AMPL-2017

PULSED LASERS AND LASER APPLICATIONS

September 10–15, 2017
Tomsk, Russia

ABSTRACTS

GENERAL SPONSOR

Special Systems. Photonics, St. Petersburg, Russia

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MEDIA SPONSORS

Atmospheric and Oceanic Optics Journal, Tomsk, Russia
Photonics Journal, Moscow, Russia

Scientific & Technical Translations
STT
PUBLISHING
Tomsk, 2017

UDC 533.9; 621.373.8+621.375.8; 535.14; 535.33:621.373.8;
535.33/.34:621.373.826; 61

P 97

Pulsed Lasers and Laser Applications – "AMPL-2017" :
P 97 Abstracts of XIII International Conference. – Tomsk : STT, 2017. – 150 p.

ISBN 978-5-93629-597-3

The book contains the materials on the fundamental and applied problems of pulsed lasers. May be interesting for researches and engineers working in the sphere of quantum electronics, spectroscopy, plasma physics, medicine, remote sensing and laser technologies.

UDC 533.9; 621.373.8+621.375.8; 535.14; 535.33:621.373.8; 535.33/.34:621.373.826; 61

Edited by
Anton V. Klimkin and Olga V. Lobankova.

Printed from electronic forms presented by the authors.

ISBN 978-5-93629-597-3

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PLENARY SESSION

P-2

THL-100 MULTI-TERAWATT LASER SYSTEM OF A VISIBLE RANGE

V.F. Losev[1], S.V. Alekseev[1], N.G. Ivanov[1], M.V. Ivanov[1], G.A. Mesyats[2], L.D. Mikheev[2], Yu.N. Panchenko[1], N.A. Ratakhin[1] and A.G. Yastremsky[1]

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The development of multi terawatt and petawatt laser systems at present is based mainly on near-infrared solid-state Ti:sapphire or parametric amplifiers. However, some applications require the multi terawatt laser beams in the visible range. These laser beams can be produced by converting of the infrared high-power femtosecond laser pulses in the second harmonic. But its power is limited (not more than a few terawatts) by the size of nonlinear crystals and appearing of the intensity inhomogeneities due to the Kerr nonlinearity. A new approach to the design of the multiterawatt and petawatt femtosecond laser systems in the visible range has been developed at the P.N. Lebedev Physical Institute RAS (Moscow) and High Current Electronics Institute SB RAS (Tomsk). The approach is based on a solid-state femtosecond laser complex (2nd harmonic, 475 nm) and a photochemical XeF(C–A) amplifier with a gaseous active medium. In frame this approach the THL-100 laser systems was developed [1, 2]. Laser system consists of a Start-480M femtosecond titanium-sapphire starting complex and photochemical XeF(C–A) amplifier with a 24-cm aperture. Complex operates at a pulse repetition rate of 10 Hz and in a single pulse mode with external triggering. It produces at 475 nm wavelength 50 fs transform-limited pulses with energy of up to 20 and 5 mJ, 50 ps positive chirped pulses. Before amplification in the XeF(C–A) amplifier the 50 fs pulse is preliminary stretched up to 1–3 ps in a prism pair with negative group-velocity dispersion. These pulses are amplified in the XeF(C–A) amplifier in a multipass optical scheme (33 passes) formed by 32 round mirrors increasing in diameter. A divergent laser beam is injected into the XeF(C–A) amplifier, so that it b expands in diameter from 2 cm at the inlet to 12 cm at the exit. In the experiments on amplification of negative-chirped 2.35 ps pulses the output energy reached 2.5 J. In case amplification of 50 ps pulse the output energy increased up to 3.2 J. In presentation we will describe conditions of experiments and discuss the problems and possibilities of laser pulse compression.

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2. *Alekseev S.V., Ivanov N.G., Ivanov M.V., Losev V.F., Mesyats G.A., Mikheev L.D., Panchenko Yu.N., Ratakhin N.A., and A.G. Yastremskii.* Formation and amplification of 50-ps pulses in a THL-100 hybrid laser system // Quantum Electron. 2017. V. 47. No. 3. P. 184–187.

P-3

FLUORESCENCE SPECTRA OF ABSHERON'S CRUDE OILS DETECTED BY KA-14 LIDAR DEVELOPED AT NATIONAL AVIATION ACADEMY OF AZERBAIJAN

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Laser induced fluorescence (LIF) KA-14 LIDAR (Light Identification Detection and Ranging) developed at National Aviation Academy of Azerbaijan (NAA) have been used for detection of crude oil spills on Caspean sea surface due to oil leakage from different oil-gas production companies of State Oil Company of Azerbaijan Republic (SOCAR) and among them 8 Companies belonging to AzNeft and 4 Joint Ventures. As a source of excitation 355 nm line of CRF 200-type QUANTEL laser with the next parameters have been used: the beam diameter Ø = 5.35 mm; the repetition rate f = 20 Hz; the pulse time duration τ = 7 ns; the power 60 mJ.

Systematic measurements allowed to clarify distinctions between the fluorescence spectra of different oil spills taken from different Oil-Gas Companies. Distinctions between fluorescence spectra included not only appearance of new emission lines, but also different line shapes of emitted spectra.

Research performed in the present work allowes with quite high degree of reliabiliity to determine to which Oil-Gas Company belongs detected oil spill on Absheron beach of Caspean sea surface.

Present work is in progress with aim of creating the data bank of fluorescence spectra of oil spills taken from 12 Oil-Gas production Companies of SOCAR.

P-4

SPECTROSCOPIC/LASER METHODS OF AIR POLLUTION DETECTION – NEW TRENDS

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Modern spectroscopic techniques for air pollution detection that include lasers ensure, among other benefits, high sensitivity, accuracy and fast analysis of air at ordinary environment/working place and specific ambience [1, 2]. Quality of air is one of the most important factor effecting on human health – so that the air pollution monitoring is of high priority nowadays. Various spectroscopic methods, based on emission and absorption effects, are in use today, and in this content the use of the laser systems is of high importance. Based how the laser is employed, various techniques can be currently encountered: laser intra-cavity spectroscopy, photoacoustic spectroscopy, cavity ring-down spectroscopy, laser induced fluorescence spectroscopy, laser induced breakdown spectroscopy, etc. Generally, all of these mentioned techniques ensure high sensitivity and speed of analysis.

Examples of the use of mainly laser absorption techniques at VINCA Institute, for the analysis of organic compounds/pesticides [3, 4], as well as specific materials/gases interesting for nuclear purposes will be mentioned. Specifically, application of laser absorption method for the analysis of the deuterated ammonia gas, will be presented [5].

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P-5

RECENT DEVELOPMENTS IN LASERS AND PHOTONICS: SPIN POLARIZED ATOMS, NOVEL OPTICAL RESONATORS, AND HIGH POWER VUV LAMPS

A.E. Mironov[1], J.A. Rivera[1], A. Steinforth[1], S.-J. Park[1,2], C.M. Herring[2], and J.G. Eden[1,2]

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A brief overview of recent advances in lasers and photonics that have been realized at the University of Illinois at Urbana-Champaign (Laboratory for Optical Physics and Engineering) and Eden Park Illumination will be presented. In particular, spin polarization of alkali atoms with a circularly polarized optical field, allowing for a significant (> 50%) enhancement in atomic laser gain [1], will be discussed. Experimental results on optical microsphere resonators producing hundreds of laser beams will also be described. Novel, flat, thin microplasma lamps [2] that produce unprecedented levels of optical power (~ 2.5 kW m^{-2}) in the vacuum ultraviolet region of the spectrum (172 nm) will also be discussed.

1. *Mironov A.E., Hewitt J.D. and Eden J.G.* Spin Polarization of Rb and Cs *n*p2P3/2 (n = 5,6) Atoms by Circularly-Polarized Photoexcitation of a Transient Diatomic Molecule // Physical Rev. Letters. 2017. V. 118. No. 11.
2. *Park S.-J., Herring C., Mironov A.E., Cho J.H., and Eden J.G.* 25 W of Average Power at 172 nm in the Vacuum Ultraviolet From Flat, Efficient Lamps Driven by Interlaced Arrays of Microcavity Plasmas // APL Photonics. 2017. V. 2. No. 4.

P-6

FILAMENTATION OF MID-IR ULTRASHORT LASER PULSES IN A MOLECULAR ATMOSPHERE

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Self-focusing of high power ultrashort laser pulses belongs to the class of physical phenomena where medium optical nonlinearity is most pronounced and leads to a lot of striking effects such as laser pulse filamentation. The physical reason for laser pulse self-focusing is cubical optical polarizability of a medium leading to a self-induced increase of the refractive index in areas of high intensity and following progressive spatial and temporal pulse compression. In gases, the beam collapse is arrested by plasma generation as a result of medium photoionization. This gives rise to the development of dynamic high intensity light structures inside a laser beam, the filaments, which are nearly "diffraction-free" at a rather long distance.

In this paper, we present the results of our theoretical investigations of high power pulsed radiation self action in realistic air with frequency-dependent absorption and study the filamentation of laser pulses with the carrier in the near- and mid-IR spectral ranges centered at 0.8, 3.9, and 10.6 μm to assess the potential of these laser sources in atmospheric optical applications. Detailed comparative analysis of the main pulse parameters in the filamentation area is performed to examine the potential of various laser sources for the atmospheric optics. We found that the radiation of mid-IR lasers (3.9, and 10.6 μm) forms the longest filamentation region and the widest supercontinual spectrum in comparison with near-IR radiation. Filamentation of 3.9 μm laser pulse results in the best spatially continued plasma channel, while 10.6 μm pulse retains the widest spectral composition under the conditions of strong molecular absorption in the atmosphere.

P-7

ULTRA HIGH PEAK AND AVERAGE POWER LASERS AND APPLICATIONS FOR LASER ACTIVE OPTICAL SYSTEMS (LAOS)

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New technologies, which is able significantly increase the output peak power due to extracting the higher energy (Extracting During Pumping EDP) [1–4] and producing the shorter pulse duration (Polarization Encoded Chirped Pulse Amplification PE-CPA) [5] will be presented.

In the proof-of-principle experiments it was shown that the PE-CPA amplification with the total gain of 200 preserved a bandwidth close to 90 nm of a top hat spectral profile while broadening the spectral width of a Gaussian pulse by 40%. Recompressability of laser pulses was also demonstrated. The detailed computer modelling of high energy polarization encoded Ti : Sa amplifiers predicts an amplification bandwidth of 200 nm (with the Gaussian-shaped seed), making it a promising technique for intermediate and final amplifiers of high field (PW/few fs) Ti : Sa CPA laser systems.

The EDP method was applied to several Ti : Sa based final amplifiers of PW-scale laser systems and has reached output energies about 200 J with the current record peak power of 5 PW in a single channel [4] and for the new generation of such systems the tens of PW level has to be reached [5]. With these light sources of 10–100 PW peak power the accelerated electron beams can reach the energy up to TeV and ion beams up to GeV, as well as by using these, the secondary sources of ultrabright X and Y rays can be obtained. These results could be widely applied into many areas of science, industry and medicine. Nevertheless, it will be possible if the ultrahigh peak power laser systems also be able to combine with high repetition rate (hundreds of Hz to kHz) or high average power (kWs).

The combination of the EDP method and the Thin Disk (EDP-TD) applied to Ti : Sa amplifiers is capable to produce the higher repetition rate in the 100s TW-PW-class laser systems. Results of the proof-of-principal experiments, when the final cryogenically cooled Ti : Sa amplifier in 100 TW/10 Hz/28 fs laser system was replaced with the EDP-TD room temperature cooled arrangement will be presented [7, 8].

Very promising application of EDP-TD amplifiers in LAOS will be discussed. The results of experiments with LAOS and, first time according our knowledge, Ti : Sa amplifiers will be also demonstrated. In generally, LAOS with EDP-TD amplifiers is able to lead to significant advance in the field of laser materials processing. It aspires to develop a new class of intelligent laser-imaging systems for technological development, by exploring new means of processing surface and bulk materials of the different kinds under such remarkable parameters as TW/cm^2 intensity; kW average power; 10 fs to continuous pulse duration; Tpx/s processing speed and tens of nm resolution. Additionally to conventional Subtractive Technology (ST) manufacture, modify, or repair objects or parts, such systems could be applied to Additive Technology (AT) significantly increasing the speed and flexibility and so makes it eligible for mass production.

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P-8

QUALITATIVE INSIGHT INTO MULTIPHOTON ABSORPTION CROSS SECTION

K. Ruud, M.T.P. Beerepoot and M.M. Alam

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Multiphoton absorption processes are becoming increasingly more popular, as they offer a number of advantages over conventional one-photon absorption processes. Whereas two-photon absorption receives the largest theoretical and experimental attention, studies of three- and higher-order multiphoton processes are becoming more common.

We have in recent years developed a very general scheme for calculating multiphoton absorption cross sections [1]. Whereas this general framework allows the calculation of multiphoton absorption cross sections of arbitrary order, it is important that also qualitative insights into the structural factors that govern the magnitude of the multiphoton absorption cross sections can be obtained.

In this talk, I will discuss qualitative approaches for understanding the dependence of multiphoton absorption cross sections on molecular structure, both using few-state models [2] as well as through the use of channel interference models [3].

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P-9

STANDOFF 110-M OPEN-PATH THz SPECTROMETER WITH $GASE_{0.91}S_{0.09}$: AL(0.03 at.%) DFG

Z.-M. Huang[1], J.-G. Huang[1], Y.Q. Gao[1], W. Zhou[1], N.J. Yao[1], Yu.M. Andreev[2,3], K.A. Kokh[4], G.V. Lanskii[2], A.A. Lisenko[6], and V.A. Svetlichnyi[3,5]

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This talk will describe different aspects of design and first applications of standoff 110-m base THz spectrometer with GaSe91S0.09 : Al (0.03 at.%) difference frequency generator of a 7.8 ns Nd : YAG laser and a 3.8 ns KTP OPO. The Nd : YAG laser was seeded by semiconductor laser with $\Delta\nu = 0.003$ cm^{-1}; the 0.4–1.7 μm KTP OPO $\Delta\nu = 0.075$ cm^{-1}. GaSe91S0.09 : Al (0.03 at.%) was selected as nonlinear material due to best optical and mechanical properties. DFG was achieved at 0.05–15 THz with up to sub kilowatt peak power. THz generation efficiency was improved by the factor of ≥ 10 at principally reduced emission bandwidth by seeding with a VDI CW tunable electronic comb-oscillator: 13.75–14.42 GHz synthesizer, $\Delta\nu = \pm 0.15$ Hz, tunability step ≥ 12 Hz, frequency sweeping within ± 25 MHz supplied by three-stage high harmonic generator. It consists of 175X2[A] module (×12, tunability range 165–173 GHz, $\Delta\nu = 144$Hz, $\overline{P} = 0.1$ W), 315X2[B] (×24; 330–346 GHz, 288 Hz, 15m W), and 1.9X3[C] (×36; 495–519 GHz; 432 Hz, 2m W). The seeding leaded to decreased pulse magnitude variation for at least for 4–5 times. RT Schottky diodes and

OAD, LHe cooled Si and superconductive NbN and MoRe bolometers were used as detectors. Spectrometer was tested for 2D/3D imaging, gas and solid state matter spectroscopy, and as a remote sensor of objects with using topographical targets as reflectors.

The research was supported by RSF Grant No. 15-19-10021.

P-10

HIGH RESOLUTION SPECTROSCOPY OF NEON LINES WITH EMPHASIS ON THE 585.25 nm Ne (He,Ar) LASER

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High resolution spectroscopy of neon lines has been performed, using 10 keV electron beams in cw and pulsed mode for excitation. An echelle spectrometer with ~ 1 pm resolution at 600 nm was used. Pressure broadening and pressure shift was observed, showing red, respectively blue shift for neon and helium as perturbing species. Changing the electron beam current did not influence line widths in neon, however line narrowing with increasing currents could be observed in argon.

A prominent additional line-shape structure had shown up in the red-wing of the Ne 2p–2s 585.25 nm line in a 1000 mbar Ne (He, Ar) (laser–gas) mixture with a He : Ne : Ar ratio of 150 : 10 : 3, which could not be explained, but might lead to an unconventional lasing-in-the-flank. A 585 nm Ne (He, Ar) laser experiment was set up, using a 10 kV, 2 A, electron gun and highly reflective mirrors. Forward-sideward high resolution spectroscopy and wavelength filtered pulse shape measurements were performed, showing multi mode lasing in the line center with no additional obvious line structure. Line broadening of the spontaneous emission will be related to known collisional rate constants.

P-11

SYNTHESIS OF LASER CERAMICS

V.V. Osipov

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A short review on the synthesis and characteristics of highly transparent ceramics for gain media of solid-state lasers is reported. Special attention is given to the development of technology and investigations of properties of laser ceramics synthesized in IEP UrB RAS. Main processes taking place throughout all three stages of ceramics creation such as synthesis of nanopowders, their compaction and sintering of compacts are discussed. It is shown that during preparation of nanopowders by laser synthesis method between a liquid wall of laser crater and a vapour flow the Kelvin-Helmholtz instability is expanded and the change from vapour to dropwise ablation mode is occurred. Optimum conditions of nanopowders preparation, their compaction and sintering of compacts are reported. Details on morphological, spectral and lasing characteristics of Nd : YAG, Yb : YAG, Ho : YAG ceramics and ceramics based on Y_2O_3 are presented. It is found that the laser oscillation on the transitions of Nd^{3+} ion, in contrast to Yb^{3+}, is not appeared in Y_2O_3 based ceramics under disordering of crystalline lattice by introduction of heterovalent ions (Zr^{4+}, Hf^{4+}). It is connected with non-radiative migration of the $^4F_{3/2}$ upper laser level through the T_2 state of Zr^{4+} or Hf^{4+} ions. Creation of composite Nd : YAG ceramics and diffusional bonding of ceramics of such composition without reduction of their transparency is reported.

P-12

1 DEVELOPMENT OF A CONSTRICTION OF THE OVERVOLTAGE DISCHARGE IN A DEUTERIUM AT THE FORMING A HIGH CURRENT BEAM OF THE RUNNING-AWAY ELECTRONS

Yu.S. Akishev[1,2], A.A. Balakirev[1], V.B. Karalnik[1], M.A. Medvedev[1], A.V. Petryakov[1], N.I. Trushkin[1], and A.G. Shafikov[1]

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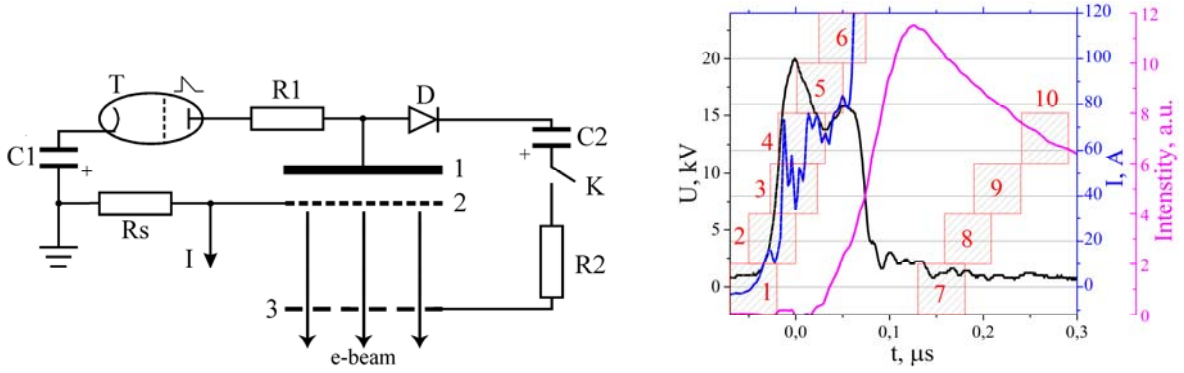
The authors have used three-electrode system with two anodes in order to generate a high current e-beam in hydrogen and a deuterium at low pressure $P = 0.2–2.0$ Torr. As it was established, duration of the e-beam is limited by formation of a spark in a narrow inter-electrode gap. The experimental results on development of a constriction of the overvoltage diffusive discharge and its transition into spark in a narrow gap are presented in the report. As an example, some part of the obtained results is shown in Figs.1 and 2. A detailed set of the received results will be presented in the full version of the report.



a *b*

Fig. 1. The scheme of three-electrode system with two anodes used for generation of the high current e-beam (*a*); the wave forms of the discharge current and voltage and PMT signal of the discharge light emission (black, blue and magenta color respectively) (*b*)

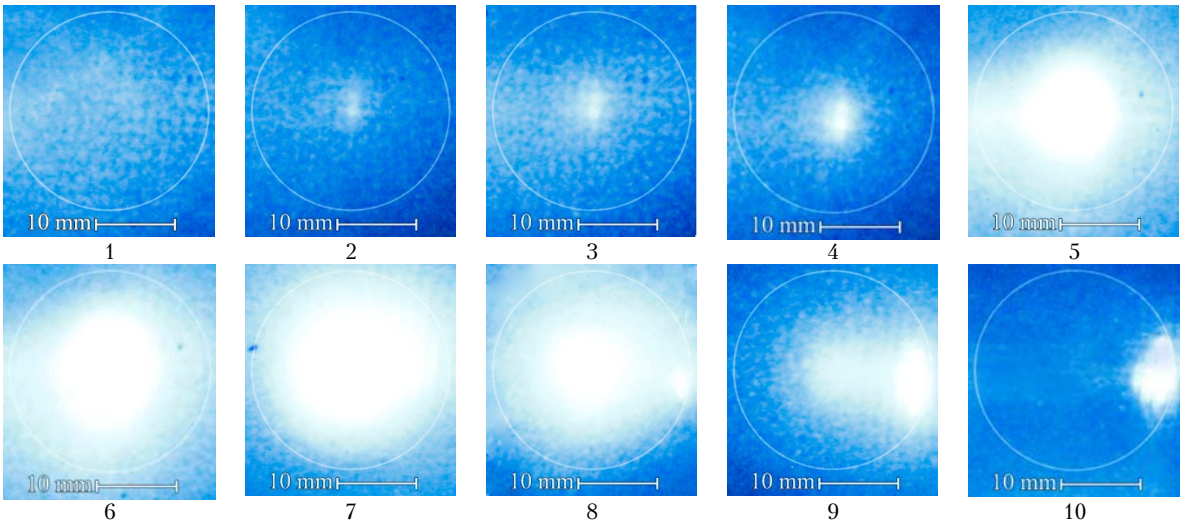


Fig. 2. Set of the discharge images showing the discharge evolution in the course of its transition into spark regime. A numeration of the shots correlates with figures shown in the legend in Fig. 1, *b*. Exposition time of each shot is 50 ns. Deuterium, $P = 2$ Torr

Work is performed with full support of Russian Science Foundation (Grant No. 16-12-10458).

Session Y
YOUNG SCIENTISTS SESSION

Y-1
PHOTONICS AND APPLICATION OF DIPYRROMETHENE COMPLEXES WITH ZINC

A.A. Prokopenko[1], R.T. Kuznetsova[1] and N.A. Bumagina[2]

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The demand for using a variety of optical devices in modern technology makes it necessary to explore the photonics of new organic luminophores such as coordination complexes of dipyrromethene with p- and d-elements depending on their structure, intermolecular interactions, temperature, etc. Systematic observation of photochemical and photophysical properties and establishment of their connection with structural features of the complexes are required for successful usage of dipyrromethene complexes and creation of various hi-tech optical devices which are based on them. Therefore, the purpose of the work is to study the spectral luminescent and sensory properties of different complexes of dipyrromethenes with zinc, the optimal combination of which will indicate the direction of the most effective use of these dyes.

For this compounds were investigated spectral-luminescent properties in different solvents. It was found that zinc dipyrromethene complexes don't have effective fluorescence but have long-lived emission due to increased nonradiative intersystem processes in the excited state. Introduction of heavy atoms into the dipyrromethene core enhances intersystem crossing, which leads to a long-lived emission. For solid samples based on zinc complexes was found dependency of the long-lived emission intensity of the oxygen concentration in gas flow. The presence of line segment indicates the possibility of the use of these complexes as optical sensors for oxygen determination. The results obtained in this work can be used as the basis for the design of optical devices.

Y-2
STUDY OF ELASTIC OBJECT CONTRACTION USING OPTICAL SENSOR

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This paper presents a detection of elastic movement of an object and measure the contractile activity of the object. An optical sensor is used to detect the Elastic object contraction, which is described. In the initial experiments, we used elastic. Next object will be animal muscle, so that we can determine the muscle contraction. Optical light is passed to the reflective plate fixed on the muscle, the backscattering is observed, and the contraction is detected by measuring the change of the distance, that occurs during muscle contraction and corresponds to muscle activity. The optical sensor converts the distance to voltage, which is recorded by digital oscilloscope. With respect to electromyography and to optical absorption-based sensors, our device has the advantage of lower invasiveness, of lower sensitivity to electromagnetic noise and to movement artifacts, and of being able to distinguish between isometric and isotonic contractions. Here electrical activity and optical activity is used to analyze the wave characteristics and muscle contractile activities.

Y-3

CONVERSION OF 8-MOP IN WATER-ETHANOL SOLUTION UNDER INFLUENCE OF IRRADIATION OF XEBR AND KRCL EXILAMPS IN THE PRESENCE OF H_2O_2

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The influence of wavelength of irradiation on the photoinduced degradation of 8-methoxypsoralen in the presence of H_2O_2 was studied. All empirical data for this compound are in good agreement with theoretical conclusions, hypotheses and calculations. For a water-ethanol solution of 8-MOP, the conversion observed under irradiation of XeBr lamp. Analyzing the data obtained in the experiment it was found that the photoproduct of 8-MOP is accumulated in the system under the influence of XeBr and KrCl excilamps. The fact of photooxidative decay of 8-MOP was fixe for the maximum concentration of H_2O_2 in the system. It was note that for most experiments in the presence of water the conversion is confirm to the following equation for conversion, which we also received for this process:

$$X = 1 - e^{-kt}$$

here k – is a constant of pseudo-first-order (min^{-1}), t – is the time of reaction (min).

Thus, the addition of H_2O_2 led to an increase of the rate of decay of 8-MOP in compared with the control variant for radiation of KrCl excilamp. In the water-ethanol solutions, the maximum values of conversion were achieve for a concentration of $1.44 \cdot 10^{-4}$ M. In addition, it was find that an increase of amount of water in the system entails to an increase of the efficiency of the phototransformation of 8-MOP.

Y-4

SPECTROSCOPIC BEHAVIOR OF PYRROLANTHRONE AND ITS DERIVATIVES IN POLAR AND NON-POLAR SOLVENTS

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New alternative substances with cytotoxic properties are actively being sought. In particular, convenient methods of producing the simplest naphto[1,2,3-cd]indole-6(2H) have been proposed [1], resulting in expanding a number of its derivatives with various functional groups, including hydrophilic ones. The compound has a high cytotoxic activity against various tissue tumors, as well as stable luminescence properties. Application of these characteristics in conjunction with the technology of encapsulation of drugs in biopolymer complexes [2] will enable to track the delivery and accumulation of the drug in problem areas of the body.

The work is devoted to comprehensive study of spectral-luminescence properties of new synthesized substances and to identification of intermolecular interactions in a set of solvents with different physicochemical properties. The impact of nature of solvents on luminescence quantum yield and lifetime is also analyzed. Using of Bakhshiev's, Lippert's and Chamma-Viallet solvatochromic shift models the contribution of specific solute-solvent interactions and general solvent effects are considered. Differences between ground and excited state dipole moments are evaluated and type of electron transition is identified.

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Y-5

STUDY ON POWDER SHG OF PROMISING NLO CRYSTALS

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The search for novel nonlinear-active materials for solving problems of nonlinear crystal optics requires a great deal of time and resources. Therefore, to obtain bulk crystal suitable for SFG, DFG, OPO and OPG, it is necessary to develop a single crystal growth technology. Determining of its optical axes and orientations, cutting, grinding and polishing are also required. Kurtz–Perry powder technique, based on of the nonlinear optical response estimation, is widely used to significantly reduce costs of the search of promising nonlinear materials. Relevance and importance of an investigation of a nonlinear conversion in powders are also related to the development of so-called ''random'' generation methods and laser conversion in atmosphere or in biological samples.

Using modified powder test a comparative study of the SHG efficiency in powders of series widely used and new nonlinear crystals under 7 ns 1064 nm Nd : YAG laser pump was carried out. Novel, poorly studied ones Ga_2S_3 and some borates (KABO, YNLSB) powders with particle size from 20 to 500 μm were tested in comparison with well-known LBO, BBO, KDP, $LiNbO_3$ and AGS. Nonlinear optical response was preliminary estimated. Laser-induced damage threshold for samples of different fraction was determined. Since the results of the present study show Ga_2S_3 as material with large SHG efficiency and high damage threshold, it is possible consider it to be a very promising for nonlinear frequency conversion of high-intense nanosecond radiation of near-IR lasers.

Y-6

CLEANING AND ACTIVATION OF THE COPPER SURFACE BY ATMOSPHERIC PRESSURE DIFFUSE DISCHARGE

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The results of the affecting on the copper surface by diffuse discharge plasma are presented in this work.

Specimens were treated in the pulse-periodic mode in atmospheric pressure nitrogen stream. For the characterization of the effect of diffuse discharge plasma on the copper surface were used methods such as Auger-spectroscopy, electron microscopy and Owens-Wendt method.

In consequence of conducted researches it was demonstrated that the surface of the test specimens is cleaned from the carbon species after 80000 and 200000 pulses of treatment (carbon concentration is reduced in ~ 2 times on the specimen surface). After 400000 pulses surface become full-cleaned from carbon and oxygen species. Moreover, surface is activated, surface energy is arisen up 3 times, disordered layer is formed, unit pulls are took place and microhardness is downed.

Y-7

ALL-FIBER MODE-LOCKED ERBIUM-DOPED RING LASER BASED ON HIGHLY-NONLINEAR RESONATOR WITH STABLE ULTRASHORT PULSE GENERATION

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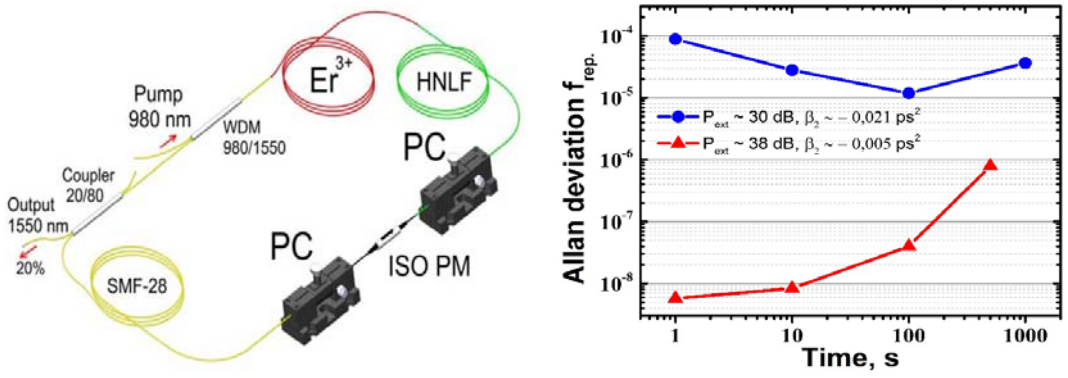
Ultrashort pulse fiber lasers have found applications in such various fields as frequency metrology and spectroscopy, telecommunication systems, etc. [1]. Recently, we have used a highly nonlinear germanosilicate fiber (with germanium oxides concentration in the core ~ 50 mol.%) inside the resonator for more reliable and robust launching of passive mode-locking based on the nonlinear polarization evolution effect in fibers. We have obtained ultrashort pulses with high peak power and energy [2]. In this work relative intensity noise and frequency repetition stability is improved by applying isolator-polarizer (ISO-PM) with increased extinction ratio P_{ext} and by compensation of intracavity group-velocity dispersion from the value $\beta_2 \sim -0.021$ ps^2 to ~ 0.0053 ps^2 at 1550 nm.



a *b*

Experimental setup of ultrashort pulse fiber laser (*a*). Allan deviation of pulse repetition frequency for various laser schemes (*b*)

The experimental setup of ultrashort pulse fiber laser is shown in Fig., *a*. Allan deviation of pulse repetition frequency in the time interval 1–1000 s with 5 Hz data depicted in Fig., *b* (before and after laser scheme variation). As a result, we have obtained the generation of stable dechirped ultrashort pulses with duration of ~ 180 fs at repetition frequency ~ 11.3 MHz (with signal-to-noise ratio ~ 59 dB) and relative intensity noise < –101 dBc/Hz.

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Y-8

THE EFFICIENCY OF PUMPING THE ACTIVE MEDIUM OF A COPPER VAPOR LASER IN THE REGIME OF REDUCED ENERGY DEPOSITION

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The analysis of electrophysical processes in the discharge circuit of a copper vapor laser with a gas-discharge tube is carried out, in which the electrodes are located in cold buffer zones. It is shown

that it is possible to realize effective generation under the condition of complete recombination of the plasma in cold buffer zones with pumping parameters at which the current through the switch will drop to zero after charging the capacitive components from the storage capacitor. Under these conditions, the pumping of the active medium is determined by the energy input from the aggravating vessel and, accordingly, the pumping efficiency can be increased by an order of magnitude if the energy input from the storage capacitor to the active medium is eliminated using a controlled switch. The efficiency of ~ 3% in a copper vapor laser with respect to the energy stored in the peaking capacitance was experimentally realized.

Y-9

THE FORMATION CONDITIONS STUDY OF SECOND HARMONIC FOR CHIRPED RADIATION PULSES

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The paper presents the results of experimental studies of the generation conditions of second harmonic for different pulse durations of the first harmonic radiation at a central wavelength of 950 nm. The experiments were carried out on a Ti:sapphire femtosecond complex, which includes a femtosecond pulse generator, a stretcher, a regenerative amplifier, two multipass amplifiers, a compressor and a second harmonic generator based on a KDP crystal. The complex provides the 50 fs pulses with an energy of 50 mJ and it is used as a frontend of THL-100 hybrid laser system, which operates in the visible region at a wavelength of 475 nm.

The search of conditions for obtaining a second-harmonic beam with a good homogeneity of intensity distribution was the main goal of the research, since for 50 fs pulse it always has small-scale heterogeneities, which increase with increasing of fundamental-harmonic energy. For this, the pulse duration of the first harmonic was increased from 50 fs to 2.5 ps due to a positive or negative chirp in the output compressor. It is shown that with the increase of the pulse duration of the fundamental harmonic, the conversion efficiency decreases, while the homogeneity of second harmonic radiation improves. At pulse durations of more than 600 fs, the radiation intensity distribution becomes close to Gaussian. The report presents the results of studies of conversion efficiency, spectral and spatial radiation parameters of both harmonics for different pulse durations.

The reported study was funded by RFBR according to the research Projects Nos. 15-08-02905, 15-08-00470 and 16-08-00204.

Y-10

A PROMISING METHOD FOR PROCESSING BRITTLE NONUNIFORMLY STRESSED MATERIALS WITH THE HELP OF MULTIWAVELENGTH LASERS

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Requirements for the accuracy and quality of glass products have now increased, and existing technologies do not provide these requirements. Therefore, there was a need to develop fundamentally new directions for highly efficient precision machining of brittle, inhomogeneously stressed materials.

On the basis of the strontium vapor laser, an experimental setup for cutting, melting and welding glass was created. A series of experiments on sealing glasses C93-3, cutting glasses with a thickness of 0.3 to 0.7 mm, and welding various glass products. The radiation power varied from 3 to 10 W. Owing to the simultaneous generation at 8 wavelengths in the 1, 3, and 6.45 μm regions, the

radiation penetrates to different depths, depending on the absorption spectrum. In addition, due to the divergence of the laser radiation, which is close to diffraction, the radiation can be focused into a spot of small dimensions. By combining energy parameters at different wavelengths, very high accuracy of glass processing with different optical characteristics is achieved.

This research carried out in 2017 was supported by "The Tomsk State University Academic D.I. Mendeleev Fund Program" Grant (No. 8.2.04.2017).

Y-11

LONG-PULSE CuBr BRIGHTNESS AMPLIFIER FOR REMOTE OBJECT IMAGING

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There are many different processes which can be researched with visual and optical methods. Some of them can be studied with typical non-destructive methods due to a combination of various accompanying factors which are destructive for diagnostic equipment. Some examples of these factors are as follow: powerful background radiation, electromagnetic radiation which can incapacitate diagnostic equipment, different type of radiation which is dangerous for humans and etc. One of the research issue is an imaging of the first wall and the divertor of a thermonuclear reactor. There is a combination of all these factors which makes the object is very difficult to imaging.

The visualization system for fast processes imaging based on a brightness amplifier has been developed and implemented. The system allows to study different processes which are blocked by background radiation, such as welding processes, high-temperature synthesis, the process of nanoparticles production by laser evaporation. The main limit of the system is a maximum distance between the brightness amplifier and the research object. This is due to the short lifetime of the inverse population, as a result, short time of amplification in active medium during one pulse. A typical value of the super-radiation pulse duration of the CuBr active medium is 30–40 ns. In this case, the theoretical maximum in distance between the research object and the brightness amplifier is about 5–6 meters. In practice, this value is smaller. To increase the pulse duration of super-radiation and, as a consequence, distance, it needs some changes in power supply and modification of active medium kinetics by different active additions. In the early works, a working model was made, in which the radiation pulse duration of 100 ns was obtained due to low frequency and increased pulse input energy [1].

In the work presents the results of compare different active media to visualization remote object in the laser monitor. The long-pulse CuBr brightness amplifier was investigated. The imaging of the object on different distaces were obtained and compared.

The work was supported by Russian Science Foundation, Project No. 14-19-00175.

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Y-12

EXCITONIC ABSORPTION IN DIAMOND NEAR THE EDGE OF FUNDAMENTAL ABSORPTION

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Due to its extreme properties, diamond can be used as a base of micro- and optoelectronics devices for space applications. In order to take into account the phenomena, associated with

nonequilibrium charge carriers in diamond, including current transport, it is necessary to consider the formation of free excitons (FE) [1].

Due to the high binding energy of the FE in diamond (80.5 meV), for nonequilibrium charge carriers it is energetically favorable to form a bound state (FE) at temperatures up to ~ 300 °C. In the optical absorption (OA) spectra, transitions to the FE state are observed near the fundamental absorption edge in the 224–238 nm region [2]. Earlier, a relationship between the values of the diamond absorption index near the edge of fundamental absorption and the possibility of observing in the sample the FE condensation into droplets of electron-hole liquid was established [2, 3].

In this paper we report the results of investigations of excitonic absorption in the OA spectra of two diamond samples synthesized by the chemical vapor deposition. The temperature dependences of the phonon components of the OA spectra in the FE state in the range 85–300 K were measured.

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Y-13

COPPER VAPOR BRIGHTNESS AMPLIFIER KINETIC MODEL

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Kinetic simulation is one of the most effective methods for a study the copper vapor active medium. Previously, the sufficiently detailed mathematical simulation of copper vapor and copper bromide vapor lasers was performed in a number of papers [1–3]. However, these models have some limitations. In particular, they lack for the possibility of a spatio-temporal study processes in brightness amplifier plasma.

This paper covers development of the spatio-temporal kinetic model of the copper vapor brightness amplifier. The developed model is a rigid system of differential equations, which describe kinetic processes in the copper vapor brightness amplifier plasma. The equations of the electrical pumping circuit and the equations describing kinetic processes in the amplifier active medium are taken into account in the model [3, 4].

The kinetic model includes equations describing the change in the reactant concentrations in the plasma, the equation describing the change in the electron temperature, and the equations describing the photon density for two brightness amplifier radiation lines (510.6 and 578.2 nm). Equations in the radial model depend both on the time and on the radius, so partial differential equations are used here instead of differential equations of one variable [5]. The testing of the developed model was also performed to show the model adequacy. In particular, the gain spatio-temporal profiles were studied for different operating modes.

The work was supported by Russian Science Foundtion, Project No. 14-19-00175.

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Y-14

OPTICAL PROPERTIES OF 8-MOP

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Substituted coumarins are widely used as laser dyes, nonlinear optical chromophores, fluorescent whiteners, as well as fluorescent labels and probes for physiological measurement. As the objects of the study was chosen 8-MOP. Spectral-luminescent properties of 8-MOP is researched. Absorption and fluorescence spectra were recorded using SM-2203 spectrofluorimeter. Spectral characteristics such as wavelength, optical density / intensity, extinction coefficient, oscillator force are obtained.

This work was supported in part within the framework of the state task of the Ministry of Education and Science of the Russian Federation, project No. 4.6027.2017 / 8.9.

Y-15

NEW STAND FOR FLUORESCENCE STUDY

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A new stand for investigation of potential of laser-induced fluorescence and Raman scattering methods for remote sensing of different gas and aerosol media has been developed and constructed on the basis of IAO SB RAS. The stand consists of three basic units. A laser emission unit includes Nd : YAG laser with emission frequencies 1064, 532, 355, 266 and 213 nm. A cell unit contains an aerosol cell of 1 meter long with quartz flanges. A receiver unit consists of a telescope, a monochromator and a CCD camera. Laser emission and receiver units are placed on the same optical platen. The principal difference of this new stand is variable length of a monitored path to the aerosol cell. The distance can vary from 10 to 100 meter.

The stand is designed for modeling of lidar measurements when the path is monitored and the content of investigated substances is monitored.

Y-16

INVESTIGATION OF COMPRESSION CONDITIONS OF SUBNANOSECOND PULSE IN THE VISIBLE SPECTRAL RANGE

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One way to obtain a multi-terawatt laser beams in the visible spectrum rang is direct amplification of the pulse in the output amplifier. Such method is being developed in IHCE SB RAS based on THL-100 hybrid laser system. This system use solid-state and gas active media, namely: Ti:Sa femtosecond frontend and photodissociative XeF(C–A) amplifier. The frontend generates a transform-limited radiation pulse of 50 fs duration or a positive-chirped 50 ps pulse (FWHM) on second harmonic (475 nm). The XeF(C–A) amplifier can gain the energy of frontend pulse up

to 2–3 J. A compressor is required to recompress the amplified 50 ps radiation pulse to the transform-limited pulse duration.

In this paper, we present the calculated parameters of the compressor based on the diffraction gratings and experimental data of the output radiation pulse compression of frontend. The compressor optics scheme, its parameters and adjustment technique are presented. The possibility of compressing 50 ps second harmonic pulse to a duration of 75 fs in the grating compressor at a pulse energy of 7 mJ and a 1 cm beam diameter are demonstrated.

The reported study was funded by RFBR according to the research Projects Nos. 15-08-02905 and 16-08-000204.

Y-17

EXPERIMENTAL STUDY OF FEASIBILITY OF FORMING A LASER BEAM WITH ORBITAL ANGULAR MOMENTUM IN THE SYSTEM OF COHERENT SUMMATION OF FIBER-OPTIC LASER BEAMS

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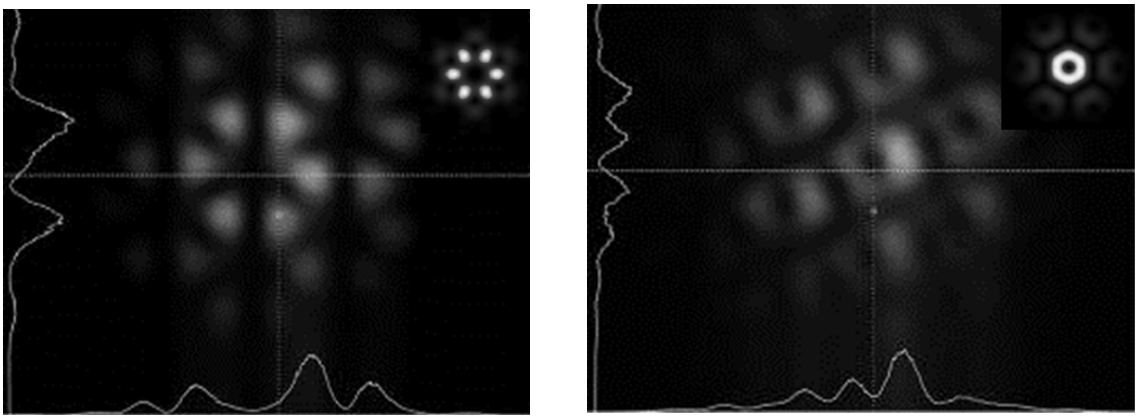
The feasibility of formation of optical vortex (OV) beams having zero intensity at the beam center with the use of phasing methods, which are applied in problems of coherent summation of laser beams, is studied.

An OV beam is defined as a beam, whose phase varies azimuthally along the direction of propagation. The OV beam is characterized by a topological charge corresponding to the number of turns in the phase front within one wavelength. Due to rotation of the phase front, the phase at the center of the beam has multiple value, which leads to the phase discontinuity (singularity) generating vanishing amplitudes at this point and zero intensity at the axis.

In the experiment in the system of coherent summation of beams, beams with dislocation at the center (at the axis) with the topological charge $l = 1$ and $l = 2$ were formed. In this system, the radiation of a fiber-optic laser was divided into six channels containing controllable phase-shifting cells and then directed into free space through a six-aperture collimator (it forms parallel beams oriented hexagonally). At the initial time, all the beams are phased and summed up coherently in the far zone. Then the phase state of one beam is fixed, while the phases of other beams are shifted by $2\pi/3$ at $l = 2$ (Fig., *a*) and $2\pi/6$ at $l = 1$ (Fig., *b*) relative to each other. As a result of interference, a synthesized optical vortex beam is formed (calculations are shown in the right top corner).



a *b*

Intensity distribution of synthesized vortex beam with a phase shift $2\pi/3$ ($l = 2$) (*a*); $2\pi/6$ ($l = 1$) (*b*)

Y-18

OPTICAL METHOD OF DEFECTOSCOPY OF $ZnGeP_2$ MONOCRYSTAL WITH APPLICATION OUTPUT RADIATION OF Sr VAPOR LASER

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In the production process elements of $ZnGeP_2$ important role played by the timely detection and classification of defects at the stage of cutting the work piece fast, contactless and non-destructive methods. Optical methods of defectoscopy are most suitable to solve this problem. In this paper the optical method of fault detection of single crystal $ZnGeP_2$ based on obtaining a shadow picture of the defects with application output radiation of Sr vapor laser is proposed. The visualization of internal defects in plate $ZnGeP_2$ size 23×17 mm and 6 mm thick cut parallel to the axis (100) has been implemented. Visualization of the defects was implemented due to the radiation of Sr vapor laser at wavelengths of 1.03 and 1.09 mkm and a laser beam analyzer "BeamCube" company "Ophir".

