PLASMA DIAGNOSTICS

EUV EMISSION SPECTRA FROM EXCITED Ar, Xe AND Sn IONS PRODUCED IN CAPILLARY DISCHARGES

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This work presents preliminary results of an extreme ultraviolet emission obserwations of a capillary discharge plasma. The main purpose of measurements was to demonstrate the spectral range covered by the system working parameters. The spectroscopic studies were carried out by means of an XEUV spectrometer in the Johann geometry. The results provide general information about the radiation processes from the xenon, argon and tin plasma in the range from 12 to 63 nm.

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INTRODUCTION

Gas discharges in capillary are the promising candidates for generation of EUV radiation and thus are quite often studied by various experimental techniques [1-8]. There are studied as intense soft X-ray sources and a cheap alternative to laser-plasma, free-electron, synchrotron sources, as well as sources based on higher harmonics generation. These sources are of potential interest in a wide field of applications such as lithography, holography, characterization of material and microscopy [9,10]

The capillary construction is a very simple but it creates a sophisticated multiparametric system. The device consists of a non-conductive duct placed between two electrodes which are connected to a bank of low-inductance high voltage (HV) capacitors charged to several of kV. Driver characteristics (current amplitude, current rise-time), initial conditions (gas pressure, prepulse capillary current) and boundary conditions (length and diameter, material of capillary and electrodes) are important for achieving an efficient population in gas discharges. It is desirable to find optimal conditions, especially initial conditions of the discharge, to get from the device coherent EUV radiation with good repeatability [11].

In this paper we made a first step in observations of extreme ultraviolet emission from capillary discharges. Mainly we studied the spectral range over which the system was capable to work and provide general information about the radiative processes in the plasma generated in our capillary device.

EXPERIMENT

A cross sectional view of the capillary discharge experimental setup used for generating the EUV radiation is shown in Fig.1. The discharge setup consists of a brass electrode and an alumina capillary of 1,5 mm inner diameter and 8-mm length.

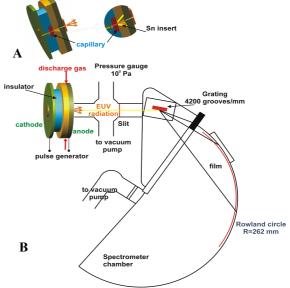


Fig. 1. The experimental setup for the capillary discharge measurements. A - the capillary discharge device,
B - the spectrometer

The capillary was mounted between two specially designed electrodes with the help of an electrically insulating holder, in such a manner that the two ends of capillary had good contact with electrodes. The discharge voltage of the condenser battery of 0,375 μ F was equal to 8 kV (I=~3,5kA achieved in about 1 μ s). The capillary was evacuated below 10-5 mbar using a turbo-molecular pump (Pfeiffer TC100). The processes were conducted with two kinds of the filing gas: pure xenon or argon. The working gas flows through the capillary and was differentially pumped out from the system. The gas pressure near the electrodes was controlled up to tens of Pa. Number of single discharges was equal to one thousand. In case of Sn ions registration a tin insert was mounted in the brass anode (see Fig.1).

The spectroscopic studies were carried out by means of the XEUV spectrometer in the Johann geometry. The

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spectrometer uses a 524 mm radius rectangular gold coated Grating grating of 4200 lines/mm. LxHxW = 40x30x8 mm. Our experiments demanded a very precise justification and calculation of correct position of all elements. A calibration was performed using a red laser light (λ =630nm). In our experiment the spectrums were taken at incident angle 110 degrees thought 1,5 mm slit. The grating, the slit and detector (film) are exactly mounted on the Rowland circle (R = 262 mm). It was calculated that in this configuration the spectrometer covers a wavelength range of 12-65 nm. The radiation was registered on the Kodak BioMax MS films. The capillary unit was connected with the spectrometer by metal tube, which was pumped during the process.

RESULTS AND DISCUSSION

The emission spectra taken in the EUV radiation region obtained in the present experiment are shown in Fig.2 - Fig.4. Fig.2 and Fig.3. show a spectrums obtained in argon and xenon filled capillary and Fig.4 shows the radiation from argon filled capillary where the Sn insert was mounted in brass anode (Fig 1). The main purpose of the spectroscopic measurements of capillary discharges was to demonstrate the spectral range over which the system was capable of working.

In our experiment the spectrums were registered in the 12 - 64 nm, 12- 61 nm and 15- 55 nm wavelength ranges for Xe, Ar, and Sn + Ar ions, respectively. Some of the spectral lines were assigned to the corresponding wavelengths. Spectrums identification is not too easy because of numerous lines corresponding to material of brass electrodes.

The analysis of the emitted spectra shows the presence of different lines corresponding to xenon (XeVII, XeVIII, XeIX [12]) and argon (ArII, ArIV – ArIX [2,12,13]) ions, originating from the working gas, as well as tin (SnV [12]), copper (CuIV, CuV, CuXVIII, CuXIX [13]), oxygen (OV, OII [12]) and aluminium ions (AlVI, AlVII [12]), originating from the material released from the electrodes and from the alumina capillary. The lines of argon, xenon and tin ions are marked with black arrows. A lot of lines overlap and thus they are very difficult to the identification.

