Development of Xe and Sn discharge EUV light source

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Abstract. A high rep-rate, compact and low-debris xenon Z-pinch discharge system has been designed and fabricated as an EUV light source, in which a newly developed gas jet-type Z-pinch source is used. The discharge head has a coaxial double nozzle and diffuser. Xenon Z-pinch plasma that emits EUV light is produced in between the inner nozzle and the corresponding diffuser. An annular shell of a helium gas curtain produced by the outer nozzle is specially designed for shielding the debris and suppressing the inner gas expansion. In this work, in order to get higher EUV output power, a new pulse power supply system has been developed. This power supply delivers a current with amplitude of 22 kA, rise time of 110 ns and pulse duration of 260 ns to a low inductance load. In addition, a laser triggered discharge produced tin plasma light source has been developed. Experimental parameters such as electrode separation and laser irradiation power are varied to optimize EUV emission power. It is found that EUV emissions cannot be obtained when the laser irradiation power is too high.

1. Introduction

Extreme ultraviolet (EUV) lithography is most promising for 50 nm technology node. There are many issues for realizing EUV lithography, such as development of optical components and radiation sources [1]. One of the most important challenging tasks is to develop an EUV light source. Various technical concepts for realizing high power sources for EUV lithography are under investigation worldwide. Laser produced plasmas (LPP) and discharge produced plasmas (DPP) are the most promising schemes. In general, DPP methods are of special interest, because their prospected costs for the demanded throughput are expected to be much lower than those of LPPs. However, the discharge plasmas are of high risk, because crucial problems have to be solved before reaching the required power levels [2]. Since the DPP source generally emits the light in a cone in forward direction due to the constraint on the electrode shape, the light from the source emerges in a collection angle typically smaller than $2\pi$ sr. In contrast, in the case of LPP EUV sources, the light emerges in a collection angle equal to $4\pi$ sr [3]. The large collection angle means that higher EUV power can be obtained at intermediate focus. Further development is needed to get the larger collection angle of the DPP source and to satisfy the demands of high EUV power. Another problem of the DPP light source is debris mitigation. Though the gas curtain arrangement, which uses a high-speed gas flow to blow off the debris, is installed in front of the electrode [4], it is not easy to adapt this arrangement to the electrode with a large collection angle in the DPP source.
2. Gas jet Z-pinch light source

2.1. Gas jet Z-pinch

The developed gas jet Z-pinch source emits EUV light in the radial direction with respect to the pinch axis, and thus it has a larger collection angle than the general DPP sources. Moreover, the helium (He) gas jet from the outer nozzle removes the debris and suppresses the radial expansion of Xe discharge gas. At the same time, this light source retains the characteristics of small size, low cost and high efficiency of DPP sources.

Figure 1 shows the schematic view of the gas jet-type Z-pinch used for generating the EUV radiation. The gas jet-type Z-pinch source is comprised of coaxial double nozzles (cathode) and diffusers (anode). The inner nozzle ejects a Xe gas jet and the outer one forms a He gas curtain. The Xe gas jet is positioned on the axis between the cathode and the anode by the action of the inner nozzle. The preionization is done at a location spatially separated from the main discharge region by applying a high voltage between a preionization electrode and the cathode. The low-density cold plasma thus formed emerges from the preionization region due to the continuous flow of Xe gas. After a low-current preionization discharge, a pulsed high current is delivered from a pulse power supply to ignite the cold Xe plasma jet. The self-generated azimuthal magnetic field owing to the high current compresses the cold Xe plasma to form a hot and high-density pinch plasma. This high temperature plasma mainly radiates light at around 13.5 nm within a full solid angle [5].

Fig. 1 Schematic view of the gas jet type Z-pin source

2.2. New pulse power system

A new pulse power supply system has been developed. It has two magnetic pulse compression stages to achieve higher discharge current as shown in Fig.2. We are fabricating this pulse power supply system and will characterize the EUV emission. The power supply delivers a current with amplitude of 22 kA, rise time of 110 ns and pulse duration of 260 ns to a short circuit load as shown in Fig.3.