Y-19

CONTROL SYSTEM FOR BISTATIC LASER MONITOR

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The visualization of high-speed processes blocked from an observer by the background light is one of the most promising applications of active optical systems. These processes have small interaction zones and high speed [1].

The use of active optical systems based on copper bromide vapor lasers is one of methods of monitoring such processes. The high spectral brightness and the high gain in the narrow spectral range allow to "look through the flame".

There is active optical system is laser monitor – this term was introduced by I.I. Kilmovsky [2]. The operation of laser monitor is based on obtaining image and its filtering in active medium with inverse population. The bistatic laser monitor is an active system which is based on the use of two lasers. One of them is used as an external illumination source, the other one is used as image amplifier. This ensures independence between illumination and gain parameters. Thus, the space of vision of the system and the limiting distance between a brightness amplifier and an object can be increased.

The operation of such system requires the synchronization of two active elements with pulse duration of generation about 40 ns. It means that jitter about 10 ns or more can lead to a distortion of information.

The paper presents control systems for bistatic laser monitor. It consists of digital circuit on base microcontroller and high voltage modulator. The time delay between pulses of generation is provided by change speed of rise current in modulator. Variable inductance is used for this adjustment.

The results of investigation of the bistatic laser monitor are presented. The dependence of output power of the system on the time delay between the generator pulse and the superradiance pulse of the amplifier is described. Images of test objects and the laser cutting process are obtained.

The paper was supported by Russian Science Foundtion, Project No. 14-19-00175.

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Y-20

STAND-BY MODE OF CuBr LASER

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Metal vapor lasers operate in pulsed-periodic mode with high repetition frequency of the lasing pulses and high power of pulses. Such lasers are used in various fields of applications due to their unique characteristics [1].

The possibility of operating metal vapor lasers in the stand-by mode has great interest for a number of applications. This mode allows to increase the lifetime of laser pumping sources and optimize energy consumption.

In this paper we used the system, which controls by pulsed-periodic mode, train mode and stand-by mode of CuBr lasers [2]. The duration of the stand-by mode varies from 1 to 1000 ms. The stand-by mode finishes and next the restoring of stationary generation follows. This process occurs in three stages. Each stage is described.

The total duration of all three stages is important from a practical point of view. The first stage in the process of restoring represents most science interest. The first stage is the time interval, when stand-by mode is over, the excitation pulses of the active volume follow and the generation pulses are still absent. Probably, this time delay is due to low pre-pulse concentration of electrons.

The relaxation of the active medium is more intense with an increase time of stand-by mode from 0.2 to 10 ms. Further increase of the stand-by mode duration leads to the fact that time of generation absence (the first stage) stabilizes and averages 15 ms.

The paper was supported by Russian Science Foundtion, Project No. 14-19-00175.

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Y-21

USE OF ABSORPTION SPECTRA AND THEIR SECOND-ORDER DERIVATIVE TO QUANTIFY DEGRADATION OF HUMIC SUBSTANCES BY MICROMYCETES

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Soil fungi are actively involved in the processes of humic substances (HS) synthesis, transformation and mineralization due to production of extracellular nonspecific oxidative enzymes. The objective of this work was to evaluate the transformation dynamics for the potassium humic products (HP) from lignosulfonate by soil fungal cultures *Alternaria alternata, Cladosporium cladosporioides,* and *Trichoderma harzianum* using spectral measurements.

Growth of the fungal cultures was performed on the liquid Czapek medium. The sampling of supernatant liquid was performed on 7^{th} and 14^{th} days. The samples were filtered through a filter with a pore size of 0.2 microns before spectral measurements. Absorption measurements were carried out with a spectrophotometer Unico (UK) within the spectral range 200–1000 nm placing liquid samples into a quartz cuvette with the 1 cm optical path length.

A spectroscopic study of HS introduced into the nutrient medium and its transformation during fungal growth is challenging due to strong absorption of light by the nutrient medium, development of absorption bands of fungal metabolites, partial utilization and destruction of HS by fungi and therefore due to the need to register tiny changes in weak overlapping bands in the presence of strong scattering and medium absorption in the UV range. To accomplish that task we proposed a novel algorithm for processing the spectral curves of absorbance values which has not previously been used to study fungal cultures. We calculated the second-order differentiated absorption spectra of the HS during fungal growth. The analysis of the differentiated absorption spectra let us to detect the following characteristic "patterns" which characterize the introduced HS: in the UV region with maxima located at 270–285 and 305–320 nm and the minimum in the wavelength area of 290–300 nm. According to the decrease in the mentioned peak amplitudes we concluded about the HS degradation during fungal growth. Because of the absorbing light present in the medium of the chromophores in the same spectral range as the HS the utilization of absorbances at 270 nm was impossible. In this regard, to quantify the HS concentration we used the amplitudes in the second-order derivative spectrum at 284 nm (absorbing HS, nutrient medium, and fungal metabolites), 290 nm (absorbing nutrient medium and fungal metabolites, but no significant contribution of HS) and 304 nm (absorption by fungal metabolites and minimum absorption of the nutrient medium) and calculated the following indices: I_{HS}, the index value reflecting the relative content of HS according to the formula $(SD_{284}–SD_{290})\cdot 1000$, where SD_{284} and SD_{290} are amplitudes in the second-order derivative spectra taken at wavelengths 284 and 290, correspondingly. The indices I_{HS} were normalized to the values observed in the initial nutrient medium.

Basing on typical UV-vis absorption spectra and the proposed indices we resume that all three strains utilized HP in the 0.02 and 0.1% concentrations better at 30 g/L sucrose in the medium than at 3 g/L. Intensity of the HP consumption by micromycete in the lower sucrose concentration medium can be activated by preliminary growth without HP addition when active generation of fungal metabolites occurs. Thus the second-order differentiated absorption spectra helped to quantify degradation of the HS during fungal growth.

The research was supported by the Russian Foundation of Basic Research (Grant No. 16-34-00690 mol_a). The strains were kindly provided by Marfenina O. E. and Ivanova A.E. from the collection of the Soil Biology Department at the Soil Science Faculty (MSU).

Y-22

HIGH-FREQUENCY PUMPING SOURCE OF COPPER BROMIDE VAPOR BRIGHTNESS AMPLIFIER

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The problem of high frequency radiation (amplification) pulses obtaining in brightness amplifiers on metal vapors is sufficiently important. This is due to necessity of creating high-frequency brightness amplifier which is used in high-speed optical systems [1]. It was shown in a number of studies that obtaining of high repetition frequencies in metal vapor active media is possible with using the low energy input mode in the discharge in a small-volume GDT [2, 3].

In this paper, we present the results of a high-frequency copper bromide vapor brightness amplifiers pumping source development, based on a modulator lamp GMI-27B. The developed pump source allows to generate high-voltage pulses (up to 5 kV) with a repetition frequency of up to 1.1 MHz. Low discharge input energy mode is achieved by forming the pump pulse of short duration (up to 30 ns). Experimental study on obtaining high pulse repetition rates on GDT with a dimmer 0.8 cm and core length 25 cm was completed using the developed pumping source. Emission pulse frequency of 520 kHz was experimentally obtained in generator mode (laser). The frequency of superradiance pulses exceeded 100 kHz for the first time when the active medium operation in brightness amplifier mode.

The work was supported by Russian Science Foundation, Project No. 14-19-00175.

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Y-23

EXPERIMENTAL STUDY OF THE CHARACTERISTICS OF THE PROPAGATION OF FEMTOSECOND RADIATION IN THE ATMOSPHERE. RESULTS OF THE DISPERSION SPREADING

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A series of laboratory and nature experiments on the propagation of the high-power terawatt radiation via the femtosecond stand of the IAO SB RAS have been carried out. The problem of the spreading of femtosecond pulses in air is considered. The results of the investigation of dispersion spreading of femtosecond pulses in air are presented.

The reported study was funded by RFBR according to the research project No. 16-35-00173 Mol_a.

Y-24

FLUORESCENCE OF DISSOLVED ORGANIC MATTER FROM KARELIAN LAKES FRACTIONATED ACCORDING TO HYDROPHOBICITY

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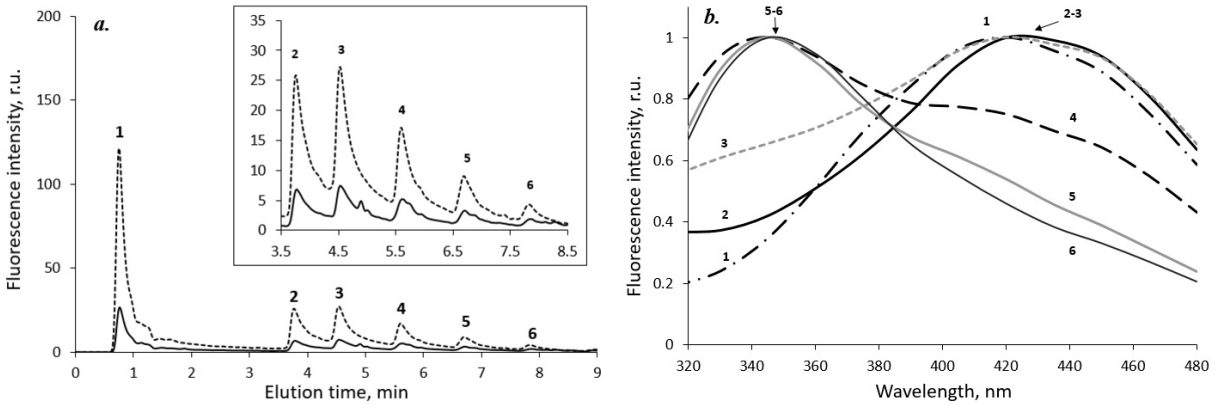
Fractionation of dissolved organic matter (DOM) using reversed-phase high performance liquid chromatography (RP-HPLC) with online detection of fluorescence and absorbance spectra allows to divide DOM samples according to their hydrophobicity and get important information about their fluorophores and chromophores. The DOM samples from three freshwater lakes of Karelia (one eutrophic and two oligotrophic lakes) were studied and the main spectral characteristics of the fractions 1–6, which correspond to the peaks on the chromatogram (Figure 1), obtained. The fluorescence of the fractions consists of two overlapping bands: «protein-like» emission with maximum at 350 nm and «humic-like» fluorescence with maximum at about 420–450 nm, however, these bands are manifested differently for fractions differing in hydrophobicity.

The analysis of fractionated DOM revealed, that chromatogram profiles of all three lakes are qualitatively similar and DOM of natural water samples contain at least three types of fluorophores: (1) hydrophilic «humic-like» fluorophore(s) with emission maximum around 420 nm; (2) hydrophobic «humic-like» fluorophore(s) with emission maximum at 450 nm; (3) «protein-like» fluorophore with emission maximum in the area of 340–350 nm, which is characteristic for proteins and peptides containing tryptophan. The quantum yield of the humic fluorescence increased with the increasing of the hydrophobicity of the fraction.



RP-HPLC chromatogram of DOM from Onezhskoe lake (eutrophic basin) with the registration of fluorescence at $\lambda_{ex}/\lambda_{em}$ 270 nm/450 nm (- - -) and 270 nm/350 nm (—) (*a*). Fluorescence spectra (normalized to the amplitude of the main maximum) of fractions 1–6 of Onezhskoe lake with λ_{ex} = 270 nm (*b*)

Acknowledgements: the work has been supported by RFBR (Grant No. 15-04-00525).

Y-25

IMAGING SYSTEM BASED ON CuBr LASER FOR WELDING PROCESSES STUDYING

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Optimization of the welding process is an important issue in terms of reducing the number of defects and increasing the quality of welds. To obtain new fundamental knowledge, optimize of welding parameters it needs to study heat and mass transfer processes during welding process with simultaneous registration of electric arc parameters. For visual and optical studying of welding processes, it is proposed to use laser backlight sources, as well as spectral and temporal filtering systems [1]. Features of CuBr laser allow to use this laser type for welding imaging. This is due to the ability to get images in several modes without changing the light source: in shadow mode, in reflected light, in laser monitor mode.

Each of the methods allows to study the various stages of the welding process. Shadow photography can use to study the process of droplet formation; the laser illumination method can be used to observe the formation of droplets and the flowing processes in the bath of the melt. Imaging with a laser monitor allows to completely suppress the effect of background arc radiation and to investigate processes without additional means for filtering the arc radiation.

The work presents the results of the development and application of a research system to study of heat and mass transfer in welding processes with different parameters. Some results of visual and optical investigation of processes with comparison with the energy parameters of the arc are presented.

The current work was supported by the Russian Science Foundation, Project No. 16-19-10010.

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Y-26

CUBR LASERS WITH MATCHING LINES IN A DISCHARGE CIRCUIT

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Metal vapor lasers have many features which allow to solve many issues in different science regions. For example, the metal vapor lasers can be used for spectroscopy, material processing, fast imaging etc. However, this type of laser has a number of disadvantages and limits. And most of them are connected with pumping sources and mechanism of inversion creating. To improve the efficiency, it is necessary to fulfill several conditions: to get a higher concentration of high energy electrons and to reduce the values of currents in the interpulse period.

The work is directed on increasing of efficiency of CuBr laser via some changes in discharge circuit. In the typical circuit, the switch (thyratron) directly discharges the energy of store capacitor into a gas discharge tube (GDT).Some modification of the discharge line which is included capacitor, line, thyratron and GDT, allowed to increase the efficiency of the laser by 1.5 times. It needed to use complementary passive elements (capacitor, transformer) for matching source and GDT. The result of which was increased the power of laser radiation from 13 to 20 W. With the use of a matching line in a discharge circuit the time delay between the current and voltage on the GDT was got. As a result the pumping electrons acquire more energy. The input excited energy before the end of the lasing pulse increases from 40 to 60% of the total energy input in compare with the circuit without matching line.

The paper was supported by Russian Science Foundation, Project No. 14-19-00175.

Y-27

LOW-TEMPERATURE VACUUM CELL FOR STUDYING THE ABSORPTION SPECTRA OF ATMOSPHERIC GASES

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The paper presents a new low-temperature cell for studying the absorption spectra of atmospheric gases at temperatures down to 73 K. The design of the cell makes it possible to control the temperature of the investigated gas within the range of 1 K in the range from 73 to 300 K. The internal volume is a cylinder with a diameter of 43 and a length of 180 mm. The cell is provided with wedge-shaped windows of ZnSe with a vacuum seal. The parasitic absorption caused by the outer surface of the windows water condensation at low temperatures was eliminated by using an external vacuum casing with wedge-shaped windows from the KBr. The design of the cell was based on the data of [1], the essential difference of which is the absence of the possibility of temperature control.

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Session A
GAS AND PLASMA LASERS, METAL VAPOR LASERS

A-1
MULTIWAVELENGTH GENERATION IN METAL VAPOR LASERS WITH A NANOSECOND PULSE DURATION

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The report gives an overview of the work on lasers with nanosecond pulses of generation in vapor-gas active media performed in the last few years at the Tomsk State University under the guidance of the author.

The main attention is paid to two directions: firstly, the possibilities of expanding the set of generation wavelengths that would overlap the visible and infrared spectrum are investigated; secondly, attention was paid to a significant increase in the energy characteristics of the strontium vapor laser due to an increase in the volume of the active medium and using the "generator-amplifier" system.

This research carried out in 2017 was supported by "The Tomsk State University Academic D.I. Mendeleev Fund Program" Grant (No. 8.2.04.2017).

A-2
LUMINESCENCE SPECTRA OF ACTIVE MEDIA OF LASERS ON P-S AND D-P TRANSITIONS OF INERT GASES UNDER ION BEAM EXCITATION

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Research on studying of luminescent radiation of the inert gases was conducted at DC-60 heavy ion accelerator. In this paper the emission spectra of inert gases and their mixtures were measured in the broad spectral range (200–1100 nm). Intensities were adjusted for the relative spectral sensitivity of the experimental facility at the range of 400–1000 nm, which embraces almost all lines of 2p–1s transitions of inert gases atoms. In UV spectral region, besides the molecular bands, connected with the presence of admixtures of water vapors, nitrogen, so-called "third continuums" of argon, krypton and xenon are observed. First time strong bands of heteronuclear ion molecules were registered at the average power of pumping. Population mechanisms of working levels in lasers with the ionizing pumping on transitions of inert gases atoms is discussed; influence of admixtures in gases at luminescent properties was studied.

A-3
CIRCULARLY POLARIZED LASER EMISSION ON THE ALKALI D_2 LINES: OPTICAL PUMPING OF A TRANSIENT DIATOMIC MOLECULE

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Spin exchange optical pumping has been known for more than 30 years [1]. This process has been mainly used for producing hyperpolarized noble gases for nuclear magnetic resonance measurements.

In virtually all spin exchange (optical pumping) experiments, spin polarized alkali atoms are produced in their ground state by depopulation optical pumping.

This work introduces a novel pumping technique allowing for pumping specific hyperfine *excited* states of the alkali atoms by the photodissociation of a transient alkali-rare gas diatomic molecule [2]. It has been shown that this technique can be used to manipulate the upper laser level populations and, therefore, the atomic gain of the alkali atomic lasers.

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A-4

COMPACT UV NITROGEN LASER PUMPED BY A PULSED LONGITUDINAL INDUCTIVE DISCHARGE

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The creation of a compact emitter of an inductive nitrogen laser (λ = 337.1 nm) is reported. For this purpose, a scheme for the formation of a pulsed induction longitudinal discharge of a transformer type has been developed. The emitter was a closed discharge circuit, which consisted of a capillary – a thin tube, which is the main working zone for generating radiation and the so-called "bypass channel". Its diameter is greater than the diameter of the capillary; this was done in order to reduce the impedance of the discharge gap. The length of the active zone of this emitter was 25 cm, the diameter of the capillary was 0.3 cm. An inductor was located along both sides of the discharge tube. In the literature, inductors of this type are called antennas. The method of pumping the active medium of a nitrogen laser with a pulsed induction longitudinal discharge of a transformer type was used for the first time. The experiments used a high voltage excitation system based on the Blumlein scheme.

In the created inductive emitter, the generation energy was about 0.35 mJ. The duration of the generation pulses was 15 ± 5 ns (FWHM), depending on the Q of the resonator. When a semi-confocal resonator was installed, it was possible to obtain a profile of the generation beam close to the Gaussian one. The spectral characteristics of spontaneous and laser radiation are analyzed. Just as with the pumping of nitrogen by an inductive discharge of cylindrical geometry, infrared radiation corresponding to low lying 1^+ transitions was not observed.

A-5

GAS LASERS PUMPED BY DIFFUSE DISCHARGE FORMED BY RUN-AWAY ELECTRONS

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Laser parameters in run-away electron preionized discharges (REP DD) are presented. Efficient lasing was obtained in different spectral ranges from IR to VUV.

Ultimate efficiency of nitrogen and HF(DF) lasers was realized in the N_2–SF_6 and $H_2(D_2)$–SF_6 gas mixtures. The maximal energy at 337 nm in N_2–SF_6 mixture was 4.1 mJ which corresponds to ultimate efficiency of N_2 laser of > 0.2%. Peak radiation energy on HF molecules attained ≈ 110 mJ corresponding to the ultimate internal lasing efficiency ≈ 10%.

Pulse duration and efficiency of exciplex lasers on XeF*, KrF*, ArF* molecules and VUV laser on molecular fluorine pumped by REP DD were shown to be comparable with those parameters obtained in conventional transverse discharge with preionization.

A-6

ELECTRON DRIFT CHARACTERISTIC IN He–Cu

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In this paper we consider the drift of electrons in helium with copper vapor in order to study the effect of copper concentration (fraction) on the electron transfer coefficients. The computational experiment is based on the consideration of an ensemble of noninteracting electrons, the motion of which is determined by given fields and instantaneous collisions with atoms.

The collision model is based on the procedure for generating random numbers-a method such as Monte Carlo. The realization of electron-atom collisions by the Monte Carlo method allows one to take into account the energy balance of electrons on the basis of elementary processes, including in inelastic collisions.

Calculated and analyzed the characteristics of electron drift in argon with mercury vapor when the electric field strength $E/N = 1 - 100$ TD taking into account inelastic collisions.

It is shown that even minor additives of the mercury in argon, since a fraction of a percent, greatly affect the discharge, in particular, on the characteristics of inelastic processes. The influence of the percentage of atoms of mercury in argon on kinetic characteristics – the coefficients of diffusion and mobility, frequency of ionization, etc.

A-7

ON THE MECHANISM LIMITING THE FREQUENCY AND ENERGY CHARACTERISTICS OF THE METAL VAPOR LASERS

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The analysis of electrophysical processes in the discharge circuit of pulsed metal vapor lasers is carried out. The greatest attention is paid to the initial period of the development of the discharge and the conditions for the formation of inversion. It is shown that the limitation of the frequency-energy characteristics of the generation is caused by the process of populating the metastable levels of metal atoms on the front of the excitation pulse and redistributing the rates of population of the laser levels in favor of metastable with increasing prepulse electron concentration. Which of the processes plays a decisive role in limiting the frequency energy characteristics of the generation depends on the electrophysical process in the discharge circuit of the laser, the development of which is influenced by the location of the electrodes in the discharge tube. The arrangement of the electrodes in the discharge tube also determines the conditions for the formation of inversion and the choice of the optimum pump parameters. Technical solutions for which the pumping efficiency of a copper vapor laser can be ~ 10% are discussed.

A-8

METHODS FOR NUMERICAL OPTIMIZATION OF THE CHARACTERISTICS OF THE STRONTIUM AND CALCIUM VAPOUR RECOMBINATION LASERS

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Ion recombination strontium ($\lambda = 430.5$ and 416.2 nm SrII) and calcium ($\lambda = 373.7$ and 370.6 nm CaII) vapour lasers are efficient sources of short wavelength radiation. In the present work the mathematical models of the He–Sr and He–Ca lasers was developed which comprises the description of the electrical pump circuit, the plasma of a repetitively pulsed discharge, and the laser

radiation. By means of mathematical models, a series of numerical experiments was carried out in which an automatic search for optimal laser regimes for a number of active elements of He–Sr and He–Ca lasers was peformed by utilizing the methods of numerical multi-parameter optimization. For the solution of the task of numerical optimization of recombination lasers preference was given in to two methods: the method of Nelder-Mead and to the genetic algorithm method. The basic advantages of the first method are the simplicity of its realization on computer and the lack of necessity to calculate derivatives. The second method refers to the class of evolutionary methods of optimization which is based on the principles of evolutionary genetics. The genetic algorithm is capable of finding the global optimum of target function, when no other method can cope with it. Numerical optimization will allow us to predict the optimal conditions for the excitation of recombination lasers of different geometry, and to calculate the attainable lasing parameters.

A-9

HIGH-FREQUENCY POWER SUPPLY FOR A COPPER VAPOR LASER BASED ON SOLID STATE SWITCHING ELEMENTS

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Traditionally, thyratrons or modulator lamps are used as a switching element in power sources for metal vapor lasers. The main disadvantage of such systems is the limited lifetime of the switch and, as a consequence, the need for frequent replacement when operating at high frequencies.

The paper presents a new scheme for constructing a pump source for lasers, based on the serial connection of switching modules with bipolar transistors with an isolated gate (IGBT). Each module has its own power source, a storage capacitor and a control circuit for power transistor. The sum of voltages on all cells is applied to the load without using a pulse transformer and chains of magnetic compression. This realization allows to obtain the maximum possible rise time of the signal in the load and to provide a high resource even at high frequencies.

A-10

PECULIARITIES OF LASING IN METAL HALIDE VAPOR LASERS WITH IN-BUILT REACTOR

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Metal halide vapor lasers with in-built reactor are not inferior in performance to conventional metal halide vapor lasers. In addition, they have some advantages noted in [1, 2]. In the work presented, the generation characteristics of such systems in copper, manganese, lead and their alloys are investigated. Gas discharge tubes with internal and external (capacitive excitation) electrodes were used. The effect of hydrogen and hydrogen halide additives on the output characteristics of these lasers is studied. As the halogen generators were used: iodine in pure form; Dibromides and dichlorides of metals; Zeolite screens saturated with halogen. It is shown that using of hydrogen additive in the active medium of CuBr laser with an internal reactor using a zeolite generator allows, as in conventional CuBr laser, to double the radiation power. The results showed that it is more convenient and efficient to work with a zeolite halogen generator. Its operating temperature, depending on the concentration of halogen, is 50–150 °C. In addition, it has the property of reversibility. In the case of an excessive concentration of halogen in the active medium, the temperature of the generator heater is restored to its optimum pressure.

The paper was supported by Russian Science Foundtion, Project No. 14-19-00175.

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A-11

INVESTIGATION OF THE LASER ON THE THALLIUM SELF TERMINATING TRANSITION PUMPED BY SUBNANOSECOND SWITCH

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The frequency energy characteristics of the laser on the self terminating $7s\ ^2S_{1/2}-6p\ ^2P_{3/2}{}^0$ transition of a thallium atom ($\lambda = 535$ nm) were studied. Investigations were carried out with a gas-discharge tube described in [1]. It's improvement was the introduction of an additional electrode, which was used to ignite the discharge between it and the cathode, that made possible to accelerate the development of the discharge in comparison with the power supply circuit used in [1], in which the excitation was performed by a cold cathode thyratron TPI3-10k/25. As switching devices were used: a kivotron in the regime of regular pulses up to a pulse repetition frequency of 2 kHz and up to 10 kHz in the burst mode operation an eptron (switch based on the combination of open and capillary discharges) in the burst mode operation with the pulse repetition frequency of up to 40 kHz.

As a result of comparative studies it was demonstrated that in both cases the energy parameters of the laser radiation and the optimal pulse repetition frequency are higher than those achieved in [1].

This work was supported by Russian Science Foundation, Research Project No. 14-19-00339.

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A-12

AMPLIFICATION RADIATION ON SODIUM D LINES USING OPTICAL PUMPING

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In recent years, much attention of researchers is riveted to the creation of efficient and compact laser vapor of alkali metals diode pumped resonant transitions $n^2P_{3/2,1/2}-n^2S_{1/2}$ (D_2 and D_1 line) of these metals. Amplification characteristics were not studied these metals for possible creation of the amplifiers of brightness image. However, the gain of such media up to 2.5 cm^{-1} according to the calculated and experimental data. Amplification and efficient generation by resonant pumping of the $n^2P_{3/2}$ level is observed on the D_1 line, at high pressure (200–300 Torr) of buffer gas (usually helium). Possible non-resonant pumping at higher pressures of the buffer gas (600 Torr and more) with a large detuning of the pump from the $n\ ^2P_{3/2}$ level in the short wavelength side. In this case, the lasing and amplification are possible at both D_2 and D_1 lines [1].

In this experimental work deals with the process of obtaining amplified spontaneous emission (ASE) in the cell with sodium vapor under longitudinal pumping by a dye laser at a detuning of pump radiation from the $3^2P_{3/2}$. We used the cell with sodium vapor, with a diameter of 1.6 cm and a length of heating zone of 10 cm. The temperature changes of the active medium from room to 350 °C, with an accuracy of ±1 °C. As the pump was used the radiation of a dye laser Pyrometer 597 excited solid-state Nd^{3+} : YAG laser (LQ-529B, Solar LS), with a wavelength of 532 nm. Pulse

frequency was 1 Hz. Line width of the dye laser (FWHM) was 5 nm, and its maximum was varied in the range from 580 to 590 nm. The energy of the pump pulse is changed by using the filters in the range from 1 to 12 mJ. Experiments were carried out with single pass and double pass of radiation through the active medium.

Amplified spontaneous emission (ASE) was recorded on both lines of sodium at densities of pump power more than 1.5 MW/cm^2, at detuning pump from $3^2P_{3/2}$. Namely, when the maximum of the broadband pumping is in the range from 584.5 to 586.5 nm. The temperature of the external wall of the cell was 230–260 °C (working concentration of Na-atoms reaches 10^{14} cm^{-3}), the pressure of helium buffer gas was 600 Torr (initial 300 Torr) at operating temperature. ASE lost when changing the detuning of the pumping line from the specified range, despite the large increase in the density of pumping.

The work was supported by Russian Science Foundation, Project No. 14-19-00175.

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A-13

SIMULATION OF SPATIO-TEMPORAL CHARACTERISTICS OF METAL VAPOR BRIGHTNESS AMPLIFIERS

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One of the most promising applications of metal vapor active media on is use them as brightness amplifiers in active optical systems [1]. Active optical systems allow to visualize the processes and objects hidden from observation by power background illumination. The quality of the obtained images in such systems directly depends on the parameters of radiation and amplification (duration of inversion, radial profile, etc.) of the used active media. So, the task of a detailed study of the spatio-temporal characteristics of metal vapor active media is quite relevant.

An effective method for solving this problem is mathematical modeling of the kinetic processes taking place in the active medium plasma. In papers [2–4] a fairly detailed mathematical simulation of copper and copper bromide vapor lasers was carried out. However, in these papers, studies were carried out when the active medium was operating as the generator, without detailed study of the radial characteristics.

This work is devoted to the development of a spatio temporal kinetic model of the copper vapor active medium. As a result of the work, radial profiles of radiation and amplification of the copper vapor active medium in different operating modes were obtained. In particular, it was shown that during the pump pulse the gain first appears at the tube wall, then on the GDT axis. Theoretical studies of the process of image transmission through a brightness amplifier taking into account the radial unevenness of the gain were also carried out.

The work was supported by Russian Science Foundtion, Project No. 14-19-00175.

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A-14

INVESTIGATION OF CO_2 LASER CHARACTERISTICS IN HELIUM FREE MIXTURES WITH OXYGEN

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The development of an economical and small size portable high pressure pulsed high pressure CO_2 discharge laser operating in helium free mixtures is still of considerable interest. Carbon dioxide lasers with high peak power and radiation pulse duration from several to tens of nanoseconds are used, for example, in environmental protection to monitor the atmosphere at different height from the earth's surface [1].

In this paper, we present the results of experimental and theoretical studies of a pulsed electric discharge CO_2 laser operating on helium free mixtures with oxygen. Experimental studies were carried out to detect the influence of electrode material, pressure and the gas mixture composition on uniformity of discharge in the interelectrode gap. The paper also presents the results of studies on optimizing the efficiency of the laser. The switch was a TPI1-1k/35 thyratron based on a superdense glow and arc discharge with a low working gas pressure. To ensure the operation of the thyratron in the regime with constant and pulsed preionization, a small size control unit was assembled. Power high voltage pulse generator was supplied from a small sized high voltage source up to 40 kV.

The calculations were carried out using the theoretical model developed by us earlier [2]. The model included a system of balance equations for the plasma components of the active medium. The constants, depending on the electric field strength, were calculated using the Boltzmann equation.

The dynamics of the main components of the active medium and the parameters of the laser pulse were calculated. The results of the calculations were in satisfactory agreement with the experimental data.

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A-15

STABILITY OF DISCHARGE IN EXCIMER GAS MEDIA WITH HIGH SPECIFIC PUMP POWERS

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The results of a study on the formation of a uniform volume discharge in XeCl and KrF lasers with a high specific pump power are reported. It is noted that in the existing commercial discharge XeCl and KrF lasers with a specific pumping power of 1–2 MW/cm^3, the radiation pulse duration does not exceed the pulse duration of the half cycle of the discharge current. The main reasons are delay generation formation and discharge contraction. It is shown that for the formation of a stable homogeneous discharge with an active medium during the pump pulse, must comply with certain conditions. First, it is necessary to have a front current duration of at least ~ 1E12 A/s. Secondly, to realize the growth of the electron density in the plasma to 1E14 cm^{-3}, in the presence of an electric field on the discharge gap ~ 10 kV/cm. It was demonstrated that in the developed discharge XeCl and KrF lasers, the generation duration is maintained during the pump pulse, into which there are 3–4 half cycles of the discharge current.

The work was supported by RFBR (Projects Nos. 15-08-00470-a, 16-29-09474-ofi_m).

A-16

FLUORESCENCE OF DIMERS AND TRIMMERS IN ELECTRIC DISCHARGE EXCIMER LASERS

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In this paper we present the results of experimental and numerical studies of the spectral emission of a discharge plasma in excimer mixtures with fluorides and chlorides. The output radiation of the volume discharge contained emission spectra of dimers on the transitions B–X, C–A, D–X in the UV range of the spectrum, and also Kr_2F, Xe_2Cl, Ar_2F trimers at 4^2G-$1,2^2G$ transitions in visible and near UV range of the spectrum. It is shown that, at the existing relaxation times of the trimer molecules ~ 150 ± 30 ns and the interaction cross section ~ 10^{18} cm^{-2}, one of the main conditions for achieving lasing at these transitions is the stability of the volume discharge. To create an active medium with a gain of at least 10^{-3} cm^{-1}, it is necessary to have a concentration of excited trimer molecules ~ 10^{15} cm^{-3}, which is provided by pumping a discharge with a specific power ~ 1–2 MW/cm^3, for 200–300 ns. It is demonstrated that the formation of a bulk plasma with a duration of ~ 400 ns is possible in a KrF laser, which makes it possible to create an active medium on a Kr_2F molecule with a gain of 3.14×10^{-4} cm^{-1}.

The work was supported by RFBR (Projects Nos. 15-08-00470-a, 16-29-09474-ofi_m).

A-17

HIGH ENERGY N_2 LASER WITH LONGITUDINAL PUMPING

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The results of an investigation of an N_2 laser with longitudinal pumping by a pulsed anomalous glow discharge are reported. The possibility of forming a stable homogeneous plasma at a maximum specific current density of ~ 2.75 ± 0.25 kA/cm^2 and a specific pumping power of more than 1 MW/cm^3 is shown. Keeping the discharge stable structure, provides automatic switching on preliminary ionization of the gas volume, by introducing sharp inhomogeneous distortions in the electric field of the discharge gap. A LC inverter was used as the pump generator, with storage capacitances of 11 nF, 5.6 nF, and a discharge capacitance of 3.8 nF.

It was demonstrated that at a nitrogen pressure (purity 99.6%) P = 10 mbar, the pulse duration of the generated radiation corresponds to the duration of the pump pulse. With a charging voltage U_0 = 24 kV, the energy in the radiation pulse reached 1.3 ± 0.1 mJ with a half-intensity duration of up to 14 ± 2 ns. The maximum peak power of the output beam was 80 kW. The radiation was generated near the inner wall of a discharge tube with an internal diameter of 9–12 mm, with a ring width of ~ 2.5 mm, and the cross section of the laser beam was 0.6 cm^2. The internal efficiency (relative to the energy stored in the discharge capacitance) was 0.11%. When nitrogen in the discharge tube is replaced by atmospheric air (~ 78% N_2, ~ 21% O_2) with a pressure of 8 mbar and the charging voltage U_0 = 24 kV, the energy in the radiation pulse was 0.6 mJ at a pulse duration t = 12 ns is noted.

The work was supported by RFBR (Projects Nos. 15-08-00470-a, 16-29-09474-ofi_m).

A-18

HIGH POWER E-BEAM CONTROLLED CO_2 LASER WITH PLASMA ELECTRON EMITTER

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A repetitively pulsed electron beam controlled CO_2 laser driven by an electron accelerator with a plasma electron emitter based on low pressure glow discharge with hollow anode and cathode is

presented. Application of the proposed emitter makes it possible to sharply increase the current and to control the electron beam duration and, hence, the energy and time characteristics of the laser. It is demonstrated that the radiation pulse duration ranges from 300 to 1200 μs, whereas the radiation energy amounts to 200 J at an efficiency of 18%.

In the course of lasing, the focal spot is not affected by the heterogeneous heating of the active medium. A significant heterogeneity in the gas flow upon an incomplete renewal of the gas in the zone filled with radiation leads to a differences of the focal spot owing to the wavefront distortions.

A-19

DEVELOPMENT OF A MATHEMATICAL MODEL FOR THE STABILITY OF AN OPTICAL SYSTEM BASED ON A PSD SENSOR

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At present, laser sources and their optical systems have found wide application in various fields of industry. During the operation of the laser, due to vibration of the laser housing, a temperature gradient of components in optical devices, and others. There is a misalignment the optical system, which leads to a violation of technological parameters. To stabilize the position of the main optical and mechanical components of the laser system, were used two-dimensional position sensors PSD (Hamamatsu). Optimal parameters of the light beam for effective control of the detector are determined. Realized correction conditions excimer laser resonator mirrors with accuracy stabilization ± 15 microns. The mathematical model allows to prepare and ensure, the operation of the laser in the automatic mode.

The work was supported by RFBR (Projects Nos. 15-08-00470-a, 16-29-09474-ofi_m).

A-20

LOW PRESSURE NITROGEN LASER WITH DIFFERENT TYPES OF PUMPING GENERATORS

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One of the most important applications of lasers based on molecular nitrogen is optical technologies associated with the processing of thin films in micro- and nanoelectronics [1].

Pumping of lasers on molecular nitrogen at low pressures is realizing in plasma of longitudinal pulsed discharge in ceramic capillary from pulse transformers. In this case, the amplitude of high voltage pump pulses reaches up to 100 kV and the excitation energy less than 1 J [2].

High voltage pulses with these parameters in most cases formed by means of pulse transformers with a closed or open magnetic core. Each of these types of transformers has its advantages and blemishes. Pulsed transformers with a closed magnetic core ensure the formation of high voltage pulses with a very short leading front, but their weak point is the low electrical strength. Pulse transformers with an open magnetic core is more simple to manufacture and easy to provide the necessary electric strength.

The purpose of this paper is investigation of laser radiation characteristics of molecular nitrogen when using two main types of pulse transformers in the pulse repetition frequency range 50 Hz ÷ 2 kHz. The results of such observation of radiation will characteristics applied to more rationally creation of nitrogen lasers with enhanced reliability.

The investigations were accomplished on a standard active element with a discharge channel from beryllium ceramics and water cooling. Pulsed transformers with a closed magnetic core were manufactured using ferrite rings 125 × 80 × 12 mm and high voltage wires of the VZM mark. For the manufacture of pulsed transformers with an open magnetic core ferrite rings 65 × 40 × 15 mm were

used. As conductors for primary and secondary windings, ordinary copper wires with varnish insulation and diameters from 0.56 to 2 mm were used.

The results of the research showed that the magnitude of the leading front of the high voltage pulse when using a pulsed transformer with a closed magnetic core reaches 50×70 ns at amplitude of 100 kV. As a consequence – breakdown of the discharge tube occurs at higher voltages than in the case of pulse transformer with open magnetic core. Accordingly, the level of radiation power for the first type transformers to $15 \times 20\%$ higher. However, pulsed transformers with an open magnetic core is easier in manufacturing, cheaper and more reliable and this type of transformer can be successfully used for pumping low pressure nitrogen lasers.

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A-21

CHARACTERISTICS OF A SMALL SIZED TEA–CO_2 LASER WITH CARBON COATINGS CATHODES

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Small sized TEA–CO_2 lasers are currently used in optical location, environmental monitoring, as well as for testing high speed IR photodetectors and systems based on them.

Pumping of TEA–CO_2 lasers is carried out in plasma of a volume self sustained discharge. The volume discharge belongs to the category of glowing discharge of high pressure. The main mechanisms for the reproduction of electrons at the cathode are ion–electron and field emission.

In this case, the contribution of field emission to the total volume discharge current is commensurable with the current that is provided by ion–electron emission (γ – processes).

To increase the autoelectronic components of the pumping current on the surface of the cathode from nickel were covered carbon films and soot containing carbon in nano structured forms. The carbon soot obtained in the electric arc reactor at the ignition of high current discharge between graphite electrodes in helium atmosphere.

The studies were accomplished on a small sized TEA–CO_2 laser with a transparent shell from quartz. The geometric dimensions of the active element were: lengths – 400 mm; diameter – 86 mm. The volume discharge was ignited in the gap $V = 180 \times 8 \times 8$ mm. The electrodes were made from nickel. Preionization of the gas in the main discharge gap was produced by VUV radiation from auxiliary spark discharges. The main generator for excitation of TEA–CO_2 laser has produced high voltage pulses with amplitude of up to 32 kV and a maximum current of up to 2.5 kA.

The studies included measurements of the current voltage characteristics of the autoelectronic current between the electrodes in a separate vacuum chamber, which was pumped out by an electric discharge pump to a residual pressure $P < 10^{-8}$ Torr, measurement of the main discharge current in the active element with a low inductive resistive shunt, the excitation energy and the energy of laser radiation in the pulse.

It was found that when the carbon coatings incased incases the surface of the nickel cathode, autoelectronic currents and discharge current increase and a volumetric discharge in $CO_2 : N_2$ mixtures without helium are easily formed at any ratio of CO_2/N_2. The excitation energy and the radiation laser energy per pulse increased by a factor of 1.2×1.5 compared with the ignition of a volume discharge between electrodes without carbon coatings.

A-22

TEA–CO_2 LASER WITH A MODIFIED METHOD OF PUMPING

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Pumping of TEA–CO_2 laser is accomplished in plasma of volume self sustained discharge, which in most cases is initiated by means of plasma or VUV radiation of the auxiliary discharges [1]. When the volume discharge is igniting in interelectrode gaps of 5×10 cm, the use of VUV radiation causes serious technical difficulty. In such gap it is advisable to use auxiliary discharge plasma, which can be formed directly in the near cathode region. Moreover, the filling of the entire interelectrode gap by free electrons prior to breakdown provides the possibility of obtaining a volume discharges in gaps more than 10 cm [2].

In this paper, the results of investigations of a TEA–CO_2 laser with an interelectrode gap of 4.5 cm when using a modified pump method are given. The discharge was formed in the volume of $V_A = 60 \times 4.5 \times 4.5$ cm. The cathode was a set of plates from aluminum, between which was laid in glass capillaries with a diameter of 6 mm. Inside of the glass capillaries were laid thin wire from nickel or molybdenum with a diameter of 0.2 mm. The outputs of these wires and the cathode were connected to an auxiliary pulse transformer, which produced a order of damped high voltage pulses. The magnitude of the first pulse reached 60 kV, the oscillation period was in the range from 1 to 2 μs.

The anode and cathode of the main discharge gap were connected to the generator pumping (main pulse transformer). The main storage capacitor ($C_H = 0.5$ μF) was commutated to pulse transformer using two switches. The first of them was started simultaneously with the auxiliary pulse generator, and the second one was started after $5 \div 10$ μs. In the circuit of the first switch was a limiting resistor. Such a construction of the pump generator was allowed during the initial period of time of $5 \div 10$ μs to generate a voltage not sufficient to breakdown of the gap "anode–cathode". During a time of $5 \div 10$ μs, the auxiliary discharge plasma is formed in the near cathode region and free charges are transferred in the main gap. After $5 \div 10$ μs, the main switch was started and the voltage in the gap very quickly (for 0.2×0.5 μs) reached the breakdown value.

The application of this pumping method provides an increase in the energy pumping and the energy radiation in a pulse of 1.5 to 1.8 compared.

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A-23

ASE ATOMIC LINES, OBSERVED UNDER OPTICAL PUMPING OF YTTERBIUM VAPORS BY KrF* LASER

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Emission of KrF* laser ($\lambda = 248$ nm) has been used for pumping of ytterbium vapor. This choice of the laser is conditioned by presence of pumping quasiresonance with ytterbium resonance transition $6s6s\ ^1S_0$–$6s7p^1P^0_1$ c $\lambda = 246.5$ nm. Tuning-out of KrF* laser emission under excitation of this transition equals $\Delta \sim 320$ cm^{-1}. This work is a continuation of the work [1].

Due to some technical reasons, only transformed visible range emission, available for visual observation, has been studied.

While focusing pumping laser emission with $\lambda_H = 248.6$ nm to a cell with ytterbium vapor, intensive ASE (amplified spontaneous emission) lines have been detected. The detected lines are

caused by transitions between groups of even ($6s5d^1D_2$, $6s6d^3D_{1,2,3}$) and odd ($6s6p^1P^0_1$, $6s6p^3P^0_{1,2}$) ytterbium levels.

Generation of coherent emission on the ytterbium resonance lines $\lambda = 398.8$ nm and $\lambda = 555.6$ nm has ben of irregular nature. Due to some technical reasons, straightforward determining of experimental conditions for observation of these lines is still a failure.

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A-24

ON MECHANISMS OF THE CHANGE IN THE EMISSION COLOR OF PLASMA EXCITED BY AN ALTERNATING ELECTRIC FIELD

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The study of the influence of an alternating electric field on the radiative characteristics of atoms is a topical problem of modern physics. One of manifestations of the influence of the electric field on atoms is the change in the emission color of plasma under changing the electric field frequency. This effect was registered in many experiments; however, exact reasons for it were only assumed.

In this work, a theoretical study of reasons for the change in the wavelength of emission from plasma excited by a circularly polarized electric field is made. The calculations are performed in the framework of the method of diagonalization of the energy matrix of an atom in the electric field. Rare gas atoms (He, Ne, Ar, and Kr atoms) are chosen as the objects of study, because these gases are widely used in different radiation sources.

Based on the results of calculations, it was shown that the influence of the electric field leads to restructuring of atomic energy spectra, in doing so, the spectra behave consistently. Owing to these reasons, the Stark states sharply change their shift directions under an increase in the electric field frequency. This fact, in its turn, leads to the change in the wavelength of emission from plasma.

