria 79
Ivanov Yurii 58, 62, 102
Ivanov Yu.F. 105
Ivanova A.I. 49, 50
Ivlev G.D. 38
Izhnin I.I. 147, 148

J

Jagielski Jacek.....27, 43, 82
Jing L. 16
Jo S. 176
Joe M. 176
Jovanović Zoran 31
Jozwik I. 27

K

Kaigorodova Larisa.....59
Kaikanov Marat 67, 75, 77, 175
Kalashnikov Mark P. 47, 102, 103
Kalin Boris.....70, 107, 157
Kanjilal Dinakar.....36
Kański Michał.....119
Karanskiy Vadim 80
Karavaev Aleksey.....116
Karipbayev Zhakyp.....158
Karpov Semen.....152
Karpov Valeriy.....152
Kashkarov Egor B. 109, 152
Kawasaki Tadahiro.....170
Khiem L.H. 33, 145
Kim Maeng Jun.....37
Kim Chorong.....37
Kim Jae-Sung.....176
Kim J. 176
Kinomura Atsushi.....144
Kireev D.S. 15
Kiryakov Arseny 155

Kisić Danilo....69
Klie R. 52
Klopotov Anatolii....102
Klopotov Vladimir....102
Kluth P. 177
Knyazeva Anna....128
Kobayashi Tomohiro 163
Kobets A.G. 138
Kobzev A. P. 33, 145
Kodaira S. 118
Kokhanenko Andrey P. 149
Kокorev Oleg 184
Koloberdin M. 68
Kolobo Y.R. 48
Kolodynska D. 33, 139
Komarov Fadei 29, 38, 146, 189
Konakov Anton 21
Kondyurin Alexey 183
Konovalov Sergey 62
Konstantinov S.V. 146
Konusov Fedor 151, 152
Korenevski Egor L. 70, 107, 157
Korneva Olga 49
Kornievets A.S. 160
Korolev Dmitriy 21
Korotaev Alexander 147, 148, 149, 150
Korotin M.A. 131, 132
Kosińska Anna 43
Kostenko Valeria 60
Koval T.M. 49
Koval T.V. 50, 74
Koval Nikolay 93, 94
Kovalsky S.S. 93
Kozlovskii Artem L. 76, 77, 137, 158, 159, 175
Krivobokov Valery P. 86, 92
Krylov A. 68
Krysina Olga 93, 105
Kuang Shicheng 39, 56, 126, 169
Kučerová Š. 156
Kudryavtsev O.S. 71
Kukharenko A.S. 61
Kukharenko A.I. 131, 132
Kuleriya P.K. 41
Kuleshov Andrey 110
Kulik Miroslaw 31, 33, 139, 145
Kumar Vikas 41
Kumar Rajesh 41
Kung F.C. 65
Kuo Tsung-Yen 91
Kupchishin Anatoliy A. 114
Kupchishin A.I. 114
Kurmaev E.Z. 61, 131, 132
Kurpaska Łukasz 27, 43, 44, 45, 82
Kurzina Irina 26, 125
Kuzmitski A.M. 81, 143
Kuzuya Yoshihiro 144
Kwan Joe 175

L

Lapin Alexey 80
Laput Olesya 57
Larek F. 24
Lauk Alexander 151, 152
Le Xiaoyun....34, 53, 56, 97, 113, 122, 126, 127,169
Le X.Y. 81
Lee Chan Young 37, 66
Lei Mingkai 60
Lemeshko Boris 46
Li J.Y. 16
Li J.Q. 16
Li Chundong 79
Li Jun-Sheng....118
Li Hui-Ling 118
Liang Guoying 39, 56, 122, 126, 127, 169
Liang Jenq-Horng 154
Ligachev Alexander E. 48, 72
Lin Chih-Ming 154
Ling Yunhan 181
Liu Haocheng 121
Liu Shaoshuai 121
Liu Feng 121, 177
Liu J. 177
Liu Weihao 187
Liu Ning 187
Lopatin Ilya 58, 94
Lopatin V.S. 166
Lozovoy Kirill A. 149, 150
Lu L. 16
Lu Youping 121

