S1-2 High Power EUV Sources Based on Discharge Produced Plasma
放電プラズマEUV光源開発研究

Sunao Katsuki, Takashi Sakugawa, Hidenori Akiyama
勝木 淳，佐久川貴志，秋山秀典

Graduate School of Science and Technology, Kumamoto University,
Kurokami 2-39-1, Kumamoto 860-8555, Japan
熊本大学大学院， 〒860-8555　熊本市黒髪2丁目39番1号

We describe the basic character of xenon and tin plasmas generated by the z-pinch device developed at Kumamoto University, using a time-resolved plasma imaging system and an interferometer. Also the EUV emission of the plasma is evaluated with respect to the in-band EUV energy, spectrum, and angular distribution of the emission. In addition, the experimental result on controlling the z-pinch plasmas by using the external magnetic field is presented.

1. Introduction

Presently, the extreme ultraviolet (EUV) emission of xenon, tin or lithium ions are intensively being investigated for its use in future 32 nm or less rule photolithography process. The "usable" in-band EUV power (13.5 nm 2%BW) required for the practical lithography tool is 115 W. which is really challenging task to obtain it. High energy density plasmas that emit EUV light are produced by two concepts, namely laser-produced plasmas (LPPs) and pinched discharge produced plasmas (DPPs). So far, the DPP scheme has more progressed in terms of EUV output, and the value is going to be close to the requirement.

In DPP EUV sources with its highly repetitive operation, a huge electrical power in the range of tens of kW is dissipated in the discharge chamber of which volume is in the range of tens of cm^3. The power density at the inner surface facing to the plasma amounts to the order of 10 kW/cm^2. The thermal load at the chamber causes problems which degrade the lifetime of the components including electrodes, insulator wall as well as the light cndenser optics. Most of the problems in DPP sources attribute the thermal load. In order to reduce the thermal load, it is important to minimize the energy input to the discharge and to improve the conversion efficiency (CE) from the discharge to in-band EUV energy, in addition to cooling the system. The experimentally demonstrated CE in the case of tin target discharges is at most 2% so far. The optimization of the plasma temperature and density for the 13.5 nm emission seems the most promising way to improve the CE if new target materials and their combination for the emission are not found.

The generation process of the high energy density plasmas in the DPP scheme is relatively flexible and dependent on the current waveforms, target gas pressure, electrode geometry and initial ionization state of the target material. Also, an external magnetic field parallel to z axis has a strong influence on the process. The correct understanding of their roles in the plasma generation process to control the plasma. In addition, in order to optimize the EUV output, a more specific understanding of the plasma character is needed. There are a number of spectroscopic investigations of the plasma. However, only a few experiments on plasma diagnostics were performed despite the plasma is the core of the EUV technology.

Here, we describe the basic character of xenon and tin plasmas generated by the z-pinch device developed at Kumamoto University, using a laser imaging system and an interferometer. Also the EUV emission of the plasma is evaluated with respect to the in-band EUV energy, spectrum, and angular distribution of the emission. In addition, the experimental result on controlling the z-pinch plasmas by using the external magnetic field is presented.

2. Z-pinch device

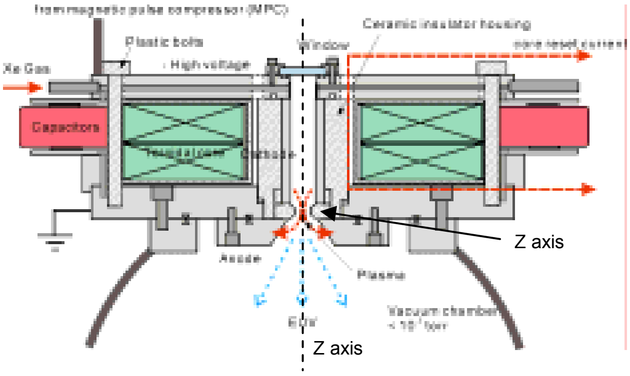

Fig. 1 Z-pinch discharge based EUV light source installed at Kumamoto University.