Thus, the research has allowed us to reveal mechanisms of the change in the emission color of plasma excited by the electric field. The results obtained have practical applications in plasma spectroscopy, gas discharge physics and laser physics.

A-25

OPTIMIZATION OF THE He–Sr LASER PARAMETERS IN THE REGIME OF SIMULTANEOUS OSCILLATIONS ON VISIVLE AND IR TRANSITIONS

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In the present work experimental and numerical studies were carried out of a regime of the simultaneous laser oscillations at self-terminating ($\lambda = 6.456$ μm SrI, $\lambda \sim 3$ μm SrI and $\lambda \sim 1$ μm SrII) and recombination ($\lambda = 430.5$ and 416.2 nm SrII) strontium transitions. Optimal excitation conditions for the simultaneous laser oscillations were determined. Number of patterns was found, allowing to conduct a purposeful search for optimal excitation conditions of the multiwave strontium vapour lasers. In particular, it is established that an increase in the helium buffer gas pressure leads to a monotonous decrease in the average lasing power on self terminating transitions in strontium

ions, which is stipulated by a decrease in electron temperature during the current pulse and the corresponding decrease in the rate of electron-impact excitation of the resonant SrII levels. For recombination transitions in strontium ions, the average lasing power increases with increasing helium pressure up to the optimal values of several hundred Torr. With a further increase in pressure, it decreases. A decrease in the average power at high helium pressures is caused by limitation of the cooling rate of electrons at the early afterglow stage due to heating at the trailing edge of the current pulse, which manifests itself when the cooling time of electrons, which diminishes with the pressure growth, becomes comparable with the trailing edge duration of the current pulse.

A-26

ION LASERS IN MIXTURES OF METAL VAPORS WITH PUMPING BY HETEROPOLAR CURRENT PULSES

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The optimal discharge conditions have been found for pulsed gas discharge ion lasers which emitted in visible and excited in the hollow cathode discharge plasma by pumping working media (vapors of zinc, cadmium. mercury, thallium, gallium, copper, etc.) in second kind collisions, also including dependences of laser output power on a pumping current pulse duration are found. Lasing in most media on every metal vapor is observed simultaneously at several lines (the multi wavelength regime). Also laser action on mixtures of vapors of substances from one subgroup of Periodic Mendeleev's system is realized. It is offered to realize a supply of a gas discharge tube with the symmetric construction of electrode assembly directly from alternating current mains. Shortening of width of the heteropolar current pulses to shares of millisecond is provided with use of capacity or capacity and inductive reactive ballast. Use of the ballasts of this kind increases an electrical power factor of the supply circuit of laser discharge tube and is sometimes used in gas discharge light sources. In case of discharge reignition in every of the half period there is the peak of voltage on a discharge tube that promotes increase in energy of primary electrons of the cathode area of hollow cathode discharge. Further these electrons cause the formation of plasma electrons with the increased energy that eventually provides the rise of pumping of laser transition.

A-27

COMPUTER MODELING OF DIFFUSE CHANNEL DEVELOPMENT IN NON-UNIFORM ELECTRIC FIELD OF PUMPING DISCHARGE OF KrF LASER

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Enhanced stability of the pumping discharge of excimer lasers is currently the key issue to be solved in order to increase the energy and power of laser radiation. It is well known that at high densities of the pumping power, which are required for the operation of excimer lasers, channels associated with the cathode spots (plasma formations on the cathode surface) inevitably develop in the discharge. The transition from the volume mode of the discharge to the channel mode stops the laser generation. Therefore it is important to determine the operation conditions under which the diffuse character of the channels glowing remains as long as possible.

In the present work we present results of 2D modeling of the development of a diffuse channel in the pumping discharge of the KrF laser. The cathode spot is simulated as a spherical plasma formation with a concentration of charged particles several times higher than the value of the electron concentration in the volume of the discharge. The electrodes are modeled as two half-cylinders of a given radius. It is shown that the time from the beginning of the ccurrent pulse to the moment of formation of the high conductive channel (when the whole current flows through 5–10%

of the anode area) increases noticeably if an inhomogeneous distribution of the electric field is artificially created by the proper choice of the electrode shape. This approach is demonstrated to work well for short (20–30 ns) pump pulses.

A-28

THE STUDY OF THE ASE LINES OF THE ALUMINUM ATOM, OBSERVED UNDER THE IRRADIATION OF ALUMINUM VAPOR BY TUNABLE UV LASER RADIATION

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This work is an extension study of aluminum vapor optical pumping. Earlier results have been described in the works [1, 2].

The results, obtained under irradiation of aluminum vapor by tunable UV laser radiation, are presented in this work. It has been discovered that when the pumping emission (257.51 nm) is tuned to a frequency of the transition $3p^2P^0_{3/2} \rightarrow 4d^2D_{5/2}$, it results in spontaneous emission ($\lambda = 669.6$ nm) observed on the transition $5p^2P^0_{3/2} \rightarrow 4s^2S_{1/2}$. As helium buffer gas pressure increased, the intensity of the spontaneous emission was rapidly growing. Increase of pressure up to 0.02 atmosphere resulted in transition of spontaneous emission to the regime of amplified spontaneous emission (ASE). Further increase of helium pressure was accompanied by ASE intensity rise by $\lambda = 669.6$ nm.

However, upper level $5p^2P^0_{3/2}$ of the emitting transition is above the excited level $4d^2D_{5/2}$ by the value $\Delta \sim 1330$ cm^{-1}. Thus pumping of the upper level is performed by collisional transfer of population, despite the negative value of excitation energy defect Δ.

It is interesting to note that similar transfer of population occurs between the aluminum levels $3d^2D_{3/2,\,5/2}$ and $4p^2P^0_{1/2,\,3/2}$ [2]. It provides ASE occurrence on IR transitions of aluminum. Negative effect of excitation in this case equaled $\Delta \sim 510$ cm^{-1}.

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A-29

STUDY OF INVERSION OCCURRENCE MECHANISM ON MERCURIC ATOM TRIPLET TRANSITIONS UNDER OPTICAL PUMPING OF DENSE MERCURIC VAPOR BY XeCl* LASER

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While working on optical pumping of dense mercuric vapor, we have suggested sequence of processes that results in formation of inversion on mercuric atom triplet transitions [1, 2]. Moreover, there has been no experimental prove up to now that the abovementioned scheme of inversion formation really occurs.

According to previously suggested generation mechanism, intensity of generating lines must have quadratic dependence of both pumping intensity and metal vapor concentration.

Processing of the experimental data, obtained within this work, has really demonstrated that total generation intensity of triplet lines has quadratic dependence of pumping intensity. Dense mercuric vapor has been irradiated by XeCl* laser emission with $\lambda = 308$ nm.

Dependence of total generation intensity of triplet lines on mercuric vapor concentration within the range $2 \times 10^{18} \div 6 \times 10^{18}$ cm^{-3} also demonstrates quadratic dependence for at least two pumping intensities. Breaking of the quadratic dependence that is observed for concentrations over 6×10^{18} cm^{-3} can be caused by weakening of pumping emission ($\lambda = 308$ nm).

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A-30

APPLICATION OF WAVELET TRANSFORMAION FOR PROCESSING OF ELECTRONIC SPECTRA OF METASTABLE ATOMS OF NOBLE GASES

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The present investigation is the prolongation of the work on study of long-lived states of atoms of the inert gases in the vegime of overlapping beams. In this message we discuss the spectra of energy losses by electrons in collisions with xenon atoms in metastable states.

The aim of our study is to clarify the possibility of application of continuous wavelet transformation for the processing of spectra of the electron energy losses of electrons in metastable xenon atoms.

For this purpose we developed the algorithm of calculation of continuous fast wavelet transformation, which allows in real time with high accuracy to reconstruct the spectrum of losses of energy of electrons. The programs of processing of electronic spectra are written in the language C++ and Visual Basic for Applications (VBA) for convenience of work with the electronic table Excel. In the report the experimental electronic spectra of metastable atoms, and electronic spectra after the transformation of wavelet are listed on the basis of the second derivative function of Gayce (MHAT-wavelet) with various scale coefficients.

In the report the processed spectra are analyzed where the heterogeneities are obviously visible, which characterize the physical processes of hyper elastic interaction of slow electrons with metastable xenon atoms. The position of levels of long-lived lower metastable states to create an inverse population in lasers with atoms of inert gases are considered.

A-31

COMPARISON OF Eu + Ne AND Eu + He LASERS OUTPUT CHARACTERISTICS

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The europium vapor laser is one of the most promising metal vapor lasers. Generation in this active medium takes place on the atom and ion of europium in the range from 0.66 to 6 μm [1]. In addition, the collision mode of laser operation with a helium buffer gas is realized [2]. However, there are difficulties in obtaining generation with neon buffer gas, and with helium there was a low lifetime of the laser [3]. In this connection, it becomes necessary to conduct a more detailed investigation of the Eu laser. In work [3], we showed that when using a certain design of a gas discharge tube, the Ne + Eu laser stably operated more than 100 hours while maintaining the generation parameters. In addition, the dependence of the lasing behavior on the pulse repetition frequency, buffer gas pressure, pumping power, etc., was investigated.

In this paper, the characteristics of Ne + Eu and He + Eu lasers are compared for the same pump conditions. It is shown that there are features of the operation of He + Eu laser. They are manifested

in the amount of power consumption and generation efficiency. This is most likely due to the higher thermal conductivity of helium and ionization energy.

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A-32

COPPER BROMIDE VAPOR LASER WITH MONOBARRIER OPERATING MODE

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Metal vapor lasers have come a long way. Nevertheless, there remain questions connected with increasing of the efficiency of these lasers, with elucidation of the physical processes in the active medium. It was established in [1, 2] that in the near electrode regions a higher energy release occurs in the self heating mode. It is shown in [3] that in these regions there is no working medium. Because of the edge effects, effective cooling takes place and in these regions the temperature is lower than in the central region. The combination of these factors leads to a rapid escape of the electrons after the passage of the discharge pulse. Accordingly, it is precisely in these regions that a voltage is formed that makes it possible to create population inversion in a self terminated regime. That is, the breakdown is carried out in two areas: in the cathode region and in the near anodic region. In [4], even a non simultaneous breakdown in these zones was recorded. Accordingly, the question arises: how the presence of these two barriers affects the radiation characteristics. The point is that the breakdown of one of these barriers leads to heating of electrons and sub population of metastable level by electrons of low energy. In this paper, an attempt was made to answer the question: to what extent is the presence of two barriers on the radiation characteristics significantly affected. In a two-sectional gas discharge tube, the central electrode is simultaneously applied to two sections. That is, in the near electrode region of one section, the charge carriers of the second section appear. In the case of delay, the breakdown voltage in this region should decrease or ideally this barrier should disappear. It can be said that in this case the laser monobarrier operation is realized. In the experiment, a two-section copper vapor laser was used. As a result, it was found that when the laser is switched to the monobarrier operating mode, the amplitude of the generation pulse increases and the average generation power of the section increases by ~ 10%.

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A-33

CuBr LASER WITH DOUBLE PULSE EXCITATION WITH EFFICIENCY OF 2.7%

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The possibility of a double pulse CuBr laser operation with active volume of 31.4 cm^3 with an excitation efficiency of 2.7% is shown. The repetition rate between the pulse pairs was 50 Hz. Earlier in [1, 2], we optimized the excitation parameters of this laser. Optimal value of capacitances of excitation and dissociation sources, voltage on them and delay between pulses were determined. In the work presented, a maximal efficiency is obtained due to an additional optimization of the excitation pulse by incorporating into its circuit a saturation throttle wound on ferrite rings of the M2000 MH brand. The optimum inductance of the throttle was 30–40 μH. In this case, a better matching of the pump source impedances with the plasma was achieved by selecting the optimum voltage of the excitation source and its time delay with respect to the dissociating pulse. The voltage of the exciting pulse on the gas discharge tube was 5 kV, and the average output power was 17 mW. At a voltage of 15 kV, a maximum average power of 40 mW and an efficiency of 1.4% is obtained.

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INCREASING OF A DOUBLE PULSED CuBr LASER EFFICIENCY

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Optimization of a double pulse CuBr laser operation with a small active volume was performed in order to increase the laser efficiency. In [1, 2], we established the optimal values of the dissociating and exciting capacitances, the voltage at the capacitances, the delay between pulses, and obtained an efficiency of 1.5%.

In this paper it is shown that due to optimal input energy of the excitation pulse into the discharge and its matching with the plasma impedance formed by the dissociating pump pulse, it is possible to increase the efficiency of this laser to 2.5%. As shown in [3], high efficiency is obtained at low radiation powers and vice versa. The maximum laser efficiency was 2.5% with respect to the excitation pulse with an average power of 16 mW, energy 0.32 mJ, and a time delay of 150 μs. The maximum average output power was 37 mW with energy of 0.7 mJ and laser efficiency of 0.7% for a specific dissociating energy of 24 mJ/cm^3 and exciting 2.7 mJ/cm^3 excitation pulses.

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A-35

OPTIMIZATION OF A CuBr LASER PUMPING PARAMETERS

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The operation of a CuBr laser with large volume (more than 2000 cm^3) with alternate pumping by three power supplies to increase the excitation power is considered. Each source provided pulse charging of the working capacity and, thus, ensured stable operating mode with power switching up to 1.5 kW [1]. For the full charge of the working capacitors, their step charging was carried out [2]. Under such conditions, the pumping parameters of the CuBr laser were optimized by using an incremental autotransformer (transformation ratio 1 : 2), a peaking and throughput capacitance in order to increase the average output power and laser efficiency.

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A-36

A COPPER VAPOR LASER WITH INDUCTIVE HEATING OF THE ACTIVE MEDIUM

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The conventional mode of gas discharge metal vapor lasers (MVL's) operation is self heating. That is, the energy deposited into discharge is directed to obtain the working substance vapors and to excite the metal atoms. In order to reduce the costs of heating up the active volume, different methods for obtaining vapors of working substances were proposed earlier. For example, by explosion of conductors or disruption of metal atoms from the walls of gas-discharge tube (GDT).

We have realized a simple method for obtaining lasing in MVL's using induction heating of the working zone. The design of GDT is a BeO_2 ceramic channel, over the working volume of which is an induction heater. Thus, there is no need to use quartz vacuum shirt and heat insulation materials. Using the example of a copper vapor laser, the characteristics of several GDTs with a diameter of 4–8 mm and length of 10–15 cm were studied. The lasing was obtained in the frequency range from some tens of Hz to tens of kHz. The focus was directed on the low-current mode of lasers operation. This is due to the fact that the maximum efficiency and pulse repetition rate in such lasers are realized in a low-current mode in GDT with a small active volume. In addition, using a buffer gas flow, we obtained generation in an open GDT at atmospheric pressure.

The paper was supported by Russian Science Foundtion, Project No. 14-19-00175.

A-37

THE RELAXATION PROCESS OF METASTABLE STATES IN THE ACTIVE MEDIUM OF A COPPER VAPOR LASER

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The influence of the electrode arrangement in the gas discharge tube (GDT) on the electrophysical processes in the discharge circuit is considered. The equivalent GDT circuit and the mechanism of its transformation depending on the electrode arrangement in the cold buffer or hot

discharge channel zones are designed. The breakdown mechanism at the GDT channel ends is considered. It is demonstrated that the breakdown can be considered as the time moment since which the voltage is redistributed between the GDT ends and the active medium in favor of the last. A high relaxation rate of metastable copper atom states in the near afterglow is caused by ionization electron cooling in the active medium. In this case, the energy stored in the reactive components of the discharge circuit impedance during this time period is dissipated in the cold buffer zones. The energy is dissipated in the cold buffer zones until the time when the plasma resistance at the discharge channel ends reaches the value starting from which the duct capacitive components of the GDT shunt the cold buffer zones. As a result, a high frequency circuit is formed, and the energy is further dissipated in the active medium. This reduces the relaxation rate of the metastable states during the time period between pulses and determines the characteristic bend in the time dependence of the metastable state population density determining the time moment of forming the high frequency circuit.

A-38

FORMATION OF A HIGH-FREQUENCY DISCHARGE IN THE ACTIVE METAL VAPOR LASER MEDIUM

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The evolution of an electric discharge in the active self terminating metal atom laser medium is examined. Electrodes in the gas discharge tube are placed in cold buffer zones at a distance of several centimeters from the thermally insulated gas discharge channel. It is shown that an abnormal glow discharge is initiated in the cold buffer zones, as capacitive components of the discharge circuit charge from a storage capacitor. In this case, the current voltage characteristic of the abnormal glow discharge in the cold buffer zones exhibiting a steep current growth and sharp voltage drop is illustrated in the right hand branch of the Pashcen curve. These processes cause the discharge to pinch. As the capacitive components charge from the storage capacitor for the electrodes in the gas discharge tube placed in the cold buffer zones at a distance of ≤ 1–3 mm from the thermally insulated gas discharge channel, an obstructed discharge is formed in the cold zones. On ignition of the discharge shown in the right-hand branch of the Pashcen curve the current accompanied by gas heating eliminates the contraction of the discharge in the cold buffer zones and initiates a high frequency discharge in the active medium since the instant the breakdown (pinch) occurs. In this case, the current voltage characteristic is demonstrated in the left hand branch of the Pashcen curve.

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STRONTIUM VAPOUR LASER WITH IONISATION AND RECOMBINATION MECHANISMS OF INVERSION FORMATION

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We have experimentally and numerically investigated a multiwavelength strontium vapour laser which simultaneously emits both in the IR spectrum range on the self terminating transitions in strontium atoms and ions ($\lambda = 6.456$ and ~ 3 μm for Sr I, and $\lambda \approx 1$ μm λ for Sr II) and in the visible range on the recombination transition in strontium ions ($\lambda = 0.4305$ μm for Sr II). A number of regularities in the behaviour of the output characteristics of lasing, which allow for a targeted search for optimal excitation conditions of the multiwavelength strontium vapour lasers, are established.

A-40

EUROPIUM VAPOR LASER

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The results of experimental study of a gas-discharge Ne–Eu laser are presented. In this work, lasing lines, pulse shapes in europium atom and ion in the conditions of this experiment are identified. Influence of the buffer gas pressure and pulse repetition rate on the energy characteristics of the laser is ascertained; their optimal values are determined. It is shown that under optimum operating conditions for the corresponding transitions the output power is 1 W at 1759 nm line and 70 mW at 664.5 nm line.

A-41

ENERGY LIMITING MECHANISMS OF THE LASING AT THE THALLIUM ION TRANSITIONS, PUMPED IN THE CHARGE EXCHANGE PROCESSES IN A MIXTURE OF Ne–Tl

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Lasing on transitions of thallium ion in a mixture of Ne–Tl which excited by electron beam formed in the "open" discharge was received and investigated at the thallium ion wavelength: 1922, 1385.2, 595.1, 695.3 and 707.4 nm. Modeling of the populations of laser and all lower levels of the thallium ion was made, which made it possible to formulate energy limiting mechanisms for the lasing at the thallium ion transitions associated with: – a high relaxation rate of the upper $7p^1P_1^0$ working level to the ground state of the thallium ion $6s^2{}^1S_0$, which leads to a lasing energy limitation at the singlet term transitions with $\lambda = 695.3$ and 1385.2 nm; – the presence of $6d^3D_j$ levels close to the upper working levels $7p^3P_j^0$, between which there is population mixing due to collisions of excited thallium ions with plasma electrons, which leads to a lasing energy limitation at the triplet term transitions with $\lambda = 1922$, 595.1, and 707.4 nm; – reabsorption of radiation, which prevents the lasing appearance in cascade transitions of the singlet term $7s^1S_0 \rightarrow 6p^1P_1^0$ with $\lambda = 309.2$ nm and $6d^1D_2 \rightarrow 6p^1P_1^0$ with $\lambda = 253.2$ nm. Numerical simulation predicts that with the power enclosed in the discharge increasing, the lasing on the lines of the triplet term (595.1, 1922 nm) becomes saturated, and on the lines of the singlet term (695.3 and 1385.2 nm) grows practically linearly.

A-42

FULLY SOLID STATE EXCITATION GENERATOR FOR COPPER BROMIDE VAPOR LASER

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The possibility of replacement tube (vacuum and gas filled) high voltage (HV) switches in the excitation circuits of pulsed gas discharge lasers by the fully solid state generator with a low voltage power supply (up to 1000) is investigated using the example the copper bromide vapor laser excitation generator. Feature of this generator is using the linear transformer driver topology in the forward quasi resonant converter mode, it allows to automatically eliminate the need for dynamic balancing of the voltage on each element of the HV switch, and removes from the circuit the high voltage DC unit. The development of semiconductor, especially silicon carbide, devices makes the

replacement of the tube not only relevant and promising, but also executable and economically justified.

In this paper the layout of such a generator, designed for voltages up to 12 kV, a current of 300 A with a pulse repetition frequency of up to 20 kHz and average power of 1.5 kW is investigated. The investigations were carried out with an copper bromide vapor active element with an interelectrode distance of 40 cm and inner diameter of 2.7 cm. Special attention was paid to the efficiency of energy conversion by this device (90% efficiency was obtained in a number of regimes) and the temporal stability of the excitation pulses edge, especially when using magnetic correction circuits. It is shown that this device is promising for use in powerful multi channel laser systems, for example, in the master oscillator power amplifier systems.

This work was supported by Russian Science Foundation, Research Project No. 14-19-00339.

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A FACTOR LIMITING SPECIFIC CONTRIBUTIONS OF POWER TO THE DISCHARGE

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In the 1970–1980s, simultaneously with the development of various types of lasers with gas discharge pumping, studies of the reasons of limiting specific contributions to the discharge were performed. The homogeneous form of the glow discharge that is necessary for the pumping was turned into an inhomogeneous one ending with an arc discharge with thermal plasma. Therefore, on the basis of the concept of local balance of particles it is quite natural to assume that the initial cause is the ionization overheating mechanism of development of inhomogeneities, which, according to the researchers, has been widely used up to now. However, observations show that the glow discharge can contract without turning into an arc, at the same time returning to the homogeneous phase with the recovery of laser generation. What are the reasons of this glow discharge contraction at the initial stage of transition to the inhomogeneous phase?

Recent investigations show [1] that the space charge of the near electrode areas, first of all of the cathode layer, determines the action of compression forces in the cross current direction of the entire quasi homogeneous discharge column. The action of these forces increases as the squared pressure of the plasma forming gas. This situation would seem hopeless for increasing specific contributions! Nevertheless, there are well known technical solutions for increasing specific contributions of power and the gas pressure. Thus, experimentally determined discharge schemes show a solution to the problem: the plasma generation zone of the cathode layer should be electrically separated from the pumping zone or the drift space. Although this solution has been technically implemented for pulsed discharges, it can also be used for atmospheric pressure stationary discharges. Another method of eliminating the effect of the cathode layer charge can be implementing gas discharge kinds with relatively low cathode drop or its absence, as in corona or induction discharges.

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A-44

MULTIMEDIA LASER EMITTER GOLD VAPOR AND BARIUM

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The results of experimental studies of a gold and barium vapor laser at pulse repetition rates (7–10 kHz) are presented. Generation of barium atoms λ = 1.13, 1.5, 2.32, 2.55 μm, single barium ions (614.2 and 649.7 nm) and gold atoms (627.8 nm) was obtained. The total average generation power over all wavelengths was more than 1 W.

This research carried out in 2017 was supported by "The Tomsk State University Academic D.I. Mendeleev Fund Program" Grant (No. 8.2.04.2017).

A-45

EXPERIMENTAL STUDY OF EMISSION SPECTRA OF ACTIVE MEDIA OF LASERS ON TRANSITIONS OF COPPER AND GOLD ATOMS AND IONS, AND ALKALINE EARTH METALS IN A NANOSECOND DISCHARGE IN METAL VAPOR

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Experimental measurements of the emission spectra of working media in lasers on transitions of atoms and ions in a nanosecond discharge in metal vapors are carried out. In the recombination laser at the transitions of the strontium ion, the emission spectra were measured in the current stage and in the afterglow of the pulsed discharge. It is shown that the water vapor molecules are the main substance, as a rule, present in the working environment of all the above lasers and influencing the service life and the output energy parameters.

This research carried out in 2017 was supported by "The Tomsk State University Academic D.I. Mendeleev Fund Program" Grant (No. 8.2.04.2017).

A-46

INVESTIGATION OF THE EFFICIENT COPPER VAPOR LASER WITH HIGH PULSE REPETITION FREQUENCY IN A BURST MODE OPERATION

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Investigation of the copper vapor laser with a heated gas discharge tube (GDT) and active volume length of 50 cm and diameter of 2 cm was carried out. Electrodes made from silicon carbide were located outside of the GDT and could be heated independently from GDT. Study was performed with the optimal for this GTD storage (C = 1.1 nF) and peaking (C_0 = 1.1 nF) capacitors. Various electrical circuits were studied with using as a main switch: thyratron with following magnetic pulse compression; kivotron which was able to operate in a burst-mode with a pulse repetition frequency of up to 30 kHz; eptron, subnanosecond switch based on combination of open and capillary discharges, functioned with a pulse repetition frequency in a burst mode of up to 45 kHz.

The main conclusions are as follows.

Laser pulse repetition frequency properties doesn't depend in which hot or cold area of GDT electrodes are located.

Under the optimal pumping conditions laser efficiency achieves 2.5%.

Application of kivotron improves frequency-energy characteristics in comparison with applying excitation circuit with thyratron and magnetic pulse compression.

Application of eptron increases working pulse repetition frequency in comparison with kivotron.

This work was supported by Russian Science Foundation, Research Project No. 14-19-00339.

A-47

HIGH FREQUENCY BRIGHTNESS AMPLIFIERS

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The problem of high frequency radiation (amplification) pulses obtaining in brightness amplifiers on metal vapors is sufficientlyimportant. This is due to two aspects. At first, there is an interest at physical research of brightness amplifiers characteristics at high pumping pulses frequency. Secondly, it relates with use of this type of active amplifiers in fast processes optical imaging systems [1]. Theoretical and experimental studies of a CuBr laser at high frequency pumping pulses (up to 700 kHz) were carried out in [2, 3]. It was shown that a decrease of the discharge input energy should lead to a decrease of concentrations of electrons and copper atoms in the metastable state in the interimpulse period. However, in these studies the active medium was functioned as a generator.

In this paper, we present the results of experimental studies of the active medium on copper bromide vapor with pumping pulse repetition frequency above 100 kHz. Low discharge input energy mode is achieved by using the pumping source, which allows to form on the gas discharge tube (GDT), voltage pulses with a duration of less than 60 ns (at half height). In this experiment, for metal vapor active media along with the generation mode, on frequencies above 100 kHz was at first time implemented superradiance mode. The obtained results will serve as a basis for the construction of the new generation high speed amplifiers.

The work was supported by Russian Science Foundation, Project No. 14-19-00175

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A-48

FEATURES OF INDUCTIVE COAXIAL COPPER VAPOR LASERS

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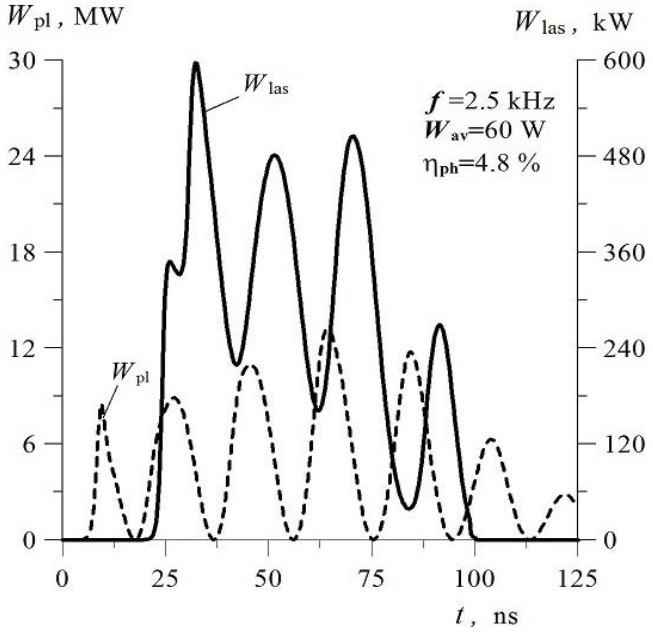
We present the results of numerical experiments considering characteristics of pulse-periodic inductive copper vapor lasers (ICVLs) pumped by trains of high frequency current oscillations. The physical model of the ICVL was described in [1–3] alongside with the first results. In these works we have demonstrated that highoutput characteristics of the ICVLs comparable to those specific to conventional CVLs pumped by longitudinal electric discharge can be achieved. The influence of the frequency of HF oscillations in the pump train on the dynamics of the plasma parameters and the shape of the radiation pulses was investigated in [4]. In this work physical features of an ICVLs with an annular working volume of 1.7 l were discussed alongside with their characteristics. New results were obtained. For example, possible generation of laser radiation W_{las} oscillating at the frequency of

HF oscillations of the Joule heat power release W_{pl} (~ 60 MHz) in the pump train was discovered (see the figure). These radiation pulses ("trains") were observed for low repetition rate f ~ 2.5 kHz of the pump pulses. The average laser power W_{av} was ~ 60 W, physical efficiency was ~ 4.8% and the duration of the radiation pulse was increased to 80 ns.



The reported study was funded by RFBR according to the research Project No. 17-08-00410 a.

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A-49

INDUSTRIAL SEALED COPPER VAPOR LASERS, HIGHLY SELECTIVE OPTICAL RESONATORS, PARAMETERS AND PROPERTIES, MICROPROCESSING CAPABILITIES

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The results of development of industrial pulsed copper vapor lasers with diffractive beam quality and radiation power up to 100 W are presented. They are designed to assemble process equipment for precise microprocessing of materialsfor applications in various fields of science and technology, as well as in medicine and biology.

A-50

COMPARATIVE ANALYSIS OF PARAMETERS OF A PULSED COPPER VAPOR LASER WITH KNOWN TYPES OF TECHNOLOGICAL LASERS

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The results of a comparative analysis of pulsed copper vapor lasers with visible emission wavelengths of 510.6 and 578.2 nm and duration of 10–30 ns with known types of technological lasers and prospects for using a copper vapor laser for microprocessing materials are presented.

Session B
PHOTONICS OF OPTICAL MATERIALS, OPTOELECTRONICS

B-1

CATHODOLUMINESCENCE AND PHOTOLUMINESCENCE CONTRIBUTION TO SIGNALS FROM CHERENKOV DETECTORS OF RUNAWAY ELECTRON BEAMS

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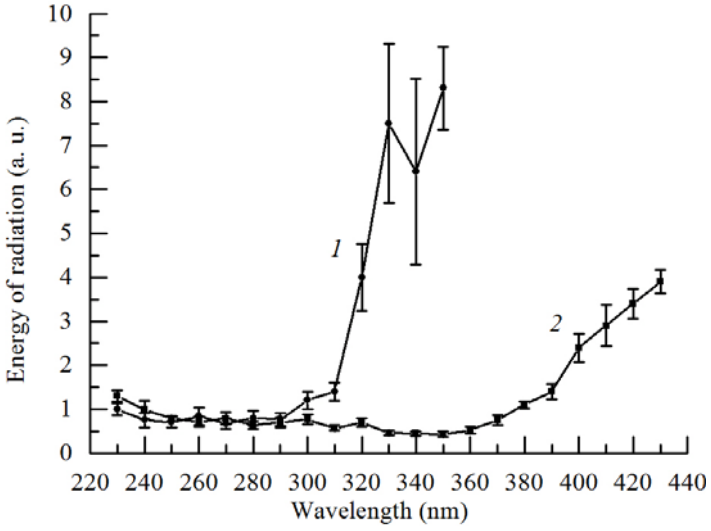
In recent years, there has been raising a significant interest in studying the generation of runaway electrons in facilities for plasma studies such as Tokamak. Cherenkov detectors are often used to determine the parameters of runaway electron streams in which radiators are usually made of diamond.

The aim of this work is to investigate the emission of natural and synthetic diamonds excited by a subnanosecond runaway electron beam with the energy of tens to hundreds keV, and to determine the contribution of Cerenkov radiation and cathodoluminescence in different spectral ranges.

It is shown that cathodoluminescence gives the greatest contribution to radiation in the region of 200–800 nm in the emission spectrum of natural and synthetic diamonds of IIa-type excited by a runaway electron beam. Cherenkov radiation is recorded only in the 225–310 (350) nm range (for natural and synthetic diamonds, respectively) and only with the help of a monochromator and photoelectronic multiplier. It is assumed that the Cherenkov radiation with a wavelength shorter than 225 nm (the edge of fundamental absorption of diamond) should contribute to the photoluminescence of diamond in the region of 350–650 nm. The delays between the pulses of Cerenkov radiation and cathodoluminescence are measured. It is proposed to use the data obtained in the creation and calibration of runaway electron detectors for facilities to study the thermonuclear fusion.



Dependence of the radiation energy of natural (*1*) and synthetic (*2*) diamonds upon excitation by a subnanosecond runaway electron beam versus the wavelength, obtained with photoelectronic multiplier and MDR-23 monochromator

B-2

REFLECTION OF LIGHT ON THE BOUNDARY PLANE NONUNIFORM LAYER GYROTROPIC

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When light is reflected by anisotropic media, the energy and ellipsometric parameters of the reflected wave are determined by optical properties of the material and also by the direction of the optical axis. The components of tensor $\varepsilon_{ij}(z)$ depend on the profiles of free charge concentrations of $N(z) = N_0 \cdot f(z)$. They affect the parameters of the reflected light. To calculate the projections of electromagnetic wave fields (EMW) in a medium, amplitude and energy reflection and transmission coefficients, and ellipsometric parameters, matrix methods are convenient [1, p. 71]. Matrix apparatus for anisotropic medium is obtained. The methods of classical electrodynamics consider the case of an oblique incidence of a plane electromagnetic wave on an inhomogeneous gyrotropic layer [2, p. 119] in an external magnetic field whose intensity vector is arbitrarily obliquely directed relative to the plane of incidence of the electromagnetic wave. A Cauchy matrix 4×4 for WKB solution describing the change in the projections of the EMW fields propagating in the planar inhomogeneous anisotropic medium is obtained. The matrix of the amplitude reflectance coefficients 2×2 and the ellipsometric parameters of the reflected light are calculated with a change in the incidence angle for media with profiles in the form of transition layers: $f(z) = 1 - e^{-az}$, $f(z) = a \cdot z$, $f(z) = \text{arctg}(a \cdot z)$.

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B-3

INHERITANCE OF PHOTOCHROMIC PROPERTIES OF NITRO SUBSTITUTED AND HALOGENATED SPIROPYRANS IN COMPOUNDS WITH THE PYRROLIDINOFULLERENE

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The nanophotochromism is associated with the synthesis and investigation of photocontrolled hybrid compounds that are composited from photochromic organic fragments and nanoparticles of different morphologies and sizes in accordance with growing technological requirements of modern molecular electronics and photonics devices.

This research has dealt with photophysical and isomerization properties of hybrid molecular systems which consist of photochromic nitro substituted or halogenated spiropyran derivatives bonded to the surface of the fullerene C60 through the pyrrolidine bridge.

Computational molecular modeling of the photoswitching processes in these systems was applied to analyze the channels and mechanisms for energy dissipation and photochromic conversions from the spiropyran forms to merocyanine phases of these individual photochromic moieties in comparison with the corresponding hybrid compounds.

The role of $n\pi$ states provided by lone pairs of substituents for changing of the electronic structure and photochromic properties of spiropyran derivatives was evaluated. The $S_{\pi\pi}$(spiro) $\rightarrow$ transition $n\pi^*$ states $\rightarrow$ $S_{\pi\pi}$(mero) channel for photo-transformation of the complex with nitro substituted spiropyran moiety is established and compared with the similar hybrid compounds combined with halogenated spiropyran where photoisomerisation doesn't process due to high probability of internal conversion from the absorption state formed on the spiropyran fragment to the singlet system of the pyrrolidinofullerene.

B-4

FÖRSTER RESONANCE ENERGY TRANSFER (FRET) BETWEEN QUANTUM DOTS AND DYE IMMOBILIZED IN BIOPOLYMER PARTICLES

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The efficiency of Fцrster Resonance Energy Transfer (FRET) is determined by spectral characteristics of donor-acceptor pair, relative orientation of dipoles and distance between fluorophores. The dependence of FRET efficiency on the distance between donor and acceptor ($\sim 1/R^6$) allows evaluating a nanostructures size in two orders of magnitude less than fluorescence wavelength. The colloidal semiconductor quantum dots (QDs) CdTe with size of about 2.7 nm and dye (Rose Bengal) were used as a donor-acceptor pair that provides the Fцrster radius of up to 5 nm (distance of 50% probability of energy transfer).

The QDs and dye were incorporated into the polymer polyelectrolyte complexes (PEC), based on chitosan and chondroitin sulfate with sizes of about 300 nm in order to realize FRET. The electron microscopy showed more than one hundred QDs per one PEC content. A high local concentration of fluorophores provides distances comparable with the value of Fцrster radius. The FRET was registered by donor (QDs) static fluorescence quenching, by enhancement of acceptor (dye) fluorescence and donor lifetime variation The Fцrster model was used to determine the efficiency of energy transfer (50–60%) and the distance between fluorophores (about 4 nm). It was shown that the efficiency of energy transfer in case of incorporation of both fluorophores in the depth of particles was 30% higher than in case of external doping by dye. The results can be used for creation of sensitive optical biosensors for detection of organic analytes and minimal changes in the size of particles following the ambient medium change.

B-5

PHOTO- AND ELECTROLUMINESCENCE OF NEW ORGANIC SEMICONDUCTORS

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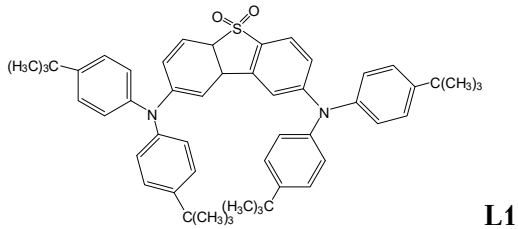
The results of investigation of the luminescence under photo- and electroexcitation for four new compounds are presented. The structure of the molecules is given below.



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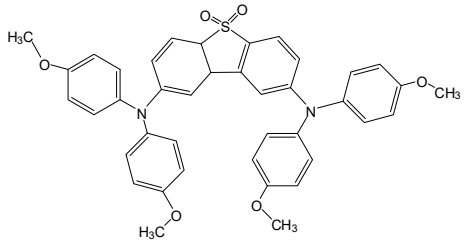

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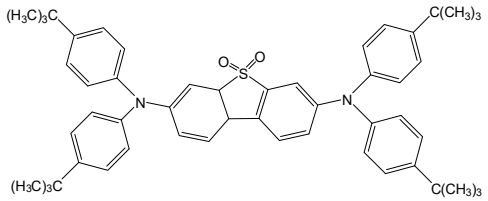

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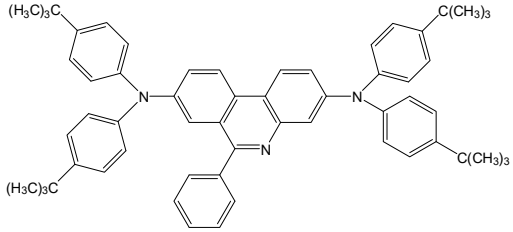

L4

The spectral properties and photoluminescence are studied in ethanol, chloroform solutions and in films formed by thermovacuum deposition (TVD). The phosphorescence of compounds is investigated in ethanol at 77 K temperature. The phosphorescence times of molecules are given.

The electroluminescence is obtained in multilayered structure ITO/PEDOT/NPD/L /Ca/Al. It is shown, that spectral region of the photoluminescence of TVD films and electroluminescence coincide. Relations of electroluminescence efficiency with molecule structure, photoluminescence quantum yield and possibility of thermally activated delayed fluorescence are discussed.

B-6

PECULIAR WAVES IN PLANAR CONTINUOUSLY HETEROGENEOUS STRUCTURES WITH OPTICAL BIANISOTROPY

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The peculiar waves of the mixed spectrum of an inhomogeneous bianisotropic structure can be found in the form of an expansion over the complete set of waves of a discrete and continuous spectrum of a regular reference structure with the corresponding boundary conditions. It is an asymmetric planar waveguide, in which the coating and the substrate are homogeneous. The waveguide layer has tensors of dielectric and magnetic permeabilities with non-zero diagonal elements, and they depend on the transverse coordinates. Maxwell's equations were decomposed into two independent systems of quasi-differential equations for determining the transverse components of the eigenvectors of the discrete and continuous spectra.

Then we obtained equations with polynomial coefficients and they were not Fuchsian. Nevertheless, for their analytical solution we used the Frobenius' method. Thus, we found the transverse and longitudinal components of the electric and magnetic fields for the waveguide characteristics of the compositional structure. As a result, we obtained the eigenwaves corresponding to the discrete part of the spectrum whose wave numbers satisfy the dispersion equation. Their longitudinal wave number is complex (complex waves), and when the transverse wave number is imaginary, then the waves become surface waves. We found the natural waves of the continuous part of the spectrum. The wave numbers of these waves are real or imaginary and allow us to describe pseudosurface waves. Our research provides an opportunity to analyze the entire variety of waves existing in planar continuously heterogeneous structures with optical bianisotropy.

B-7

INVESTIGATION OF CHANGES IN THE OPTICAL PROPERTIES OF A COLLOIDAL SOLUTION OF SILVER NANOPARTICLES WITH THE ADDITION OF EUROPIUM IONS

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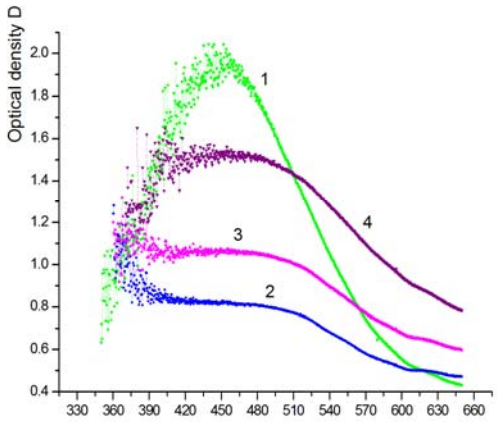
Mixed solutions containing metallic nanoparticles and ions of rare earths are used in the preparation of nanoparticles doped with rare earths, which in the near future can prove to be promising materials for photonics and nanoplasmonics. It is known that plasmon resonance is observed in silver nanoparticles, which leads to a significant increase in the local field strength and is accompanied by optical effects (amplification of luminescence, light absorption, Raman scattering, up conversion, etc.) related to "plasmonics" [1].

At present, the interaction of plasmonic effects of metallic nanoparticles and the optical properties of rare-earth metals begins [2]. In this paper we investigated the effect of the europium ions Eu^{3+} (specifically the concentration of the aqueous solution of $Eu^{3+}NO_3$) on the optical spectra of silver nanoparticles obtained by the "green" synthesis method.

Four mixed aqueous solutions were prepared:
1) $AgNO_3$ + peppermint extract + $Eu^{3+}NO_3$ (concentration 4 mg/ml);
2) $AgNO_3$ + peppermint extract + $Eu^{3+}NO_3$ (concentration 8 mg/ml);
3) $AgNO_3$ + mint extract + $Eu^{3+}NO_3$ (concentrated 16 Mg/ml);
4) $AgNO_3$ + mint extract.

Spectra of optical absorption of silver nanoparticles were obtained (Figure) and analyzed using known techniques [3].

The absorption spectrum of mixed solution 4 has a peak of 460 nm, which is characteristic for silver nanoparticles. The absorption spectra of solutions 1, 2, and 3, in comparison with the absorption spectrum of 4, are more broadened, do not have a pronounced peak, and the magnitude of the maximum of the spectrum is below the solution.



As a result of the studies, the following results were obtained: the height of the absorption spectra of mixed aqueous solutions increases nonlinearly with increasing concentration of the solution $Eu^{3+}NO_3$, the absorption spectra are more broad, indicating an increase in the size of silver nanoparticles.

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B-8

PROTON PHOTOTRANSFER IN CARBOSTYRILS

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The increased interest in the creation of various optical devices based on organic molecules is due to their wide use as active media for tunable lasers, laser limiters, and optical sensors in various fields of science and technology. Considerable attention is also paid to the possibility of creating new, more efficient photosensitizers of singlet oxygen, which are necessary for successful use in photodynamic therapy (PDT) in the fight against infectious and oncological diseases, as well as photocatalysis of oxidative reactions.

In this paper, the dependence of the fluorescence efficiency of carbostyril and fluorocarbostyril on the pH of the medium is obtained and explained, due to a change in the efficiency of nonradiative processes in directed specific intermolecular interactions in the solvated shell of the excited complex. It was found that along with the charged forms of carbostyril in the excited state, there exists a tautomeric form with a strong charge separation (zwitterionic form), which has the longest

wavelength fluorescence. The introduction of the CF_3 group leads to an increase in the probability of detachment of the hydrogen proton from the OH group in the excited state and, as a result, the absence of neutral form fluorescence in aqueous solutions of fluorocarbostyril.

The work is supported by the scientific foundation of TSU (No. 8.1.10.2017).

B-9

ORGANIC DYES AND QUANTUM DOTS AS MODERN FLUORESCENT MARKERS

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Active over many decades of research in the field of synthesis, spectral properties and quantum chemical calculations of fluorescent organic dyes are associated with such applications as biomarking, photosensitization, the creation of active laser media. The study of semiconductor water-soluble quantum dots (QD) began about 15 years ago, but over time, they became no less popular fluorophores. The high extinction coefficient and the quantum yield of photoluminescence, photochemical stability, the variability of the stabilizing functional groups, and the possibility of adjusting the position of the emission spectra by changing the particle sizes also contribute to their successful use in telecommunications, biosensorics, biomarking. At the same time, the different nature of the fluorescent states of the considered organic and semiconductor fluorophores causes a fundamental difference in the approaches to the interpretation of the experimental results with their participation.