M

Ma Tian-Li 118
Ma Wenzong 187
Ma Huan 187
Makarevich Nikolay 130
Makarov A.V. 61
Makarov Efrem 120
Makhavikou Maksim 29
Makhinko Fedor 40
Malashevich A.A. 137
Malherbe J.B. 78
Mamaev A.S. 61
Mandal Samit Kumar 36
Marchenko Ekaterina 184
Marychev Michael 21
Maryin Pavel 185
Matrenin Sergey 60
Matsunami Noriaki 23, 129

Matsutani Takaomi 104, 170
Matys Vladimir 189
Me Xianxiu 35
Medvedev N.A. 32
Mei Xianxiu 28
Merlan Dosbolayev 66
Michalcova A. 52
Mikhailov Yu.V. 46
Mikhailov Mikhail 79, 80
Mikhailov N.N. 147, 148, 150
Mikhaylov Alexey 21
Mikula Milan 51
Milchanin Oleg 29
Milovich Filipp 90
Mirjalilova Mavluda 65
Mishra Puspashree 142
Mlambo M. 78
Modebadze Georgy 50, 74
Morgiel J. 148
Mozharovsky Sergey 59
Mravik Željko 31
Musil Jindrich 18, 152
Muška Martin 69
Mynbaev K.D. 147, 148

N

Nagimov Rustem 108
Nagornyh Sergey 21
Nakao Setsuo 144
Nazarov Almaz 15, 108
Nebogatikova Nadezhda A. 31
Nechaev N.S. 38
Nenadović Miloš 69
Neshchimenko Vitaly 79
Nesmelov S.N. 147, 148
Nikolaenko Yu.M. 160
Nikolaev A.G. 186
Nikolaev Aleksey.....173
Nikolskaya Alena 21
Nikonenko Alisa 103, 125
Nikonenko E.L. 125
Njoroge E.G. 78
Nochovnaya N.A. 190
Noga Pavol 51, 54, 69
Novaković Mirjana 54
Novikov Pavel 136
Nowicka-Scheibe J. 145

O

O'Connell J.H. 32, 137
Obrosov A. 109
Ohno N. 23
Okraska M. 43
Oks Efim M. 26, 88, 100, 167, 168, 173, 186
Olejniczak Andrzej 31
Oskirko V.O. 180
Oskomov K.V. 100
Ostroverkhov Evgeny 94
Otake Yoshie 163
Ovchinnikov Vladimir 40, 59, 116, 120

P

Pak Alexander 101
Pandey Rakesh Kumar 142
Paperny Victor.....140
Paperny V.L. 140
Parkhomenko Irina 29, 38
Pasternak D.G. 71
Pavlenkov Vladimir 21
Pavlov Dmitriy.....21
Pavlov Sergey 28, 151, 152, 172, 182, 190
Pavlov A.P. 180
Petrikova Elizaveta 58, 105
Petrov Anatoly 172
Phuc Tran Van 33
Pichon Luc 24
Pigasova V.S. 81
Podanev Alexey 47
Poltavtseva Valentina 73
Poplavsky Vasily 189
Popović Maja 54
Popova N.A. 125
Postawa Zbigniew 117, 119
Potekaev Alecsandr 102
Potemkin Geliy 48, 72
Prokopenko Nikita 93, 104
Prokuratov I.A. 46
Prosolov Konstantin 95, 98
Prucnal S. 153
Pushkarev Alexander 60
Pyatkov I.N. 166
Pyszniak K. 145, 153

