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EUV Radiation of Xenon Plasma Streams Generated by Magnetoplasma Compressor

I.E. Garkusha[1], V.V. Chebotarev[1], A. Hassanein[2], M.S. Ladygina[1], A.K. Marchenko[1], Yu.V. Petrov[1], D.G. Solyakov[1], V.I. Tereshin[1], S.A. Trubchaninov[1]

[1] *Institute of Plasma Physics, NSC KIPT, 61108, Kharkov, Ukraine*

[2] *Purdue University IN 47907-2017, USA*

Introduction

Extreme ultraviolet (EUV) radiation from hot, dense plasma produced by pulsed gas discharge or laser is considered to be prospective light source for the next generation lithography. In both approaches xenon has advantage to be used as working gas due to considerably emission of Xe^{10+} ions at λ~13.5 nm wavelength, which is quite suitable for Mo-Si multilayer mirror optics.

Different concepts of plasma devices for generation of EUV radiation are under investigations worldwide: z-pinches, plasma foci, capillary, plasma jets and others [1-4]. Gas discharge pulsed plasma devices may have the potential advantages for lithography as far as they can be simpler in design, compact and cost-effective. However, one of the critical issues for all discharge plasma sources using Xe as working gas is strong absorption of EUV radiation by neutral atoms and low charged ions in the periphery of pinching plasma column.

This paper presents the investigations xenon plasma streams generated by magnetoplasma compressor (MPC) of compact geometry with pulsed gas supply and the analysis of EUV radiation from plasma stream in different regimes of MPC operation and varied scenarios of Xe injection in MPC.

Experimental setup

Magnetoplasma compressor consists of two copper coaxial electrodes with disk current collector (separated by figured insulator) and pulsed gas supply system. Schematic view of the source is presented in Fig.1. The outer electrode has solid cylindrical part of 110 mm in diameter and 147 mm in length and also output rod structure including 12 copper rods with diameter of 10mm and length of 147mm. The rods form the frustum of cone surface with apex angle of 30^0. The central electrode consists of the cylindrical part (60mm in diameter and 208 mm in length) and cone mouthpiece with the same apex angle of 30^0 and length of 120 mm. Pulsed injection of xenon is realized with fast electrodynamic valve into discharge gap through the holes in the inner electrode (Fig.1a), or directly to the compression region with different time delays, while helium is used for discharge ignition (Fig.1b).

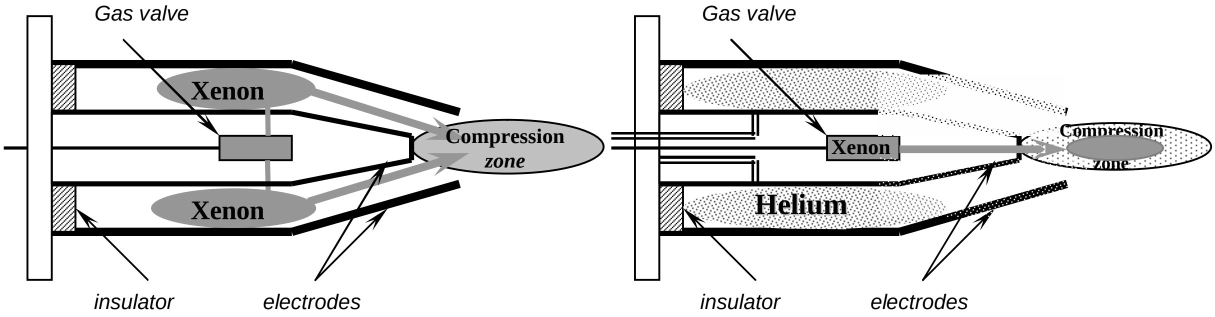

Fig.1. a) – pulsed regime of MPC operation with pure Xe; b) – use of helium as working gas in the discharge gap and Xe injection directly to compression region with varied time delays.

The power supply of MPC discharge and gas valve comes from capacitor banks. The capacity of discharge power supply system is 90 μF and the typical operation voltage is 20 kV. MPC plasma source is installed at the end-flange of vacuum chamber, which consists of two cylindrical sections of 420 mm in diameter and of 1300mm and 1000mm in the length (total length is 2300 mm). MPC device is described in more detail in [4,5].

Experimental results

Spectroscopy measurements of plasma density and electron temperature in compression region of MPC have been performed on the base of Stark broadening of spectral lines and intensities ratio in visible wave-range. The influence of self absorption of XeII and XeIII spectral lines on results of plasma density measurements was taken into account. Radial distributions of the plasma density were estimated using Abel inversion procedure. It was found that maximum value of plasma density in compression region achieved 10^{18} cm^{-3}.

AXUV photodiodes with different multilayer coatings-filters have been applied for the measurements of Xe plasma radiation in the wave range of 5-80 nm. For pure Xe discharges the total radiated energy and peak power strongly depend on operational regime, and in particular, considerably depend on time delay τ_{delay} between the gas supply start and the discharge ignition. Fig. 2 shows AXUV signals for plasma pulses with different τ_{delay}. Regimes which characterized by increased intensity of EUV radiation from the focus region were chosen. It is obtained that the maximum radiation corresponds to the spectral range of 12.2-15.8 nm (Fig.4). Measurements of radiation spectrum with EUV spectrometer are performed also. The spectrometer was calibrated in visible, UV and EUV regions. The results of measurements are compared with AXUV measurements. Time integrated EUV spectra obtained with spectrometer also confirm that MPC device is able to produce EUV radiation from highly ionized Xe in the vicinity of 13,5 nm.