In this paper, we compare the absorption, photoluminescence (spectral, time-resolved, polarization) properties of organic dyes and QD solutions. As examples, the spectral properties of a number of fluoron dyes (fluorescein, eosin Y, erythrosine B) and water-soluble QDs CdTe are considered. Examples of the study of the mechanisms and spectral manifestations of the binding of both types of fluorophores to biological molecules (proteins, polysaccharides) are given, and the possibility of their joint use as an effective donor-acceptor pair in the problems of biosensorics is considered.

B-10

ON THE BASIC MODELS FOR EFFECTIVE PARAMETERS OF MEDIA WITH PARTICLES OF COMPLEX STRUCTURE

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The main approximations used in calculating the effective parameters of inhomogeneous media are Bruggemann effective medium approximation and Maxwell-Garnett model [1–4], which are now widely used in describing composites containing various nanostructured objects such as graphenes and carbon nanotubes [5]. In this paper we consider a simple method for obtaining these approximations, which makes it possible to extend them to the most general case of media with particles with an arbitrary internal structure, and also to clarify the physical meaning of the approximations adopted. The results essentially depend on the choice of "effective cells" used in estimating the field and induction values averaged over the volume.

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B-11

LASER Fe^{2+} : $MgAl_2O_4$ CERAMIC

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In this work the creation technology of Fe^{2+} : $MgAl_2O_4$ ceramic is reported. The nanopowder for this ceramic was prepared by the laser ablation method. In this case the laser target was synthesized from coarse powders of Fe_2O_3, MgO and Al_2O_3 in spinel stoichiometry. X-ray diffraction analysis of the obtained nanopowder has shown that the particles contain 3 different phases: corundum, spinel and iron-doped spinel. Further the nanopowder was compacted at the pressure of 10 MPa. These compacts were hot pressed at 100–200 MPa and a temperature of 1400–1600 °C. Ceramics samples with a thickness of ~ 3 mm had a diameter 11 or 20 mm. The results of investigations of sample's characteristics are presented. In particular, it is demonstrated that the composition of ceramic is uniform and have a cubic structure specific to magnesium aluminate spinel. It is shown that contrary to well-known matrices such as ZnSe and ZnS the use of this technology allows to increase the content of iron ions in spinel and to homogeneously distribute them in the samples.

The work was funded by RFBR according to the research Project No. 17-08-00064 A.

B-12

MAGNETO-OPTICAL PROPERTIES OF OXIDE CERAMICS

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As is known, optical ceramics can have a number of characteristics that are not available for single-crystal samples. Large values of the effects of magnetic gyrotropy, including the Faraday effect (Verdet constant), typical for magnetoactive ceramics, make them laser technology materials.

In this paper we present the results of investigations of the magneto-optical properties of optical ceramics made of nanopowders. Sintering of optical ceramics with different chemical composition is made from nanopowders obtained by laser ablation [1]. The nanoparticles obtained in this way were calcined in air at 900—1100 °C for 3 hours, which transferred them from the metastable monoclinic phase to the cubic phase. These calcined nanopowders are pressed in a steel mold at 200 MPa pressure into 15 mm diameter pellets. The removal of organic components is carried out by annealing at a temperature of 800 °C for 3 hours. The samples are then sintered in a vacuum at 1780 °C for 20 hours. Then ceramic samples are annealed at 1400 °C for 3 hours, which removes oxygen vacancies.

From the ceramic blanks are made samples with plane-parallel polished surfaces and a thickness of about 2 mm. Determination of Verdet constant of ceramics samples is carried out on a zero-type installation. The sample is placed in a magneto-optical armor electromagnet, on both sides of which the Glan-Taylor polarization prisms are mounted. When the magnetic field is off, the intensity of the light passing through the sample is zero. As a radiation source, the semiconductor laser at 650 nm is used. The laser radiation is modulated by an obturator at frequency of 1515 Hz. When the magnetic field is on, the Faraday rotation of the sample is compensated by an inverse rotation of the Glan-Taylor output analyzer until the light intensity comes to zero. The rotation angle measurement of the plane of light polarization is done by dial of the analyzer. The error in measuring of rotation angle is approximately 2—3 angular minutes.

The electric signals of the photodetector are registered with a selective voltmeter Unipan-232B. Stabilized current supply of the electromagnet comes from a DC source B5-76 / 1.

The transmission spectra of the samples were measured. Various samples of optical ceramics were investigated, including Y_2O_3, $94Y_2O_3 + 6ZrO_2$, $1Ho : Y_2O_3$, $1Nd : Y_2O_3$, Yb_2O_3. For example, the measured Verdet coefficient for Yb2O3 was 52.2 mrad/mm × T. The ytterbium oxide sample of

1.94 mm thickness, for magnetic field of 0.86 T and for 650 nm light rotates polarization plane by an angle equal to 5°13'.

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B-13

INVESTIGATION OF PHOTO- AND ELECTROLUMINESCENCE OF ZINC AND BERYLLIUM METAL ORGANIC COMPLEXES

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Three decades have passed since the publication of the first light emitting diodes based organic compound 8-hydroxyquinoline aluminum (Alq3) [1] and devices based on OLED are producing in the industrial scale, but the synthesis of new compounds and their investigation is continuing. A number of goals are pursued: a high efficiency of the device, the radiation in the required spectral range, stable performance.

In this paper we investigated metal-organic complexes with zinc and beryllium ($Zn(AM\text{-}TAZ)_2$, $Be(TB\text{-}TAZ)_2$ and the $Be(AM\text{-}TAZ)_2$ Photoluminescence characteristics were studied in solutions and films. OLED-structures were established on the basis of these compounds. The greatest emission intensity is ~ 1000 cd/m^2 provides $Be(AM\text{-}TAZ)_2$. $Be(AM\text{-}TAZ)_2$ and $Zn(AM\text{-}TAZ)_2$ with different metal, have different intensity of brightness and spectral characteristics. The electronic and photoluminescence of OLED-structures coincide. The greatest emission intensity ~ 1000 cd/m^2 provides $Be(AM\text{-}TAZ)_2$. $Be(AM\text{-}TAZ)_2$ and $Zn(AM\text{-}TAZ)_2$ with different metal, have different intensity of brightness and spectral characteristics. The spectral characteristics of electrical and photoluminescence OLED structures coincide.

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B-14

SPECTRAL-LUMINESCENT AND LASING CHARACTERISTICS OF THIN-FILM STRUCTURES BASED ON SEMICONDUCTOR POLYMERS

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The creation of injection laser based on organic semiconductors is urgent direction of organic electronics [1]. The solution of this problem is impossible without investigating the emission features of thin-film lasers based on organic semiconductors by various types lasers photoexcitation, including laser diodes [2–4].

The report presents the spectral-luminescent and lasing characteristics of copolyfluorenes and polyphenylenevinilene derivatives pumped by the third harmonic of $YAG:Nd^{3+}$ laser. Copolyfluorenes were synthesized at the Institute of Macromolecular Compounds RAS. Also spectral-luminescent characteristics of thin-film structures by pulsed diode pumping were investigated. Thin-films based on selected semiconductor polymers were used as laser active medium.

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B-15

ELECTROLUMINESCENCE OF COPOLYFLUORENES IN THE VISIBLE RANGE OF THE SPECTRUM

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Organic electronics in the world has been actively developing for more than 25 years. Synthesis and research of new semiconductor materials for devices of organic electronics (organic light emitting diode – OLED, organic light-emitting field-effect transistor – OLET, organic semiconductor lasers – OSLs, etc.) is urgent task.

The report presents the spectral-luminescent and electroluminescent characteristics of new copolyfluorenes synthesized at Institute of Macromolecular Compounds RAS.

The electroluminescence of copolyfluorenes in light-emitting diode of the following structure ITO/Pedot:PSS/Copolyfluorene/Ca/Al is recorded in the visible range of the spectrum. Multilayered organic light-emitting diodes based on them were developed and analysis of the current-voltage and current-brightness characteristics was performed depending on the structure of the diode.

B-16

SPECTROSCOPY AND PHOTOCHEMISTRY OF HUMIC ACIDS

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Humic substances representing the main fraction of organic matter receive increased attention because of their reactivity as light absorbers. Depending on their origin and structure, humic substances have a remarkable ability to absorb light and transfer this energy to other substrates and in some cases strongly affect photolysis of xenobiotics. In water and in soils humic substances have been found to act as photosensitisers and they have also been reported to produce oxygen species upon irradiation, and be able to photoinduce the transformation of ecotoxicants. The photoquenching effects of humic substances on some chemicals are also known. Also, the possibility of an UV screening by humic substances on chemicals cannot be excluded since the energy-transfer and charge-transfer between the chemical and humic substances can deactivate the excited molecules. Excited singlet and triplet states of dissolved humic acids (HAs), the major component of humic substances, are important players for the transformation of organic chemical contaminants in natural waters. Our knowledge about these processes is still very limited. Spectroscopy and photochemistry of humic acids are disscused.

The results in a flow reactor for photodegradation of ecotoxicants are presented. A specific feature of the reactor is the use of barrier discharge excilamps (Xe_2, KrCl and XeCl) with different radiation wavelengths (λ = 172, 222, 308 nm). The discussion includes comparative analysis of the direct and indirect photolysis. The samples of HAs fractions were obtained from Aldrich Chemical Co and prepared from peat of Tomsk region.

This work is supported by the Base Part of State Task of Board of Education and Science RF No. 4.6027.2017/BTCH.

B-17

SIMULATION OF FLUORESCENCE OF *N*-ALKYLATED TETRABENZOTETRAAZA[8]CIRCULENES

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The ratio between the rate constants of the radiative and nonradiative electronic transitions for the *n*-alkylated tetrabenzotetraaza[8]circulenes, depending on the substituents, has been studied using the modern *ab initio* methods of quantum chemistry XMC-QDPT2 and MCSCF. It is shown that the rate constant of intersystem crossing (k_{st}) increases with the increasing of number of substituents due to the decrease of the energy gap between the first excited singlet (S1) and the first triplet (T1) excited electronic states. The decrease in the energy gap between S1 and T1 is due to the distortion of the geometry of the circulene macrocycle and, in general, the π-conjugation within it. In this case, the matrix elements of the spin-orbit interaction are completely insensitive to the number of external substituents. In this connection, the rate constant of the radiative electronic transition (kr) between S1 and the ground electronic state (S0) decreases with the increasing substituents. The increase (kst) and the decrease (kr) with the increasing number of substituents lead to a regular decrease of the fluorescence quantum yield.

The results obtained are in useful in the field of optical tuning of organic light-emitting diodes (LED), since they give an idea of how to control the photophysical properties of the *n*-alkylated tetrabenzotetraaza[8]circulenes by the introducing of various substituents into the macrocycle of these molecules.

B-18

FEATURES OF MEASUREMENTS OF PARAMETERS OF WEAKLY SCATTERING NANOOBJECTS ON A FLAT SUBSTRATE

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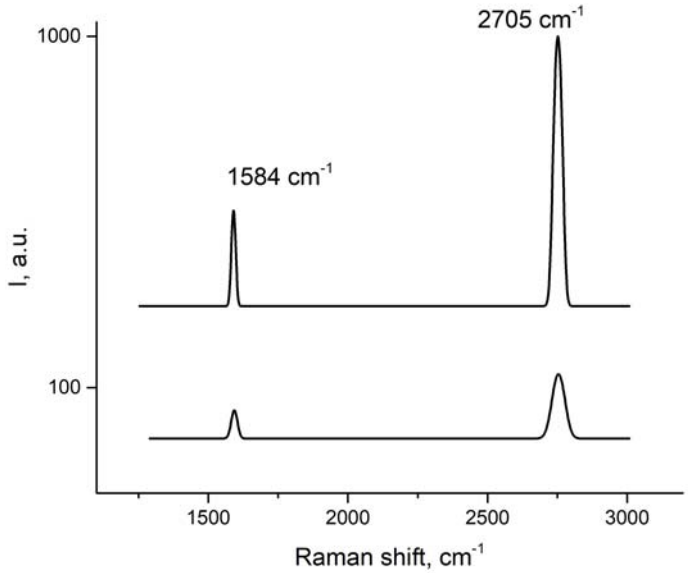
In recent years, research has been developing on nanoscale objects, for which the concept of permittivity has a conventional meaning and requires a separate analysis. The paper analyzes the change in the intensity of Raman scattering of objects on a flat metal substrate and shows the conditions under which scattering increases by more than an order of magnitude. If a nanoscale object (for example, a graphene layer) is placed on a metal substrate, the Raman scattering on the graphene will be strongly suppressed approximately 2–5 times, depending on the metal and the wavelength of the incident light. If, on the surface of a metal substrate, a layer of an insulator of the order of a quarter of the wavelength of the incident radiation is applied, then theoretically it is possible to increase the intensity of the Raman of the visible range by a factor of 6–20, and practically by a factor of 10 (Figure).



B-19

EFFECT OF THE CONCENTRATION OF MINT SOLUTION ON THE ABSORPTION SPECTRA OF SILVER NANOPARTICLES IN THE PRESENCE OF THALLIUM IONS

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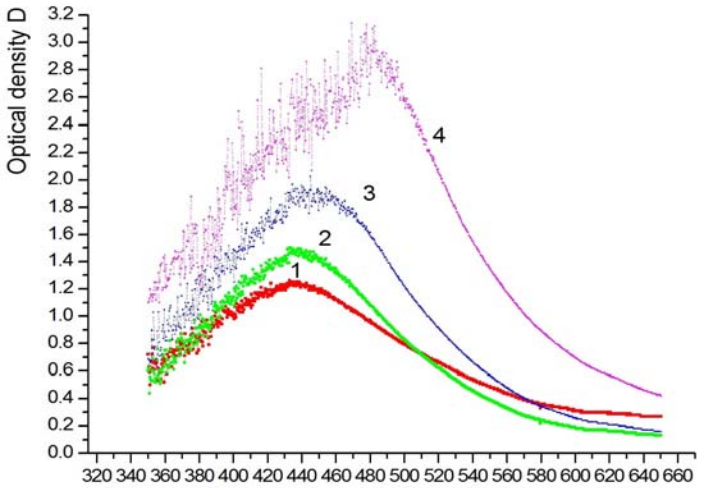
Among the methods of obtaining nanoparticles an important place is occupied by the methods of "green" synthesis, when the products of plant metabolism are used as reducing and stabilizing reagents [1]. In this paper we consider the "green" synthesis of silver nanoparticles in the presence of thallium ions using a plant extract obtained from the leaves of peppermint. Such an approach, depending on the synthesis conditions, is aimed at obtaining both bimetallic particles and core-shell particles. The influence of different concentration of mint solution on the absorption spectra of mixed aqueous colloids of the composite nanoparticles obtained at the same time was studied. Four mixed aqueous solutions were prepared: 1 — 0.04 ml of peppermint extract + 5 ml of $AgNO_3$ solution + 0.5 ml of $TmCl_3$ solution, 2 — 0.08 ml of peppermint extract + 5 ml of solution of $AgNO_3$ + 0.5 ml of $TmCl_3$ solution, 3 — 0.16 ml of peppermint extract + 5 ml solution $AgNO_3$ + 0.5 ml solution $TmCl_3$, 4 — 0.32 ml extract peppermint + 5 ml solution $AgNO_3$ + 0.5 ml solution $TmCl_3$. Absorption spectra were taken, see Figure and their data were analyzed for all the solutions listed above.



Two features were noted:

1. The wavelength corresponding to the maximum of the absorption spectrum of the nanoparticles is shifted to the long-wavelength region with an increase in the concentration of the mint extract.

2. The maximum of the absorption spectrum increases nonlinearly with increasing concentration of mint extract.

In other words, both the dimensions of silver nanoparticles and their volume fraction in solution increase with increasing concentration of mint extract.

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B-20

OPTICAL METHODS FOR CONTROLLING THE DEGREE OF DEHYDROCHLORINATION OF POLYVINYL CHLORIDE

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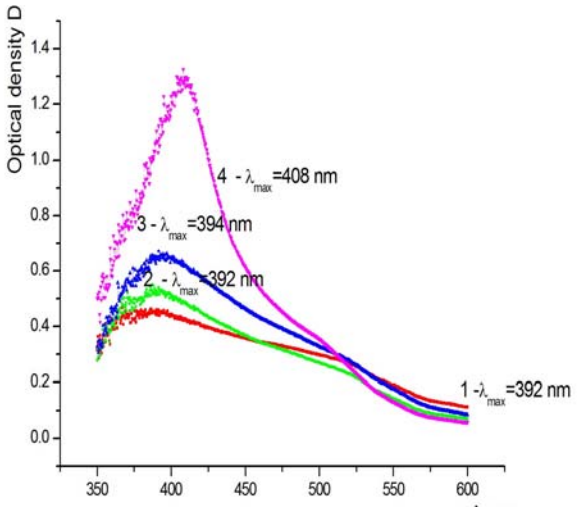
The influence of the degree of dehydrochlorination on the optical properties of polyvinyl chloride samples was studied in [1–3]. In these papers, the influence of the time of thermolysis on optical spectra was studied both in solutions and in polyvinylchloride films. In order to ascertaining the influence of the degree of dehydrochlorination on the optical properties of polyvinyl chloride (PVC), a series of PVC samples was developed in this paper by the method of thermal dehydrochlorination (thermolysis) at various times of thermolysis and process temperature t = 195 °C. The samples of PVC were created in the form of films with a thickness of 10 μm (1 – sample of PVC thermolysis time 240 min, 2 – sample of PVC thermolysis time 320 min, 3 – sample of PVC thermolysis time 480 min) and thickness 200 μm (4 – PVC sample thermolysis time 480 min.). It is known that in the dehydrochlorination of PVC material, it creates long chains of conjugated carbon double bonds that cause polymer color and increase absorption [4]. To study these processes, absorption spectra were obtained for all dehydrochlorinated samples (Figure). Figure shows the following features:

1. The optical density of the absorption spectrum increases nonlinearly with increasing thermolysis time and thickness of PVC samples.

2. The maximum λ_{max} of the absorption spectrum shifts to the long-wavelength region with increasing thermolysis time and thickness (from λ_{max} = 392 nm to λ_{max} = 408 nm).



The following conclusions were made, analyzing the data of the absorption spectra::

1. The number of conjugated double bonds of carbon PVC samples and the length of their chains increases nonlinearly with increasing thermolysis time

2. The length of chains of conjugated carbon double bonds of PVC samples depends on the thickness of the sample at the same time of thermolysis

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B-21

APPLICATION OF TIME-RESOLVED FLUORESCENCE SPECTROSCOPY TO PROTEIN STRUCTURE

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The fluorescence spectroscopy is a very sensitive technique to monitor the changes in protein structure during the different biochemical processes. Typically, tryptophan residues are used as an intrinsic fluorescent probes in proteins due to a high degree of sensitivity to their local environment, including polarity and viscosity. However, the fluorescence spectra and lifetimes for multi-tryptophan proteins are difficult to interpret unambiguously, since the single tryptophan proteins have at least two lifetimes. In this work, we applied the time-resolved spectroscopy to analyze the fluorescence lifetimes and corresponding decay associated spectra for proteins with different number of tryptophan residues upon conformational changes.

The fluorescence decays of four proteins were fitted by three lifetimes both for native folded conformation (τ_1 = 5.4–7.0 ns, τ_2 = 1.3–2.3 ns, $\tau_3 \leq 0.1$ ns) and for unfolded protein (τ_1 = 4.4–5.0 ns, τ_2 = 1.7–2.0 ns, $\tau_3 \leq 0.05$ ns). It was shown that it is not the absolute value of the tryptophan fluorescence lifetime that depends on the specific structure of a protein, but rather the relative contribution of the decay-associated components. For unfolded proteins, irrespective of their initial structure, the time-resolved spectra and relative contributions of lifetime components became similar. The lifetime components were compared with a classification of tryptophan residues in the structure of these proteins within the discrete states model. Based on the data that were obtained by time-resolved fluorescence spectroscopy, we were able to resolve the fluorescence spectrum of the multi-tryptophan protein into components that correspond to different tryptophan groups that are present in its structure. The spectrum of the long lifetime component τ_1 is bathochromically shifted, indicating that the tryptophan residues of this group are accessible to bulk water because of high polarity and mobility in their local environment. The result of this work can be further employed to investigate the stages of protein unfolding/folding and the involvement of different protein domains in its conformational dynamics that are associated with catalysis.

B-22

INTERMOLECULAR PROTON TRANSITION IN THE EXCITED STATES OF ACRIDINE

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In the present report results of theoretical studying of the acid-base properties of acridine in different electronic states are presented. Numerous experimental measurements show, that at transition from the ground state in S_1 a $\pi\pi^*$-state basicity of acridine considerably increases. Estimations were spent by the Ferster techniques. A number of researchers calls these results into question. For example, A. Terenin specified, that at excitation resolvation occurs and, means, entropy can essentially change [1]. It is feature it is not considered at calculations by the Ferster techniques. Experimental basicity T_1 state (the same orbital nature, as S_1, and the same distribution of electronic density) is close to basicity of a S_0 state. It too brings doubts as basicity does not depend from state multiplicity.

Our calculations (estimations using MEP) also testify to close basicity of all three states [2]. At the analysis of results of calculations it has been established, that basicity in S_3 $\pi\pi^*$ – state strongly increases (values MEP). S_1 and S_3 states are also connected by strong internal conversion, i.e. by strong electron-vibrational interaction. It does possible borrowing of basicity of S_1 state from S_3 state.

Features of intermolecular proton transition (basicity) in the electronic excited states of acridine taking into account the borrowing mechanism are discussed.

This work was supported by the Base Part of State Task of the Ministry of Education and Science of the RF (Project No. 4.6027.2017/8.9).

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B-23

SPECTRAL-LUMINESCENT AND PROTON-ACCEPTOR PROPERTIES OF BIOLOGICALLY ACTIVE HYDROXYL-SUBSTITUTED BENZALDEHYDES

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Using methods of electronic spectroscopy and quantum chemistry (INDO method) the electronic structure and spectra of some hydroxyl-substituted benzaldehydes have been investigated. Comparison of accuracy of the description of spectral-luminescent properties and intramolecular photophysical processes in the isolated molecules received in calculations and experiments is spent. Influence of hydroxyl and tret-butyl substitution on distribution of electronic density and proton-acceptor ability of molecules in the basic electronic state is considered.

Possibilities of investigated derivatives to form intra- and intermolecular hydrogen bonds are estimated. The substitutes entered in phenol fragment of investigated molecules, make various impact on proton-acceptor ability of derivatives of benzaldehyde. Thus appreciable influence renders not only a replacement place, but also a spatial structure of substituting fragments. Correlation between value of MEP, connected with hydroxyl substitutes, and antiviral activity of compounds under investigated,, estimated on cell culture of viruses of a herpes of flu [1] is established.

This work was supported by the Base Part of State Task of the Ministry of Education and Science of the RF (Project No. 4.6027.2017/8.9).

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B-17

LUMINESCENCE PROPERTIES OF HEAVILY DOPED *ALGAN* FILMS UNDER OPTICAL AND ELECTRON BEAM EXCITATION

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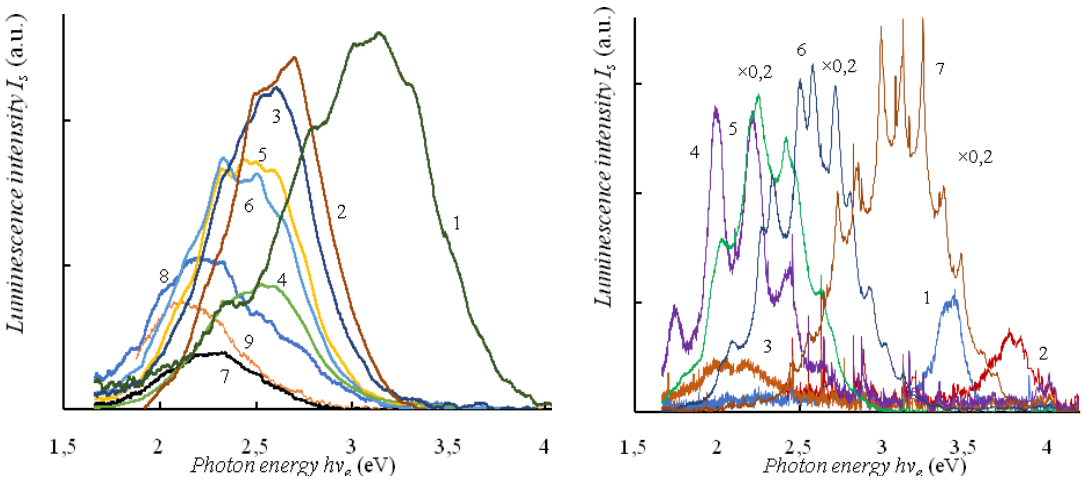
Spectral characteristics of spontaneous and stimulated luminescence were investigated from the $Al_xGa_{1-x}N/AlN$ solid solutions with Si dopant concentration more than 10^{20} cm^{-3} at $x = 0 \ldots 1$, which were grown by molecular beam epitaxy on sapphire substrates. The excitation of $Al_xGa_{1-x}N$ films was carried out by pulsed laser radiation ($\lambda = 266$ nm) from the Nd: YAG laser with a power density of up to 9 MW/cm^2 and an electron beam with an electron energy of up to 20 keV and the current of up to 100 A, formed in an "open" discharge. Figure (*a*, *b*) shows typical spectra of spontaneous photoluminescence – (*a*) obtained at an angle of 45° to the surface and cathodoluminescence spectra from cleaved edges of the structure – (*b*).



Photoluminescence (*a*) (x = 1(1); 0.74(2); 0.68(3); 0.65(4); 0.62(5); 0.6(6); 0.56(7); 0.5(8); 0.47(9)) and cathodoluminescence (*b*) (x = 0(1); 0.29(2); 0.42(3); 0.47(4); 0.6(5); 0.74(6); 1(7)) spectra for $Al_xGa_{1-x}N$ films

The photoluminescence spectra demonstrated inhomogeneous broadening with half widths of more than 0.5 eV, and covers full visible range. The photoluminescence and cathodoluminescence spectra from cleaved edge of the AlGaN films at high pump power splits into several narrow components with two different polarizations of each one. This phenomenon indicates the transformation from spontaneous to the stimulated emission due to the light propagation in the planar waveguide with population inversion medium. The optical gain is $g \approx 70$ cm^{-1} for $Al_{0.5}Ga_{0.5}N$ film at λ = 528 nm and for $Al_{0.74}Ga_{0.26}N$ film at $\lambda \approx 468$ nm – $g \approx 20$ cm^{-1}.

This work was supported by RFBR Grant No. 16-02-00018.

Session C
FEMTOSECOND LASER SYSTEMS

C-1

FILAMENTATION OF FOCUSED FEMTOSECOND LASER PULSES

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In the presentation focused pulse filamentation including multifilamentation is considered. Influence of waveform distortions on focused pulse filamentation is studied. Possibility of filaments fusion and superfilamentation is discussed. This work was supported by the RFBR 17-02-00722.

C-2

OPTICALLY DRIVEN Xe_2CL AS A NEW ACTIVE MEDIUM FOR SUBEXAWATT LASER SYSTEMS

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At present, broadband active media of photochemical lasers, such as XeF(C–A), Kr_2F, Xe_2Cl, are of considerable interest for the amplification of femtosecond pulses in hybrid laser systems. The active medium Xe_2Cl is particularly attractive for amplifying such pulses to a high peak power due to a wide amplification band (100 nm) in the 500 nm region and a long lifetime of the excited state (250 ns). In addition, during optical pumping of a working mixture of chlorine and xenon, it is possible to realize a pulse-periodic operating mode without changing the working mixture.

In the present study, amplification was observed for the first time in a Cl_2/Xe gas mixture optically excited by XeCl laser radiation (308 nm), which leads to the photoassociative reaction $Xe + Cl + h\nu \rightarrow XeCl$ (B, C), accompanied by the formation of the Xe_2Cl^* active medium during recombination of XeCl (B, C) with Xe. The small signal gain at a wavelength of 532 nm in a mixture of 1 mm Hg was measured in the mixture of 1 Torr Cl_2 with 2 atm Xe, amounting to $(1.1 \pm 0.3) \times 10^{-3}$ cm^{-1} in the active volume of $0.5 \times 1 \times 80$ cm in size with an excitation energy of 170 mJ in a 60 ns pulse. In terms of the maximum of the Xe_2Cl^* amplification band located at a wavelength of 504 nm, the gain reached $(1.3 \pm 0.3) \times 10^{-3}$ cm^{-1}, which is comparable to the gain characteristic of the XeF (C–A) amplifier currently used in hybrid femtosecond multiterawatt systems of visible range. The excitation efficiency of the active medium, defined as the ratio of the energy of the active molecules stored in the active medium by the time of maximum gain achievement, to the pump energy absorbed by this moment is close to 10%.

According to the results of numerical simulation of the active medium, there are prospects for a significant increase in the Xe_2Cl^* active medium gain with increasing pump energy. The scalability of this active medium due to its gas nature and the currently available technologies of electron beam driven XeCl lasers with an energy of at least 2 kJ make it possible to judge Xe_2Cl^* as a promising active medium for subexawatt femtosecond systems in the visible.

This work was supported by the Presidium of the Russian Academy of Sciences (Programme "Extreme laser radiation: physics and fundamental applications"), and the Competitiveness Programme of the National Nuclear Research University MEPhI.

C-3

INFLUENCE OF THE TEMPORAL CONTRAST ON THE CHARACTERISTICS OF LASER-PRODUCED ULTRAFAST Kα HARD X RAY SOURCE

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High-intensity femtosecond lasers are now routinely used in laboratories to produce energetic photons and particles via strong-field laser-plasma interactions using solid, liquid, cluster or gas targets. Relatively simple and efficient way to produce intense ultrashort pulses of X radiation is to focus a femtosecond laser beam upon a solid target, thus reaching the intensities of $> 10^{16}$ W/cm^2 on its surface. In this case, the dominant fraction of laser radiation is absorbed into the created plasma via non-collisional processes, generating suprathermal (hot) electrons with energies exceeding dozens of keV [1]. These electrons hit the atoms and ions of target material producing characteristic line and broadband Bremsstrahlung X rays. The Kα-line dominates in the spectrum because of the highest transition probability. Note that energy of emitted Kα-photons can be "tuned" by changing the target material. The source emission is isotropic. Produced X ray pulses have picosecond duration due to the fact that hot electrons are created only during the fs laser pulse and due to a very fast afterglow energy relaxation. The X-pulse duration can be reduced few hundreds of fs for proper design and conditions.

The experiments are performed at LP3 Laboratory on the Ti : Sa laser system "ASUR" (designed by Amplitude Technologies). P-polarised 30 fs laser pulses of up to 10 TW peak power are delivered at 10 Hz repetition rate and 45° incidence angle to the surface of rotating disk in Molybdenum. Peak intensities of $>10^{19}$ W/cm^2 in a focal spot of 6 μm (FWHM) containinging 40% of the beam energy are obtained using Ag-coated f/3.6 off-axis parabola and adaptive deformable mirror. High temporal contrast of up to 10^{10} with respect to the intensity of nanosecond ASE (amplified spontaneous emission) pedestal is provided by incorporating 3 saturable absorbers (RG-850 Schott glass) into the amplification laser chain [2]. Absolute spectrally-resolved energetic characteristics of the X ray emission are determined applying an original algorithm for numerical treatment of the X-photon absorption traces registered by direct-detection X-CCD camera.

The observed dependencies of the energy conversion efficiency from laser radiation to Kα emission demonstrate the crucial role of the laser temporal contrast ratio. The origin of this drastic effect is attributed to the heating and ablation of the target surface by the ASE pre-pulse, which results in the formation of plume consisted of atoms of the target material surrounding the interaction region. The front of main femtosecond pulse rapidly ionizes the plume, thus creating the pre-plasma with the scale length, which decreases with the laser contrast. This pre-plasma strongly influence the interaction regime and the resultant Kα-conversion efficiency. The kind of interaction regime at certain values of laser contrast and peak intensity is examined by the dependence of its efficiency on the angle of incidence of laser radiation. The latter helps attributing of the actual interaction regime to the well-known laser-plasma interaction processes: resonance absorption (RA), vacuum heating (VA), plasma profile steepening (S) and hole boring (HB), and/or ponderomotive heating (J B).

The knife-edge shadowgraphy technique is applied to measure the X ray source size. The results also demonstrate strong dependence on the laser pulse contrast. The source size of ~ 10 μm is observed at highest contrast values of 10^{10}. Much larger source size is observed at lower contrast.

The works are in progress now aiming the source application to the in-line phase-contrast bio-medical imaging and to the time-resolved studies of ultrafast structural transitions in solids.

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C-4

THE ANALYSIS OF INTEGRALS OF MOTION FOR THE NONLINEAR SCHRODINGER EQUATION IN THE PROCESS OF FILAMENTATION AND FULLY CONSERVATIVE NUMERICAL SCHEME

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A mathematical model for the phenomenon of self focusing and filamentation, is the nonlinear schrodinger equation (NSE) for which only in the simplest case, the Kerr nonlinearity is known to a very limited set of rigorous analytical results [1]. It turns out, as we will show below that for the more general case of nonlinearity, it is possible to simply number of simple relations for the integral parameters. They involve not only a number of important qualitative conclusions, but they are a good test to check the accuracy of the numerical solution of the NSE that is used to describe filamentation. In this paper, on the basis of numerical calculations it was found that the standard scheme of constructing the adaptive computational domain lead to a catastrophic violation of the conservation law for the Hamiltonian in filaments. Found the conditions on the numerical mesh for which, it is possible with any acceptable accuracy to satisfy the conservation law if to use a fully symmetrical scheme, and the scheme of splitting on physical factors including scheme crank-Nicolson.

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C-5

PARAMETRIC AMPLIFIERS WITH MULTIPLE BEAMS PUMPING FOR HIGH-POWER LASER SYSTEMS OF THE FEMTOSECOND RANGE

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Laser systems based on parametric amplification cascades are the most promising for creating femtosecond radiation sources with ultrahigh intensity and ultra-high contrast. The use of parametric amplification stages with multiple beams pumping makes it possible to reduce the requirements for the energy of the pump pulses and, consequently, to increase the pulse repetition rate in laser systems with ultrahigh peak power.

The possibilities of realization of the output amplifier cascade of a powerful laser system based on parametric amplification of femtosecond pulses with multiple beams pumping are investigated. A method for choosing the optimal arrangement of the pump beams of a parametric amplifier, which makes it possible to achieve a broad spectral gain band with minimal losses from parametric diffraction, is proposed. A number of optimal arrangements of the pump beams in LBO and DKDP crystals are chosen. Simulation results of the parametric amplification taking parametric diffraction into account are presented for these crystals. The results of numerical calculations of the model describing the field envelope and the carrier resolving model are compared. The dependence of the amplification efficiency and the amplified pulse duration on the number of pump beams is analyzed. It is shown that as the number of pump beams increases, the depth of modulation of the spatial profile of the amplified radiation also increases. The possibility of its complete elimination with the use of spatial filters is demonstrated. The influence of small scale self focusing of the interference pattern of the total pump beam on the peak intensity of beams is investigated.

C-6

EVOLUTION OF PLASMA RADIATION SPECTRUM OF FILAMENT IN AIR

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Results of experimental spectral investigations of the filament plasma created by a femtosecond laser pulse in air under atmosphere pressure and various focusing conditions are presented. In our experiments the laser radiation pulses had an energy of 10–15 mJ, the pulse duration was 50 fs and the central wavelength was 940 nm.

It is shown, that for different focusing conditions, there are three typical time ranges for spectral components of the filament plasma glow in the transverse direction. The greatest luminescence times are observed for atomic nitrogen and oxygen lines (10^{-8}–10^{-7} s), which appear with "hard" focusing (focal length $F = 5 - 15$ cm). In this case, an electron density of the order of 10^{16}–10^{18} cm^{-3} is achieved in the plasma [1]. Molecular nitrogen lines are observed for a time of 10^{-10} s. These lines appear at a "medium" ($F = 15 - 40$ cm) and "weak" ($F > 40$ cm) focusing of the laser beam. For the same conditions, lines of the molecular nitrogen ion are observed, which have the shortest lifetime - about 10^{-11} s. In this case, the electron density is about 10^{15}–10^{14} cm^{-3} according to [1].

It is noted that there is a delay time of some picoseconds between pulses of laser radiation and radiation lines of the molecular nitrogen ion, which emission appears first. Then, with a delay of ~ 10–15 ps, the radiation lines of molecular nitrogen appear on the second positive system. Atomic lines appear only with a "hard" focusing conditions, and they can be observed without any delay relatively to the laser radiation pulse.

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C-7

OPTICAL COMPRESSORS FOR ULTRA-WIDEBAND NEAR AND MID-INFRARED PULSES

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The creation of sources of powerful femtosecond radiation of extremely short duration in the near and middle IR range opens possibility of investigating new phenomena, such as filamentation, generation of attosecond pulses, laser-wake acceleration of charged particles. One of the promising schemes for the generation of ultra-wideband radiation in the region of 1.4–17 μm is proposed in [1]. It is based on multistage parametric amplification of chirped pulses of signal and idle waves of a two-channel, multi-TW femtosecond laser system, created in ILP SB RAS. The realization of such schemes of pulse generation at the terawatt and multi-TW power level requires the development and creation of compressors for the amplified pulses chirp sign inversion, compressors with high transmission and high contrast of compressed pulses in different spectral ranges.

In this work we present an algorithm for developing optimal schemes of optical compressors with high contrast of compressed pulses based on reflective and transmitting gratings in the spectral range of 0.8–17 μm. It is shown that the required accuracy of the adjustment of the optical elements of the stretcher-compressor system in different spectral regions is weakly dependent on the operating range.

The effect of the frequency-angular chirp of pulses arising in the case of a noncollinear parametric interaction on the efficiency and contrast of the compression process in the compressor is investigated. Methods of its compensation are proposed and discussed.

Comparative computational and experimental data on compression of amplified pulses with energy of 0.3–1 J in a compressor based on reflective and transmitting gratings in the region of 0.8 and 1.4 μm are presented and analyzed.

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C-8

USING OF TERAWATT RADIATION IN CASES OF THE REMOTE SENSING OF CLOUDS

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At present, methods of remote sensing of the environment by femtosecond lidar systems are actively developing in Russia and abroad. The attraction of sounding by short (from tens to hundreds of femtoseconds) powerful pulses (with energies in the unit pulse – hundreds of milli-joules) is due to nonlinear effects arising from the propagation of them in the atmosphere. For remote sensing of the atmosphere, in particular the cloud cover, the main wavelength (800 nm) of the femtosecond optical stand of the IAO SB RAS was used in conjunction with the Newton telescope with a 30 cm diameter of the main mirror and a focal length of 80 cm. The entrance window of the receiver, 10 mm in diameter, plays the role of the diaphragm, which limits the field of view of the telescopic system, forming a half-field angle of view $\alpha_т = 6{,}25 \cdot 10^{-3}$ rad. A series of full-scale experiments was carried out and the results on cloud probing over the city of Tomsk on an inclined sounding path were presented and discussed, and the main parameters were detected and monitored.

The reported study was funded by RFBR according to the research Project No. 16-35-00173 mol_a.

C-9

A NEW MECHANISM OF FEMTOSECOND PULSE SELF-SHORTENING BASED ON MULTIPLE FILAMENTATION IN KERR MEDIA

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At present, the chirped pulse amplification (CPA) method has achieved a petawatt (10^{15} W) power level in solid-state femtosecond systems. As a rule, in such systems it is difficult to obtain pulses shorter than 20–30 fs because of narrowing of the spectrum during amplification. At the same time, for numerous applications in the strong fields – matter interaction and femtosecond optics (obtaining high order harmonics and generating isolated attosecond pulses, investigating the dynamics of ultrafast processes, etc.), it is timely to obtain shorter pulses approaching a period of light wave. The solution to this problem is the development of nonlinear methods for pulse reduction at the output of femtosecond systems. The methods currently used are based on the broadening of the spectrum due to self-phase modulation (SPM) in media with Kerr nonlinearity with compensation of phase modulation acquired (by using diffraction gratings, chirped mirrors, or prism pairs) or without the use of the latter, if the spectrally limited pulses are formed directly in a nonlinear medium (self compression). At the same time, currently developed self compression methods are limited in energy by tens of mJ and do not have the prospect of further scaling.

In this paper, we present the results of investigations of a new mechanism for self-shortening of the duration of femtosecond pulses in thin optically transparent materials with Kerr nonlinearity. It is based on the formation of multiple filaments in the trailing edge of the pulse, which leads to a sharp increase in diffraction and refraction losses when recording radiation in the near-axis region. Experimental studies were carried out in a convergent Gaussian beam, incident on a quartz plate 1 mm thick. The duration of the original spectrally-limited pulse was 87 fs at a wavelength of 475 nm. The intensity of the radiation on the quartz plate varied in the range 0.8–2.9 TW/cm^2 in a beam 0.63 mm in diameter at $1/e^2$ level. Using a diaphragm 100 μm in diameter, adjacent to the back surface of the sample, a region of uniform intensity in the central part of the beam was selected. The radiation at the exit of the diaphragm consisted of a central core whose size did not depend on the intensity in the initial beam, and conical emission with a divergence angle of up to 0.1 rad (the angle of convergence of the initial radiation was < 0.01 rad). At an intensity of 3 TW/cm^2, the radiation spectrum of the core emitted had a shape close to Gaussian with a center at a wavelength of ~ 495 nm. The pulse duration was reduced to 19 fs.

The obtained experimental data show that the output pulse in the near-axis region is formed at the leading edge of the pulse, which is not subject to filamentation. At the same time, due to the SPM, the broadening and red shifting of the spectrum take place.

The mechanism of the observed phenomenon indicates that the method of self-shortening pulses based on it allows its scaling by energy when using super-Gaussian beams.

C-10

THE EVOLUTION OF CRYOGENICALLY COOLED PUMP CHANNEL OF HIGH INTENSITY LASER SYSTEM WITH 1 KHz REPETITION RATE

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Recently, special attention is paid to research on the development of principles and elements of both high peak and average powers laser systems. Such systems are needed for research of the physics of extreme laser fields and to perform experiments on new technological applications such as laser acceleration of charged particles, laser-assisted thermonuclear fusion, etc. Investigations show that the most promising way is the creation of such systems based on OPCPA technique of femtosecond pulses by using for pumping radiation of DPSSL.

The system that is being developed at the ILP SB RAS consists of two channels: the BBO-based channel of parametric amplification and the CPA pump channel forming and frequency doubling of the radiation of the picosecond pulses [1]. For the first stage of amplification in the CPA pump channel multipass Yb : YAG crystal amplifier with dual diode end-pumping was developed. It increases energy of pulses produced by regenerative amplifier (1 kHz) to 10–15 mJ. During the second stage based on liquid-free closed-loop cryogenically cooled Yb : YAG multidisk amplifier energy of pulses is risen to 300 mJ level. We use modern closed loop system with low vibration pulse tubes for heatsink cooling. This system is able to keep the crystals at operating temperature (~ 120 K). The experimental data on instabilities of radiation in short and long terms and during the full cycle of cooling to cryogenic temperature – warming to room temperature and on weak signal amplification are presented.

This work is supported in part by RAS Program “Extreme laser radiation: physics and fundamental applications”, Grant No. 0307-2015-0018 and Government Program No. 0307-2016-0006.

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C-11

SPATIAL AND SPECTRAL CHARACTERISTICS OF THE POST-FILAMENTATION ZONE FEMTOSECOND LASER PROPAGATION PULSES ALONG THE TRACK

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The propagation of laser radiation of ultrashort duration upon reaching critical values of the pulse power P_{cr} is accompanied by its self-focusing and filamentation [1, 2]. In this case, significant changes occur in the energy, spatial, spectral, and angular characteristics of laser radiation. The radiation energy is localized in narrow light filaments containing a pre-threshold density of light energy flux, the spectral composition of the radiation is substantially enriched. These properties have priority values for atmospheric optics problems - laser sounding of the atmosphere and transportation of localized light energy through the atmosphere. At the same time, the task of translating the filamentation region to a considerable distance from the source is necessary, and for the atmospheric optics, the most attractive are the multiple filamentation of the beam. Studies to control the position of the multiple filamentation zone on the track using geometric focusing, changes in the initial diameter of the beam and its power have shown that there are restrictions that do not allow extending this region to many kilometers distance [3]. It was found that after the "decay" of the filamentation zone, i.e. after the termination of plasma formation and the disappearance of visible luminous filaments (filaments), behind each of them a narrow, slightly divergent light channel is formed [4]. The use of these channels, which are much longer than the filamentation zone, requires careful study of their energy, spectral and spatial properties, as well as the physical mechanisms of their formation.

The processes of formation of the transverse structure of a laser beam after multiple filamentation were investigated. It is shown that the spectra of post-filamentary light channels (PFC), rings and beam differ substantially. The spectrum of PFC has a significant and symmetrical spectral broadening and covers a range of 600–1100 nm. The broadening of the spectrum of the rings is asymmetric and is directed mainly to the short wavelength region of the spectrum. The broadening data are stable and do not change when moving away from the multiple filamentation region. The annular structure of radiation in the cross section of the beam is formed around individual filaments within the region of multiple filamentation, and at a distance of tens of meters from it begins to form a common ring structure surrounding post-filamentary channels.