Q

Qu Miao 53

R

Rakočević Zlatko 55, 69
Ramazanov Kamil 108

Rath Shyama 36, 142
RauJ. 98
Remnev Alexey 179, 188
Remnev Gennady....22, 28, 34, 152, 171, 175, 190
Ren Jianhui.....39,56 ,126, 169
Ripenko V.S. 150
Rodriguez R. 185
Romshin Alexey 71
Rubannikova Yulia 62
Rudin Sergei.....136
Rui X. 52
Rusalsky D.P. 110
Ryabchikov Alexander 25, 74, 96, 109
Rydakov S.G. 46
Rygina Maria 58
Rymzhanov Ruslan 31, 32
Ryzhkov Vladislav 166

S

Safonov Dmitry.....70, 107, 157
Saladukhin I.A. 137
Salvadori M.C. 26
Samarin Sergey 116
Samoilova G.V. 61
Sataka M. 23
Saveliev M.D. 46
Savkin Konstantin 26, 57, 186
Savytskyy H.V. 148
Seitbayev A. 68
Semenov V.A. 180
Semyonkin V.A. 120
Seo J. 176
Sergeev V.P. 47, 103
Shabunin Artem 106
Shafii S.A. 114
Shalomov Konstantin 116
Shamanin Vitaly 169, 171
Shandrikov Maxim 100, 168, 186
Shang Hongfei 89, 99
Shao Tianmin 89, 97, 99
Shardakov Igor 183
Sharkeev Yury 95, 98
Shchapova Julia 155
Shen Jie 34, 122, 127
Shen Tongde 121
Sheng W.H. 177
Sheremet E. 185
Shevelev Alexey 42, 50,109
Shi L.B. 16
Shipilova O.I. 140
Shmygaleva T.A. 114
Shugurov V.V. 93, 105
Shulepov M.A. 150
Shulov V.A. 96
Shymanski Vitaliy 81
Sidelev Dmitrii V. 86, 92, 106
Sidorov G.Yu. 147
Siemek Krzysztof 30, 138
Sitek R. 44
Sitnikov ikolay 90
Sivin Denis 42, 74
Skuratov V.A. 30
Skuratov Vladimir A. 30, 31, 68, 137, 138
Slobodyan Mikhail 182
Smagina Zhanna 136
Sodikjanov Jahongir 64
Sokhoreva Valentina 151
Solovyev Andrey 180
Song Shu-Mei 91
Sonoda Tsutomu 144
Staltsov Maksim 157
Stepanov I.B. 42, 49, 74
Stepanov Andrey 169
Steshenko I.G. 96
Su Yue 187
Sun Liangting 16
Sun L.P. 16
Sun Hui 91
Surzhikov Anatoliy 60
Sushkov Artem 21
Suzuki Kohtaku 144
Swiatek Z. 148
Syrtanov Maxim 109, 152

T

Tai Yuki 104, 170
Tarasenko V.F. 150
Tarbokov Vladislav 55, 151, 152, 172, 190
Tashmukhamedova Dilnoza 64
Tereshchenko Alexey 21
Teresov Anton 58, 102
Teryaev D.A. 96
Tetelbaum David 21
Teterev Yu. 68
Tian Xiubo 87
Tian Jun-Long 123
Tikhii Alexander 160
Tikhonov Alexander 67, 75, 77, 175
Tilekkabul Ramazanov 66
Tokitani M. 23
Tolkachev O.S. 105
Torrisi A. 52
Trautmann C. 177
Tsuchiya B. 23, 129
Tuan Phan Luong 145
Turek M. 27, 145, 153
Tverdokhlebov S. 185

U

Uglov Vladimir.....81, 110, 137, 143
Umapathy G.R.....36
Umirzakov Baltakhadja.....64
Usseinov Abai.....158