Figure 1 shows the cross sectional view of the z-pinch discharge device assembled together with the final pulse compression circuit, which delivers the pulsed current with amplitude of 35 kA and duration of 110 ns to the short circuit. Xenon gas flowing into the chamber is controlled.

Figure 2 shows a still photograph of the pinched Xenon plasma operating in 100 Hz. The plasma appears a needle and spatially stable. The diameter and the length along z-axis are approximately 500 μm and 5 mm, respectively in this condition.

The EUV emission from z-pinch discharge is characterized using a transmission spectrometer, a calibrated in-band EUV energy detector, and a fast EUV detector. A time-resolved imaging based on Schlieren method and interferogram, and Thomson scattering system are employed to characterize the Z-pinch plasma.

3. Xenon and tin target plasmas

Tin target has significant potential for high CE at 13.5 nm. Several theoretical calculations[2] show that predominantly 4d-4f transitions in a number of adjacent ion stages (Sn^{8+}-Sn^{13+}) produce unresolved transition arrays (UTAs) that are localized near 13.5 nm. We introduced Tin target to the z-pinch discharge. Tin vapor including atoms and ions is produced by the ablation of the solid tin rod (6 mm), which is due to the energy flux from the plasma. Xenon or argon is used as a background gas. Figure 3 shows the EUV energy as a function of the repetition rate of the discharge. The repetition rate influence the surface temperature of the tin rod placed 15 mm far from the plasma. The EUV emission also depends on the distance between the plasma and the rod surface (~ 10s mm).

4. Effects of an external magnetic field

An external longitudinal magnetic field applied to the z-pinch plasma makes the plasma implosion softly, so that the plasma density and temperature, which are strongly associated with the EUV spectrum, might be reduced. Therefore, the EUV spectrum can be controlled by adjusting the magnetic field strength, in addition to lengthening the duration of EUV emission. Besides, the soft implosion helps suppressing plasma instabilities and possibly changing the property of high energy ions generated during the implosion process[2].

5. Prospect

Until the beginning of 2004, the most important issue for the EUV source development was the source output. However, the 3rd EUVL conference held at Miyazaki in November 2004, some of major developers announced the output is no longer the top issue. The top issue is the lifetime of condenser optics. The development of EUV sources is surely being progressed.

Fig. 2 Still photograph of the Z-pinched EUV plasma. View from 30° for the z axis. The diameter of the discharge tube is 5 mm ϕ.

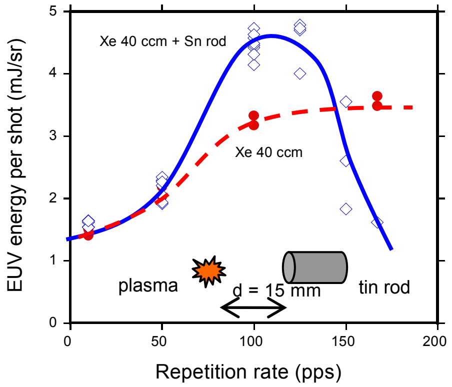

Fig. 3 Contribution of Tin emission on the EUV yield as a function of pulse repetition rate.

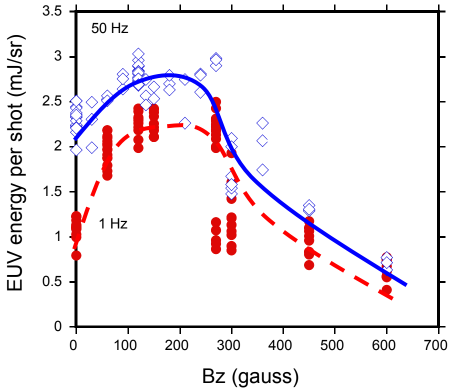

Fig. 4 In-band EUV energy per shot as a function of amplitude of the external magnetic field.

Acknowledgments

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References

[1] Gerard O'Sullivan, EUVL Source Workshop, Antwerp 2003; available at www.sematech.org.
[2] Information obtained at 3rd EUVL Symposium, Miyazaki, Nov. 1~4, 2004.