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C-12

LUMINESCENCE SPECTRA OF NITRIC OXIDE IN ULTRA-INTENSE OPTICAL FIELDS

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A variety of laser-based standoff techniques are currenly being de developed for the detection of explosives. Many approaches focus on the detection of NO as an indicator for the presence of nitro-based explosives. Most related reports have focused on using 236 nm or 247–248 nm for the laser excitation of vibrationally hot NO. However, in some works, e.g. in [1], reported the use of other laser wavelengths. The authors [1] suggested the use of 532 nm and 236нм for desorption, evaporation and photo-fragmentation explosive samples. A potential interference mechanism was found for using 532 and 236 nm. The laser pulse width was 10 ns FWHM, 100 mJ/pulse of laser energy (532 nm) and about 1 mJ for 236 nm. A maximum power density 250 GW/cm^2 was in the focus of 400 mm lens. The interference mechanism is based upon multi-photon excitation (532 nm) or two-photon excitation (236 nm) into excited states of molecular nitrogen and subsequent energy transfer from nitrogen to NO, followed by NO luminescence.

To test the possibility of the interference mechanism with much more powerful laser pulses with different from [1] wavelengths, we used a femtosecond Ti : Sa laser with a main wavelength of 950 nm and the second harmonic of 475 nm. The duration of laser pulses was varied from 50 fs to 300 ps. The power of a single pulse was varied from 300 TW to 15 MW. Using lenses with different focal distances, the laser radiation intensity in the irradiated volume of medium was changed from a threshold of a single filament to the threshold of optical breakdown. The experiment was produced both in ambient air and in the chamber filled with pure nitrogen N_2 and NO, and a mixture of N_2 and NO. Comparison of luminescence spectra of gas media allows to assume that proposed by the authors [1], the interference mechanism can be used to interpret the obtained results.

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C-13

THE INVESTIGATION OF THE DIODE-PUMPED LASER AMPLIFICATION UNIT WITH CRYOGENIC CLOSED-LOOP COOLING

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Presently, there are researches worldwide aimed to design and development of principles of laser systems with simultaneously high peak and average power. At the Institute of Laser Physics the all diode-pumped laser system with cryogenic closed-loop cooling is developed. The system is designed to work with a pulse repetition rate up to 1 kHz [1]. The system consists of two synchronized channels: subjoule-level pump channel and parametric amplification channel [2]. The pump channel consists of two multipass amplifiers and is designed to produce pulses with energy more than 300 mJ at the output of the channel.

Spatial, spectral, temporal and energetic properties of amplified small signal in the pump channel depending on diode pump parameters were experimentally investigated.

To optimize the pump channel it is proposed to replace the first multipass amplifier with cavity dumped and passively mode-locked seed laser. Operation regimes at room (300 K) and cryogenic (77 K, 120 K) temperatures were modelled, with a thermal field distribution inside the active Yb : YAG elements taken into the account. Based on the numerical data obtained, the optimal parameters of the seed laser allowing to obtain more than 500 mJ at the output of the pump channel

were determined. The influence of parameters variation from optimal values to output pulse properties is estimated.

The obtained results will be used to develop all diode-pumped laser system with cryogenic closed-loop cooling and pulse repetition rate up to 1 kHz.

This work is supported in part by RAS Program "Extreme laser radiation: physics and fundamental applications", Grant No. 0307-2015-0018 and Government Program No. 0307-2016-0006.

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C-14

TOPOLOGICAL CHARGE AS A TOOL FOR CONTROLLING A VORTEX LASER BEAM OF FEMTOSECOND DURATION

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Investigated the possibility of controlling vortex ring beam of radiation of femtosecond duration in a turbulent atmosphere [1]. This possibility is investigated on the basis of the stationary version of the nonlinear Schrцdinger equation (NSE) [1] in a medium with a random refractive index. The analysis is based on numerical solutions of the equations, and formulated equations for effective radius showed that the topological charge is an effective management tool coordinates the global focus of the light beam.

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C-15

UPGRADING OF KILOHERTZ SOLID-STATE LASER SYSTEM WITH STABILIZATION CEO FOR NONLINEAR INTERACTION RADIATION WITH OPTICAL MEDIUM EXPERIMENTS.

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The design and creation of femtosecond laser systems with high intensities are one of the most important trends in laser physics. Laser facilities with the intensity reaching the level of 10^{25} W/cm^2 or higher open a way to the experimental research in the wide range of problems in fundamental physics, chemistry, biology and their applications.

The focus on our work was concentrated on the study of the characteristics and upgrading of a solid-state femtosecond laser system consisting of a master oscillator and a nine-pass amplifier, for further experiments of nonlinear interaction radiation with optical medium. The system has following parameters: output energy – 600 mJ, pulse duration – less than 30 fs, central wavelength – 800 nm, pulse repetition rate – 1 kHz. The stabilization system implemented has allowed one to achieve phase residual instability ~ 0.17 radian (rms) for the 30 fs-pulse, which is sufficient to for nonlinear interaction radiation with optical medium in forthcoming lightwave electronics experiments.

This work is supported in part by RAS Program "Extreme laser radiation: physics and fundamental applications", Grant No. 0307-2015-0018 and Government Program No. 0307-2016-0006.

C-16

INFLUENCE OF THE THL-100 AMPLIFIER PUMP POWER ON THE OUTPUT LASER BEAM CHARACTERISTICS

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Numerically investigation the gain of laser pulses of picosecond duration in the amplifier of the laser system THL-100 with increasing of pump energy is the purpose of the work. Output laser beam characteristics and the efficiency of energy conversion were investigated.

The results of numerical simulation of the amplification of picosecond laser pulses with an increase in the pumping energy of the amplifier from 270 to 400 J are presented. It is shown that when the pump energy is increased, the use of a mirror system, providing a fewer passes of the Amplifier with a laser beam and a larger divergence angle of radiation is more effective. A system of mirrors with 27 passes (instead of 33 passes) of the amplifier provided a laser radiation divergence angle of 1.5 mrad (instead of 1 mrad) are investigated. It is shown that at an input pulse energy of 2 mJ, this system of mirrors makes it possible to increase the energy of the output laser radiation to 7 J with a maximum laser radiation intensity of not more than 12 GW cm^{-2}. The internal efficiency of energy conversion in this case reaches 2.8%.

C-17

THE OPTIMIZATION OF CRYOGENIC COOLING SYSTEM OF THE DIODE-PUMPED HIGH POWER LASER AMPLIFIER

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The development of high peak and at the same time average power systems have been extensively studied in the last years. At the ILP SBRAS has been designed a diode-pumped laser system with closed-loop cryogenic cooling operating at 1 kHz repetition rate [1]. The system consists of two synchronized parallel channels - a sub-joule level pump channel of the parametric amplifier and parametric amplification channel [2].

To increase the energy of the pulses up to 300 mJ a cryogenic multidisc laser amplifier has been developed in the pump channel of the parametric amplifier of the femtosecond laser system. The amplifier consists of 8 bonded crystal elements based on Yb : YAG that fixed in crystal holders and mounted to closed-loop cold heads. Under the influence of (due to) diode pumping there is a thermal field that leads to decreasing of the amplification efficiency and phase distortions. The entire optical path length inside the amplifier leads to a high sensitivity to mechanical influences on the elements. Although the cryogenic cold heads have a low level of vibrations, they do not provide sufficient spatial stability of the radiation. The current system of the crystal holders should be improved regarding thermal and mechanical properties. The study of the thermal field was carried by the numerical modeling of 3+1D heat transfer equation.

Based on the thermal field calculations an improved construction of the crystal holders using flexible twisted copper braids was developed. The construction allows suppressing the vibrations and maintains an effective cooling. The data, both simulated and experimental, are used in the development of the diode-pumped high power laser amplifier.

This work is supported in part by RAS Program “Extreme laser radiation: physics and fundamental applications”, Grant No. 0307-2015-0018 and Government Program No. 0307-2016-0006.

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C-18

STABILITY OF DISCHARGE IN EXCIMER GAS MEDIA WITH HIGH SPECIFIC PUMP POWERS FEATURES OF THE FEMTOSECOND RADIATION PULSES FILAMENTATION UNDER ABERRATION CONDITIONS

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The filamentation of a femtosecond radiation pulse in air under aberration conditions studies in this paper. The laser beam had a wavelength of 940 nm, an energy of $W = 10–15$ mJ, a beam diameter of 14 mm, and a pulse duration of 70 fs. It is shown that two spatial quasisolitons are realized behind the visible filament upon astigmatic focusing of radiation by a spherical mirror (the angle of incidence of the laser beam on the mirror ~ 15°). Their diameter is ~ 0.3 mm and they exist in the propagation region of laser radiation ~ 100 cm. Quasisolitons are a consequence of the balance between the Kerr nonlinearity and linear diffraction of radiation in the presence of an energy reservoir of a laser beam in their periphery. The formation of quasisolitons is due to the specific distribution of the light field with astigmatism and the appearance of inhomogeneities on the wave front in the filament region. The formation of such structures creates the conditions for appearance of a highly directional supercontinuum of white color, which then propagates with a divergence close to the diffraction limit.

C-19

ON THE POSSIBILITY OF OBTAINING FEMTOSECOND PULSES FROM MULTI-WAVELENGTH GAS LASERS

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Ultrashort laser pulses of femtosecond duration are obtained by mode-locking of the broadband lasers such as Ti: sapphire or dye lasers. The pulse duration τ of the laser with an amplification bandwidth of $\Delta\nu$ is roughly equal to $\tau \approx 1/\Delta\nu$. However, just as for achieving ultra-high angular resolution in radio-telescopes it is not quite necessary to increase the size of one large mirror, but to use synchronized operation of several far-spaced small mirror antennas, so to obtain ultrashort laser pulses mutual mode-synchronized operation of several laser lines can be used, scattered across a large spectral range. Then the minimum duration of the laser pulses will be defined by a spectral interval between the farthest lines of generation: $\tau \approx 1/(\nu_{max} - \nu_{min})$. The more laser lines generate together within a given spectral interval, the better will be a waveform (quality) of an ultrashort pulse. There are many gaseous laser media with multi-wavelength generation such as metal vapor lasers, argon ion laser, etc. Especially, a lot of laser lines oscillate simultaneously on the vibrational-rotational transitions in molecular lasers (CO and CO_2 lasers, and others). There are also solid-state laser media with multi-wavelength operation. For example, a neodymium laser with $\lambda = 0.92$; 1.06; 1.37 μm. However, the feature of active media based on gas is a small dispersion that may contribute to joint mode-locking of different lines in a wide spectral range. The report analyses the calculation results on the simultaneous mode-locking of several laser lines in some multi-wavelength metal vapor and gas lasers.

C-20

STABLE MULTI-BOUND SOLITONS GENERATION IN HIGHLY-NONLINEAR RESONATOR OF PASSIVE MODE-LOCKED RING LASER

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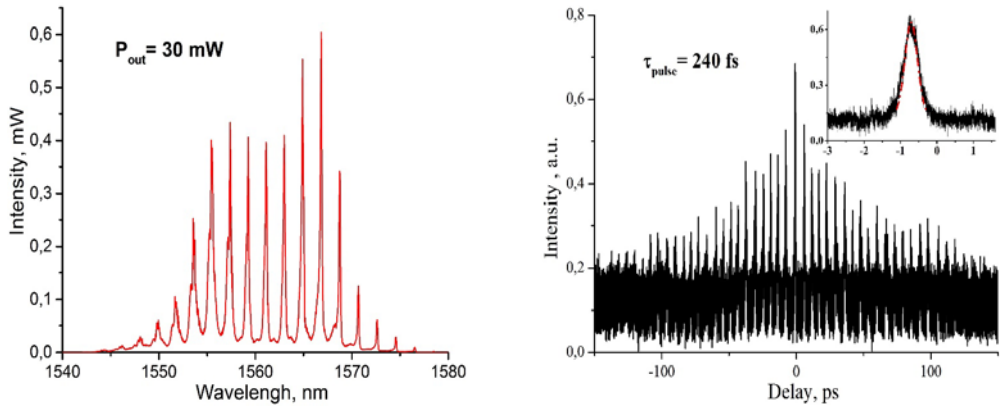
In this paper we demonstrate stable multi-bound solitons generation in highly-nonlinear laser resonator with passive mode-locking. This generation regime is of considerable interest in various fields of application, such as telecommunication transmission systems, in metrology field of optical frequencies, etc. [1]. The experimental setup of mode-locked laser presented in paper [2]. Note that the value of intracavity group velocity dispersion is $\beta_2 \sim -0.0053$ ps^2. Fig. *a* shows the output multi-bound solitons generation spectrum, and fig. *b* shows the intensity autocorrelation traces of the output ultrashort pulses.



a *b*

Output spectrum of multi-bound solitons generation (*a*); intensity autocorrelation trace of multi-bound solitons. Inset: central peak of autocorrelation trace with Gaussian fitting (*b*)

As a result, stable multi-bound solitons generation is obtained (more than 20 bound pulses with intertemporal width ~ 5 ps) with duration of ~ 240 fs at repetition frequency ~ 11.3 MHz (with signal-to-noise ratio ~ 73.3 dB). Note that the relative intensity noise is < –112 dBc/Hz, and Allan deviation of the repetition frequency have not exceeded ~ $1.3 \cdot 10^{-8}$ with the time averaging ~ 100 s.

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C-21

THERMO-OPTICALLY INDUCED WAVEFRONT ABERRATIONS IN DIODE-PUMPED Yb : YAG MULTIPASS AMPLIFIER OF HIGH INTENSITY FEMTOSECOND LASER SYSTEM

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In recent years many efforts has been directed to researches and design of high power femtosecond laser systems. The main interests are acceleration of high energy particle beams, X ray generation, nuclear fusion and nonlinear processes. One of such laser systems has been developing at

the Institute of Laser Physics of SB RAS. It is based on the principles of CPA technique and can be divided into two: amplification and pump channels [1]. The expected output pulse parameters of the laser system are duration 10 fs and energy 10 mJ with 1 kHz repetition rate.

The pump channel consists of 6-pass amplifier based on water-cooled crystal that increases pulse energy up to 10 mJ. The second amplifier consists of 8 cryogenically cooled Yb : YAG bonded crystals and is used to amplify pulse energy up to 300 mJ.

One of the crucial points of high power laser systems is a thermal lensing in active elements of multipass amplifiers under pumping [2]. This work is devoted to investigations of thermal processes and of thermo-optically induced wavefront aberrations in diode-pumped water and cryogenically cooled Yb : YAG crystals of multipass amplifiers. The solution of the thermal conductivity equation have been performed to obtain temperature distribution in amplifier at room and cryogenic temperature as well as parameters of thermal lens. Wavefront aberrations have been determined experimentally using Shack-Hartmann wavefront sensor. The obtained results are used for optimization of the beam parameters at the output of pump channel of high power femtosecond laser system.

This work is supported in part by RAS Program “Extreme laser radiation: physics and fundamental applications”, Grant No. 0307-2015-0018 and Government Program, No. 0307-2016-0006.

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C-22

ABOUT THE MECHANISM OF A HIGHLY DIRECTIONAL SUPERCONTINUUM GENERATION IN THE VISIBLE SPECTRAL RANGE UPON FILAMENTATION

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The physical parameters and conditions for the formation of a stable directed anti-Stokes supercontinuum (SC) arising in the propagation of a focused femtosecond pulse in the air with a central wavelength of 940 nm are studied. With aberration-free long focusing and a certain power, a single filament appears, which is the source of the directed SC. With aberrational focusing (the inclination of a lens or a spherical mirror with $F = 744$ mm), two highly directed beams of light SC diverging relative to each other at a certain angle arise after a visible filament. In contrast to the aberration-free focusing the SC beams in the second case are more stable.

It is shown that the transformation of the initial spectrum of laser radiation in the SC occurs along the propagation path both in the visible filament region and after it. The most significant sequential change in the spectrum from the IR region ~ 900 nm up to wavelengths ~ 350 nm occurs in two beams in which stable spatial quasi- solitons are formed as a result of self-channelization of the radiation. In these regions, the balance of the Kerr self-focusing and the diffraction divergence of the laser radiation is realized. The experimentally measured electron concentration in these regions does not exceed ~ 10^{13}–10^{14} cm^{-3}, so a considerable broadening of the spectrum in the anti-Stokes range can be not explained by phase self-modulation (FSM).

A comparative analysis of the obtained experimental data and various mechanisms of the appearance of a directed SC in transparent dielectrics, gases, in microstructured and hollow photonic crystal fibers is carried out. It is shown that the most probable mechanism for converting of the laser radiation spectrum into the visible and UV ranges of the SC is a cascade parametric four-wave mixing (CPFWM). At the first stage, the spectral broadening of the laser radiation is due to the combined effect of Stokes Roman scattering on the rotational transitions of air molecules, parametric four-wave mixing, and fsM. These processes of spectral broadening are realized already in the regions

up to the filament and in it. The largest anti-Stokes broadening is realized at a distance of 10–100 cm behind the visible filament. The proposed mechanism for spectral transformation is justified by numerical modeling and behavior of the spectral composition of SC at various laser beam propagation zones. The development of the CPFWM under our conditions is due to the nonlinear susceptibility of the third order of air and the propagation of light in the optical light guide during self-channelization of laser radiation.

Session D
LASER SYSTEMS AND NEW LASER AND OPTICAL TECHNOLOGIES, LASER APPLICATIONS

D-1
OPTICAL CIRCUITS OF MULTIWAVE REMOTE LASER SENSING

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The paper is aimed to review some aspects of design of transmitter-receiver components of multiwave remote sensing systems for detection of aerosol and gas admixtures in the atmosphere. Examples of application of the developed optical circuits in particular devices and some experimental results of their operation are presented.

D-2
LASER WELDING: ACHIEVEMENTS, PROBLEMS AND PROSPECTS

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World sales of lasers have nearly doubled over the Decade and should reach in the year 2017 11.09 billion dollars.

Welding takes only 9% of materials processing sector and had the year 2016 amount to 296.9 million dollars United States [1].

Despite its relatively small size, it is one of the basic processes in the manufacture of metal structures for virtually all industries and the national economy, as well as determining the technological process when designing and creating new designs of modern technology.

Sales of lasers for welding for 2016 year increased by 3.4% due to an increase in demand in the automotive industry for oil and gas industry in the manufacture of pipes for oil wells and pipelines [1, 2], the energy sector, including: Atomic [3].

In welding is an active CO_2 displacement-lasers (up to 20 kW) «fibers» IPG and other manufacturers (to 30/100 kW), as well as begin to apply powerful diode lasers (up to 30 kW). Strong position in the global mass production have automated systems based on disk lasers (up to 16/32 kW) German company TRUMPF [4, 5].

Industrial lasers are key components in automated material handling systems. The transition to a decentralized system of production, fast track fluctuations in supply chain-controlled sensors and computers, and lasers are inherently flexible component that is well integrated into a modern, rapidly changing, and in many cases individual and small-scale production that provides good prospects of application of laser technologies in industry [2].

Several hinders the wider application of laser welding is the relatively high cost of the equipment, as well as training requirements and welding assemblies, including to minimize backlash. With a view to improving the quality of laser welding, expanding its applications, especially in recent years intensive research work on the development of laser hybrid welding [6–9], by scanning [6–8, 10] also multi-pass welding [6–8, 11].

Most active demand for laser technology is expected in key industrial sectors: automotive, aerospace, energy, telecommunications and microelectronics, with growth expected in 2017 year at 4.9% [2].

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D-3

THE STUDY OF VAPOR DROPLET ABLATION MODE DIELECTRIC TARGETS UNDER THE ACTION OF LASER RADIATION

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One of the areas of using of powerful lasers is obtaining of nanopowders of refractory oxides. The method consists in the laser evaporation of targets of oxide and the condensation of vapor in the air stream. For this purpose we are using for a long time the pulse-periodic CO_2 laser with an output average power of 600 W, and in recent years, CW fiber ytterbium laser with a radiation power of 700 watts. The resulting nanoparticles of YSZ, Nd : Y_2O_3 and Al_2O_3 have almost the same average size ($\approx 10 \div 15$ nm). However, the performance of the synthesis of nanoparticles and their mass exit in the case of the fiber laser is smaller than for CO_2 laser. High-speed photography showed that when the fiber laser evaporation targets of Nd : Y_2O_3 and YSZ, we can see a lot more micron droplets of the melt than in the case of CO_2 laser. When the power density of radiation of the fiber laser of 0.46 MW/cm^2, the first major drop from the target of the Nd : Y_2O_3 start to spray after 150–200 μs after the formation of the laser plume. Since that time, the substance starts to move away from the target in the form of vapor-droplet mixture.

The objectives of the present work was to study the distribution of drops by size and theoretical search for plausible mechanism of splashing.

Using CW fiber laser with 600 W power and a pulse-periodic CO_2 laser with an average radiation power of 500 W was obtained nanopowders of Nd : Y_2O_3. Obtained in the evaporation chamber powders by sedimentation were separated to fraction of particles (drops and target fragments) and photographed after than. Regardless of the type of laser, the vast majority of the droplets has a diameter of from 0.3 to 10 μm, and their total mass is less than 0.8% by weight of all droplets. Maximum weight proportion of drops with sizes from 10 to 140 μm. Their maximum share (90 wt.%) the evaporation of the target by the radiation of fiber laser with $I = 1.2$ MW/cm^2 when implemented minimum capacity of production of nanopowder (18 g/hour). Least drops of such size is formed by the evaporation of the target CO_2 laser (56 wt.%). The rest consists of isolated droplets with sizes up to 240 μm.

The development of the instability of Kelvin-Helmholtz on the border between the steam flow and the molten crater wall can be a probable reason for the formation of drops. The theoretically calculated characteristic scale of such a perturbation (fashion) amounted to the value of 20÷90 microns. Qualitatively this corresponds to diameters of the droplets with the largest mass content (10÷140 μm) found in the experiment. The characteristic time of instability development, i.e. the formation of droplets in the calculations was 20÷50 μs. Thus, the characteristic time of formation of the drops is less than the pulse duration of CO_2 laser radiation (370 MS), the duration of exposure to continuous radiation of a fiber laser on a moving target or the duration of the pulse emission of a fiber laser with high-speed photography of scattering laser torch (1 msec). However, this perspective cannot explain the formation of a huge number of drops with sizes less than 10 microns and a few drops of diameter greater than 140 microns. For this you need to look for other mechanisms of their formation.

Work is performed under the topic of the state task No. 0389-2014-0027, and is supported in part by RFBR Grant No. 17-08-00064 A.

D-4

PULSED LASER ABLATION AS A METHOD OF NANOPARTICLES OBTAINING: PHYSICAL CHEMISTRY OF THE PROCESSES, PROPERTIES AND APPLICATION (SECTION, INVITED)

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Pulsed laser ablation (PLA) of bulk targets has been used for about 25 years as a method of nanoscale structures obtaining. Relative simplicity of the method, a wide variety of nanoparticles obtained and their chemical purity have determined the demand for such materials in biomedicine, catalysis, optoelectronics and other high-tech areas. Two main tasks have to be meet for further development of the technology of nanomaterials synthesis via PLA: productivity increasing and effective managing the composition and structure of the particles produced.

In this work we present the results of the processes investigation occurring during PLA when excited by a nanosecond Nd : YAG laser. Various optical schemes and excitation modes affecting the productivity of nanoparticle synthesis are considered. The physical chemical processes taking place in the medium under the primary and secondary interaction of laser radiation with a number of metals with different chemical activity are studied. The processes affecting of the composition and properties of the obtained nanoparticles were investigated.

We also provide examples of the use of nanoparticles obtained in nonlinear optics, catalysis (including photocatalysis), biomedicine.

The work was carried out with the partial financial support of the Ministry of Education and Science of the Russian Federation (State task, Project No. 3.9604.2017 / BC).

D-5

THE EFFECT OF UV LASER RADIATION ON THE SCLERAL TISSUE OF THE EYE OF PATIENTS WITH OPEN-ANGLE GLAUCOMA

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The results of experimental investigations of the effect of high-power UV laser radiation on the scleral tissue of the human eye are presented. Isolated flaps of scleral eye tissue of patients with

open-angle glaucoma of degree 2 and 3 were used as samples. The experiments were carried out with both dried and wet flaps. For the action, the radiation of an excimer XeCl laser with a wavelength of 308 nm and a laser with a tunable wavelength in the region of 210–350 nm was used. The energy of excimer laser generation was about 100 mJ, the pulse duration was 15 ± 2 ns (FWHM). The generation energy of a tunable laser depended on the wavelength and did not exceed the fraction of mJ. The energy density on the surface of the tissue to be affected varied depending on the task – from fractions mJ/cm^2 till 15 J/cm^2.

Investigations of the ablation process under the effect of radiation with a wavelength of 308 nm showed that the rate of evaporation of the material depending on the stage of glaucoma and taking into account the individual characteristics of patients can vary within 25–30% at an energy density above 4 J/cm^2.

Experimental studies of excitation matrices for laser-induced fluorescence (LIF) emission of scleral tissue of the human eye using a laser with a wavelength tunable in the region of 210–350 nm have been carried out. An attempt is made to analyze the spectrum of LIF of scleral tissue depending on the excitation wavelength and the stage of open-angle glaucoma.

D-6

DETECTING OF CO_2 LASER RADIATION BY THE METHOD OF ACOUSTIC THERMOMETRY

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In our work we investigated the possibility to detect the CO_2 laser radiation ($\lambda = 10.6$ μm) by by the effect of the sound speed changing in the gas that absorbs this radiation. The detector based on this principal was developed. We found out that SF_6 (elegas) has the optimal parameters for our purpose in the considered spectral range: low sound speed and high radiation absorption coefficient. The dependence of sound speed changing on the absorbed energy was linear. The minimal energy pulse that we managed to detect was 4 mJ. Some ways of improving the method sensitivity were found.

In general, our results show that using the considered method it is possible to create middle- and far-IR-detectors, operating at room temperature.

D-7

EFFECT OF FERROUS OXIDE NANOPARTICLES ON THE BLOOD COAGULATION ACCORDING TO LIGHT SCATTERING DATA

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The paper shows that ferrous oxide nanoparticles obtained in acoustoplasma discharge with cavitation affects the rate of one of the reactions of the process of blood coagulation – cleavage of fibrinogen by thrombin. As a result of the reaction, a fibrin gel is formed. By means of dynamic and static light scattering we reveal that adding of thrombin previously mixed with nanoparticles to a solution of fibrinogen leads to dramatically acceleration of gel formation. Adding of nanoparticles to the solution of fibrinogen (before thrombin addition) leads to stop reaction on the first stage (without gel formation). This data shows that ferrous oxide nanoparticles can act as regulators of enzyme reaction – in one case accelerating it, and in the other – by inhibiting it.

D-8

IDENTIFICATION OF SYNTHETIC DIAMONDS BY THE OPTICAL ABSORPTION AND CATHODOLUMINESCENCE SPECTRA

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The development of technologies for the synthesis of materials capable of imitating diamonds makes it necessary to improve the methods for diamond identification [1, 2]. Particular complexity is the task of identifying synthetic diamonds, as well as natural diamonds subjected to radiation-heat treatment to increase their cost.

At present, the main methods of synthesis of diamonds are high-pressure high-temperature method (HPHT) and chemical vapor deposition. The difference in the conditions of synthesis causes the difference in the impurity-defective composition of diamond samples and, consequently, the difference in the optical absorption (OA) and cathodoluminescence (CL) spectra. The OA and CL spectra of natural and synthetic diamonds contain information on the initial composition of the batch/gas mixture, the conditions of synthesis and subsequent radiation-heat treatment [2, 3].

The paper presents the results of investigations of OA and CL spectra of 9 diamond samples of natural and HPHT synthesis. An algorithm for identifying the synthesis method of diamond by OA continua, OA and CL vibration-electronic systems and nonstructural CL bands is proposed.

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D-9

LASER INSTALLATIONS BASED ON COPPER VAPOR LASER FOR PRACTICAL AND SCIENTIFIC MEDICINE

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The first generation of domestic medical installations with pulsed copper vapor lasers (CVL) was created in the "RPC" Istok ". These include installations such as "Yantar-2F" and "Yakhroma-2", developed on the basis of CVL "Course" with wavelengths λ = 510.6 nm and 578 nm and average radiation power 5–10 W and dye-laser with wavelength tunable in the range of λ = 620–670 nm, for use in oncology for treatment with PDT, angioplasty of intravascular destruction of atherosclerotic lesions, dermatology and cosmetology for the treatment of facial skin defects, as well as in otorhinolaryngology, gynecology, Proctology, urology. Delivery of laser radiation to the area of the affected area of the bioobject is performed using a flexible fiber-optic cable with a diameter of 400, 600 or 800 microns, which is one of the most convenient medical instruments. Modern is the compact

and air-cooled medical device of the new generation "Yakhroma-Med" on the basis of the pulsed CVL "Kulon" with an average output power of the light-guide cable. 1–3 W for use in dermatology and cosmetology (together with the Physical Institute RAS). Today, Yakhroma-Med is the leader in non-ablative technologies and is optimal for removing vascular, pigmented and unpainted skin defects, treating acne and wrinkle smoothing. It is used in more than 100 clinics in Russia and abroad. In each clinic, hundreds and thousands of patients are treated. A compact, air-cooled industrial multifunctional high-intensity medical device of the new generation "Kulon-Med" (analogous to "Yakhroma-Med") was developed on the basis of two pulsed lasers: CVL "Kulon" with an average radiation power 10 W and dye-laser with wavelength tunable in the wavelength range of $\lambda = 620–750$ nm and radiation power 1–3 W for scientific and practical medicine in the field of oncology, laser low-intensity therapy and surgery, dermatology and cosmetology, and others (together with LLC NPP "VELIT", NRC Kurchatov Institute and MNIOI P.A. Gertsena). Laser radiation is transported through four flexible fiber-optic cables with a diameter of conducting quartz fiber of 400 and 600 microns, which allows to perform therapeutic-prophylactic procedure simultaneously in several rooms. Medical installations of this class were delivered to many medical institutions. It should be noted that in this small report on the use of LPM in medicine, we are limited to the development of the Moscow region.

D-10

ACTIVE QUANTUM FILTERS FOR VISUAL AND OPTICAL DIAGNOSTICS

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The development of methods and instruments for research is an integral part of the engineering science. One of the objectives is the development of new methods for high-speed video and photo registration. Nowadays, there is a great number of high resolution cameras for different areas of research, for example, a high-speed recorder with an ultrafast shutter. This equipment can be used for different purposes, one of the advances is the registration of light propagation with an ultra-fast shutter camera. One of the challenges of modern science is to study fast processes in the region of intensive energy fluxes interaction with matter. A great number of works are focused on the study of the extreme state of matter aimed at understanding some fundamental research issues and creating new technology for civil purposes. Visual and optical methods can be successfully used in this research. Imaging of such processes requires the use of the technology allowing to visualize objects blocked from viewing by the background radiation. For achieving this goal, methods based on high speed imaging with external illumination can be used. In such methods, the passive filtration of images and short exposure of the recorder are used to decrease the blocking effect of the background radiation. In general, this method of imaging is based on temporal and spectral filtration [1]. Temporal filtration is achieved by means of the cameras with a fast shutter and spectral filtration by passive band-pass filters. Active quantum filters for temproal and spectral filtrations can be used for imaging. A great number of works focused on the study, development and use of quantum filters for optical signal filtration justify the idea of using this method for this type of imaging. The ideal media for visual research are metal vapors, which have been used as brightness amplifiers [2].

This work discusses the feasibility of developing active filters based on metal vapors for imaging processes blocked by the background glare, in particular a compact active filter for high-speed imaging has been designed. The system with external illumination and active filtration by the quantum filter has been created and used for test object imaging. The results demonstrate the possibility of using such systems for studying real objects.

The current work was supported by the Russian Science Foundation, Project No. 14-19-00175.

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D-11

DUAL-CHANNEL LASER IR RANGE GAS DETECTOR

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The described apparatus is designed for remote sensing of explosive substance vapors and accessory marker agents at the distances from 50 to 100 meters. The gas detector is composed of laser emission unit, emission detection unit and data processing and control unit. Laser emission unit includes two sensing lasers: one is tunable within the range 10.99÷11.4 μm, the second is tunable within the range 7.1÷7.6 μm, as well as it includes a visible range laser (wavelength 0.532 μm) for precise targeting of the gas detector to a selected diffuse reflecting target. The emission detection unit is composed of receiving mirror lens, compensative optical wedge, dividing plate and two photodetectors. The data processing and control unit is composed of AD converter board and a computer. The computer controls operation of the lasers and stepping motors, as well as provides processing and storage of the detected signals.

D-12

A DETERMINATION OF TEMPERATURE AND CONCENTRATION OF GASES BY A METHOD OF APPROXIMATION POLYNOMIALS FROM AN ATTENUATION OF GAS LASER RADIATION

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At present the gas lasers (CO_2, CO, et al.) are widely applied for remote sensing of hot gaseous media due to both advances in theoretical methods of calculating spectral characteristics of gases and improvements in constructions of laser systems. Particularly it is caused by a stabilization of wavelengths of laser radiation, an expansion of spectral ranges by nonlinear crystals, and using of isotopes as laser active media.

In this work temperature and concentration of various gases, including toxic ones, are determined by a method of approximation polynomials [1, 2]. The attenuations of radiation of gas lasers in the gas media are applied as initial data. The spectral characteristics of the gases are modeled on the basis of spectral line parameters from the well-known spectroscopic databases. In the case of the toxic gases (H_2S, SO_2, and NO_2) the spectroscopic databases developed by authors are used that are free for downloading (http://dept5.rff.tsu.ru/slpdb/slpdb.html). The absorption coefficients of the H_2S, SO_2, and NO_2 gases at wavelength of CO_2 laser are also presented in a wide temperature range.

The study was conducted with support from the Russian Foundation for Basic Research (Grant No. 15-01-03176) and by the stipend of the president of the Russian Federation (SP-2547.2016.1 and SP-1766.2015.5).

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D-13

THE ROLE OF AEROSOL AND GAS COMPONENTS OF ANTHROPOGENIC AND NATURAL SOURCES IN EXTINCTION OF RADIATION OF CO AND CO_2 LASERS

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For an interpretation of remote sensing of high-temperature gas-aerosol media (engine exhaust, volcanic eruptions, forest fires, et al.), the knowledge of quantitative contributions of different physical factors in extinction of radiation is necessary. The most important factors are the scattering on aerosols and molecular absorption. The results of measurements of real environments when there are no information by their parameters (gas ratio, concentrations of gases and aerosols, size and spatial distributions of aerosols) are difficult to process. This problem can be solved by accumulating and analyzing the information by these parameters from literature, for example, [1].

In this work the contributions of gas and aerosol components in extinction of the radiation of the CO and CO_2 lasers were determined and their validities were estimated.

The study was conducted with support from the Russian Foundation for Basic Research (Grant No. 15-01-03176) and by the stipend of the president of the Russian Federation (SP-2547.2016.1 and SP-1766.2015.5).

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D-14

THE SOFTWARE "TRAVA+CO_2 LASER" FOR MODELING AN ABSORPTION OF CO_2 LASER RADIATION BY HEATED TOXIC GASES (H_2S, SO_2, AND NO_2)

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The developed software [1] is modified for analyzing a propagation of CO_2 laser radiation in thermodynamically and spatially non-uniform gas media consisting of three gases: H_2S, SO_2, and NO_2. An original part of the software is databases of spectral line parameters of these gases appropriated at temperatures of 300–1500 K that are specially developed by authors.

The concentration and temperature profiles of gases in medium along an optical path are applied as initial data. The shape and width of the radiation line of the CO_2 laser are considered as variable due to the variety of CO_2 laser designs. The possibility of taking into account the absorption of atmospheric gases is also provided.

Finally, the transmittances of different gas media were calculated and the factors were revealed determining the extinction value. The results of numerical calculations were verified on the basis of independent experimental data from literature. The adequacy of a prediction of the extinction characteristics was analyzed. The most informative wavelengths of the CO_2 laser for remote sensing of the considered gases were offered.

The study was conducted with support from the Russian Foundation for Basic Research (Grant No. 15-01-03176) and by the stipend of the president of the Russian Federation (SP-2547.2016.1 and SP-1766.2015.5).

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D-15

ELECTROCONDUCTIVE PROPERTIES OF TITANIUM OXIDE FILMS INDUCED BY LASER ABLATION IN ETHYL ALCOHOL CONTAINING 5% H_2O

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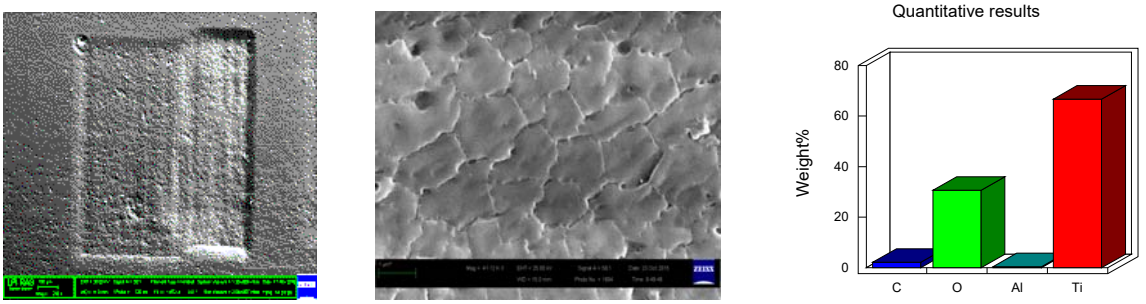
Thin films based on titanium oxide have unique physical and chemical properties [1]. The development of photocatalysts and elements with memristive properties on their basis is a perspective direction.

The oxide films were obtained on the titanium surface by laser ablation method in a C_2H_5OH medium containing 5% H_2O. The Nd : YAG laser was used: $\lambda = 1064$ nm, $\tau = 250$ ps, $\nu = 20$ Hz, $Q = 0.3$ mJ, $Q_S = 0.6$ J/cm^2. The cell with the target was moved under laser radiation by using motorized Standa tables. The treatment area was 2 mm^2.

The analysis of the samples surface at various processing stages was carried out using a scanning electron microscope Carl Zeiss Evo 50 and a specially designed attachment for the readout of volt-ampere characteristics (VAC).

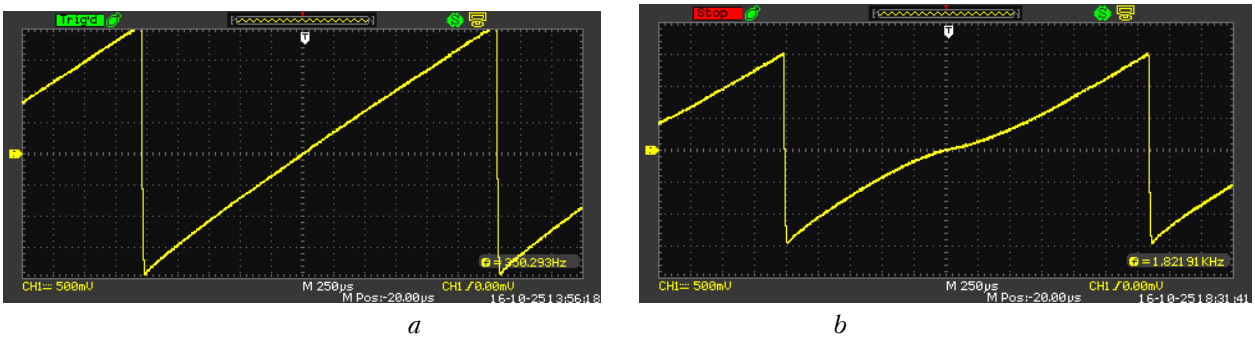
As a result of laser ablation in the medium of ethyl alcohol, the Ti surface of the target was oxidized (Fig. 1).



a *b* *c*

Fig. 1. Surface Ti of the target after laser ablation. QS = 0.6 J/cm^2 (*a*, *b*); EDX analysis of Ti target surface (*c*)

The VAC was readout from the surface of the titanium target before (Fig. 2, *a*) and after (Fig. 2, *b*) laser irradiation in an ethyl alcohol media. As a result, a change in the current-conducting properties of the sample surface characteristic for a memristive structure based on TiO_2 is observed.



a *b*

Fig. 2. VAC of the Ti target surface initial surface (*a*); surface after laser ablation (*b*)

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D-16

THE INFLUENCE OF REFRACTIVE INDEX ON THE SCATTERING OF LASER RADIATION IN THE POWDER DIELECTRIC MEDIA

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The method of laser evaporation is now widely used for the production of nanopowders of oxides, which used for the synthesis of ceramics based on YAG and YSZ. This method is the evaporation of solid target, pressed from the microparticles of desired composition, by the powerfull laser radiation and subsequent condensation of its vapors in the gas stream. In our institute for this purpose use the pulsed CO_2 laser ($\lambda = 10.6$ μm) and ytterbium CW fiber lasers ($\lambda = 1.07$ m) with power up to 1 kW. Using these lasers was obtained Y_2O_3 nanopowders, ceramics Al_2O_3, YSZ, etc. These materials are opaque for the wavelength of 10.6 μm but they have a high transparency for the wavelength of 1.07 μm. In the latter case, the absorption of radiation depends on the concentration of the absorbing material defects. Another important factor is the dispersion of laser radiation in compressed of micron-sized particles of the target, which depends on the refractive index n of its material. For example, CaF_2, and 1% Nd : Y_2O_3 have the same level of domestic absorption ($\sim 1^{-3} \cdot 10^{-3}$ cm^{-1}), but different n (1.42 to 1.85 for CaF_2 and Y_2O_3). The radiation power of the fiber laser 600 W Performance production of nanopowder of 1% Nd : Y_2O_3 were 23 g/h and the goal CaF_2 not even evaporated.

The report presents the results of numerical simulation of scattering of the radiation of the fiber laser in the target from transparent balls with diameters from 400 nm to 3 μm, the packing density of (~ 55% and one particle. This model is described by the wave equation for electromagnetic wave. Absorption internal exposure in the target were not considered. The calculation was carried out for materials with different refractive index: MgF_2 (1,38), CaF_2 (1,42), Al_2O_3 (1,75), Y_2O_3 (1,85), YSZ (2.12). The intensity of the incident laser radiation is always taken equal to 0.46 MW/cm^2.

The calculated field distribution for a porous target, and for a single particle has a complex structure with local maxima of the radiation intensity I, which is caused by interference of light, reflection and refraction at the boundaries of the particles. The radiation intensity in these maxima depends on the diameter of particles, their refractive index n and the wavelength of the radiation. For example, when Y_2O_3 ($\lambda = 1.07$ μm) increase in particle diameter from 1 to 3 μm leads to periodic bursts of I from 2 to 10 MW/cm^2. With increasing n the maximum value of I in local maxima increases. For example, for porous targets of CaF_2 I is equal to 11 MW/cm^2, and the YSZ, I = 67 MW/cm^2. Thus, the characteristic penetration depth of the radiation in CaF_2 is 60 μm, and the YSZ due to the higher dispersion of only 18 μm.

In porous target local maximums of radiation can occur in the space between the particles, on their surface or volume. The high radiation intensity in the point of local maximum contributes to radiation damage such particles. Qualitatively, this could explain why the Y_2O_3 extruded under the influence of radiation of the laser to 600 W fiber evaporates, and not CaF_2.

Work is performed under the topic of the state task No. 0389-2014-0027, and partially supported by the RFBR Grant No. 17-08-00064 A.

D-17

LASER EVAPORATION OF FAST-MOVING TARGET

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Evaporation of a stainless steel target moving with high speed (~ 50 m/s) under action of laser radiation was investigated theoretically and experimentally. In our experiments we used an e-beam controlled CO_2 laser, which generated pulses with duration of up to 1 ms and energy of up to 100 J.

We carried out the microscopic research of laser beam trace on the target's surface and investigated the dynamics of the laser plume luminescence.

For theoretical research we used 3D numerical model, taking which took into account: heating, melting and evaporation of target by laser beam, and, thermal effect of oxidation reaction. The results of calculations can explain the experimental data quite good. In particular, it is possible to explain occurrence of interrupted trace on the target at 12–24 kW of laser power that corresponds to intensity in the focal spot of ~ 10^7 W/cm^2. This power is a threshold of unstable mode of laser evaporation. The unstable mode is caused by a lack of oxygen, which was pushed away with metal vapor. The lack of oxygen leads to shutting down the oxidation reaction on target's surface.

The reaction resumes when the vapors fly away and oxygen enriches the surface. As the result pulsed mode of evaporation takes place. This phenomenon was observed as pulse mode of laser plume luminescence and was obtained by calculations.

D-18

IMPROVING THE DECODING CHARACTERISTICS OF DIGITAL IMAGES WITH A COMPUTER-AIDED CORRECTION OF DISTORTION CAUSED BY PHASE SHIELD

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The task of filtering the distortion caused by phase shield represents a great practical importance in many application areas. Of special interest are cases where these distortions are caused by the light passing through an unstable environment, for example, a turbulent fluid or gas. The classical problem of this type is a correction of optical atmospheric distortion during astronomical observations [1]. A similar problem arises in the laser ranging of objects located at a distance of several kilometers. The traditional solution is the use of adaptive optics systems, which requires the wavefront sensors and deformable mirrors. There are also works [2, 3], where distortion during observation adjusted only by calculations, but it does require some modifications of the optical system.

It is proposed to consider the problem in the following formulation. There is an image of an object captured through a phase shield, i.e., having indefinite distortion. Besides, no information about the structure of the phase shield is recorded. We need to eliminate distortions as much as possible to enhance the probability of correct decryption (or recognition) of an object in the image. Thus, the problem statement differs from the traditional one in the following peculiarities: 1) it is impossible to get more information about wavefront, because the image captured without the use of specialized equipment; 2) there is no special requirements to the performance efficiency of correction procedure. Such a problem is very actual for the processing of photo and video images obtained by popular digital devices, like smartphones, car video recorders, CCTV cameras, etc. Currently, the possibility of improving the quality of these materials is limited by digital filtering tools, not taking into account the nature of the occurrence of distortion.