V

Vacik J. 52
van Vuuren Jance A. 32, 137
Vaňa Dušan 54, 69
Vanazzi M. 45
Vaniš J. 156
Varavin V.S. 147, 148
Vardanyan Eduard 108
Vasenina I.V. 26
Vassilyeva Yuliya 101
Vereschaka Alexey 90
Veselý J. 156
Vizir A.V. 100, 168
Vlasov I.I. 71
Vlasov Yurii 102
Vlasukova Ludmila 29, 38, 158, 159
Voitsekhovskii Alexander V. 147, 148, 149, 150
Volkov A.E. 32
Volkov N.V. 70, 107
Volkov Nikolay 157
Volokitin Gennadii 102
Voronova N.A. 114

W

Waldron Will 175
Wang Younian 28, 35
Wang Yugang 53, 121, 178, 187
Wang Tiancheng 89
Wang Kun-Lun 91
Wang Qi 118
Wang Chenxu 121
Wang M. 153
Wang P.F. 177
Wang M. 177
Wang X. 177
Wang Y.G. 177
Wang Xudong 187
Warzybok P. 44
Wei Ronghua 87
Wen Q. 177
Wendler Elke 29, 38, 78, 146
Wu Gwomei 65
Wu Houpu 87
Wyszkowska E. 27, 44, 45, 82

X

Xia Songqin 178
Xiao Yu 39, 126
Xu X.B. 16
Xu Mofei 39, 56, 122, 126, 127, 169
Xu Huaizhe 56
Xu Ming-Ming 118
Xue Jianming 53

Y

Yakushev M.V. 147, 148, 150
Yakushin Vladimir 157
Yan Sha 34, 39, 53, 113, 122, 126, 127, 169
Yan Zhanfeng 121
Yan D.X. 177
Yang Y. 16
Yang Rui-Xia 118
Yang Tengfei 121
Yang Gen 121
Yang Jie 141
Yang Gen 187
Yasenchuk Yuriy 184
Yashin A.S. 70, 107
Yashin Alexander 157
Yeo Sunmog 37
Yu Xiao 34, 56, 122, 127, 169
Yun S. M. 176
Yurkov D.I. 46
Yuryev Semyon 80
Yuryev Yuri 106
Yuryeva Alena V. 86, 106
Yushkov G.Yu. 100, 168, 173, 186
Yusupjanova Maxsuna 64
Yuzhakov Mikhail 184

Z

Zaborowska Agata 45
Zaguliaev Dmitrii.....62
Zaikov V.A. 146
Zakharov A.N. 180
Zatsepin Anatoly 155
Zatsepin Dmitry.....155
Zavegilsky A.D. 15
Zdorovets Maxim 68, 76, 77, 137, 158, 159
Zenkin Sergey.....184
Zhai Y.H. 16
Zhang C.C.....60

Zhang Dong-Hai 118, 123
Zhang Gaolong 16
Zhang Huanqiao.....165
Zhang Jie.....34, 122, 127
Zhang Nan 39, 56, 126, 169
Zhang S.J. 81
Zhang Shijian.....39, 56, 122, 126, 127, 169
Zhang Xiaonan.....28, 35
Zhang Xiaofu 169
Zhang Z.M. 16
Zhang Zhengjun 181
Zhang Zhi.....118
Zhanibek Rayimkhanov 66
Zhao H.W. 16
Zhao Wei 115, 141
Zhendong Wu.....165
Zheng Wei-Tao 91
Zhidkov M.V. 48, 72
Zhidkov Ivan 61, 131, 132, 160
Zhong Haowen 34, 39, 56, 81, 122, 126, 127, 169
Zhou S. 153
Zhou Qingyun 181
Zhu Xiaopeng 60
Zhuravlev Mikhail 166, 175
Zinovie Vladimir 136
Zlotski S.V. 137
Zuk Jerzy 29, 33, 139, 145, 153
Zuza D.A. 57

Editor: M.Yuzhakov, O. Lapteva, M. Slobodyan, V. Tarbokov, G. Remnev
Publisher: Mozart, Tomsk, Russia
August 2019, Tomsk

smmib.ru