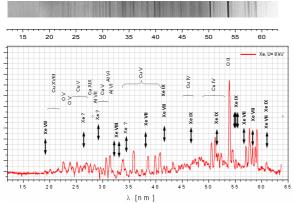


Fig. 2. EUV spectra of the radiation from a Xe capillary discharge in the 12–65 nm spectral region at 30Pa gas pressure

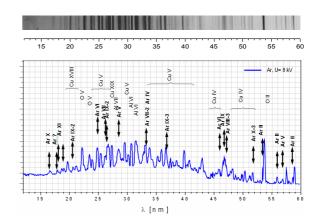


Fig. 3. EUV spectra of the radiation from an Ar capillary discharge in the 12–60 nm spectral region at 40Pa gas pressure

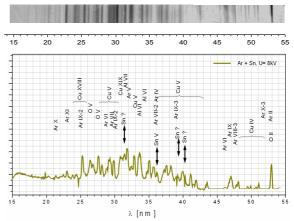


Fig. 4. EUV spectra of the radiation from an Ar filled capillary discharge with Sn inser in the 15–55 nm spectral region at 40Pa gas pressure

We learned from our measurements that a significant problem of debris generation exists. The brass electrode and alumina capillary ablates what leads to gradual enlargement of an inner diameter. The material ablated from the capillary when the electrodes' walls absorb energy can introduce difficulties in laser amplifications. A melting and evaporation probably were caused by interaction between the heat loads from the pinching plasma and the surface.

This founding contributed to improvements of the capillary discharge device. We have changed some of the parameters of processes and the material of the electrodes to reduce evaporation which enhanced the quality of generated radiation. Currently observations of EUV radiation from capillary discharges with tungsten electrodes and with the higher current are carried out.

CONCLUSIONS

The results of our investigation show that the capillary discharge is the interesting object to study. We measured the EUV emission spectra of Xe, Ar and Sn in the range of 12-65 nm, generated in the small capillary device. The spectroscopic studies were carried out by

means of the XEUV spectrometer. The spectrums were registered in the 12 - 64 nm, 12- 61 nm and 15- 55 nm wavelength ranges for Xe, Ar, and Sn + Ar ions, respectively. Additionally we learned that the brass electrode and alumina capillary ablates and therefore a problem of debris generation exists.

REFERENCES

- 1. S. R. Mohanty, E. Robert, R. Dussart, R. Viladrosa et al. // *Microelectronic Engineering*. 2003, v. 65, p.47–59.
- 2. K. Kolacek, J. Schmidt, V. Bohacek, M. Ripa et al.// *Plasma Physics Reports*. 2003, v. 29, p. 290-295.
- 3. J.J. Rocca, D.C. Beethe, M.C. Marconi// *Opt. Lett.* 1988, v. 13, p.565.
- 4. C. Steden, H.-J. Kunze// *Phys. Lett. A.* 1990, v. 151, p. 534.
- 5. D. Hong, R. Dussart, C. Cachoncinlle, W.E. Rosenfeld et al. // *Rev. Sci. Intrum.* 2000, v. 71, p.15.

- 6. S.S. Ellwi, L. Juschkin, S. Ferri et al.// *J. Phys. D.* 2001, v. 34, p.336.
- 7. J.J. Rocca, M.C. Marconi, F.G. Tomasel // IEEE J. Quantum Electron. 1993, v. 29, p.182.
- 8. S. Götze, S. Ellwi, Ž. Andrei'c, R. Dussart et al.// *Physics Letters A*. 2002, v. 299, p.571–576.
- 9. T. Beetz, M. Feser, H. Fleckenstein et al.// *Synchrotron Radiation News*. 2003, v. 16, p.11-15.
- 10. T. Mocek, H.J. Shin, D.G. Lee, C.M. Kim et al.// Lasers and Electro-Optics, 1999. CLEO/Pacific Rim '99. The Pacific Rim Conference. 1999, v. 3, p. 928 929.
- 11. J. Schmidt, K. Kolacek, V. Bohacek et al.// First Cairo Conference on Plasma Physics & Applications, Cairo, Egipt, Oct 11-15, 2003. p.15.
- 12. *NIST Atomic Spectra Database*. http://physics.nist.gov/PhysRefData/ASD/index.html.
- 13. L. Soto, P.Silva, G. Sylwester, J. Moreno, A. Esaulov, A. Nazarenko// *Revista Mexicana de Fisica*. 2002, v. 48, sub 3, p.142-144.

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ВУФ- ЭМИССИОННЫЕ СПЕКТРЫ ВОЗБУЖДЕННЫХ Ar, Xe И Sn ИОНОВ, ПРОИЗВЕДЕННЫХ В КАПИЛЛЯРНОМ РАЗРЯДЕ

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Представлены первые результаты наблюдения эмиссии вакуумного ультрафиолетового (ВУФ) излучения в плазме капиллярного разряда. Основной целью измерений являлась демонстрация покрытия спектрального диапазона рабочими параметрами системы. Спектроскопические исследования проведены с помощью ВУФ спектрометра Джоханновской геометрии. Результаты дают общую информацию о процессах излучения из ксеноновой, аргоновой и свинцовой плазмы в диапазоне от 12 до 63 нм.

ВУФ- ЕМІСІЙНІ СПЕКТРИ ЗБУДЖЕНИХ Ar, Xe И Sn ІОНІВ, ЗРОБЛЕНИХ У КАПІЛЯРНОМУ РОЗРЯЛІ

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Представлено перші результати спостереження емісії вакуумного ультрафіолетового (ВУФ) випромінювання в плазмі капілярного розряду. Основною метою вимірів була демонстрація покриття спектрального діапазону робочими параметрами системи. Спектроскопічні дослідження проведені за допомогою ВУФ спектрометра Джоханнівської геометрії. Результати подають загальну інформацію про процеси випромінювання з ксенонової, аргонової і свинцевої плазми в діапазоні від 12 до 63 нм.