Described problem can be reduced to a problem of multidimensional nonlinear optimization. As is known, the phase distribution $\varphi(x,y)$ of wavefront can be represented as an expansion in Zernike polynomials:

$$\varphi(x,y)=\sum_{p=1}^{n} a_p Z_p(x,y),$$

where $Zp(x, y)$ – the p-order Zernike polynomial; n – the number of polynomials; a_p – unknown coefficients which are usually estimated using data from a Shack- Hartmann sensor. Knowing $\varphi(x, y)$, the distortion correction is accomplished by direct and inverse Fourier transform as follows:

$$I(x,y)=F^{-1}\left(\frac{F(I'(x,y))}{F(\varphi(x,y))}\right)$$

Here $I'(x, y)$ – the original image of the object; $I(x, y)$ – the corrected image, F and F^{-1} – direct and inverse Fourier transform, accordingly.

Let's construct the correction quality function, which will be used as an optimization target:

$$D(I,\ I') \equiv D(a_1,\ a_2, \ldots\ ,\ a_n) \to \min$$

Optimization is performed in the R^n, the unknown parameters are the coefficients of expansion in Zernike polynomials. The particular form of the function D may be defined in various ways [4], the best option depends on the specific type of the image. Thus, widespread method is the use of image quality evaluation function based on the entropy:

$$D = \frac{\sum\limits_{x,y} p_{xy} \log_2 p_{xy}}{\log_2 N},$$

where p_{xy} – the probability of the presence of brightness value $I(x,\ y)$ in a pixel, i.e. the normalized value of histogram for $I(x,\ y)$; N – the number of pixels.

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D-19

A UNIT FOR REGISTRATION OF LUMINESCENCE SPECTRA OF NATURAL OBJECTS

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In the paper a simple spectral unit designed for excitation and registration of luminescence spectra of natural objects is described. The unit is composed of two basic systems: an excitation system and a registration system. Either X-ray or laser emission can be used for luminescence excitation.

The registration system is based on lattice monochromator. The studied object is placed directly at the monochromator entrance slit. Two lead plates are located inside the monochromator case. They protect photodetector that is located behind the monochromator exit slit from X-ray radiation. When emission is decomposed by the diffraction grating, spectrum aliasing occurs, which can be eliminated using optical filters.

The diffraction grating rotation is controlled by a computer. Manual control of the rotation angle is also provided.

The PMT signal, amplified by dc amplifier, goes to analog-digital converter (ADC). Digitized ADC signal goes to COM port of the computer. Spectrum projection is displayed on the screen and can be recorded to computer's memory.

Switching of analog devises to the dc amplifier output is provided.

Examples of processing of the experimental results, obtained using the abovementioned unit, are presented in the paper.

D-20

MOBILE MULTIWAVE AEROSOL FLUORESCENT LIDAR

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The task that faced the authors was construction of a mobile lidar complex for detection and investigation of aerosol-gas formations in the atmosphere. The complex must be constructed of commercial industrially produced components as much as possible. Many of engineering solutions had been previously worked out by the authors when the first lidar of such type was developed [1].

The complex is designed for study of capabilities of lidar sensing for remote investigation of aerosol-gas formations by their fluorescence and Raman scattering spectra, as well as topographyc objects by fluorescence spectra of their surfaces. The complex has been tested in 2016, and may be applied for atmospheric sensing, for detection of potentially hazardous and dangerous admixtures above the cities, industrial and agricultural emissions, including emissions after disclosures of agricultural animal burial sites. The complex is mounted on a motor vehicle chassis and is energy-independent, and that allow using it for remote sensing of different objects in different natural conditions. Probing distance: 30000 m in elastic scattering channel and 5000 m in fluorescence channel.

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D-21

CONDUCTIVE TRACKS FORMATION BY LASER SINTERING OF SILVER INK

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D-22

SPECTRAL STUDY OF ANOXYGENIC PHOTOTROPHIC MICROORGANISMS IN THE STRATIFIED RESERVOIRS OF THE KANDALAKSHA BAY AT THE WHITE SEA

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The natural reservoirs found in different stages of isolation from the White Sea are a special group of hydrological objects. Their origin and evolution are associated with the elevation of the Kandalaksha Bay coast with the speed of about 4 mm per year. Stratified structure in such water

bodies is formed under the influence of conditions affecting not only physicochemical characteristics of the water but biological ones as well.

In aquatic systems with abnormal circulation of water the anoxygenic phototrophic microorganisms, green sulfur bacteria (GSB), may be of a particular interest. These bacteria are widespread in such areas because they are able to use hydrogen sulfide instead of water in photosynthesis. Photosynthetic pigments of GSB are bacteriochlorophylls (BChls) and carotenoid pigments. GSB are divided into two types according to their pigmentation: green-coloured bacteria containing bacteriochlorophylls *c* and *d* and carotenoid chlorobactene, and brown-coloured bacteria containing bacteriochlorophyll *e* and carotenoid isorenieratene. The presence of the certain type of bacteria in environment depends on several conditions and may vary depending on the status of the reservoir and external factors. The optical properties of the pigments make possible the environmental *in situ* monitoring and the study of the properties of microorganisms using spectral methods.

During the spring expedition of 2017 water was sampled at various horizons from several relic lakes: Trekhtzvetnoe ("Tricolor"), N. Ershovskoye, Lagoon on the Cape Zeleny ("Lagoon on the Green Cape") and Bolshie Hruslomeny ("Large Hruslomeny"). Absorption spectra and fluorescence emission and excitation spectra of the water samples from different depths were measured in laboratory. The recorded results were compared with the spectra of pure cultures of GSB. The concentrations of different types of bacteria were found applying mathematical methods to detected spectra.

D-23

HIGHLY EFFICIENT EXCITATION OF THE ACTIVE LASER ELEMENTS, THE STRONTIUM VAPOR WITH THE VOLUME OF THE MEDIUM UP TO 1000 cm^3

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Currently, the metal vapor lasers are highly efficient sources of optical radiation, however, many characteristics of laser radiation, this class of lasers is superior to solid state and semiconductor lasers. Therefore, the study of possibilities of increasing the specific characteristics of efficiency and expansion of spectral range is of interest to scientists. This paper presents the results of investigations of dependencies of the output power of the active element with a large volume of the active medium on the parameters of the excitation pulse. The obtained total average lasing power on all IR transitions 20W more than one active element with an unstable resonator.

This research carried out in 2017 was supported by "The Tomsk State University Academic D.I. Mendeleev Fund Program" Grant (No. 8.2.04.2017).

D-24

DESIGN OF TECHNOLOGY OF THE HARDENING LASER TREATMENT OF METAL-CUTTING TOOL ON THE METHOD OF FINITE ELEMENTS

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The results of the investigation of the regularities of the formation of the temperature field at the hardening of the cutting tool by pulsed laser radiation, taking into account the geometric parameters of the tool and the spatial, temporal and energy characteristics of the laser radiation are given in the work. The task of heating of the tool cutting wedge at the laser hardening was solved in three-dimensional formulation by finite element method using the software package ANSYS Workbench. The laser treatment of the cutter from steel R18 with a wedge angle equal to $\beta = 60$, with a nose

radius between the main and end cutting edges equal to $R = 0.8$ mm and with a sharpening radius equal to $r = 0.1$ mm was modelled. It was assumed that hardening laser treatment was realized using the pulse triangular shape with uniform distribution of energy density of laser radiation the cross section of the laser spot. Special attention was paid to analysis of heating features of the cutter tip.

The parametrical electronic model and methods of calculations of the temperature field on the cutting edges and at the tip of the cutting wedge at the monopulse laser hardening were developed taking into account geometrical parameters of cutting tool and spatial, power and temporary characteristics of laser radiation. The regularities of formation of temperature field at hardening cutting tools by pulsed laser radiation were established. The efficiency of the hardening was estimated by values of length, width and depth of hardened zones which obtained by modelling. The regimes of laser treatment providing the best parameters of a zone of hardening were defined.

It was shown that the developed model can be used for selection of process parameters of pulsed laser hardening of cutting tools of various types and their applications.

D-25

NON-LINEAR OPTICAL PROPERTIES OF NANOSIZED METAL OXIDE PARTICLES OBTAINED IN PLASMA DISCHARGE IN LIQUID PHASE UNDER ULTRASONIC CAVITATION

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The nonlinear response of metal oxide nanoparticles obtained by the acoustic plasma method is measured in aqueous disperse systems at a wavelength of 532 nm. Induced absorption is detected in the Cu_2O, WO_3 and ZnO disperse systems, and bleaching is detected in the Fe_2O_3 system. The real and imaginary parts of nonlinear third-order susceptibilities are determined.

This work has been partially supported by RFBR, Projects No. 15-02-03559.

D-26

DEPTH DISTRIBUTIONS OF FLUORESCENCE AND CONCENTRATION OF GREEN SULFUR BACTERIA BACTERIOCHLOROPHYLL FROM WHITE SEA RELIC LAKES

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Spectral methods to study natural water bodies play an important role in the research of the Arctic region. Anoxygenic phototrophic bacteria (green or purple sulfur bacteria) which are important for the existence of the microbial ecosystems can inhabit at a certain depth the anaerobic zone of water reservoirs. Different types of bacteriochlorophyll (BChl) are the main photosynthetic pigments of bacteria that have different spectral characteristics [1]. Fluorescence spectra of green sulfur bacteria demonstrate two bands in the IR spectral region: (1) with maximum at wavelengths 740–770 nm depending on the concentrations ratio of two types of bacteria with different pigmentation: green-colored (containing BChl *d* with emission shifted towards longer wavelengths) and brown-colored (containing BChl *e* with emission shifted towards shorter wavelengths); (2) emission band of BChl *a* with maximum at 815 nm [2–3]. Water samples from several reservoirs separated from the White Sea [4] that contain green sulfur bacteria were collected by multisyringe water sampler from layers with maximal concentration of microorganisms with a step of 2.5 cm in depth at the end of July 2016. Fluorescence spectra were registered by luminescence spectrometer Solar CM2203. BChl concentration was calculated according to the technique [5] using absorption

spectra of acetone-methanol (7 : 2) extractions measured with a Solar PB2201 spectrophotometer. Vertical distributions in chemocline were plotted using fluorescence measurement data (fluorescence intensity maxima that correspond to BChl emission at region 740–770 nm) and BChl concentration calculations. It was discovered that vertical distributions of fluorescence intensity and BChl concentration were not similar: the water layer with maximum fluorescence intensity was located 10–15 cm lower than the depth of highest bacteria pigment concentration in all studied water bodies. This fact can be explained by BChl fluorescence quenching in the upper layer of chemocline with insufficient value of redox potential Eh. As normal functioning of anoxygenic phototrophs requires certain conditions (including Eh), the redox-dependent fluorescence quenching index defined as the ratio of BChl fluorescence intensity to pigment concentration, may serve as an indicator of physiological state of phototrophic bacteria in the anaerobic layer.

The reported study was funded by RFBR according to the research Project No. 16-05-00548a.

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D-27

ON THE POSSIBILITY OF DETERMINING PARAMETERS OF A HOLOGRAPHIC LAYER USING THE TRANSMISSION SPECTRA OF HOLOGRAPHIC SENSORS BASED ON SILVER EMULSIONS

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Holographic sensors are thick-layered Denisyuk holograms, with their polymer matrix configured to detect a certain class of test substances. When the substance interacts with the sensor dipped into the solution, the sensor changes its swelling and higher concentration of the test substance in the solution leads to higher swelling of the sensor. As a result, the reflection line changes its position in the spectrum. This fact can be detected with the use of a spectrometer or visually as the sensor color under exposure to white radiation is changed.

In the present work it is shown using the Maxwell-Garnett approximation for a composite medium that the transmission spectrum of holographic layers based on silver nanograins (i.e. losses are present in the system) is governed by three additional parameters alongside with the parameters of the Bragg dip. One parameter is related to light scattering and another is attributed to absorption.

D-28

LASER TECHNOLOGIES FOR COMPUTER-AIDED CUTTING OF 3D GLASS OBJECTS

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Designing new devices (in particular, the devices for space and aviation applications) that would provide the desired technical properties and superior performance is impossible without the development of novel technologies. The air velocities achieved in the state of the art aviation dictate the need for new materials that could withstand high loading. Plexiglass which is extensively used in designing the lights for aircrafts has a number of drawbacks. First, one should mention poor fire behaviour and high value of the thermal-expansion coefficient. In addition to that, plexiglass reveals low surface hardness as compared to that of silicate glass, i.e. plexiglass is more prone to slight mechanical damage. Therefore, utilization of details made of silicate glass appears to be very promising. These details demonstrate improved environmental durability. However, processing of the silicate glass is much more complicated and it is hard to give it the desired shape and properties. In our point of view, controlled laser thermocracking (CLT) is the most advanced technique for cutting the silicate glass as this method provides high strength of the obtained details and high precision and rate of the glass cutting process. The work on processing of large-sized silicate glasses carried out at our institute promoted the development of several promising laser technologies such as computer-aided cutting of 3D glass objects [1], obtaining blunt edges during the cutting [2], cutting of large-sized flat glass objects using the glasses of small thickness (as small as 0.2 mm), laser technique for peeling off thin conducting coatings from large-sized curved glasses [3] and etc. Further development in the area of the laser processing of glass would provide significant improvement in performance of the glasses with respect to their use for constructing optical elements.

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D-29

OBTAINING OF HYDROGEN IN ACOUSTOPLASMA DISCHARGE IN LIQUIDS

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The paper shows, that a low-temperature plasma initiated in liquid media in interelectrode discharge gap is able to decompose hydrogen containing organic molecules resulting in obtaining gaseous products with volume part of hydrogen higher than 90% (up to gas chromatography data). Tentative assessments of energy efficiency, calculated with regard for hydrogen and feedstock heating

value and energy consumption, have shown efficiency factor of 60-70%, depending on the source mixture composition. Theoretical model calculations of discharge current and voltage have been performed; the values are in good accordance with experimental data. The problems of excitation of hydrogen molecules for the purpose of creating effective VUV sources are discussed.

This work has been partially supported by RFBR, Projects No. 15-02-03559-a.

D-30

STUDY OF PHYSICAL PROPERTIES OF METAL OXIDE NANOPARTICLES OBTAINED IN ACOUSTOPLASMA DISCHARGE

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Nanoparticles of tungsten, copper, iron, and zinc oxides were synthesized in acoustoplasma discharge. Their size distribution was studied by electron microscopy and laser correlation spectroscopy. Ultrasound was found to narrow significantly the size distribution width of zinc oxide nanoparticles. Water suspensions of zinc oxide nanoparticles showed photoluminescence in red and near infrared spectral ranges, which makes them a promising material for luminescent diagnostics of biological systems.

This work has been partially supported by RFBR, Projects No. 15-02-03559.

D-31

LUMINESCENT PROPERTIES OF NANOPARTICLES SYNTHESIZED IN ELECTRIC DISCHARGE IN LIQUID UNDER ULTRASONIC CAVITATION

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In this paper, differences in the luminescence intensity of nanoparticles of metal oxides synthesized in electric discharges in liquid media under the influence of intense ultrasonic vibrations prior to cavitation and after the start of cavitation regime have been studied.

The increase in the luminescence intensity of nanoparticles obtained by ultrasonic cavitation can be explained by the formation of defects in oxide crystals under the influence of intense mechanical action. In the process of synthesis, the particles are exposed not only to the action of electromagnetic fields, but also to shock waves during the collapse of cavitation bubbles, which leads to the formation of defective valence structures and delocalization of electrons.

This work has been partially supported by RFBR, Projects No. 15-02-03559.

D-32

DYNAMIC CHARACTERISTICS OF ELECTRIC DISCHARGE IN LIQUID UNDER ULTRASONIC CAVITATION

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The characteristics of electrical discharges in liquid media under the influence of intense ultrasonic vibrations are investigated and the difference in dynamic characteristics of discharges before cavitation and after cavitation begins. The experiments carried out during this work made it possible to establish that in a liquid in an intense ultrasonic field above the cavitation threshold there exists a special form of an electric discharge characterized by volumetric luminescence in the entire space between the electrodes and the current-voltage characteristic inherent in an anomalous glow discharge in a gas. The possibility of creating conditions for applying 3D nanocoatings to optical diffraction elements in such a discharge is discussed.

This work has been partially supported by RFBR, Projects No. 15-02-03559.

D-33

THE EFFECT OF TUNGSTEN ON THE PROPERTIES OF GOLD-DOPED SILICON

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In recent years, the influence of various coatings on the properties of a semiconductor material has been actively studied. Thus, for example, the effect of a tungsten coating on the properties of silicon during heat treatments was investigated [1]. In this study, the effect of a tungsten coating on the photoelectric properties of silicon doped with gold was studied. Samples from silicon of KEF-3.5 brand, doped with gold with a deposited tungsten film and with a free surface (i.e., without a tungsten film) were prepared. The original silicon of KEF-3.5 had a resistivity of 5 Ω·cm and a photoconductivity relaxation time of about 200 μs. The effect of tungsten atoms (tungsten coating) on the properties of silicon doped with gold was studied.

The following results were obtained after gold ligation in the presence of tungsten:

1. The resistivity of the investigated samples has increased significantly approximately four orders of magnitude.

2. The photoconductivity relaxation times have decreased noticeably by about two orders of magnitude because of the influence of both gold and tungsten [2].

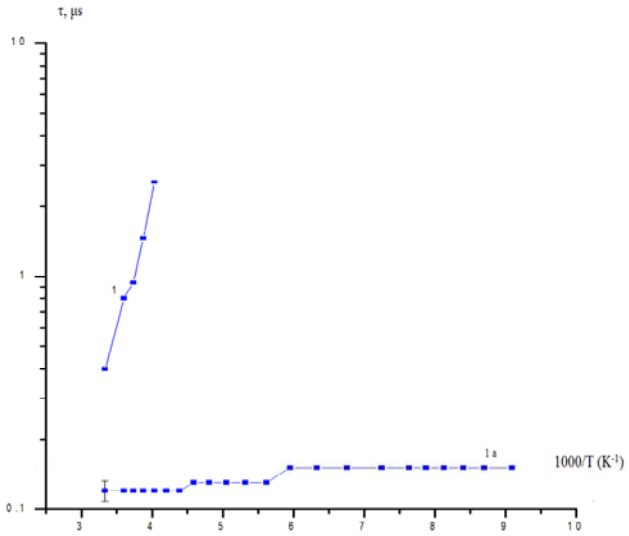
The temperature dependences of the relaxation times of the photoconductivity τ_f of the fast process and the τ_s slow process for different samples were obtained, of which the impurity activation energies were determined, see Figure, where 1 is a slow process, and 1a is the fast process of photoconductivity relaxation.

The analysis of the obtained data led to the following conclusions:

1. Tungsten helps the creation of additional recombination centers, which lead to a significant decrease in the time of the rapid process of photoconductivity relaxation.

2. Tungsten creates capture levels that reduce the time constant of the slow relaxation process by about 10 times.

3. The energy level in the band gap of silicon $E = Ec - (0.23 \pm 0.02)$ eV, associated with the centers of tungsten was discovered.



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D-34

ANTI-STOKES LUMINESCENCE IN NANOSCALE SYSTEMS

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The work is devoted to the investigation of the time dependence of the luminescence of nanomaterials that appears in the blue region of the spectrum under the impact of nanosecond pulses of a ruby laser. The nature of this luminescence, which is an anti-Stokes luminescence with respect to laser pumping, has not been finally clarified. It can be caused by both multiphoton processes and effects close to the phenomenon of triboluminescence. Triboluminescence has recently attracted great interest due to the fact that this effect can be used to create sensors of mechanical effects, in particular, for recording impacts of small meteorites on the surface of spacecraft. In our work, nanomaterials with different composition and different morphology, as highly ordered (synthetic opal matrices and composites based on them), and disordered media (nanoparticle suspensions) were used as samples. Our experiments have shown that the luminescence generated in nanomaterials under the action of laser radiation has two components - short and long. Short has a duration on the order of microseconds, the duration of a long one depends on the material and can be up to several seconds. A long component of luminescence appears only when the samples are substantially cooled. The time dependences of anti-Stokes luminescence in different samples are recorded at different temperatures. The temperature thresholds for the appearance of a prolonged glow are found. Possible mechanisms of the observed effects are discussed.

D-35

ON A PARTICULAR MECHANISM OF LIGHT ABLATION OF NANOSTRUCTURES

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Laser ablation of metals is widely used for formation of thin films, nanoparticles and other nanoobjects. In the present paper we regard the interaction between a laser pulse (LP) and a

nanoparticle (NP). Let us define the time scales under consideration. First, it should be noted that the time of propagation of the field through the volume of the nanoparticle is small:

$$\tau_v = 2a/c \leq 10^{-17} \text{ s}.$$

For the nanoparticles with the diameter smaller than 30 nm this time is shorter than the oscillation period of the incident wave corresponding to the optical band:

$$\tau_v \sim 1.6 \cdot 10^{-15} \text{ s}.$$

Moreover, it is much shorter than the thermalization time in the nanoparticle, i.e. characteristic time of energy transfer from the electron gas to the lattice:

$$\tau_i \sim 10^{-12} \text{ s}.$$

We will regard two models describing the interaction between the NP and radiation. These models are relevant for different LP durations. The first model is used for consideration of femtosecond pulses with the LP duration $\tau_p \ll \tau_i$, and the second model corresponds to pico- and nansecond pulses with $\tau_p \gg \tau_i$.

For specific LP intensities and durations with the laser operating at certain optical frequencies the temperature rises to the values higher than the boiling point of gold T_{ev} = 3129 K. However, when a near-infrared laser is utilized the effect of heating of the nanoparticle is not a governing factor anymore. The LP intensity and duration of the laser operating in the near-infrared region can be specified such that ablation will be observed without evaporation of the NP.

D-36

EFFECT OF THE FERROUS OXIDE NANOPARTICLES ON THE CONCENTRATION-SIZES RATIO IN THE BLOOD PLASMA AND SERUM, OR MODEL PROTEIN SOLUTIONS

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This paper is devoted to the study of the effect of ferrous oxide nanoparticles obtained in acoustoplasma discharge with cavitation on the concentration and the sizes of proteins and their complexes in the model solution, serum and blood plasma samples. Dynamic and static light scattering data show that the adding of nanoparticles to the protein solutions does not significantly change the distribution of the intensity of scattered light by particle sizes, while changing the concentration of particles of already existing sizes. This conclusion was drawn from a comparison of the graphs of the dependence of the concentration of particles on their sizes for blood plasma and model solutions without the addition of nanoparticles and with their addition. For blood plasma and model solution of fibrinogen with thrombin, the slopes of the lines describing the concentration-size ratio were practically the same, and were equal to $k = -(4{,}0 \pm 0.2)$. While in the case of adding nanoparticles, the slope of the straight line increased $k = -(5.6 \pm 0.3)$, which indicated a change in the concentration of particles of already existing sizes. The data obtained can provide information on the mechanisms of interaction of nanoparticles with plasma proteins.

D-37

OPTICAL-FIBER BUNDLE SYSTEM FOR FORMATION OF IMAGES ON THE BRIGHTNESS AMPLIFIER INPUT

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The application of the laser systems with brightness amplifiers, especially of so called laser monitors, is one of methods for processes diagnostics of the high-concentrated energy streams with

matter interaction. For the first time this approach has been realized experimentally in the scheme of a laser Projective microscope where the copper vapor laser tube (the main wavelength $\lambda = 510.6$ nm) was used as the brightness amplifier. The amplifier acts as the narrow-band selective filter [1] which cuts different background/parasitic flares on the photo detector. This feature resulted in broad usage of such devices in the field of visualization for processes blocked by background radiation. However, the initial optical scheme of this monitor possesses one essential drawback – an object has to be motionless relative to the device. When this object is exposed to high power energy flux (for example, during laser welding where complex mutual movements of the processed details and laser beam are implemented), this drawback creates a number of considerable, or sometimes even non-fixable, problems.

It is possible to solve this problem by utilizing classical optical scheme of fiber-optic bundle [1], serving for transfer of the image from one end face to another, combined with additional lens to transfer the image into active medium for a spectral filtration. Due to mechanical flexibility of a fiber-optic bundle, in such a scheme the objective located before the object is not rigidly mechanically connected with the brightness amplifier and, thus, can rotate for any angle within some predefined range. In current work we present the results of development of the laser monitor scheme with a fiber-optic bundle to transport the image the entrance of the brightness amplifier. We report resolution measurements and assess image quality. Finally, we compare the images on the entrance and the exit of the brightness amplifier.

1. *Optical* systems with brightness amplifiers / ed. by Petrash. // Proc. FIAN. 1991. V. 206. 152 p.

D-38

DEVELOPMENT OF THE EXPERIMENTAL SETUP FOR DETERMINATION OF NANOPARTICLES SIZES BY NANOTRACING

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Optical methods for studying of nanoparticles in liquid dispersions are widely used because they are highly sensitive, non-invasive and can be performed with high speed of measurement.

Nanoparticle tracking analysis (nanotracing) is a combination of optical microscopy and light scattering methods. In this method, nanoparticles sizes are determined using direct measurement of Brownian motion trajectory for each observed particle in liquid. The method allows to measure particle size distribution and concentration of individual components in a polydisperse colloidal system, even for extremely low particle concentrations.

At present, nanotracking is widely used in the scientific community all over the world. However, lack of available devices for nanoparticle tracking analysis prevents the using of this method for scientific research in Russia, because foreign devices have a high cost and there are no domestic analogues.

Thus, there is a necessity to develop an available domestic device for nanoparticle tracking analysis. For this purpose we have developed the experimental setup for analysis of nanoparticles trajectories. Laser with a wavelength of 635 nm is used as a radiation source. In the experiment, light scattered by particles is captured using the CCD camera with the 20x microscope objective. The resulting video of the particles Brownian motion allows to analyze individual particles trajectories and determine diffusion coefficient and particles size.

The first results of analysis for samples of polystyrene latex nanoparticles were obtained using developed experimental setup.

The obtained results will be used for development of device for nanoparticle tracking analysis.

This work was financially supported by the Ministry of Education and Science of the Russian Federation (Agreement No. 14.584.21.0021, identificator RFMEFI58417X0024).

D-39

A MECHANISM FOR CREATING AN INVERSION OF THE POPULATIONS OF ENERGY LEVELS

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Let us consider an active medium in which the following processes occur under the neutrons influence: the nucleus X + a neutron → the nucleus Y in an excited state → the nucleus Y in an isomeric (metastable) state → the nucleus Z in the basic state. For example, $Gd^{155}+n \rightarrow Gd^{156*} \rightarrow Gd^{156m} \rightarrow Gd^{156}$. The nuclei Y and Z undergo the radiation neutron capture, that is they are "bombarded". The isomer Gd^{156m} has the half-decay period of 1.3 ms and decays releasing gamma quantum with the energy of 2.1376 MeV.

For evaluating the possibility of active medium neutron pumping by means of radiation neutron capture it is necessary to solve the differential equation system:

$$\begin{cases} \dfrac{dx}{dt} = -\sigma_1 x\Phi \\ \dfrac{dy}{dt} = -\sigma_1 x\Phi - \sigma_2 x\Phi - \lambda y, \\ \dfrac{dz}{dt} = -\sigma_3 z\Phi + \lambda y \end{cases}$$

where X, Y, Z are nuclei concentration, Φ is the neutron flux density, σis the microscopic cross section of neutron capture, λ is the decay constant of isomers nuclei.

To determine the possibility to achieve the inverse population condition when pumping the active medium created by Gd nuclei and the neutrons with the flux density Φ up to $10^{16}\ \mathrm{sm}^{-2}\cdot\mathrm{s}$, the following formulae can be used:

$$\frac{y(t)}{z(t)} \approx \frac{\lambda t - (\sigma_1 - \sigma_2)\Phi t}{S\lambda},$$

where

$$S = \frac{1-(\lambda+2\sigma_3\Phi)t}{\lambda+\sigma_3\Phi} - \frac{1-(\sigma_1-\sigma_2+2\sigma_3)\Phi t}{(\sigma_1-\sigma_2+\sigma_3)\Phi} + \frac{(\lambda-(\sigma_1-\sigma_2)\Phi)(1-\sigma_3\Phi t)}{(\sigma_1-\sigma_2+\sigma_3)\Phi(\lambda+\sigma_3\Phi)}.$$

Pumping the active medium created by Gd nuclei, the neutrons with the flux density Φ equal to $10^{13}\ \mathrm{sm}^{-2}\cdot\mathrm{s}^{-1}$, the condition $\dfrac{y(t)}{z(t)} \approx 1$ is achieved within several tens if seconds.

D-40

STIMULATED LOW-FREQUENCY RAMAN SCATTERING IN AN AQUEOUS SUSPENSION OF NANOPARTICLES

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Cupric oxide nanoparticles with average size of 213.2 nm, were synthesized in acoustoplasma discharge for investigating their vibrational properties. The low-frequency acoustic mode in cupric

oxide (CuO) nanoparticles has been studied by stimulated low-frequency Raman scattering (SLFRS). SLFRS conversion efficiency, threshold and frequency shift of the scattered light are measured.

D-41

DIELECTRIC ANISOTROPY OF HUMAN BONE IN THE THZ FREQUENCY RANGE

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Terahertz time domain spectroscopy was applied to study anisotropic properties of a human jawbone in transmission geometry. A fiber femtosecond laser with a pulse width of 113 fs, and wavelength of 800 nm with average power of 120 MW was used as a laser source for pumping and detecting terahertz pulses. The polarization of the THz pulse was linear. The experimental results indicate that the refractive indices $n(\omega)$ and the absorption coefficients $\alpha(\omega)$ of a human jawbone change with the alteration of the direction of the linear polarization vector of the electric field of the THz pulse relative to the axis of the plate of the human jawbone.

D-42

EXCILAMPS FOR SEWAGE TREATMENT

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District sewage treatment facilities designed and built during the Soviet era to clean up drains of residential areas, towns and neighborhoods located beyond the city limits, and having a population of up to 10 thousand people, as a rule, no longer fulfill their design functions. Budgets of rural settlements and districts do not cope with the timely reconstruction of such treatment facilities. On a national scale, these are thousands of district treatment facilities that are sources of pollution of reservoirs by pathogenic microflora and helminth eggs. The main reason for the unsatisfactory operation of such wastewater treatment facilities is the presence in the drains of high concentrations of detergents and petroleum products that disrupt the design work of biofilters. The solution of the problem can be ultraviolet (UV) disinfection of sewage at the biofilter outlet.

The use of mercury UV lamps for wastewater post-treatment poses a danger to the environment in the event of the destruction of the bulb and requires special measures for the disposal of used lamps. In addition, the emission of mercury vapor in the atomic line at 254 nm inefficiently destroys the helminth egg shell.

Alternative sources of spontaneous UV radiation – barrier-discharge excilamps, emitting in molecular bands with maxima at wavelengths of 222 and 282 nm – do not contain mercury, effectively destroy the shells of helminth eggs (KrCl, 222 nm) such as *Opisthorchis felineus* and *Diphyllobothrium latum* [1], provide disinfection of wastewater from coliform bacteria and thermotolerant coliform bacteria (XeBr, 282 nm), including bacteria of the genus *Proteus* [2].

The use of excilamps as radiation sources in UV decontamination units at the outlet of biofilters of district treatment facilities that discharge water into the rivers of the Ob basin can provide purification of wastewater from eggs of *O. felineus* and *D. latum*, which in the future (20-30 years) can reduce the intensity of a natural epidemiological focus of diseases such as opisthorchiasis and diphyllobothriasis.

In this paper we report preliminary results of the use of an experimental setup based on barrier-discharge KrCl (222 nm) – and XeBr (282 nm) excilamps for sewage treatment at the outlet of the biofilter of district sewage treatment facility in the settlement Airport, rural settlement Mirnenskoe of Tomsk district, Tomsk region. At the surface irradiation dose of up to 25 mJ/cm^2, the number of viable eggs of *O. felineus* decreased by a factor of 6.

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D-43

THE EFFECT OF THE IMPURITY-DEFECTIVE COMPOSITION OF A DIAMOND SAMPLE ON THE OPTICAL ABSORPTION AT A NEUTRAL VACANCY

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Intrinsic defects and impurity-defective complexes (primarily nitrogen ones) generate several dozen vibration-electronic (vibronic) systems in the optical absorption (OA) spectra of diamond samples [1].

The GR1 vibronic system, associated with a neutral vacancy, consists in the zero-phonon line (ZPL) doublet at 740.9 and 744.4 nm and the phonon sideband in the spectral region of 660–730 nm. From a practical point of view, GR1 vibronic system is of interest as a basis for creating primary luminescent converters of ionizing radiation for the nuclear industry and experimental physics of elementary particles due to subnanosecond luminescence decay time at room temperature.

Despite the existence in the literature of extensive experimental data on the luminescent characteristics of the vibronic system of neutral vacancy in diamond, the relationship between the ZPL of GR1 vibronic system in OA spectra as a function of the impurity-defective composition of samples has not been adequately studied.

In this paper, we present the results of an investigation of the OA spectra of 4 diamond samples demonstrating GR1 vibronic system, as well as a number of other vibronic systems, associated with nitrogen impurity-defective complexes. Measurements of the OA spectra were made in the temperature range 85–300 K.

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Session E
NON-COHERENT UV AND VUV SOURCES

E-1

THE APPLICATION OF UV LEDS FOR DIFFERENTIAL OPTICAL ABSORPTION SPECTROSCOPY

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Modern UV LEDs represent a potentially very advantageous alternative to thermal light sources, in particular xenon arc lamps, which are the most common light sources in trace gas-analyzers. So, the light-emitting diodes are very attractive for use of as light sources for Long Path Differential Optical Absorption Spectroscopy (DOAS) measurements of trace gases in the open atmosphere. Recent developments in fibre-coupling telescope technology and the availability of ultraviolet light emitting diodes have now allowed us to construct a portable, long path DOAS instrument for use at remote locations and specifically for measuring degassing from active volcanic systems. First of all, we are talking about the measurement of sulphur dioxide, carbon disulphide and, oxides of chlorine and bromine. The parallel measurements of sulfur dioxide using a certified gas analyzer, were conducted and showed good correlation.

E-2

CATHODOLUMINESCENT UV RADIATION SOURCES

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Research in the field of new UV radiation sources is topical due to several reasons. First, there is a decision to get rid of mercury-containing light sources, both in industry and in the private life. Second, the UV radiation sources with improved spectral and timing characteristics are required for photochemical processes, disinfection, medical treatments, and for pumping active media in lasers.

Cathodoluminescent light sources imply an essential current density in the electron beam, 10^{-5} to 10^{-4} A/cm^2. Also, pulse excitation with a high momentary power is important for some applications. These features require a radiation-proof luminophor and a stable against pulse current cathode.

Lithium tetraborate (LTB) doped with different impurities is promising cathodoluminophor for UV-radiation sources. LTB is highly stable against radiation, and it effectively adopts various impurities in its structure. Doping LTB with copper yields to a luminescence band peaked at 370 nm, and with silver – at 270 nm [1].

Prepared from carbon fibre auto-emission (non-glowing) cathodes have been already proposed and investigated [2]. They were intended to provide cathode-ray excitation in light sources, and are quite suitable for UV radiation sources.

We studied luminescent ceramics based on LTB doped with copper, silver, tin, zinc, manganese in different combinations. The dopants enter both into the boron-oxygen structure of LTB and on the lithium positions. The impurities at boron positions in the boron-oxygen structure determine the excitation spectrum in UV and VUV range. Besides, these defects serve as hole traps and annihilation centres for excitons. Their excitation energy, however, is radiated by a closely situated

at lithium position impurity, which is either the same impurity at lithium position, or some other one, intentionally introduced for effective energy transfer. We observed the excitation energy transfer from incorporated in boron-oxygen structure sensitizer to luminescence centres in LTB ceramics doped with different elements. The energy transfer is most probably connected with the partial overlap of wave functions of donor and acceptor excited states. For effective production of luminescent ceramics, a technology of successive doping with impurities is developed and being patented (priority of LPI RAS by 29.12.2016).

LTB based luminescent ceramics is stable against a high current density at cathode-ray excitation. For a high efficiency of energy transfer, one needs to select complementary pairs of sensitizer and acceptor. For example, a copper-oxygen structure (with copper situated at boron position) sensitizes well the luminescence of Cu^+ at lithium position. One could expect the Ag^+ luminescence to be sensitized by structures containing either zinc or tin at boron position.

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E-3

USE OF UV RADIATION FROM A KrCl EXCILAMP FOR THE PURPOSE OF REMOVING 2.4-D WITH H_2O_2 / FENTON ADDITIVES

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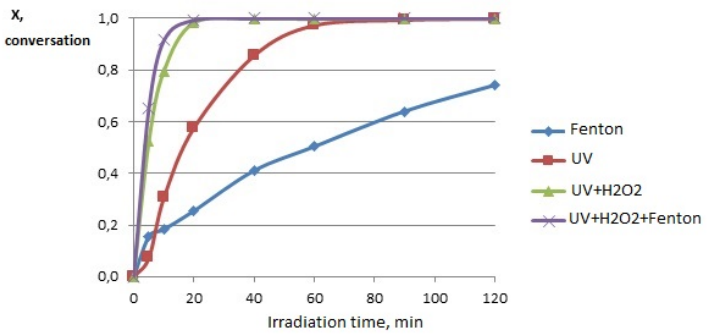
Investigation of the destruction of 2.4-dichlorophenoxyacetic acid (2.4-D) under the influence of UV radiation from the KrCl excilamp with the use of additives of hydrogen peroxide, the Fenton reagent. Effective rate constants of degradation reactions of the initial compound were calculated. The estimation of efficiency of both each system separately, and together is given. The use of hydrogen peroxide additives and Fenton's reagent is due to the fact that the use of direct photolysis in some systems is ineffective. Addition of hydrogen peroxide in such cases increases the efficiency, due to the formation of active forms of oxygen in aqueous solutions. Thus, studies have been carried out to find the most effective amount of hydrogen peroxide additive and to create the most effective system for the destruction of chlorinated phenoxy acids when excited by a KrCl excilamp (222 nm).

In previous studies [1], an effective mass ratio of 2.4-D and the addition of hydrogen peroxide for decomposition under the conditions of a flow photoreactor with a KrCl excilamp were found. Based on this, the system was compared with systems that were previously used by other authors (Fenton, photo-Fenton, direct photolysis). And also the effective rate constants of these reactions are calculated.



Photodegradation results of 2.4-D (50 mg / l) using a flow reactor

As can be seen in Figure, the degree of degradation of the initial compound is not the same when using different systems. In the case of using only the Fenton reagent, complete decomposition for 120 min does not occur. However, the conversion schedule of the starting compound tends to completely decompose 2.4-D, however over a longer period. The reaction of Fenton is primarily a chemical reaction. Generation of hydroxyl radicals in this case is slow. The limiting stage in this case is the formation of a hydroxyl radical as a result of a chemical reaction. The reaction rates of direct photolysis are much higher. The 222-nm radiation is absorbed by the high lying electronically excited states of the molecule being studied. As a result, one of the possible ways of the reaction is the population of photodissociative states responsible for breaking the chemical bonds in the initial molecule and, consequently, increasing the degree of degradation. Nevertheless, phenoxy acids are quite resistant organic toxicants.

The use of hydrogen peroxide additive increases the degree of degradation of 2.4-D. This is due to the fact that in addition to the reactions of direct photolysis of 2.4-D, the decomposition of hydrogen peroxide occurs under the influence of UV radiation, so there are two ways of destruction of 2.4-D in solution (direct photolysis on the one hand, interaction with hydroxyl Radical on the other). The most effective is the photo-Fenton system and hydrogen peroxide additives. Adding Fenton's reagent to the UV / H_2O_2 system gives the best results. The formation of hydroxyl radicals in the system due to the photolysis of peroxide is the determining factor affecting the degradation rate of 2.4-D.

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E-4

PHOTOPHYSICAL AND PHOTOCHEMICAL PROCESSES IN BORON FLUORIDE COMPLEXES OF DIPYRROMETHENES AND THEIR APPLICATIONS IN MODERN OPTICAL DEVICES

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Boron fluoride complexes of dipyrromethenes (BODIPY) have good solubility in many solvents and are effective fluorophores in the visible region of the spectrum. This causes the possibility of their use as active media of liquid and solid-state tunable lasers. It is suggested to use as sensitizers for hydrogen generation under the action of sunlight on the medium used, in biological studies as fluorescent sensors and labels. Fundamental study of the photochemical and photophysical properties of boron fluoride complexes of dipyrromethenes will solve the problem of optimal practical use of compounds of this class.

The objects of study were chosen a number of BODIPY derivatives with substituents of different nature. The study of the photonics of these compounds revealed that they can be used as a base for developing active media of tunable lasers with a high service life, operating in the ranges of 548–585 and 680–692 nm. The introduction in the meso-position of the dipyrromethene molecule of the nitrogen atom (aza-BODIPY) leads to a decrease in the fluorescence efficiency due to the appearance of closely arranged energy states of different orbital natures and multiplicities, which increases the probability of intersystem crossing. In addition, for halogenated aza-BODIPYs, the ability of generation of singlet oxygen by an indirect method was studied using 1,3-diphenylisobenzofuran (DPBF) as the trap. According to the obtained data, the compounds studied can be recommended as a medium for effective generation of singlet oxygen, which is promising for use in medicine as a photosensitizer for photodynamic therapy.

E-5

RADIATION SPECTRA OF MERCURY BACTERICIDAL LAMP ENCASED INTO LIGHT-TIGHT BOX

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The low pressure mercury bactericidal lamp as the volume lengthy source of discrete light was investigated. The lamp was encased into light-tight cylindrical box with small aperture at its middle box. The decreasing of resonance line intensity of mercury atom at 253.6 nm for the lamp placed in the box in compare with that one without box was registered. This effect depends on quality of inner surface of the box. It appears in box with reflective inner surface most strongly. This effect is necessary to consider for bactericidal mercury lamps which are placed into box for protection of personal from UV radiation.

The work realized within the Grant RFBR No. 15-08-00726.

E-6

OPTICAL CHARACTERISTICS OF THE PULSE-PERIODIC DISCHARGE IN MIXTURES OF SULFUR VAPORS WITH ARGON

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Discharges in mixtures of noble gases with sulfur vapors allow to obtain spectrum of radiation, close to solar; such spectrum is caused by radiation of S_2 dimers, which bands of the $^3\Sigma \rightarrow {}^3\Sigma$ system are approximately on equal distances from each other and merge in a continuous spectrum in the wavelength range of 280–600 nm. The luminescent spectra of plasma of the longitudinal pulse-periodic discharge in argon-sulfur mixtures are presented in the wavelength range of 300–1000 nm. It is shown, that radiation efficiency of sulfur dimer bands grows with increase in the gas-discharge lamp wall temperature.

The electron energy distribution function and kinetic coefficients of electrons in Ar-S_2 mixtures at concentration of S_2 vapors in the mixture of 0.5–10% were calculated using solution of the Boltzmann equation in the two-term approximation. Calculated dependences of the mean electron energy, transport coefficients, rate constants of elastic and inelastic collisions of electrons with S_2 molecules and argon atoms are discussed. It is shown, that increasing the S_2 molecule concentration in Ar–S_2 mixtures promotes decreasing the mean electron energy, rising rate constants of the electron attachment to sulfur molecules and atoms and diminishing the ionization and excitation rate constants of S_2 molecules and Ar atoms. Increase in the reduced electric field E/N results into growth of the ionization and excitation rate constants of both S_2 molecules and Ar atoms as well as into diminution of rate constants of the electron attachment to sulfur molecules and atoms. Strong dependence of the rate constants of inelastic electron collisions with S_2 molecules and Ar atoms on concentration of S_2 molecules in the mixtures as well as on the reduced electric field E/N drives to existence of the optimal conditions in the discharge for the S_2 band radiation. The E/N values, which are optimal for excitation of S_2 ($B^3\sum \rightarrow X^3\sum$) bands are estimated for Ar–S_2 mixtures with S_2 vapor additives of 0.5–10%.

E-7

A PULSED DISCHARGE EXCILAMPS IN APOKAMP MODE

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First in the mixtures Xe—Cl_2 and Kr—Cl_2 plasma jets (apokamps), formed on bend of the channel of a pulse-periodic barrier discharge obtained. Experimentally shown that the presence of electronegative gases in the mixture is one of conditions for the formation of apokamp. The possibility of creating a source of ultraviolet radiation on the basis of apokamp formed in typical environments for excilamps of capacitive and barrier discharges.

The work is performed in the framework of the Russian Science Foundation (the Project No. 14-29-00052.

E-8

EMISSION SPECTRA OF APOKAMP-TYPE ATMOSPHERIC PRESSURE PLASMA JETS IN AIR, ARGON, AND HELIUM

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Emission spectra of atmospheric pressure plasma jets formed in the areas of strengthening of the electric field near the bends of potential channel of the pulse-periodic discharge and are studied. Plasma jets consists of a bright narrow branch (offshoot) connected with the discharge channel and with the diffuse jet – apokamp. It is shown that, in argon, apokamp emission spectra contain not only N_2 and N_2^+, but also Ar lines. In emission spectra of apokamp in helium the N_2 and N_2^+ bands are dominates, while offshoot emission consists on lines and bands of He, N_2, N_2^+, O, and OH. We proposed that the surrounding air plays an important role in the formation of apokamp in helium and argon.

This study was supported by a grant of the Russian Science Foundation, Project No. 14-29-00052.

The work was performed in the framework of the State task for HCEI SB RAS, Project No. 13.1.3.

E-9

DEVELOPMENT OF A XeCl EXCILAMPS FOR AGRICULTURE AND STOCK FARMING

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The parameters of irradiation units based on electroluminescent XeCl excilamps developed in the optical radiation laboratory of High Current Electronics Institute SB RAS are presented. The results of studies of the action of XeCl excilamp radiation on animals and plants are summarized. It may be inferred that the irradiation units is convenient for compensation ultraviolet failure of animals and increase crop yields.

The work performed in the framework of IHCE SB RAS theme No. 13.1.3.

