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Experimental study of capillary Z-pinch discharge plasma for EUV lithography

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1. Introduction

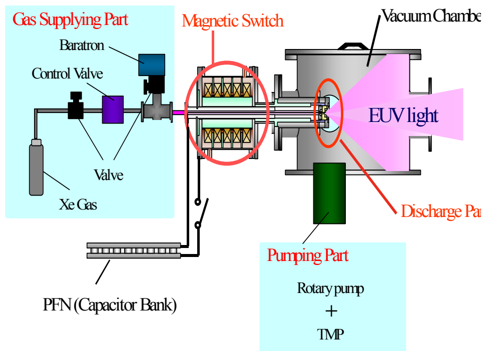
Extreme-ultraviolet (EUV) lithography is most promising technology for 50 nm technology node which will be used from around the year 2007. The use of EUV radiation around 13 ~ 14nm wavelength in comparison to the longer wavelength UV radiation allows reducing the structure sizes and offers as well a sufficient large depth of focus. The usable spectral band is defined by the fact that there is a consensus to use molybdenum-silicon multilayer mirrors, which best compromise high reflectivity and usable bandwidth around a wavelength of 13.5nm [1].

For realizing EUV lithography, a debris free EUV source with collectable radiation power of about 115W and repetition rates exceeding 7 - 10 kHz will be required. Various technical concepts for realizing high power sources for EUV lithography are under investigation. Since the electrical energy is directly converted into the plasma energy, discharge produced plasma (DPP) is one of the promising high-efficiency radiation source for achieving the required parameters. However, it has a problem of debris generation, which is due to the melting and evaporation of electrodes and a capillary caused by the excess input of heat into their surfaces and the fact that the pinching plasma interacts more strongly with the insulator surface than others.

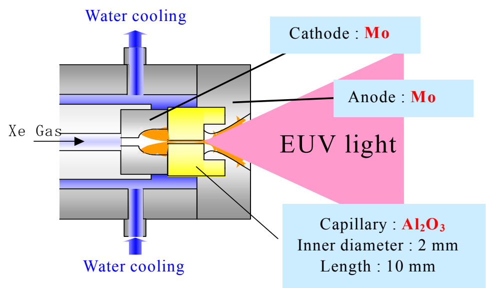
In order to overcome these difficulties and to satisfy the source requirements, a capillary Z-pinch discharge light source devise has been designed and demonstrated [2]. In present study, the characteristics of EUV radiation and dynamics of pinching plasma in a xenon-filled capillary are experimentally observed using two types of power supply. The results from a slow pulse power supply, which has the discharge current of slow rising time and long duration, and a fast pulse power supply, which fast rising time and short duration are presented.

2. Experiment

The devise used in experiment is schematically shown in Fig. 1(a). Discharge part is consisted of molybdenum anode/cathode and alumina capillary, having 2 mm inner diameter and 10 mm length as shown in Fig. 1(b). The xenon gas which fed through mass flow controller was flowed into the capillary through the hollowed cathode and was differentially pumped out of the system by use of the capillary itself as the differential pumping tube. The pressure of the xenon gas near the electrode was estimated to be controlled up to several hundreds mTorr and that time, the chamber maintains several mTorr. A magnetic switch is connected in series with capillary cathode electrode. The magnetizing current leaking through the magnetic switch during the holding phase is used as the preionization current. Figure 2(a) and (b) show two types of pulse power supply circuit. The pulse power system is composed of all solid-state components. The slow pulse power supply without magnetic pulse compression of Fig. 2 (a) has the discharge current of 500 ns rising time and 3 μs pulse width and the fast pulse power supply with pulse compression of Fig. 2 (b), which used a high voltage pulse transformer and 40 nF capacitor has 160 ns rising time and 320 ns pulse width [3]. Figure 3 shows the measured discharge current waveforms for each pulse power supply.