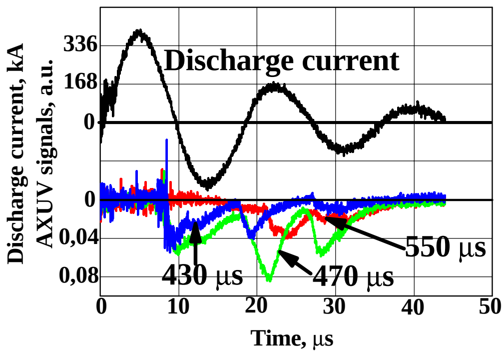

Fig 2. Waveform of discharge current I_d and AXUV 20 Mo/Si signals (wave range 12.2-15.8 nm) for Xe discharge and different time delays.

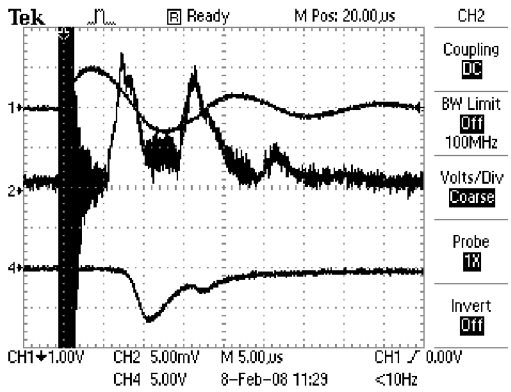

Fig. 3. Waveforms of I_d (1), EUV 12.2-15.8 nm (2) and photodiode signal in visible range (4) for MPC discharge with helium and Xe injection into compression zone. P_{He} =5 Torr.

Increasing of EUV radiation intensity is achieved with changed scenario of Xe injection. In this case the discharge was ignited with He under different pressures (2 -10 Torr). In result, helium plasma stream is generated and compression zone is formed close to the end of central electrode (Fig.1b). New gas valve provided Xe supply into compression zone directly through the end of inner electrode. EUV radiation detected with AXUV in this regime is shown in Fig.3. Several intensity peaks correspond to repeated formation of pinches under damped oscillations of discharge current. Similar peaks were observed also in experiments with pure Xe discharge.

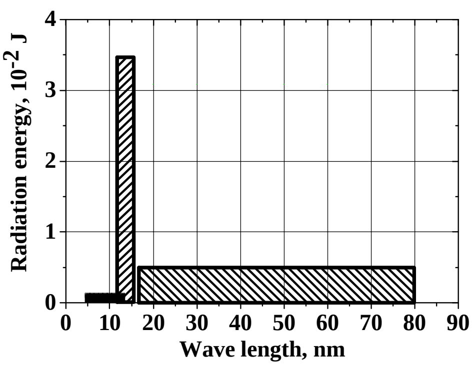

Fig. 4. Average radiation energy in ranges: 5-13 nm, 12.2-15.8 nm, 17-80 nm. I_d= 400 kA, U_c= 20 kV, τ_d= 460 µs, ΔV_{Xe}=10 cm^3.

Total energy of EUV radiation, generated from compression zone and passed through circumambient helium plasma is estimated as (7.0-9.0) 10^{-2} J in full solid angle and average radiation power (during plasma discharge) achieved (2400-2700) W in full solid angle.

Conclusions

EUV emission in wave range of 5-80 nm was investigated for both pulsed Xe supply of the discharge and for Xe injection directly into compression zone of magnetoplasma compressor.

In the case of pure Xe discharge total radiation energy and average radiation power strongly depend on MPC operation mode, namely time delay between gas valve starts and discharge ignition. As follows from the measurements performed in the ranges of 5-13 nm, 12.2-15.8 nm and for 17-80 nm in all the cases the maximal radiation intensity is achieved for time delays of 460-470 µs. In observed wave length range of 5-80 nm the maximum of radiation intensity correspond to 12.2-15.8 nm. EUV radiation energy in 12.2-15.8 nm wave length range measured by AXUV was about $4x10^{-2}$ J in full solid angle and average radiation power (during discharge duration) was about 1.3 kW in full solid angle. Maximum radiation power in the first peak achieved 6-9 kW in full solid angle.

Injection of Xe through the central electrode directly to compression zone while light gas He is used as working gas for plasma discharge gives the possibility to decrease resonant absorption of EUV radiation from the axis region by periphery xenon plasma or/and neutrals. Due to transparency of helium “coat” the measured EUV radiation in 12.2-15.8 nm wave length range became increased at least in two times in comparison with Xe plasma discharges achieving $9x10^{-2}$ J. Maximum power of radiation peak achieved 15-18 kW in full solid angle.

Time integrated spectra obtained with EUV spectrometer confirm that MPC device is able to produce highly ionized xenon EUV radiation in the vicinity of 13,5 nm. Measurements of time resolved spectra as well as optimization of MPC to increase the intensity and brightness of radiation source are in progress.

ACKNOWLEDGMENTS

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