E-10

TEMPERATURE MODE OF BARRIER DISCHARGE XeCl EXCILAMP

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The energy parameters of axial radiation of barrier discharge XeCl excilamp located in a closed opaque cavity are measured. The excilamp excitation was performed by a high voltage pulses at f = 15 kHz. It is shown that a decrease in the nominal lamp supply voltage by 10% led to increase in the emission intensity of the λ_p = 308 nm, as well as to decrease (by 16.7%) in the level of thermal radiation, to accelerate of radiation flux reaching and to reduction in instability by 19.6%.

This study was partially supported by a Project RFBR No. 15-08-00726.

E-11

CALCULATION OF PLASMA PARAMETERS OF THE GLOW DISCHARGE ON THE WATER IN AIR AT ATMOSPHERIC PRESSURE

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For the calculation of the electrical characteristics of plasma are used normal conditions for air and experimentally measured CVC. It allows to estimate the maximum value of the electron density for the threshold mode and breakdown. Thus, near the cathode the obtained maximum values are following $E = 1.7 \cdot 10^8$ V/m for the electric field, $2.6 \cdot 10^{-6}$ m – size of the cathode layer, 0.0134 m^2/s – electron mobility, $2.36 \cdot 10^6$ m/s – drift velocity and E/N = 7184.5 Td. E = 77250 V/m, the mobility of 0.6398 m^2/s, 49426.93 m/s – drift velocity, E/N = 3.2 Td for the positive column.

In the discharge with the cathode on the basis of distilled water the estimated value of the electron concentration is equal to $(1–2) \cdot 10^{11}$ cm^{-3} for the positive column and to $(2–9) \cdot 10^{12}$ cm^{-3} for the cathode layer. For chemically-active molecules and radicals the concentration evaluated from the ratio of OH and NO with the N_2 emission intensities by selection of the partial pressures in the Specair software can reach the order of 10^{16} cm^{-3}.

E-12

PARAMETRIC STUDY OF DBD EXCILAMPS SUPPLIED WITH CONTROLLED SQUARE CURRENT PULSES

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A parametric study of a system dedicated to non-coherent UV emission, by means of DBD excilamps, supplied by a controlled square shape current source is proposed. The presentation highlights on the one hand the performances experimentally obtained by combining together:

A set of 20 different bulbs with different diameters, gap and wall thicknesses (all the bulbs are filled with the same XeCl gas mixture, the length is 600 mm and the injected electrical power can reach up to 500 W) 13;

Different electrical power supplying conditions: magnitude, frequency (in the 30–200 kHz range) and duty cycle of the square shape current pulses 2 injected into the bulb. Low frequency burst modulation, with adjustable duty cycle of this supply is also superimposed.

The performances concern the system power efficiency, the efficiency of the bulb conversion (electrical power to UV) and the adjustability of the power.

On the second hand, we propose to present design considerations 4 of the power supply which has been especially developed for the purpose of these experiments. Finally, optimization developments, on the basis of the obtained experimental results are proposed.

Acknowledgement: part of this work is supported by ECOS-Nord / COLCENCIAS / ICETEX French-Colombian cooperation program.

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E-13

CHANGES IN THE IR SPECTRUM OF DRINKING WATER, MELT WATER FROM SNOW AND HEAVY WATER BY IRRADIATION OF AN ELECTRON BEAM OF NANOSECOND DURATION

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Examines the absorption spectra of drinking water, melt water from snow and heavy water irradiated by a stream of electrons of nanosecond duration. After repeated irradiation of the water changes the absorption spectrum of the substance. A Fourier analysis of the absorption spectra in the infrared range showed differences in the absorption spectra of irradiated and non-irradiated drinking water. Changes in the absorption spectrum of drinking water and meltwater from snow was that the band of stretching vibrations of OH-groups expanded without clearly defined peaks for the studied liquids. Changes in absorption of heavy water, a mixture of the concentrations of H_2O, HDO and D_2O molecules after irradiation of e-flow was that changes to the molecules H_2O, HDO. Changes in the absorption spectra of heavy water after irradiation of e-flow was that the band of stretching vibrations of OH-groups of H_2O and HDO broadened, and the absorption band HE overtones of deformation vibrations of HDO molecules became more intense while maintaining range. Deformation vibrations of molecules of H_2O and HDO heavy water have the maximum displacement in the direction of higher frequencies and the maximum deformation vibrations of the D_2O molecules remains unchanged. The conductivity of all the investigated liquids after irradiation increased. Thus, the irradiation of water flow can be used for modifications of water and aqueous solutions.

E-14

RADIATION RESISTANCE OF POLYMER MATERIALS AT EXPOSURE COSMIC RAYS

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The results of the action of an electron beam on the radiation resistance of polymers are presented. It is shown that the radiation resistance of polymers depends on the structural characteristics of polymer materials.

E-15

EXCILAMPS FOR THE *OPISTHORCHIS FELINEUS* TREMATODES INACTIVATION

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Opisthorchis felineus trematodes (Rivolta, 1884) are the causative agents of a dangerous disease of man and animals - opisthorchiasis, widespread in the Ob basin. Infection occurs when people eat raw or poorly processed fish. To effectively disinfect items used in cutting fish (knives, cutting boards, conveyor belts, etc.), ultraviolet irradiation can potentially be used.

For a long time, the main available source of ultraviolet (UV) radiation was mercury lamps of low pressure. The light power of the mercury «quartz» lamp emission is of 90% concentrated in a narrow atomic line $\lambda = 254$ nm with a width at half-maximum $\Delta\lambda \sim 0.1$ nm.

The development of new sources of UV radiation - excilamps - allows us to carry out the action of ultraviolet with a spectral maximum at wavelengths $\lambda = 222$, 282 and 308 nm [1]. The working mixture of the excilamp contains an inert gas (Kr or Xe) and no more than 4% of halogen (Cl_2 or Br_2). Therefore, unlike a mercury lamp, it does not pose an environmental hazard in case of a bulb failure. As a rule, the radiation spectrum of the excilamp contains several molecular components: the dominant band of the $B \rightarrow X$ transition of an exciplex molecule (KrCl*, XeBr* or XeCl*) with a width at half-maximum $\Delta\lambda \sim 2$–3 nm, less intense $D \rightarrow X$ and $C \rightarrow A$ transitions of the exciplex molecule and the band of the excited halogen molecule.

In the report results of research of effect of excilamp UV radiation on eggs and metacercariae of *O. felineus* trematodes are presented. The highest efficiency of inactivation of *O. felineus* eggs was shown by KrC excilamp radiation at 222 nm at the surface dose of 15 mJ/cm^2. To inactivate the *O. felineus* metacercariae, the XeCl excilamp radiation at 308 nm was most effective. The surface inactivation dose was 28 J/cm^2, i.e. by three orders of magnitude greater than for eggs of *O. felineus*.

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Session F
CONVERSION OF LASER RADIATION, OPTOELECTRONIC DEVICES, NONLINEAR OPTICS

F-1

OPTICAL PROPERTIES OF BORATES IN THE THz RANGE AND PERSPECTIVES OF APPLICATIONS IN DOWN-CONVERTERS

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Borate family crystals are widely used as laser frequency converters operating within maximal transparency window. Optical properties of borates in this spectral range are well studied in difference to those in the THz range. Dispersions of refractive indices, absorption coefficients spectra and their temperature dispersions were not studied yet in here in details. Potential application of borate crystals in down-converters was also not known. In this study, all mentioned problems were solved in relation to the most often used two oxide crystals: LBO и BBO. Measurements were carried out by THZ TDS and Bruker family Fourier-spectrometer. Refractive index dispersions recorded at 300 and 81 K were approximated in the form of Sellmeier equations. Phase matching curves were calculated including that calculated for the first time for frequency conversion within the THz range. It was established that BBO crystal saves phase matching ability at cryogenic cooling. Its absorption coefficients abrupt down but still strong anisotropic. Changes of LBO properties with a cooling seem to be too complicated but optical loss for THz wave polarized parallel to ***X*** axis drops down at LN temperature. Other details to be discussed.

The research was supported by RSF Grant No. 15-19-10021.

F-2

TRANSMISSION AND REFLECTION IMAGING IN THE THz DOMAIN

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Tunable ns down-converter of Nd : YAG laser and continuously tunable 0.445–1.75 μm KTP OPO is designed and applied in long, over 110 m, length standoff spectrometer for 2D/3D imaging. Dow-converter is based on an optimally double-element doped GaSe → $GaSe_{91}S_{0.09}$: Al(0.03 at.%) crystal and demonstrating high mechanical and optical properties in difference to GaSe. Open waveguide trace was formed by home-made high pressure polyethylene lenses. Narrow bandwidth ($\Delta\nu < 0.1$ cm^{-1}) of the generating emission, in line with continuous tunability (0.2–4 THz), allowed us to select emission wavelength that coincides a micro transparency window in the atmospheric water vapor absorption spectrum, special at 0.5–1 mm range. THz detector and data acquisition system based on Schottky diode 2DL12C2500A1 (ACST GmbH, Germany), operate at room temperature with voltage response 27000@70 GHz/1400@1000 GHz. It results in an order larger output signal to that from LHe cooled Si bolometer (Infrared Laboratories Inc., NEP = $4.3 \cdot 10^{-14}$ W/Hz$^{1/2}$). We met no problem in recording of 2D imaging of hidden objects in transmission regime, as well as 3D imaging in remote (reflection) regime of objects located on finished optical plates whose parameters were also determined. Space resolution of 3mm is demonstrated and can be further improved. Topographical targets can be used as reflectors.

The research was supported by RSF Grant No. 15-19-10021.

F-3

OPTICAL PROPERTIES AND PHASE MATCHING FOR THz GENERATION IN $PBIN_6T_{E10}$

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Systematic study of optical properties of nonlinear crystal $PbIn_6Te_{10}$ is carried out to define possible application for THz generation. PIT demonstrated low absorption $\alpha < 0.07$ cm^{-1} at 3–17 μm and large nonlinearity coefficient 51 pm/V. Transparency spectrum features dictated by heavy molecular weight allowed down-conversion into 9–15 THz range unreachable for other crystals. THz TDS measurement shown α up to a few hundred cm^{-1} at 0.2–2 THz that is a common property for majority of known crystals. It appoints on reasonability of an improvement of growth and post-growth technology, using cryogenic cooling. Thin PIT samples are useful for fs laser down-conversion into the THz range including phase matched conversion by *ooe* and *eoe* type that comes from for first time designed dispersion equations. Efficient figure of merit $FOM_{eff} \leq 65$ (pm/V)^2 is calculated. By variation of the PIT chemical composition it is possible to control phase matching conditions. Non-critical 90° phase matching conditions can be realized for this type of interaction. Fragility and low damage threshold says about preferable PIT application for low power frequency conversion. Searching for new prospective nonlinear crystals to cover hard reachable 5–15 THz range is reasonable to carry out amongst light crystals like LBO, BBO, SiC.

The research was supported by RSF Grant No. 15-19-10021.

F-4

MULTIWAVELENGTH GENERATION IN METAL VAPOR LASERS WITH A NANOSECOND PULSE DURATION

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The report gives an overview of the work on lasers with nanosecond pulses of generation in vapor-gas active media performed in the last few years at the Tomsk State University under the guidance of the author.

The main attention is paid to two directions: firstly, the possibilities of expanding the set of generation wavelengths that would overlap the visible and infrared spectrum are investigated; secondly, attention was paid to a significant increase in the energy characteristics of the strontium vapor laser due to an increase in the volume of the active medium and using the "generator–amplifier" system.

This research carried out in 2017 was supported by "The Tomsk State University Academic D.I. Mendeleev Fund Program" Grant No. 8.2.04.2017.

F-5

PHYSICAL ORIGIN AND DAMAGE THRESHOLD IN GASE CRYSTALS

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Systematic study on impact of laser pulses on nonlinear layered GaSe crystal versus pulse duration and wavelength have been carried out in detail by using published data. The inconsistence of the widely used visual criterion to determine the optical damage threshold has been finally confirmed. More reasonable term "limit pump intensity" instead of "optical damage threshold" and simple criterion for it determination, as decrease in transmitted power down to acceptable in preselected level, were proposed. Two regions with almost linear dependence of the limit pump intensity versus pulse duration were established that are reflecting two different origins of the limitation: thermal and field effect results. Limit pump intensity was approximated in the form of nonlinear relation that can be used in estimation of frequency conversion efficiency. Established wavelength dependence of limit pump intensity is found too complicated that reflects combined effect of linear and nonlinear (second and third order) absorption, transient field effects (extremely irregular behavior of the transparency curves), dissociation of GaSe and plasma dynamics effect. Specific features of GaSe application in THz down-converters are considered.

This work was supported by the Russian Science Foundation, Grant No. 15-19-10021.

F-6

THZ DETECTORS: COMPARISON AT IDENTICAL EXPERIMENTAL CONDITIONS

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Selection of the most suitable THz detector by using specification or published data is a hard task due to differences in spectral sensitivity, response time and experimental conditions. We have

studied in comparison several detectors for registration of 4ns pulses at 0.55–1 mm (340–620 GHz). This range is free from water vapor absorption and prospective for out-of-door applications. 4 GHz Teledyne LeCroy WaveRunner 640Zi oscilloscope was used to exclude distortion of pulse time shape-form. Detectors studied are: a LHe-cooled Si bolometer (Infrared Laboratories): $\Delta\lambda$ = 15–2000 μm, responsivity $S_v = 6.1 \cdot 10^5$ V/W, response time $\tau \sim 1$ ms; two (MoRe/NbN) LHe-cooled Superconducting Hot-Electron Bolometers (Scontel) with LHe-cooled high electron mobility field-effect transistor amplifiers: $\Delta\lambda$ = 100–1000 μm, Sv = 10000/3000 V/W, τ = 1/0.05 ns, closed-cycle refrigerator; two RT Schottky-diodes: 2DL12CLS2500A1/2DL12CLS2500A2 (ACST GmbH) with an integrated amplifier $(10\text{-}10^6)/(10^7\text{-}4\times10^9)$ Hz, τ = 1 ns/50 ps, Sv(V/W) = 27000@70 GHz/1400@1000 GHz / 289 ± 35@70 GHz/10 ± 5@1000 GHz; a RT Gollay cell GC-PS/1 (Tydex): $\Delta\lambda$ = 15–8000 μm, responsivity $(1–1.5) \cdot 10^5$ V/W@15 Hz, response time 25–30 ms. It was established that: Teledyne LeCroy WaveRunner 640Zi possesses nonlinear response, 8 mm emission can be recorded by Si bolometer, optimal operation temperature for MoRe/NbN bolometers are (5–6)/(9–10) K, output signal from Schottky diode 2DL12CLS 00A1 is 2 orders smaller than from superconductive bolometers, 10 times larger than from Si bolometer, and few times smaller than from 2DL12CLS2500A2 diode.

The research was supported by RSF Grant No. 15-19-10021.

F-7

GENERATION OF SUPERRADIATION BY MOLECULAR IONS OF NITROGEN IN AIR UNDER CONDITIONS OF FILAMENTATION OF A POWERFUL FEMTOSECOND PULSE

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At present, special interest is in the generation of superradiance. This phenomenon relates to the nonresonant generation of laser radiation. Experiments have repeatedly confirmed the possibility of generating superradiance at transitions between the vibrational levels of the nitrogen ion, not only in cuvettes, but also in the atmosphere. Sometimes, in order to realize the conditions for generation of superradiance, radiation from several lasers generating radiation at different wavelengths is used.

We also carried out experiments on the generation of superradiance on ions of atmospheric nitrogen molecules under conditions of filamentation of a powerful pulsed femtosecond radiation. Experimental conditions: the position of the central wavelength of the pump radiation varied in the wavelength range 780 ÷ 810 nm, the pulse energy varied in the range 25 ÷ 40 mJ, the pulse duration was 50 fs, and the generation frequency was 10 Hz. The radiation was focused with short-focus lenses. Recording spectra in the range 195 ÷ 1150 nm (towards the radiation) was carried out using an HR4000 spectrometer. When pumping at 800 nm, the generation of superradiance with a molecular nitrogen ion was detected at a wavelength of 427.8 nm (transition $B^2\Sigma^+_u(0) \Rightarrow X^2\Sigma^+_g(1)$). It should be noted that under the conditions of this experiment, superradiance was obtained only at a wavelength of 427.8 nm. Generation of radiation at other wavelengths was not observed.

During the experiments, attention was paid to the generation of the third harmonic in the filamentation zone, as a condition for increasing the probability of generating superradiance at the transition $B^2\Sigma^+_u(0) \Rightarrow X^2\Sigma^+_g(1)$. In the multiphoton excitation of the autoionization state of a nitrogen molecule with an energy of 18.7 eV, both photons of the fundamental frequency (corresponding to $\lambda \approx 800$ nm) and photons of the third harmonic ($\lambda \approx 266.6$ nm) can participate. The required number of such photons is 12 or 4, respectively. This hypothesis was confirmed experimentally: when the wavelength of the main radiation was tuned in the range 780–810 nm, superradiance generation under filamentation conditions was observed with simultaneous pumping at a wavelength of 800 nm and at a wavelength of the second harmonic (λ 266.6 nm). The presence of seed photons was provided by the emission of the supercontinuum in the filamentation zone. The broadening of the supercontinuum spectrum to 400 nm and below, as a condition for the presence of seed photons, was controlled by a change in the energy of the pump pulse.

This work was supported by the Russian Science Foundation (Agreement No. 16-17-10128) and the leading scientific school NSh-8199.2016.5.

F-8

SPONTANEOUS AND INDUCED RADIATION AT A RESONANT ELECTRONIC TRANSITION OF A MOLECULAR NITROGEN ION OF AIR IN PLASMA FILAMENTS UNDER OPTICAL PUMPING BY A LASER WITH A WAVELENGTH OF 800 nm

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In the work, the integral spectra of radiation from plasma filaments under optical pumping by pulsed radiation with a wavelength of 800 nm, energy up to 70 mJ and duration ~ 50 fs are experimentally studied. Filamentation was observed when femtosecond radiation was rigidly focused by lenses with $F = 10 \div 30$ cm.

The emission spectra from the filamentation zone were recorded in the longitudinal and transverse directions with respect to the direction of propagation of the femtosecond laser pumping pulse. When the energy of femtosecond pump pulses is varied within $10 \div 50$ mJ, the induced radiation is observed along the direction of the pump beam.

Under pumping conditions with femtosecond pulses, the spectrall width of the multiphoton excitation of the resonance state $B^2\Sigma_u^+$ of the molecular nitrogen ion $N2^+$ was measured for the first time.

The selective excitation of the lower vibrational-rotational levels (v'' = 0.1) of this state leads to population inversion with respect to vibrationally rotational levels of the ground state of the nitrogen ion $X^2\Sigma_g^+$. Conditions are created for the generation of spontaneous and induced radiation at the resonant electronic transition of the molecular nitrogen of air in plasma filaments.

The observed spectra are compared with the spectra of optical breakdown of air with nanosecond pulses with an energy of up to 100 mJ, with wavelengths of 249 nm (KrF), 1064 nm (Nd : YAG), and 10.6 μm (CO_2). The general features and principal differences in the emission spectra for various physical parameters of pump radiation are revealed.

This work was supported by the Russian Science Foundation (agreement No. 16-17-10128) and the leading scientific school NSh-8199.2016.5.

F-9

OPTICAL PROPERTIES AND THz GENERATION IN ZGP CRYSTALS

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Recent development of THz technologies (spectroscopy, visualization of T-imaging, communication systems) requires new effective nonlinear materials. $ZnGeP_2$ (ZGP) is well known to be the best nonlinear crystal for phase matched mid-IR generation (so called mid-IR "standard" nonlinear crystal). However, at the dawn of T-rays era, it showed low THz generation efficiency due to significant optical losses at pump wavelength 0.8–1.5 μm, as well at generation region 0.2–3 THz.

In order to fully exploit potential of ZGP in THz applications, we began careful study on its optical properties to find out how they affect the down-conversion efficiency into the THz domain. Anisotropy of the absorption coefficients and refractive indices for different polarization waves in the extra-wide spectral range (5–50000 cm^{-1}) and their temperature dispersion were studied. Internal

optical uniformity and microdefects were studied by modified shadow method with ZGP sample installed on the way of Nd : YAG pump beam to KTP SHG and other methods.

Recent achievements in ZGP growth and post growth processing technologies allowed us to use high optical quality ZGP samples. Efficient generation at of 0.2–3 THz was obtained by phase matched optical rectification in in these samples under the pump by a fs Ti:Sapphire laser system with a BBO OPA operating at the wavelength ≥ 1.9 μm. The generation efficiency was from 3 to 5 time higher than that in traditionally used isotropic GaP and GaAs crystals.

F-10

VAPOR BY A FEMTOSECOND LASER AT A WAVELENGTH OF 800 nm

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This report presents the experimental results of generation of superradiation in a mixture of strontium vapor with an inert gas when pumped by powerful femtosecond pulses.

Optical pumping was carried out by radiation of a powerful femtosecond laser system of the IAO SB RAS (development of the Russian company "Avesta-project"). At the output of the laser system, radiation at wavelengths of ~ 800 nm had a duration of 50 fs and energy of up to 50 mJ. The radiation was focused by lenses with focal lengths of 15–20 cm into the heated cuvette. The radiation spectrum from the cuvette was registered according to the scheme "towards the beam" using the HR4000 Ocean Optics spectrometer. Uses conventional broadband filters, including neutral filters.

In optical pumping by femtosecond radiation, the generation in strontium vapor in a mixture with an inert gas of helium was obtained at a pressure of about 1 atmosphere. Superradiance on the intrinsic transitions of the strontium atom and ion to the ground electronic state of the $5s^2S_{1/2}$ ion has been recorded, at resonance transitions from the levels $5p^2P_{3/2}$ (407.8 nm) and $5p^2P_{1/2}$ (421.6 nm), as well as to Lines terminating at the resonance levels

$$5p^2P_{1/2}–6s^2S_{1/2} \text{ (416.2 nm) and } 5p^2P_{1/2}–6s^2S_{1/2} \text{ (430.5 nm).}$$

The conditions and parameters of the superradiance lines obtained are shown and comparisons are made with the generation of transitions of the strontium ion in a pulsed gas discharge. It is shown that the main mechanism for creating a population inversion is the selective multiphoton excitation of the operating states of the ion through the autoionization states of the atom.

The work was supported by the Russian Science Foundation (Agreement No. 16-17-10128) and The leading scientific school NSh-8199.2016.5

F-11

THz GENERATION BY SEEDED DOWN-CONVERSION

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Output parameters of recently designed down-converter based on $GaSe_{1-x}S_x$ crystal were further improved by seeding THz wave from an electronic source. A modular electronic transmitter (VDI)

incorporating tunable CW 13.75–14.42 GHz synthesizer and three harmonic generation stages: 175X2[A] (multiplication factor ×12, operation range 165–173 GHz, $\Delta\nu$ = 144 Hz, $\bar{P}$ = 100 mW), 315X2[B] (×24, 330–346 GHz, 288 Hz, 15 mW), 1.9X3[C] (×36, 495–519 GHz, 432 Hz, 2 mW) were used as the seeding source. The synthesizer was locked to external 10 MHz reference source with absolute frequency precision of $\pm 1.5 \cdot 10^{-8}$. LabView program was used to control the synthesizer settings: tunability step within 0.012–100 kHz, frequency sweeping within ±25MHz and peak frequency deviation at 3–100 kHz rate.

Down-conversion efficiency at 340 GHz was improved by a factor of ≥ 10 under injection of 0.1–0.2 mW of the seeding wave. Minimal tunability step was 288 Hz, bandwidth was about a few hertz that is principally lower to ~ 2.36 GHz achieved in unseeded crystal. It is also much lower to spectral resolution limit of ~ 0.8 GHz for THz TDS. Besides, it is also much lower to 2 MHz Doppler bandwidth of the atmospheric absorption lines. We found that THz pulse magnitude variation caused by OPO output pulse instability were simultaneously decreased for at least for 4–5 times.

The research was supported by RSF Grant No. 15-19-10021.

F-12

REACTOR EXPERIMENTS TO STUDY LUMINESCENCE OF He–Ne AND HE-KR GASEOUS MIXTURES, EXCITED BY PRODUCTS OF NUCLEAR REACTION ^{6}Li (N, A) ^{3}H

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The spectral studies of optical radiation of a gaseous mixtures is of interest for solving problems associated with finding gaseous media having a high energy conversion efficiency of nuclear reactions in the energy of a laser or spontaneous emission [1, 2]. Such media can be used to extract energy from nuclear and thermonuclear reactors in the form of optical radiation, and also to control and adjust the nuclear reactors parameters.

This paper presents results of a reactor experiments to study luminescence of He–Ne , He–Kr gaseous mixtures, at different levels of the stationary power of the reactor IVG-1M; the values of the energy yield of gaseous mixtures were calculated.

1. *Batyrbekov E.* Converting nuclear energy into the energy of coherent optical radiation // Laser and Particle Beams. 2013. V. 31. Is. 4. P. 673–687.
2. *Khassenov M.U.* Nuclear-induced plasmas of gas mixtures and nuclear-pumped lasers / Monograph. Almaty, 2011. 87 p.

F-13

SUM FREQUENCY GENERATION OF CRYOGENICALLY COOLED SLAB RF DISCHARGE Q-SWITCHED CO LASER IN $ZnGeP_2$ NONLINEAR CRYSTAL

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The spectral characteristics of a compact cryogenic slab RF discharge Q-switched CO laser operating in a nonselective mode was measured. The influence of various external parameters, such as

the duration of the RF discharge pulse and the time delay between RF discharge pulse and switching-on of the resonator was investigated. The power and dynamic characteristics of individual spectral lines was measured. The experimental data will be taken into account in the simulation of the frequency conversion of CO laser radiation in nonlinear crystals. The operation mode of the CO laser was selected, in which the maximal peak power of the radiation reached 3 kW, and the duration of the radiation pulse was 0.72 μs.

The experimental study of the sum frequency generation of CO laser was carried out in a $ZnGeP_2$ crystal. The CO laser spectrum consisted of ~ 90 lines in the wavelength range from 4.9 to 6.7 μm. The maximal internal conversion efficiency was up to 8.2%. In this case, the sum frequency generation spectrum consisted of more 200 emission lines in the wavelength interval from 2.5 to 3.2 μm.

This work was supported by the RNF (16-19-10619).

F-14

EMISSION SPECTRA OF APOKAMP-LIKE DISCHARGE AT ATMOSPHERIC PRESSURE IN AIR, ARGON, AND HELIUM

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Emission spectra of atmospheric pressure plasma jets formed in the areas of strengthening of the electric field near the bends of potential channel of the pulse-periodic discharge and are studied. Plasma jets consists of a bright narrow branch (offshoot) connected with the discharge channel and with the diffuse jet – apokamp. It is shown that, in argon, apokamp emission spectra contain not only N_2 and N_2^+, but also Ar lines. In emission spectra of apokamp in helium the N_2 and N_2^+ bands are dominates, while offshoot emission consists on lines and bands of He, N_2, N_2^+, O, and OH. We proposed that the surrounding air plays an important role in the formation of apokamp in helium and argon.

This study was supported by a Grant of the Russian Science Foundation, Project No. 14-29-00052.

F-15

OPTIMAL FOCUSING DURING HIGH EFFICIENCY SECOND HARMONIC GENERATION IN NONLINEAR UNIAXIAL CRYSTALS

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A new approach is suggested to the solution of a set of nonlinear wave equations responsible for the second harmonic generation (SHG) of laser radiation in a nonlinear uniaxial crystal. Possibilities of significant reduction of the program running time due to an insignificant decrease in the calculation accuracy within the approach suggested are shown. A specific problem of SHG of the green line of a BBO Cu vapor laser is taken as an example to show how optimal focusing parameters vary with an increase in the fundamental power. It is shown that a focusing system of two crossed cylindrical lenses with strongly different focal lengths is optimal in the case of high efficiency SHG, like in the given-field approximation (i.e., at low fundamental powers). The focal lengths of these lenses increase with the green line power, but each in its own way.

F-16

INVESTIGATION OF THERMAL TRANSITION PROCESSES IN ACOUSTOOPTICAL DEFLECTORS BASED ON PARATELLURITE

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Experimental investigation of thermal transition processes in acoustooptical deflectors was carried out. The spectral dependence of the deflector scan angle on the frequency of the drive signal was studied with varying the temperature of the device. It was demonstrated that the diffraction angle changes with increasing the operational temperature of the deflector. Additionally, we discovered an anomalous dependence of the derivatives of refractive indices on temperature for deflection of optical radiation at wavelengths about 0.5 μm.

F-17

ANTI-STOKES SHIFT OF STIMULATED RAYLEIGH SCATTERING IN AG NANOPARTICLES SUSPENSIONS

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The spectral characters and increments of stimulated Rayleigh scattering in pure liquids and suspensions of Ag nanoparticles in toluene and hexane of principally different nature were investigated in this work. The correlation of two photon absorption spectra and stimulated scattering efficiency were discovered and analyzed. It is shown experimentally that the frequency shift of the scattered signal relative to the pump frequency greatly exceeds the theoretical value. It is also shown theoretically that the frequency shift value does not depend on the linewidth of the pump.

Session G
ROUND TABLE "BIOPHOTONICS"

G-1

STUDY OF THE PROCESS OF BLOOD CLOTTING BY SPECKLE-CORRELATION OF IMAGES

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Laser is a source of coherent and monochromatic light, which often used for monitoring the changes of the object. Laser speckles produced by reflected or transmitted light, which is free to mix in the space, and produce the interference space with varying brightness. If shoot a photograph of this area in some plane, we obtain the image with speckle, called speckle image. Due to the fact, that the scattered coherent light forms it, in a sense, a change in the speckle image corresponds to the change of the object properties.

As an optical method, in the recent years researchers in different fields have studied speckle correlation. The method is based on the analysis of speckle images generated by transmitted and reflected coherent light from object under observation, and then obtain the corresponding parameters to describe the dynamic changes of object.

The sample can be a body fluid, particularly blood. Time of blood coagulation is an important parameter to characterize the blood diseases. Too strong or too weak clotting capacity can indicate about such diseases. Thus, development of fast and easy method of the clotting time measuring is very important and necessary task.

The aim of the present work is to investigate the clotting process of known sample, using laser speckle correlation method; and compare the statistical parameters of the speckle images with the characteristic prothrombin time of the reagent.

In the present experiments, we assess the clotting time of reagent by means of digital speckle correlation. The solution consists of two separate parts – reference serum of human blood and Tekhplastin from Tehnologia-Standart firm, Russia. Tekhplastin is soluble calcium-thromboplastin reagent of cadaver brain, standardized by the international sensitivity index (ISI) – analogue rabbit thromboplastin.

In this experiment we use two types of plasma: with normal and pathological clotting time. The test was designed to assess the prothrombin clotting time of citrated plasma obtained from venous blood by the Quick method manually or using coagulometer. Determination of prothrombin time is used to test the prothrombin complex factors (II - prothrombin, V, VII, X) and monitor treatment indirect anticoagulants.

Object can be illuminated directly by laser beam and by partly diffused light. He-Ne laser beam is directed on the diffuser using a rotating mirror. The diffuser is used for pre-diffusing light. The pre-diffused light transmitted through the solution in the reactor and diffused again. The scattered light interferes in space and forms a speckle image, which recorded by high-speed camera CMOS HiSpec FastCam 1.

The analysis of correlation coefficient of speckle images shows that it can be used for measuring of the clotting time of human blood. Time dependence of correlation coefficient corresponds to the typical prothrombin time for the reagents used in the experiments.

In the future, further research on actual blood is imperative, in particular study the dependence of measuring accuracy on the experiment parameters, such as blood samples, speckle size, and exposure time of camera, etc.

G-2

PRESOWING IRRADIATION OF AGRICULTURAL CROPS XeCl EXCILAMP: FIELDWORK AND PERSPECTIVES

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The effect of ultraviolet radiation of an exciplex barrier-discharge lamp on working XeCl* molecules on seeds of agricultural crops is investigated. The excilamp radiant flux falls on the wavelength range 290–320 nm (82–88%). It is shown that presowing ultraviolet treatment of seeds has a stimulating effect on the processes of intergrowth, germination and growth of plants. After processing, the seed germination power increases by 20–30%. There was also an increase in the fresh weight of the plant by 54% higher than in the control untreated samples. The root system was well developed in the treated samples. The seeds had long roots, which are closely intertwined. The obtained data formed the basis for further experiments with the upgraded irradiation facility for seed treatment process scaling.

This study was performed under state assignment of the Institute of High Current Electronics SB RAS, theme No. 13.1.3.

G-3

MECHANISMS OF THE EFFECTS OF VUV RADIATION ON THE MICROSCOPIC FUNGI CELLS

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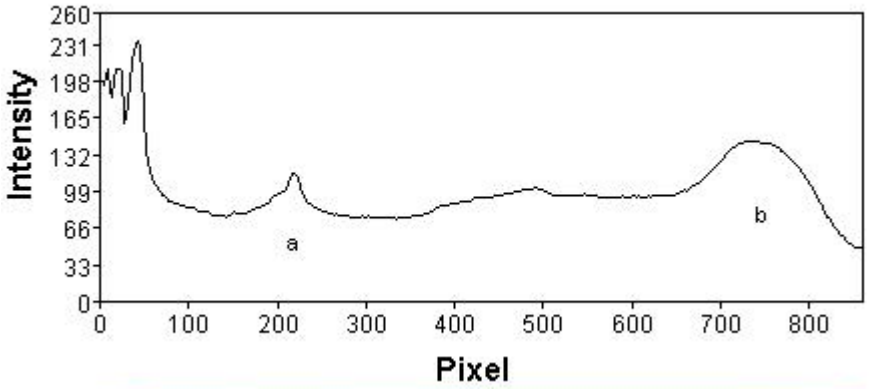
The aim of the work was to study the effect of vacuum ultraviolet (VUV) radiation on cells of microscopic fungi (micromycetes). As radiation sources were used barrier discharge xenon excimer lamps (I = 1–2 mJ/cm^2, λ = 172 nm, P = 300 Torr). The effect was carried out on the cells of various types of micromycetes (*Aureobasidium pullulans, Cladosporium herbarum, Geomyces pannorum, Penicillium aurantiogriseum, Rhodotorula colostri*), isolated from Antarctic habitats, developed increased resistance to external influences.

Potential mechanisms of the effects of VUV radiation on the cells of micromycetes coincide with the mechanisms of action of ionizing radiation: destruction of chitin of the cell wall, the destruction of the phospholipid membrane, degradation of DNA [1]. These processes can occur both as a result of direct absorption of VUV emission quanta, and as a result of exposure to highly reactive VUV products of water photolysis and lipid oxidation products.

The change of the cell wall structure by VUV radiation was studied by IR spectrometry and atomic force (AFM) microscopy. The intensity of the IR transmission spectra of the irradiated samples increases in the bands corresponding to the absorption of proteins λ = 1313 cm^{-1},1376 cm^{-1}, 1400 cm^{-1}, and polysaccharides λ = 1454 cm^{-1}, indicating the destruction of the cell wall material. Studies on AFM indicate the absence of mechanical destruction in macromolecular scales at distances $d \geq 0.1$ μm (d- AFM resolution).

In the work a study on the effect of VUV radiation on the DNA molecule has been carried out. The results of electrophoresis indicated DNA degradation during VUV irradiation: in the irradiated samples appear low molecular weight fragments and a peak corresponding to fragments with a length of 20 000 pairs of nucleotides (Figure).



DNA electrophoresis curve of *Rhodotorula colostri* VUV-irradiated cells (I = 25 mJ/cm^2), a – peak of 20 000 pairs of nucleotides; b – low molecular weight fragments

1. *Kudryashov Yu.B.* Radiation Biophysics (Ionizing Radiation), M.: Fizmatlit, 2004. 442 p. [in Russian]

G-4

VISUALIZATION OF APTAMERS ON THE SURFACE OF PLANAR ELECTRODES BY THE METHOD OF CONFOCAL LASER SCANNING MICROSCOPY

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Advances in optical technologies, precise mechanics, computer control technologies, and image processing, as well as the development of fluorescent approaches in conventional microscopy, have significantly enhanced the capabilities of optical microscopy, and make it a unique tool for research and diagnostics. The confocal laser scanning microscopy method can be successfully applied for the microscopic analysis of the biological or organic objects that have auto-fluorescence or stained with the fluorescent dyes. It is also possible to visualize the object by staining it with fluorescent labels. The main difficulty of this type of research may be the need to separate various parts of a complex object by staining them with different substances. The operating wavelength of the detected fluorescence is in the range of 400–800 nm.

In the present work the results of a study of the localization of biological objects–DNA aptamers, specific for proteins oncomarkers, on the surface of planar gold or graphite electrodes modified by gold nanoparticles (a sensor system for cancer in the early stages detecting) are presented. The conditions for the study of the aptamer/electrode samples using confocal laser scanning microscopy LSM 780 NLO Carl Zeiss instrument) were selected and optimized. On the basis of the results obtained, a method of applying aptameters to the electrodes that provides the best filling and uniformity of aptamer distribution over the entire surface of the working electrode is proposed.

The work was carried out with the financial support of the Russian Foundation for Basic Research, Grant No. 16-42-240662 p_a "Biomedical technologies and microfluidic systems for the development of effective nanoconstructions and methods of targeted magnetodynamic therapy".

G-5

LASER ABLATION OF BONE TISSUE AT A WAVELENGTH 6.45 μm

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In this paper, we present the results of a study of laser resonance ablation of bone samples performed using a unique laser apparatus based on a strontium vapor laser. The length of the incisions in the bone samples varies from 1 to 3 mm with a width of 0.1–0.35 mm. Analysis of the ablated areas showed that the depth of the section increases with increasing water content.

For the cortical bone, the heat equation is solved in the one-dimensional approximation. According to the estimates made, the biological tissue in the zone of action of laser radiation with a wavelength 6.45 μm is heated to a temperature of ~ 210 °C.

The choice of wavelength is the determining factor for the process of ablation, because the change in the absorption coefficient of the tissue from the wavelength affects the volume of the heated tissue more (by 4 orders of magnitude) than the change in the physical parameters of the radiation, which vary within one or two orders of magnitude.

The choice of wavelength is the determining factor for the ablation process, since the change in the absorption coefficient of laser radiation by the biotope from the wavelength affects the volume of the heated tissue more strongly (by 4 orders of magnitude) than the change in the physical parameters of the radiation (power, pulse duration, etc.), which vary within one or two orders of magnitude.

This research carried out in 2017 was supported by "The Tomsk State University Academic D.I. Mendeleev Fund Program" Grant (No. 8.2.04.2017).

G-6

IMPROVEMENT OF THE MULTIPHOTON FLUORESCENCE MICROSCOPY IMAGES QUALITY

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Multiphoton optical devices allow to obtain images with high resolution, but the resulting image due to the complexity of the measurement process can have a poor quality: images can be noisy, part of the image may be darkened or vice versa illuminated, the artifacts are possible. These distortions can cause the false classification [1]. As well, an important issue is temporal data measurement error, for example obtained by means of FLIM technology (each pixel records the intensity of luminescence from the time) [2].

In our study for the analysis of FLIM data the spatial filters were used: rank-order filter, the emissions filter on the base of the criteria of Pearson and Grubbs and temporary filters: Gaussian filter and median filter [3]. The data obtained with the FLIM technology are the distribution with a pronounced peak (as shown in the literature, the position of the peak allows to select different objects with the same value of intensity [2]), while during measurement the peak value is measured with inaccuracy. Spatial filtering allows to reduce the noise component, obtained in the course of measurements, including reduction the influence of the individual bursts. Filtering by time allows to determine a peak value of intensity more accurately.

This research was carried out using the equipment of Tomsk Regional Common Use Center of Tomsk State University.

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G-7

ANALYSIS OF SALIVA EXOSOMES AND BLOOD PLASMA BY THE METHODS OF LASER SPECTROSCOPY

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The spectral analysis of saliva exosomes [1] and blood plasma of patients with colorectal cancer and healthy volunteers is carried out in this work. The exosomes samples are placed in a special cuvette, and stored frozen at a temperature of 193 K. For the frozen samples using the THz spectrometer in the range from 0.3 to 3 THz the corresponding absorption spectra are obtained. The obtained spectra are analyzed on the database of the 217 spectra of different compounds to identify the component composition of exosomes.

It is shown in the work that in the terahertz range in the saliva actsoma and blood plasma for some of the samples the presence of certain components typical either to the patients with colorectal cancer, or healthy volunteers can be identified.

This research was carried out using the equipment of Tomsk Regional Common Use Center of Tomsk State University.

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G-8

THE ABILITIES OF THE PROSTATE CANCER TISSUE CYTOSPECTROPHOTOMETRY IN THE THz SPECTRAL RANGE

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The problem of prostate cancer diagnosis based on the analysis of spectroscopic characteristics of different human tissues in the terahertz range is considered in this study. The samples of the investigated tissues are enclosed in paraffin blocks according to the standard methods of biological material sampling. There is a medical report for each sample that allows to use this information as a reference. Samples in paraffin blocks are scanned using a system for THz spectroscopy with time resolution in the range from 0.3 to 3 THz with regular increments in two-dimensional space. Visualization of these features and their comparative analysis with high-performance systems allows to select the most informative spatial areas of biological tissues. For all informative spatial areas the corresponding set of spectra are created. To the obtained set of spectra the principal components method is applied.

It is shown in the work that spatial visualization allows to analyze the biological samples, enclosed in paraffin blocks, and in the space of principal components the areas of biological samples corresponding to the healthy tissue and tumors are separated.

This research was carried out using the equipment of Tomsk Regional Common Use Center of Tomsk State University.

G-9

THE KERNEL SELECTION IN CLASSIFICATION OF BIOMEDICAL DATA BY THE SUPPORT VECTOR MACHINES

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The particular interest within the data mining by the support vector machines (SVM) has the task of coordinated choice of the optimal parameters of the classifier and the pre-processing algorithms parameters. The most famous criteria of filtration quality from the position of the classifier are the sensitivity and specificity of the classifier on the filtered data compared to initial data [1]. The formulation of the SVM in terms of kernels [2] have allowed to significantly expand the class of tasks, however the question of the choice of kernel for a given task remains challenging. In several publications (e.g. [3]) it was shown that there is a close relationship between RBF kernel of the SVM, applied for high frequency filtering, and the Green's function for the diffusion equation. Thus, the use of Green's functions with desired properties (inherited from the corresponding differential equations) can extend the range of SVM applicability at the expense of the additional parameters introduction.

In this paper we present the method of the SVM kernel selection in the task of biomedical data classification and offer a new kernel on the base of the Green's function for the Ornstein – Uhlenbeck equation.

This research was carried out using the equipment of Tomsk Regional Common Use Center of Tomsk State University.

1. *Kistenev Yu.V., Shapovalov A.V., Vrazhnov D.A., Nikolaev V.V., and Nikiforova O.Y.* Comparison of classification methods used for analysis of complex biological gas mixtures by means of laser spectroscopy // Proc. SPIE. 2015. V. 9680. P. 968049.
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G-10

THE STUDY OF THE ELECTRIC FIELD DISTRIBUTION IN THE HUMAN BRAIN ON THE BASE OF MRI AND EEG DATA

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This work is devoted to the numerical modeling of Maxwell's equations used to describe the electric field distribution in the human brain. For building the geometric model and finding the spatial distribution of electrical conductivity of biological tissues in the human head the MRI data was used. The distribution of the electric field of the human brain obtained by solving the system of equations obtained from Maxwell's equations with boundary conditions corresponding to values of electric field potentials at the EEG electrodes. Electrodes are located on the surface of the human head according to the standard 10–20 scheme.

The study of the distribution of the electric field of the human brain was carried out on the simulated data in order to develop the research technique. As the model data the MRI of a volunteer and his EEG captured one day after receiving the MRI were used.

We obtained the time dependences of different integral characteristics of the human head. The obtained integral characteristics have character dependencies resulting from a joint analysis of MRI and EEG.

This research was carried out using the equipment of Tomsk Regional Common Use Center of Tomsk State University.

Session H
GAS DISCHARGES FOR LASERS AND NON-COHERENT RADIATION SOURCES

H-1

MODELING OF STREAMER DISCHARGES

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Electric phenomena in various dielectric media are often related with formation and propagation of ionization waves - streamers, with luminous fronts moving at velocities 10^6–10^{10} cm · s^{-1} [1]. The ionization waves are key elements in pre-breakdown processes, they appear in various kinds of pulsed electrical discharges (coronas, volume and surface dielectric barrier discharges, lightning leaders). Phenomena related with fast propagation of luminous plasma objects have been observed in sprite discharges in the upper atmosphere [2] and in cold atmospheric-pressure plasma jets [3]. Recently, similar luminous plasma plumes (so-called apokamps) have been obtained in repetitive pulsed discharges (when one electrode was at high voltage and the other was at floating potential) [4]. The streamer radii are larger at lower medium densities, being in the range 10^{-2}–1 cm in atmospheric-pressure gases and reaching hundreds of meters in sprite streamers in the upper atmosphere, at altitudes of 60–80 km. In cold plasma jets, streamers (guided along the jet axis) with annular luminous fronts are often observed.

For evaluation of streamer characteristics, a number of approaches have been presented. Some helpful information, e.g. on similarity conditions, is obtained using analytical approaches. However, a detailed description of streamer dynamics and structure is based on numerical simulations. In this report, a review of simulation results, concerning specific streamer properties in the wide range of conditions mentioned above, is presented. A comparison of these results with experimental data is discussed.

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H-2

MICROSTRUCTURE OF AREAS OF SPARK DISCHARGE INFLUENCE ON SURFACES OF FLAT STEEL AND COPPER ELECTRODES IN AIR IN GAPS «POINT-PLANE»

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The paper presents the results of the experimental investigation of the microstructure of the areas of a spark discharge influence on the surfaces of flat steel (stainless steel 316L) and copper electrodes in gaps «point-plane». The experiments were performed at the positive and negative polarity of the point at the mode of single pulses with the use of a scanning electron microscope. The discharge was

generated in the air of the atmospheric pressure. The length of the interelectrode gap was 3 mm. The voltage pulse with the amplitude of about 20 kV and with the rise front of 5–10 ns was delivered to the gap. The pulse provided an oscillation regime of the current in the discharge circuit. The current amplitude was 30–100 A, half wave length was 200 ns, and fall time was about 1 μs.

