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Effective EUV radiation source based on laser-produced plasma in supersonic xenon jet and ways of its optimization.

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Investigation of laser-produced plasma (LPP), induced by interaction of laser radiation of average intensity (S ~ 10^{12} W/cm^2) with matter, is an actual problem today. The radiant emittance of such plasma in extreme ultraviolet (EUV) range (λ ~ 13.5 nm) makes LPP source one of the most promising radiation sources for nanolithography.

One of the effective debris free EUV radiation sources is LPP source based on supersonic xenon-gas jet. The gas-jet radiation source with conversion efficiency CE = 0.12% has been developed [1, 2]. As a target we used supersonic Xe jet, which was formed with pulsed Xe outflow from a supersonic nozzle.

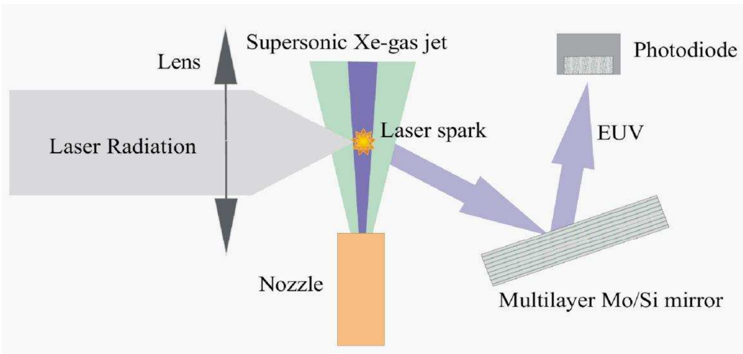

Fig.1. Scheme of gas-jet EUV source.

Low experimental value of EUV radiation output for Xe target can be explained by EUV absorption in Xe jet.

The method of visualization of supersonic xenon jet by lighting it with radiation of LPP on molybdenum metal target for determination of size of the jet has been realized. It is shown, that one of the gas-jet source imperfections is absorption of EUV radiation by gas in the supersonic jet. In working regime of gas-jet source 95-98% of EUV radiation at wavelength 13.5 nm is absorbed by Xe jet.

The simple method of calculation of LPP evolution is proposed and proved. [3, 4] This method allows to show conditions of effective generation of EUV radiation and to recommend the ways of optimization of gas-jet EUV radiation source. We consider basic processes, which take place in interaction between laser radiation and gaseous xenon target and lead to irradiation at wavelength 13.5 nm. The following processes are taken into account: electron impact ionization of atoms and ions; recombination; photoionization (multiphoton ionization); electron heating by free-free transitions in ion field; electron heating by collisions with atoms in electromagnetic field; energy loses of electron gas due to ionization; filling and death of excited states of Xe^{10+} ions, which are responsible for EUV irradiation and for output of radiant energy; EUV irradiation. We do not consider gas-dynamics of plasma in conditions of short laser pulse duration ($\tau \sim 50$ ns). The results of calculations are shown on Fig.2.

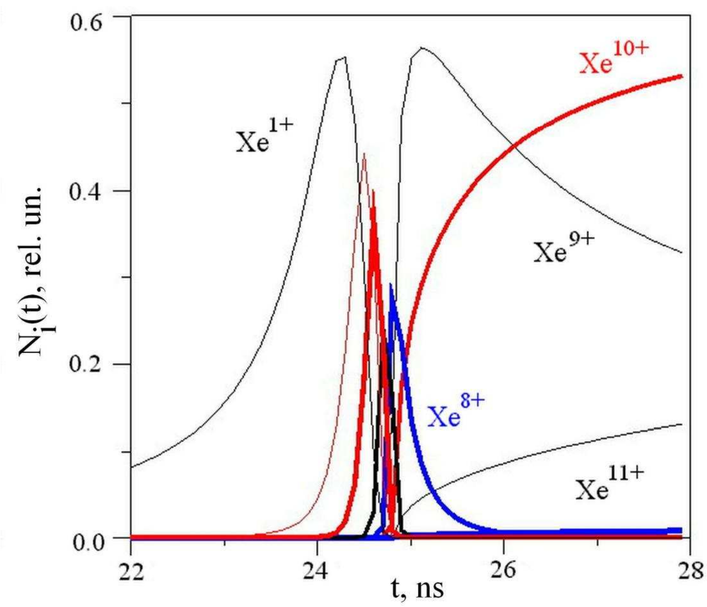

Fig.2. Ionization dynamics of LPP in xenon.

Xe plasma radiation in EUV range (13.5 nm) is generated mainly due to radiative transitions in ions Xe^{10+}. The main role in evolution of laser-produced plasma, which generates EUV, plays correlation between plasma heating and EUV irradiation. Effective generation of EUV radiation is possible just in case of balance between these two processes. Ion charges can exceed 10 ($Z > 10$) when overheating of plasma. Thus overheating of LPP and, on the other hand, EUV absorption by xenon does narrow the conditions of effective work of gas-jet EUV radiation source.

Dependences of EUV radiation output on laser radiation wavelength and gas pressure in supersonic xenon jet are calculated. We consider three different lasers: excimer laser (λ = 0.248 μm), Nd:glass laser (λ = 1.06 μm) and CO_2 laser (λ = 10.6 μm).

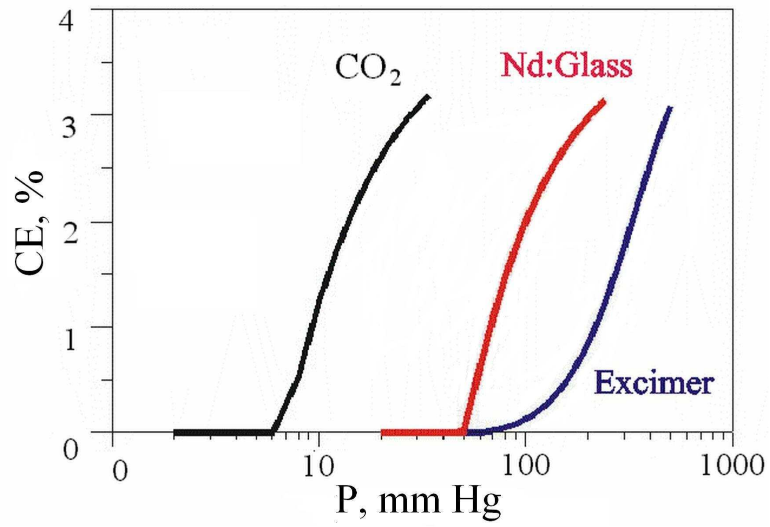

Fig.3. Conditions of generation of EUV radiation for three lasers. Dependence of conversion efficiency on Xe gas target pressure.

It is determined, that the most effective regime of EUV generation by LPP is realized when using laser radiation at wavelength 10.6 μm. In this case conversion efficiency can reach the value 3%.

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References:

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