Laser plasma sources of soft X-rays and extreme ultraviolet (EUV) for application in science and technology

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***Abstract*ð Application of laser plasma sources of soft X-rays and extreme ultraviolet (EUV) developed in our laboratory in various areas of plasma physics, nanotechnology and biomedical engineering are presented. The sources are based on interaction of high-intensity nanosecond laser pulses from commercial Nd:YAG lasers with gas puff targets formed by pulsed injection of gas under high-pressure. The use of a gas puff target instead of a solid target makes possible to generate plasmas emitting soft X-ray and EUV radiation without target debris production.**

Keywords*ð *lasers, laser-matter interaction, laser-produced plasmas, soft X-rays, extreme ultraviolet (EUV)

I. Introduction

The soft X-ray and extreme ultraviolet (EUV) regimes extend from wavelengths of approximately 1nm to 50nm. Wavelengths in the nanometer range (nanowaves) enable us to see smaller structures and write smaller lithographic patterns. In addition, the large number of atomic resonances in this spectral region provide mechanisms for both elemental and chemical identification. The soft X-ray and EUV ranges are, therefore, highly attractive for various applications in materials science and engineering, including nanoscience, nanotechnology and biomedicine. The best examples of such applications are nanoscale imaging and spectroscopy, nanolithography, however, other new applications of EUV and soft X-rays in processing materials and photoionization studies have been recently demonstrated.

In the paper laser plasma soft X-ray and EUV sources developed in our laboratory for various applications are presented. Radiation in the nanometer wavelength range is produced by irradiation of double-stream gas puff targets created by pulsed injection of working gas (xenon, krypton, argon, nitrogen or mixture of gases) into an additional annular stream of helium surrounding the inner stream of gas with nanosecond laser pulses. Efficient production of soft X-ray and EUV radiation without target debris production was demonstrated for various lasers, including Nd:glass, Nd:YAG, KrF, iodine lasers, at different intensities in the focus in the range of about 10^{11}-10^{14} W/cm^2. Sources dedicated for specific applications have been developed. The use of these sources in metrology, processing materials and plasma physics are presented.

II. Application of the Sources

For metrology applications a compact laser plasma source has been developed. In this source the targets are irradiated with 4ns laser pulses and energies up to 0.8J using a commercial Nd:YAG laser operating at 10Hz. The source has been used in characterization and degradation studies of Mo/Si mirrors and imaging with nanometer spatial resolution. Using a Fresnel zone plate with an outer-zone width of 50nm as objective and quasi-monochromatic radiation at 13.8nm imaging with resolution of about 50nm was demonstrated. Using a grazing incidence axisymmetrical hyperboloid/ellipsoid Wolter type mirror biological objects were imaged with sub-micron resolution.

The source developed for processing polymers is equipped with a grazing incidence ellipsoidal mirror to focus EUV radiation. The size of the focal spot is approximately 1mm in diameter, with a maximum fluence of up to 100mJ/cm^2. The source was used for fabrication of microstructures and modification of surfaces by direct photo-etching and formation of micro- and nanostructures. Modification of physical and chemical performances of polymer surfaces for biocompatibility control was demonstrated for the first time.

Soft X-ray and EUV radiation in the source developed for plasma studies is produced in result or irradiation of the gas puff target with laser pulses of 1ns or10ns time duration and energy up to 10J from a Nd:YAG laser operating at 10Hz. Combined with axisymmetrical grazing incidence optics the source allows to achieve a maximum fluence in the focus of about 1J/cm^2. Using this source the first experiments on formation of warm and dense plasmas in result of photoionization of gases have been performed.

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