It is determined that the areas (0.2–0.5 mm diameter) of the discharge influence for a steel electrode are those that present the morphological changes of the surface as a set of microcraters and tracks. The microcraters have a diameter of 0.3–5 μm each; the tracks have the length of about 10 μm and width of 0.3–2 μm. All the microcrtaters are located on the tracks that form a complex reticulation.

The areas of the discharge influence for a copper electrode have the form of rounded spots of the diameter from 20 up to 200 μm or a set of spots. Each set presents an accumulation of a large number of microcraters of 0.1–1 μm diameter joint in quasi-concentric ring structures. The rings differ in concentration and size of the microcraters that form these rings. It is shown that the statistical distribution of the microcraters diameters and intermicrocraters distances in the spot has several local maxima. It is determined that the spot microstructure has a fractal character; the values of its fractal dimension are defined: 1.4–1.7. It is revealed that the diameter values of microcraters and intermicrocraters distances for a copper electrode are rather lower than those ones for a steel electrode. The surface concentration of microcraters substantially exceeds the same values for a steel electrode.

H-3

EPTRON – ELECTRON-BEAM VOLTAGE SWITCH WITH END-FACE DISCHARGE

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Interest in the development and research of switches and sharpeners of high-power high-voltage pulses with a subnanosecond edge operating with high pulse repetition frequency is large, and application of these devices for laser excitation is actual. In the present work, a new type of a gas discharge device with a combined discharge is proposed, it is an electron-beam voltage sharpener with end-face discharge called an eptron. Such a device is a combination of a sequentially connected kivotron (discharge structure based on the "open" discharge with the counter propagating electron beams) and a capillary structure.

When the voltage is applied between the cathode and the anode, first discharge between the anode and the kivotron's grid through the capillary occurs. Over a time of 0.2–1 ns their potentials becoms equal, and within a time of the order of 1 ns voltage applies to the kivotron's acceleration gap. In all cases, it appears that the voltage drop during the switching period in the anode-grid gap is several times smaller than in the acceleration gap of the kivotron.

The current development time in the eptron is determined by the characteristics of the kivotron, while the total delay is determined by the sum of the delays of the discharge development in the capillary τ_c and in the kivotron τ_k. In a wide variety of conditions, it turns out that $\tau_c >> \tau_k$, which makes it possible to operate simultaneously at high helium pressure, providing a short switching time, and with a comparatively slow charging of the peaking capacitor, these conditions provide the pulse compression degree of more than 1000 and allow the device to function with high pulse repetition frequency, determined by the capabilities of the primary switch, which was TGI1-1000/25. The maximum pulse repetition frequency was 45 kHz at 20 kV and a capacitance value of 1 nF.

This work was supported by Russian Science Foundation, research Project No. 14-19-00339.

H-4

SUBNANOSECOND BREAKDOWN IN NITROGEN AT PRESSURE UP TO 1.2 MPa, INITIATED RUNAWAY ELECTRONS

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The generation of runaway electrons (REs) and X-rays is a fundamental physical phenomenon in atmospheric-pressure pulsed discharges. To date, there are several hundred publications on the generation of RE beams and X rays emission in laboratory discharges at atmospheric pressure air and other gases, see collective monograph [1, 2] and references therein.

The results of experimental studies of the amplitude-temporal characteristics of a runaway electron beam, as well as breakdown voltage in nitrogen are presented. The voltage pulses with the amplitude in incident wave ≈ 120 kV and the rise time of ≈ 0.3 ns was used. A collector behind the flat anode detected the supershort avalanche electron beam (SAEB). The amplitude-time characteristics of the voltage and SAEB current were studied with subnanosecond time resolution. The maximum pressure at which a SAEB is detectable by collector first time was 1.2 MPa. This pressure increases with decreasing the voltage rise time. The waveforms of the discharge and runaway electron beam currents was synchronized with the voltage pulses. On the basis of the obtained experimental data the mechanism of the runaway electron generation in atmospheric-pressure gases is analysed.

The work is performed in the framework of the State task for HCEI SB RAS, Project No. 13.1.3.

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H-5

SPECTRAL CHARACTERISTICS OF A CATHODE AREA OF THE OVERVOLTAGE DISCHARGE IN A DEUTERIUM FORMING A HIGH-CURRENT BEAM OF THE RUNNING-AWAY ELECTRONS

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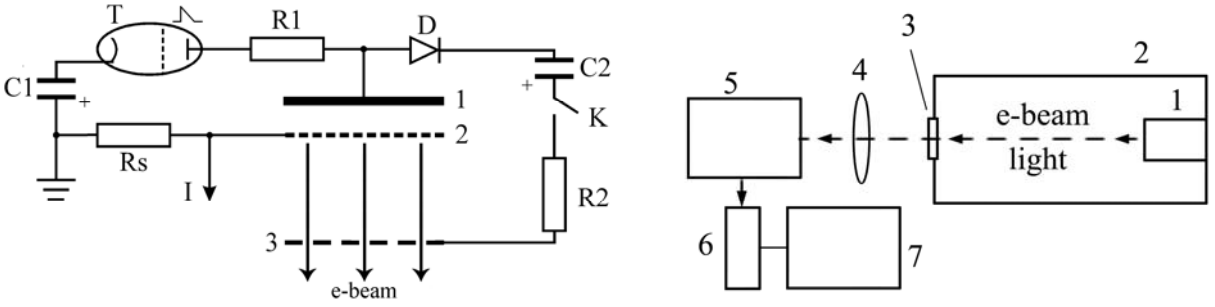
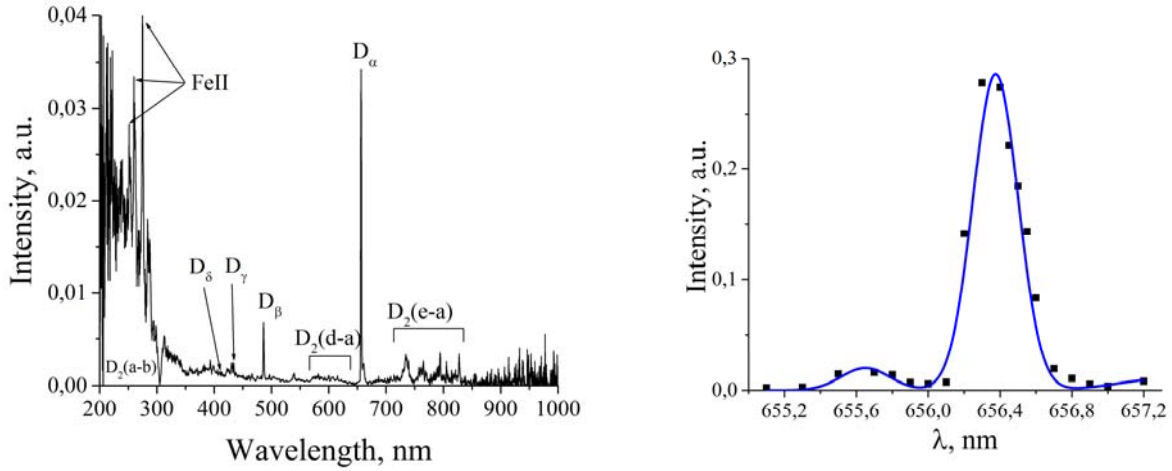
This report presents the results of spectroscopic research on the optical emission from the cathode region of the overvoltage discharge in a deuterium in three-electrode system used for generation of a high-current beam of the running-away electrons. The scheme of three-electrode discharge is shown in Fig. 1, *a*. The optical scheme for spectroscopic study is depicted in Fig. 1, *b*. As an example, the review optical spectrum of the cathode area and the shape of D_α spectral line are presented in Fig. 2. The mechanisms of spectral lines broadening for Balmer series are offered for diffusive and constricted discharge regimes. A detailed set of the received results will be presented in the full version of the report.



a *b*

Fig. 1. Three-electrode scheme for formation of a high-current e-beam: 1-the cathode, 2-the main anode, 3-the complimentary anode (*a*); scheme of optical measurements: 1-the e-beam gun, 2-the quartz tube, 3-the output quartz window, 4-the quartz lens, 5-the monochromator, 6-PMT, 7-the oscilloscope (*b*)



a *b*

Fig. 2. The review optical spectrum of the light emitted from cathode area (*a*); the shape of D_α spectral line. Deuterium, gas pressure P = 2 Torr. The amplitude and frequency of a sin voltage are 20 kV and 100 kHz (*b*)

Work is performed with full support of Russian Science Foundation (Grant No. 16-12-10458).

H-6

MATERIALS AND PRODUCTS SURFACE DISCONTINUITY DETECTION METHOD

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Liquid penetrant testing is one of the main methods of nondestructive testing to detect surface discontinuities. Luminescent method is carried out under darkening conditions and requires using of ultraviolet (UV) irradiators, for surface discontinuities are detected as brightly indications that are formed on the developing coating (developer) in places of discontinuities. The fluorescence effectiveness of indications depends on UV irradiators energy characteristics and luminescent penetrant properties. Mercury and LED UV radiation sources are widely used in the luminescent method of liquid penetrant testing in nowadays.

High-power UV irradiators based on mercury gas-discharge lamps and LED elements are used to increase the detectability of surface discontinuities. But in this case UV irradiation get increased harmful biological effect on operator. Except for harmful biological effects mercury gas-discharge lamps have big dimensions, high cost, low efficiency and represent a potential hazard for the operator and the environment. UV irradiators based on LEDs have from one side high intensity, but from another side small size of the focal spot, which makes it difficult to test objects with a large control area.

It is proposed to use excilamps as sources of UV radiation in luminescent method of liquid penetrant testing. Advantages of this type of UV irradiators are the absence of mercury in bulb, high efficiency, relatively high specific radiation intensity, the possibility of scaling, choosing of radiation surface geometry of any type.

After experimental studies and comparison of technical parameters of various UV radiation sources, we conlude the excilamp applicability in luminescent method of liquid penetrant testing.

H-7

EFFECT OF THE SOURCE VOLTAGE FORM ON CHARACTERISTICS OF THE DIELECTRIC BARRIER DISCHARGE IN $Xe–Cl_2$ MIXTURE

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The dielectric barrier discharges in $Xe–Cl_2$ mixtures are sources of the UV radiation of XeCl* exciplex molecules with high spectral density of power and are used for generation of the UV radiation in XeCl excimer lamps. Radiative characteristics of the emission are determined by composition of the $Xe–Cl_2$ mixture, pressure, supply voltage and discharge configuration. In this work effects of source voltage form on the radiative efficiency and the emission power of $XeCl^*$ excimer molecules in dielectric barrier discharges in the mixture of 99.8%Xe–0.2%Cl_2 have been studied. Discharge characteristics are modeled using the 1D fluid model [1]. Discharge parameters are varied in following limits: voltage value is varied in a range of 4.3–5.3 kV, frequency is varied in a range of 50–200 kHz, pressure of the gas mixture is 125 Torr, the discharge gap length is 3 mm and the dielectrics thickness is 1.5 mm, their permittivity is 4.

Discharge characteristics at voltage of tooth- and saw-form were compared with that at sine–form voltage of the same frequency. It is shown, that at chlorine concentration in the mixture of 0.2% the most emission of the DBD is observed in the $XeCl^*$ molecule band at the wavelength of 308 nm ($B_{1/2} \rightarrow X_{1/2}$- transition); in the most cases about 86–87% of the discharge emission falls on the $XeCl^*$ radiation. Depending on conditions the radiative efficiency of the $XeCl^*$ band varies in a range of 41–48%.

The emission power in the XeCl* band at saw-form voltage a little differs from the power at sine-form voltage (the first one is 4% higher than the second one). The emission power in the XeCl* band at tooth-form voltage is 10–20% greater than the emission power in this band at sine-form voltage. In all cases a form of voltage does not influence on discharge mode. At decreasing voltage frequency a transition of the discharge from the one-peak mode to the two-peak mode is observed. The smooth change of the voltage form in time inherent to the harmonic voltage leads to less sharp current pulses compared with that at tooth- and saw-form of the voltage, as well as to decreasing share of the power deposited into electrons and to increasing that one deposited into ions.

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H-8

RESULTS OF AN INVESTIGATION IN AIR AT ATMOSPHERIC PRESSURE OF THE MECHANISM OF MICRODISCHARGES FORMATION IN DIELECTRIC BARRIER DISCHARGE CELL WITH A ROTATING DIELECTRIC DISC

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The paper presents study results of the mechanisms of microdischarges onset and development in dielectric barrier discharge (DBD) cell with rotating dielectric disc. Study was carried out in air at atmospheric pressure. A distinctive feature of DBD cell with a rotating dielectric disc is that microdischarges can occur in it not only with AC high-voltage on metal electrodes (as it takes place in case of classical DBD systems without moving elements), but also when DC high-voltage is applied to electrodes. In this case the average repetition rate of microdischarges depends on the angular velocity of dielectric disc rotation. Also, the microdischarges differ significantly in case of positive and negative polarities of a high-voltage electrode. In particular, in the first case they have a more diffuse spatial character than in the case of microdischarges, that arise when the high-voltage electrode is negative. In addition, the spatial and temporal characteristics of microdischarges are another in case of their generation in DBD cell with a rotating dielectric disc with AC high-voltage applied to the metal electrodes. The research results are useful not only from the point of view of development of more effective plasma and plasma-chemical processes proceeding in DBD cells with a rotating dielectric disc, but also for development of incoherent radiation sources with emission duration of tens nanoseconds in different media and at different gas pressures.

H-9

PROPAGATION OF A NEGATIVE STREAMER ON A SURFACE OF A LIQUID BUBBLE

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Streamer discharges are used for saturation of liquids by various active species which are able to initiate or accelerate the necessary biochemical processes. One of ways of increase in efficiency of plasma activation consists in use of liquid in the form of the foam consisting of a set of bubbles. Therefore clarification of interaction of a streamer with a liquid bubble is of scientific and practical interest. Results of experiments on a research of interaction of a negative streamer with the bubble floating on tap water are presented in the report. A limited number of the received results is presented in Figs. 1–2. The extended information will be given in the full version of the report.

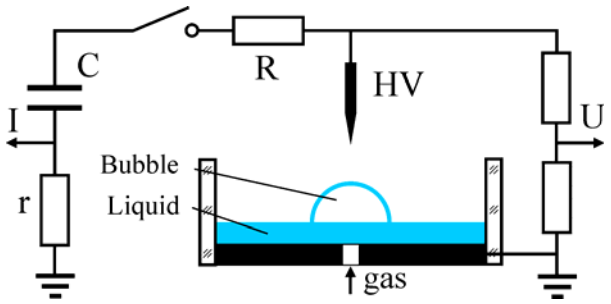

Fig. 1. Sketch of the scheme for the experimental study of the streamer-bubble interaction

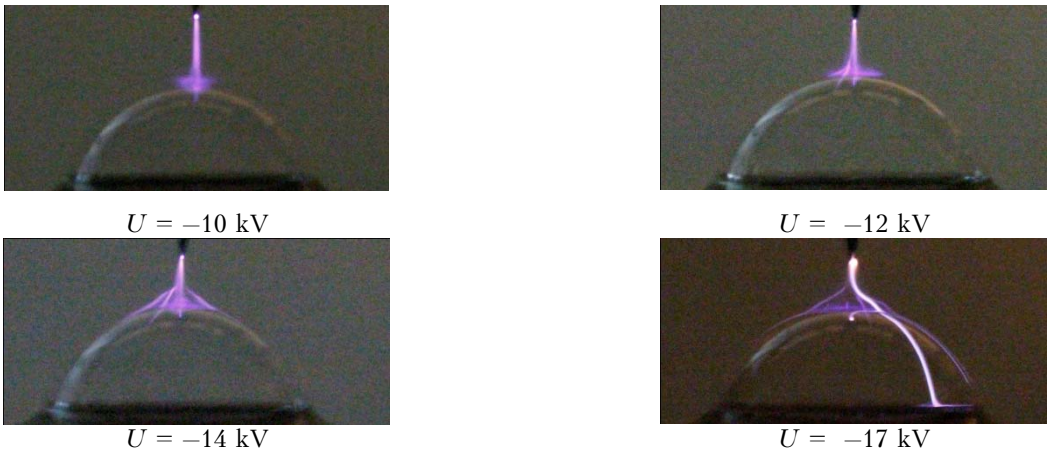

Fig. 2. Images of the streamer(s) between a pin and bubble and on a bubble surface at the different voltages applied to the cathode pin. Conductivity of a liquid is 720 μs/cm. The diameter of the bubble basis is 15 mm. At the striking, the streamer does not perforate a bubble wall. The energy released by a streamer on a bubble is equal approximately to 400–500 μJ

Work is performed with support by the RFBR (Grant No. 16-02-00613).

H-10

A TRANSVERSE STRUCTURE EVOLUTION OF A HIGH-CURRENT BEAM OF THE RUNNING-AWAY ELECTRONS ALONG THE PATH OF ITS PROPAGATION IN HYDROGEN AND A DEUTERIUM AT A LOW PRESSURE

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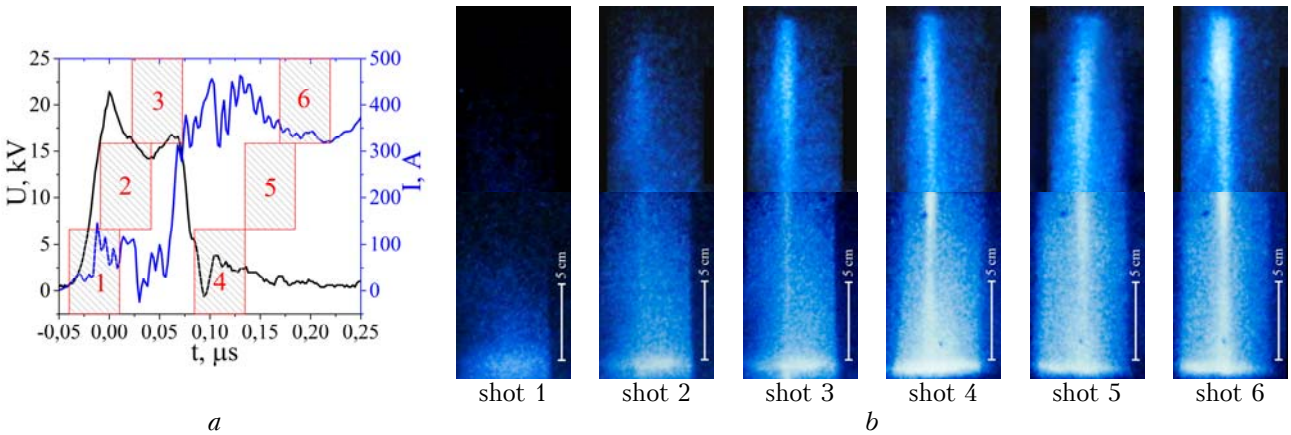
The report presents the results of the experimental search on transverse structure evolution of a high-current beam of the running-away electrons along the path of its propagation in hydrogen and a deuterium at a low pressure P = 0.5–2.5 Torr in dependence on the electron energy (ε = 7–25 keV). As an example, Fig. 1, *a* shows the current and voltage waveforms of the overvoltage discharge generating the running-away electrons.



a *b*

Fig. 1. The current and voltage waveforms of the overvoltage discharge in deuterium at P = 2 Torr (*a*); spatial-temporal evolution (side view) of the light emission from the gaseous area excited by the e-beam (*b*); exposure time of the each shot is 50 ns. The numeration of shots corresponds to the same figures in the legend of Fig. 1, *a*; the e-beam gun exit is in bottom of each shot. U = 20 kV

The set of images showing the spatial-temporal evolution of the e-beam structure at the energy ε = 20 keV are presented in Fig. 1, *b*. Fig. 2 shows the change in the spatial shape of the e-beam in dependence on its energy. The e-beam is formed without an auxiliary discharge (Fig. 2, *a*) and with the auxiliary discharge (Fig. 2, *b*). A detailed set of the received results will be presented in the full version of the report.

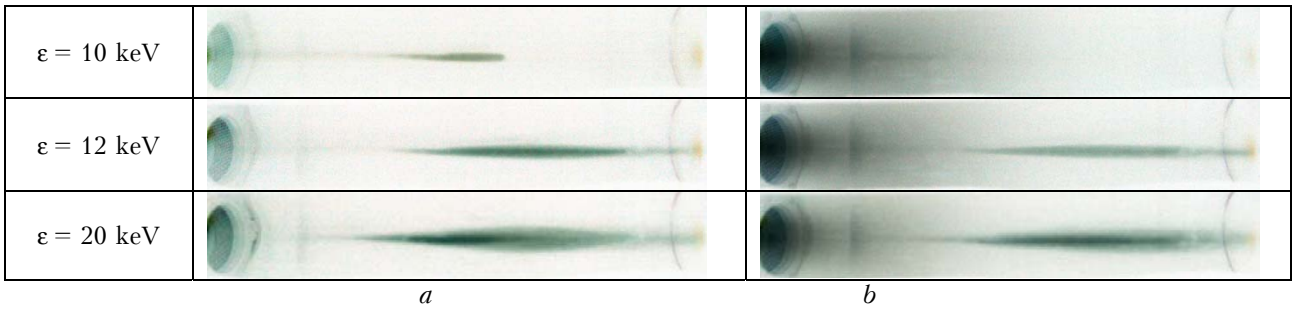


Fig. 2. Spatial structure of the e-beam at its different energies. Deuterium, P = 2 Torr: e-beam is formed without use of an auxiliary pre-ionizing discharge (*a*); e-beam is formed with use of an auxiliary pre-ionizing discharge (*b*). All images are negative ones; the e-beam gun exit is in the left in each shot. Exposure time: 1 s (a), 0.5 s (b).

Work is performed with full support of Russian Science Foundation (Grant No. 16-12-10458).

H-11

METAL SURFACE TREATMENT BY PLASMA OF NANOSECOND DIFFUSE DISCHARGE AT ATMOSPHERIC PRESSURE

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Applications of gas discharge plasma of various types are used for surface modification of metals and dielectrics since 70th years of the last century. Low pressure glow and magnetron discharges are mainly used for sputter deposition of different compound films or coatings of oxides and nitrides layer with thickness of several tens of micrometers. But one of the technological disadvantages of such discharges is usage of vacuum and gas pumping equipment.

High voltage nanosecond discharge in non-uniform electric field allows to form diffuse plasma with electron concentration up to 10^{14} cm^{-3} in various gases of atmospheric pressure due to runaway electrons preionization. The distinctive feature of surface modification by such plasma is a short pulse of this discharge with high input specific pulsed power (up to 1 GW/cm^3), as well as effect of intense UV-, VUV- and X-ray radiation. As a result, volume discharge treatment has numerous advantages as it modifies only upper surface layer and do not alter bulk properties of the material.

In this work, the results of runaway electron preionized diffuse discharge (REP DD) plasma treatment of copper, aluminum, stainless steel, niobium and titanium surface in nitrogen flow of atmospheric pressure are presented. It was shown that REP DD treatment with 10^5 discharge pulses provides fine cleaning of upper surface layer of all metals under study from carbon contaminants and formation thin oxide layer with thickness of several tens of nanometers. Moreover, discharge treatment increases surface free energy of the specimens up to 3 times. According to the results of Auger-spectroscopy, showing that the higher the quality of surface cleaning, the larger the increase in the surface free energy, while the other surface characteristics such as microhardness and roughness remains almost unchanged. Thus, the research results show that the diffuse discharge treatment provides fine surface cleaning of metals without any mechanical damages, which is important for further bonding, adhesive coating deposition, printing and medical applications.

H-12

APOKAMP – A NEW SOURCE OF IONISATION WAVES IN POTENTIAL PULSE-PERIODIC DISCHARGE

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In 2016 we have identified a new phenomenon in repetitive pulsed discharges in ambient air: a single or several plasma jets streaming off the bending point of the discharge channel. For their unusual, "off-bend" path we named such jests apokamps. Several conditions are needed for an apokamp to occur: (1) a repetitive pulsed discharge with a pulse repetition frequency of several to tens of kilohertz, (2) a high electrical potential of discharge channel with respect to ground, (3) an amplified electric field for which at least one electrode should be sharp ended, (4) a bent discharge channel, and (5) a gas mixture with electronegative components, which make the formation of an apokamp easier. In atmospheric pressure air, the apokamp represents a set of plasma bullets moving with a velocity of 100–220 km/s, which excludes plasma decay by convection, and its radiation spectrum is dominated by electron-vibrational transitions of N_2 and N_2^+ molecules.

Here we provide a review of our first findings that shed light on the dynamics of an apokamp and its parent discharge, present spectral data on apokamps in air, helium, and argon, and discuss possible applications of the novel phenomenon, in particular for simulating transient luminous events such as blue and red jets and for creating apokamp-based exciplex sources.

H-13

ELECTRON EMISSION FROM A CATHODE IN ELECTRON BEAM GENERATING DISCHARGES

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There is no single viewpoint on the mechanism of discharges, generating electron beams with high power efficiency. The basic part of the applied voltage U is concentrated in them in the cathode fall (CF) of discharge gap d, or the strong field is in all d (no CF). Actually, the universally recognized mechanism (see, e.g., the monograph by Kreindel) in the technological sources of electron beams is the electron emission from a cathode under the action of its bombardment by rapid atoms arising up at the charge exchange ions in strong discharge fields. A different mechanism is offered for an open discharge (OD) with the mesh anode – the photoemission discharge with a power efficiency ≈ 1. It is considered to be supported by the resonantly excited atom states illumination.

I will give a number of arguments from a report that testifies the inconsistence of photoemission discharge. One of opponents errors is identifying the power efficiency with a parameter η determinable on the anode and collector currents. It results in the overevaluation of the real power efficiency that can even exceed 1. So, parameter $\eta = 0.9988$ was obtained at $U = 3$ kV. Then the power losses concomitant to flight d by an electron from a cathode will make $eU(1 - \eta) = 3.6$ eV, that is even less than the atom energy in the resonant state. From where then do VUV photons, supporting a photo – discharge, come from? Besides, the charge reproduction in d and the flow of ions on a cathode are proportional to the flow of electrons from a cathode, including those due to photoemission, and the power efficiency can not grow. At the substantial contribution of photoemission (it can not be basic in principle!), additionally to the emission from heavy particles, the discharge yield would originate from the anomalous mode with a sharp current growth, as, for example, in a discharge with the additional ionization. In OD, such phenomenon is not observed, which is evidenced by the measurements in a wide range of conditions.

H-14

AMBIPOLAR TRANSPORT IN THE STRUCTURE OF GAS DISCHARGE PLASMA

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Although charged particles in plasma can move in different trajectories and in opposite directions, in attempting to leave the bulk, according to the Poisson equation, such "runaway" particles will be subject to the returning force caused by the influence of uncompensated space charge. By now, in addition to ambipolar diffusion, two other types of transport providing the motion of plasma as a whole are known: ambipolar drift known from the theory of electrolytes [1] and transport caused by the action of the energy of the plasma electric field. These three types of ambipolar transfer are sufficient for describing the structure of direct-current atmospheric glow discharge [2]. Ambipolar drift, which plays a special role in maintaining the discharge plasma at medium pressures, becomes, at atmospheric pressures, a key mechanism of transfer of charged particles from the near-electrode layers providing the existence of a discharge without ionization in the bulk.

The presence of near-electrode layers results in the fact that the field in the quasi-neutral part of the discharge is always smaller than between the electrodes, outside the plasma pinch. Therefore, the external surface of the plasma pinch in the radial direction will be subject to the action of a force, determined by the energy gradient of the electric field, compressing the pinch. On the other hand, the action of thermal energy leads to the diffusion expansion of plasma. Thus, ambipolar diffusion and ambipolar transport caused by the action of the electric field energy resist each other, determining the plasma pinch radius. A detailed analysis of the results of an experimental investigation of atmospheric pressure discharges in various gases and a comparison with estimates based on three kinds of ambipolar transport of plasma have shown that the coincidence of the plasma pinch radii is not more than 20%. Nevertheless, the role of ambipolar transport in the gas discharge has not been fully understood yet, since the concept of local balance of particles is widely used.

1. *Medvedev A.E.* Structure formation of atmospheric pressure discharge // EPJ D. 2016. V. 70. P. 37–47.

H-15

MODIFICATION OF ELECTROPHYSICAL PARAMETERS OF HgCdTe EPITAXIAL HETEROSTRUCTURES UNDER THE ACTION OF A PULSED NANOSECOND DISCHARGE IN GAS ENVIRONMENT AT ATMOSPHERIC-PRESSURE

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The search for new methods for the controlled changing of the parameters of the properties of semiconductor materials HgCdTe is still an urgent task. The first experimental results of the impact of a pulsed nanosecond discharge in atmospheric pressure air showed the promise of this type of action for modifying the properties of HgCdTe. The aim of this work was a comparative analysis of the results of the action of a low- and high-frequency impulse nanosecond discharge on the electrophysical characteristics of the HgCdTe epitaxial heterostructures.

For experiments the samples of epitaxial HgCdTe films of the p-type conductivity were prepared. Under the action of a low-frequency discharge, the RADAN-220 generator was used as the source of the pulse voltage, the pulse repetition rate was 1 Hz, the number of pulses was 100–1200 pulses. At high-frequency irradiation the NPG-18/3500N generator was used, the repetition rate was 1200 kHz, the irradiation time was 2, 5, 10 minutes. At high-frequency action, a laminar gas flow was fed into the discharge chamber, the pumping rate was 1.5 l/min. Measurements of the electro-physical parameters of the samples before and after irradiation were made at the temperature of liquid nitrogen using the Hall Electromotive Force (EMF) method in the Van-der-Pau configuration.

Experimental data have shown that the qualitative results of the action of low and high-frequency pulsed discharge in an atmosphere of air and nitrogen coincide. After the action, an increase in the conductivity of the epitaxial HgCdTe structures is observed. At the same time, there are differences. These differences are associated with different dynamics of the relaxation of the magnetic field dependences of the Hall coefficient after the action. These results allow us to make the assumption that the mechanisms of low- and high-frequency impact of volume nanosecond discharge on the electrical parameters of HgCdTe heterostuctures are different.

H-16

COMPARISON OF THE CROSS SIZES OF A VISUAL AREA AND THE MODIFIED SURFACE OF THE SUBSTRATE BEING PROCESSED BY A PLASMA JET

Yu.S. Akishev[1,2], A.A. Balakirev[1], V.B. Karalnik[1], M.A. Medvedev[1], A.V. Petryakov[1], N.I. Trushkin[1], and A.G. Shafikov[1]

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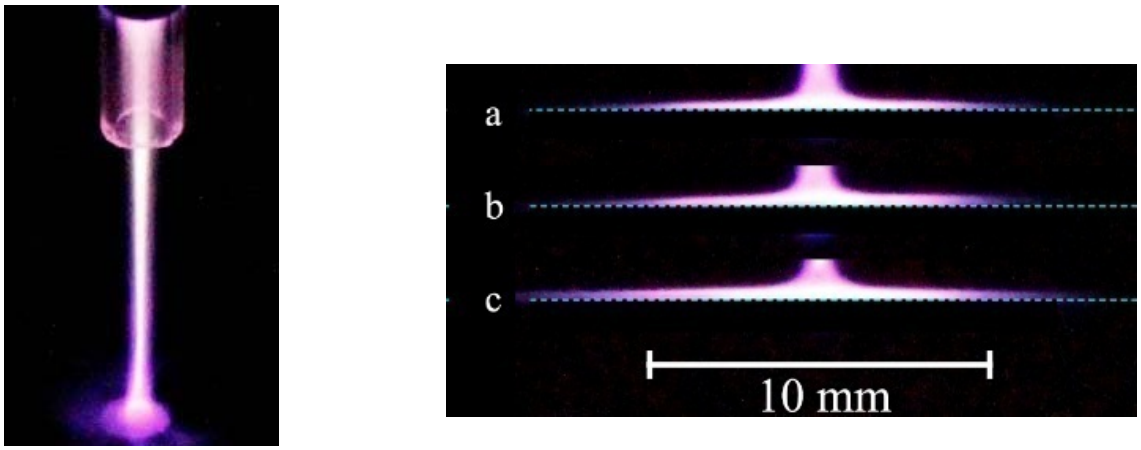
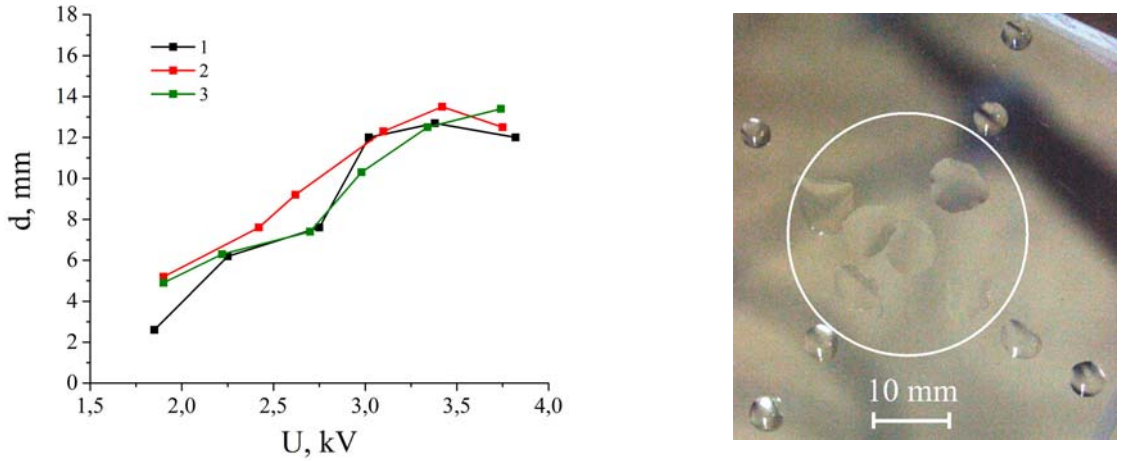
The report presents the results of experiments devoted to search on the interaction of plasma jet with the surface of the quartz. Plasma jet is generated by DBD in the flow of He and ejected into the ambient air. It is shown that the cross size of the modified dielectric surface treated by plasma jet exceeds by a factor of 2 the visual area formed by jet on this surface. The grounding of a metal surface on which the processed plate is placed practically doesn't influence the diameter of a visual spot formed by jet. As an example, a part of results is given in Figs. 1 and 2. A detailed set of the received results will be presented in the full version of the report.



a *b*

Fig. 1. Photo of a plasma jet and visual spot on a quartz plate placed on the grounded metal surface. Exposure time is 10 ms. The amplitude of sin voltage U = 2.7 kV (*a*); The increased photo of a visual spot on a quartz plate: a – metal is not grounded, b – plate in air, c – metal is grounded (*b*). The amplitude of sin voltage U = 3.5 kV



a *b*

Fig. 2. Dependence of diameter of a luminous spot on a surface of a quartz plate vs a sin voltage amplitude: 1 – metal is grounded, 2 – metal is not grounded. 3 – plate in air (*a*); photo of water droplets (top view) on processed quartz surface (droplets in a circle) and untreated surface (round droplets outside a circle) (*b*). The amplitude of sin voltage U = 3.5 kV

Work is performed with support by RFBR (Grant No. 17-02-00234).

H-17

INFLUENCE OF SPEED OF THE SUBSTRATE MOVEMENT ON A VISUAL SPOT FORMED BY THE PLASMA JET STRIKING IN A SUBSTRATE

Yu.S. Akishev[1,2], A.A. Balakirev[1], V.B. Karalnik[1], M.A. Medvedev[1], A.V. Petryakov[1], N.I. Trushkin[1], and A.G. Shafikov[1]

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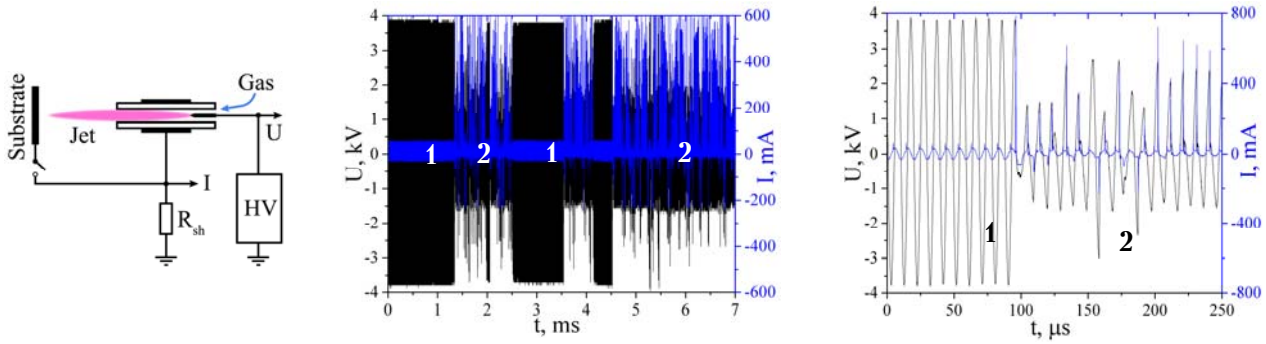
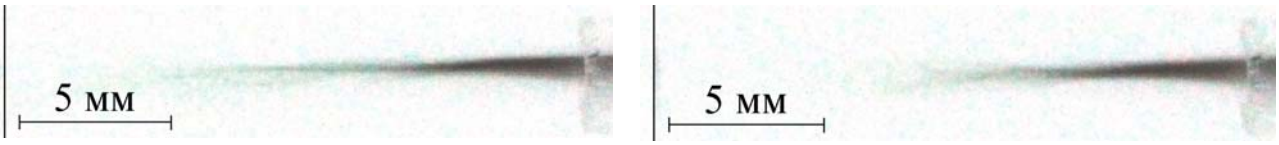
The report presents the results of experimental study on interaction of the plasma jet formed by the cylindrical barrier discharge in an argon flow with a metal surface in four modes: the surface is not grounded and does not move; the surface is not grounded and moves; the surface is grounded and does not move; the surface is grounded and moves. Essential distinction of a form of a plasma jet at its interaction with a surface in the modes mentioned above was revealed. Some part of the obtained results is shown in Figs. 1–3. Detailed information will be provided in the full version of the report.



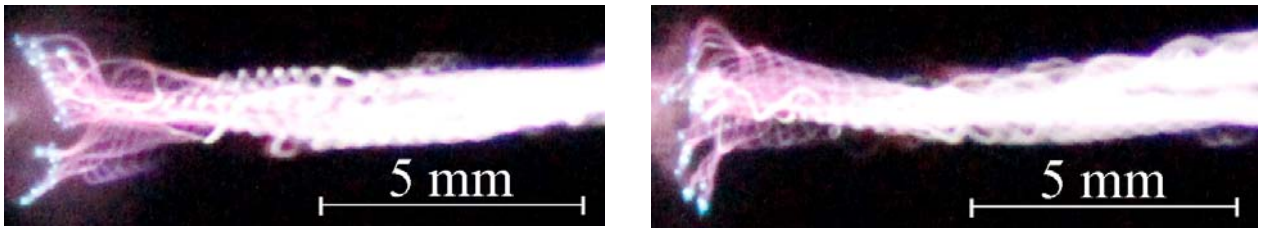
a *b* *c*

Fig. 1. The scheme of the experiment on interaction of an argon plasma jet with a surface (*a*); the current and voltage oscillograms of the discharge in regular (1) and the irregular (2) modes (*b*)



a *b*

Fig. 2. The images of a plasma jet at the regular mode of the discharge: the substrate is motionless and grounded, a jet is diffusive and long (*a*); the substrate is motionless but not grounded, a jet is diffusive and short (*b*)



a *b*

Fig. 3. The images of a plasma jet at their regular mode of the discharge. The jet consists of numerous spiral plasma filaments. a) the substrate is grounded and motionless, the plasma filaments are oriented perpendicularly to a substrate (*a*); the substrate is grounded and moves with a speed of 74 m/s, the substrate drags an ambient gas in the vicinity of a substrate and therefore creates gas flow at the boundary layer that leads to a curvature of the plasma filaments near a surface (*b*)

Work is performed with support by the RFBR (Grant No. 17-02-00234-a).

H-18

NO_X FORMATION IN APOKAMP-TYPE ATMOSPHERIC PRESSURE PLASMA JETS INITIATED IN AIR BY A REPETITIVE PULSED DISCHARGE

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The decomposition products of atmospheric pressure plasma of repetitive pulsed discharge in apokamp and corona modes were determined by optical and chemical methods. It is shown, that the decomposition products contain mainly nitrogen oxides NO_x.

A brief overview of the plasma- and thermochemical reactions in the pulsed discharges was made. The review and experimental data allow us to explain the reactive oxygen species formation mechanisms in a potential discharge channel with apokamp.

The possible applications of this plasma source for treatment of seeds of agricultural crops are discussed.

The work was performed under state task of IHCE SB RAS, theme No.13.1.3.

H-19

RAPID HEAVY GLOW-DISCHARGE PARTICLES

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Rapid heavy particles in a discharge were found out already at the beginning of the last century. They appear in the processes of charge exchange ions, accelerated in strong cathode fall (CF) fields and, as a ray ("channel ray"), they take off through a small cathode hole. Besides, atoms and molecules, ions can be present in a ray. With a mesh cathode, it is possible to get broad beams of such particles. In the experiments of $p > 1$ Torr, rapid ions in beams are not present because of charge exchange section ~ 10^{-15} cm^2. According to Massey, the atoms or molecules section excitation is determined by the flying particles speed and, for the excitation, rapid atoms need their energy of tens of keV. However, transitions are possible between pseudo – crossing potential curves of the drawn together atom complexes (Massey did not take them into account) at a flying atom energy only of tens, hundreds of eV. After particles flying apart, one or both of them appear in the excitation state with a section up to 10^{-16} cm^2.

These properties allowed us to measure the discharge parameters with the mesh anode or cathode by observing the temporal - spatial behavior of spontaneous radiation at the excitation by rapid atoms and electrons. The lines were investigated: He – 587.6 and 501.6 nm, Ne – 640.2 and 587.2 nm. The excitation features were determined for the implementation and violation of the Massey criterion. The measured CF lengths subdued the conformities of the glow-discharge law. The ion and atom energy in the He CF and that of the atoms behind the mesh cathode was up to 0.1 eU, where U is the voltage on a discharge. With the additional ionization, there is the CF length $\approx \lambda$ of the charge exchange and the ion, and atom energy $\approx$ eU. The excitation, integral on its spectrum, by heavy particles in He, Ar and in the air was substantially higher than that by the glow-discharge electrons or the electron beam formed in it. These heavy particles beams can be used in physical and quantum (laser) electronics, for atom implantation in a solid surface, plasma chemistry and diagnostic methods.

H-20

CALCULATION OF THE ENERGY ABSORBED IN THE PLASMA OF HIGH VOLTAGE NANOSECOND DISCHARGE WITH SUBNANOSECOND RISE-TIME OF VOLTAGE IMPULSE

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Calculations of the energy absorbed in the plasma of high-voltage nanosecond discharge, forming by voltage pulse with subnanosecond pulse rise time, are presented in this work. For the definition of the energy input was used method of the calculation of absorbed energy in the nonlinear load using shunt of backward current placed in coaxial transmitting line.

There is comparison of proposed in this work method of calculation of energy absorption with traditional method in which energy absorbtion is calculated using current shunt and voltage divisor, placed near the discharge area.

H-21

MARX GENERATOR ON THE BASIS OF LONG LINES FOR ELECTRON ACCELERATORS WITH BEAM EXTRACTION INTO GAS

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In electron accelerators with the electron beam extraction into gas that are used to pump gas lasers, an important task is to match the generator with a vacuum diode providing energy transfer into the diode without formation of reflected pulses. Reflections result in the accelerating voltage decrease, pulse length increase, and rise of the quantity of low-energy electrons in the beam that increases the risk of destruction of the output window foil in the electron accelerator.

The paper presents the description of the Marx generator allowing forming rectangular voltage pulses at a constant arbitrary resistive load as well as the pulses of constant duration without reflections at an arbitrary resistive load. The generator consists of 4–6 stages assembled in the form of artificial long lines with the wave impedance of ~ 4 Ω and electric length of ~ 10 μs. To eliminate the reflections, each line is supplied with a matched load and presents an analogue of the well-known rectangular pulse generator [1]. Connection of the stages and matched load is made by means of one unit of discharge gaps. The generator provides obtaining the rectangular pulses of the voltage up to 130–140 kV and length up to 10 μs at the matched load. Increase of the output voltage and current of the generator is possible at the assembling of the stages with two half-length parallel lines.

The work is supported by the Russian Foundation for Basic Research, Grant No. 17-08-01522.

1. *Auslander V.L., Ilyin O.G., and Shenderovich A.M.* Pulse forming in the arbitrary load // Pribory I Tekhnika Eksp. 1963. No. 2. P. 173–174. [In Russian]

AUTHOR'S INDEX

НАУЧНОЕ ИЗДАНИЕ

Pulsed Lasers and Laser Applications – "AMPL-2017"
Abstracts of XIII International Conference

Под редакцией
А.В. Климкина, О.В. Лобанковой

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Техническое редактирование – С.В. Алексеев

Отпечатано с готового оригинал-макета,
предоставленного Оргкомитетом.

Издательство «STT»
(Scientific & Technical Translations)
Россия, 634028, г. Томск, проспект Ленина, 15/Б–1
Тел./факс: (3822) 421-455
E!mail: stt@sttonline.com

Scientific & Technical Translations
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ИЗДАТЕЛЬСТВО

Формат 84x108/16. Усл. п. л. 15,96. Уч.-изд. л. 14,9.
Бумага SvetoCopy. Гарнитура KudrashovC. Печать
цифровая. Тираж 400 экз. Заказ № 597.