Fig. 2. A new pulse power system

3. Laser triggered Sn light source

3.1. Laser triggered Sn discharge

The Xe transition arrays with high intensity lines are found around 11 nm. On the other hand, Sn transition arrays with high intensity lines are found around 13.5 nm. Therefore, a Sn source will produce a higher EUV yield. We have developed a new DPP source called a laser triggered Sn EUV light source, in which EUV light is emitted from Sn ions.

A photograph of the inside of the chamber is shown in Fig.4. The cathode is a copper cylinder with a Sn rod covered with a copper cylinder as shown in Fig.5 and the anode is a copper cone. Separation
between the cathode and the anode can be varied in the range of 4-10 mm. The pulse power supply system consists of a 40 nF capacitor and a magnetic switch. The vacuum discharge is triggered by producing a plasma on the cathode using an Nd:YAG laser system, which provides irradiation energy of ~381 mJ at a wavelength of 1064 nm. The laser beam is focused on the Sn cathode center. The laser beam is entering at an angle of 45° and on the cathode.

3.2. Experiments

In order to measure the time evolution of EUV photon output, an EUV photodiode coupled with Zr filter was used. A Rogowski coil was used to measure the discharge current. The signals were recorded by a digital storage oscilloscope. Moreover, a high-speed framing camera was used for observing the plasma dynamics in visible region.

Pulse power supply with a 40 nF capacitor generated a discharge current of 6 kA with a pulse width of 500 ns. Photodiode inside the chamber was used to measure EUV emission waveform. The diode was kept at a distance of 10 cm from the cathode surface. At first, a cylinder copper rod was used as an anode. In this case EUV emission could not be observed. It is considered that current density is too low to obtain a hot plasma column which can emit EUV light because the current does not concentrate sufficiently in a small area. Therefore, the anode shape was changed from flat to conical, which is shown in Fig.6. In this case EUV emission could be observed. Next, the time evolution of EUV emission was compared for the different laser irradiation energy and for the different electrode separation. Typical waveforms of the discharge current as well as photodiode output are presented in Fig.7 for different laser irradiation power. The figure shows that when the laser power is too high EUV emission cannot be obtained. Moreover, when the electrode separation is changed EUV light emission waveform is changing as shown in Fig.8. More detailed experiments are needed to decide the most suitable electrode separation.

![Fig. 4 Inside the chamber](image)

![Fig. 5 Cathode electrode](image)

![Fig. 6 Point-tip copper anode](image)

![Fig. 7 EUV light waveform (laser output (a) 19 mJ, (b) 52 mJ, (c) 104 mJ)](image)
Secondly, the dynamic behaviour of plasma between electrodes was observed with a high-speed camera in visible region. The photographs taken at laser energy of 52 mJ and electrode separation of 6 mm are shown in Fig.9. The evidence of pinch phenomena of Sn plasma is not at all observed.

4. Summary

We have developed Z-pinch EUV light sources such as Xe gas jet type and Sn laser triggered ones. For a Xe gas jet type light source, a new pulse power supply system has been developed. This power supply delivers a current of 22 kA with rise time of 110 ns and pulse duration of 260 ns to a short circuit load. A Sn laser triggered EUV light source was also studied and we got EUV emission. The construction of a laser triggered EUV light source is simpler and smaller size than Xe gas jet type. Moreover, Sn plasma is expected to have higher EUV conversion efficiency. Therefore, discharge produced tin EUV light source has possibilities for a promising technology. However, the relationship between the plasma dynamics and the EUV emission is remained unclear. In order to make it clear, we are planning to use a time-resolved EUV pinhole camera.

Acknowledgment

This work was partly supported by NEDO and JSPS (the Grant-in-Aid for Scientific Research), Japan.

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