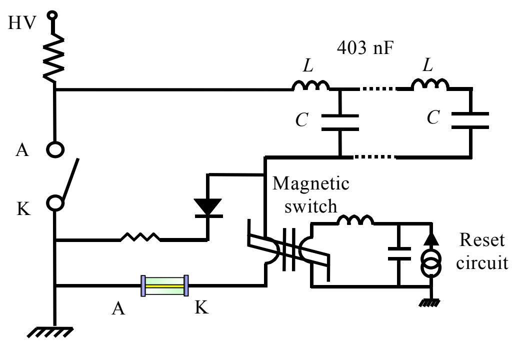


(a) Experimental facility

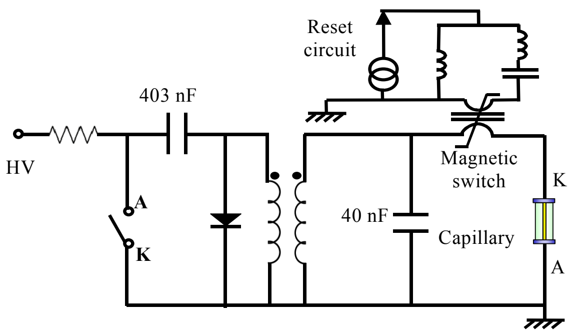


(b) Discharge electrode

Fig. 1. Schematic diagram of Experimental device.



(a) Slow pulse power supply



(b) Fast pulse power supply

Fig. 2. Pulse power supply system for EUV light source.

In order to monitor an instantaneous EUV photon output over the wavelength range of approximately 5 ~ 15 nm, the EUV photodiode (AXUV-100, IRD Inc.) with Zr/C filter (thickness 200/50 nm) is used. Streak photographs of capillary plasma in visible region are taken by using a high-speed image converter camera (IMACON 468, DRS Hadrand Ltd.) for investigating plasma dynamics in capillary inside.

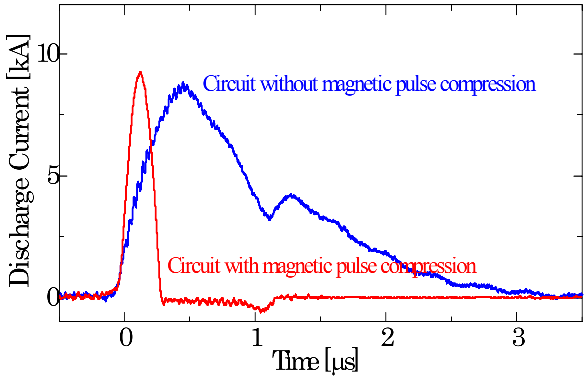
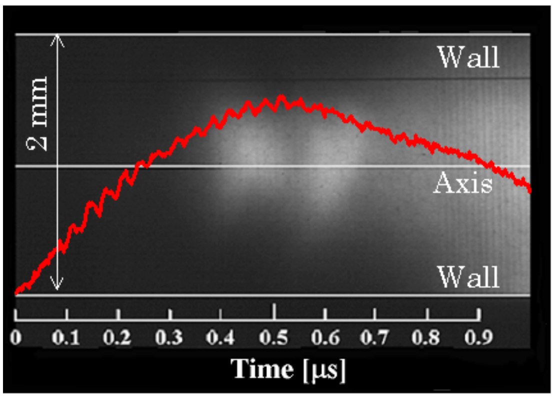


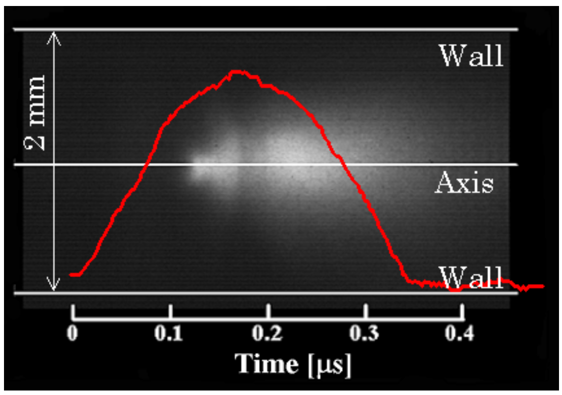
Fig. 3. Discharge current waveforms of each pulse power supply.

3. Results and discussion

Dynamics of pinching plasma is observed with a high-speed camera in the visible region. Figures 4 show the streak photographs of each pinch process with current waveform. Streak images demonstrate that the plasma inside the capillary rapidly collapses and heats up. After stagnation, the plasma column expands to the wall and the luminous region extends. Fast pulse power supply system produces better plasma symmetry with respect to the axis than slow one as shown in Fig. 4(b). The rapid compression that results produces a high density plasma column which is observed to be of smaller diameter than that produced by a long current pulse in capillary of the same conditions. We can see that the expanded plasma of slow pulse power supply contacts with capillary wall for a long time as compared with fast one. This contact heats the wall of the capillary and thus produces particles from the wall material.



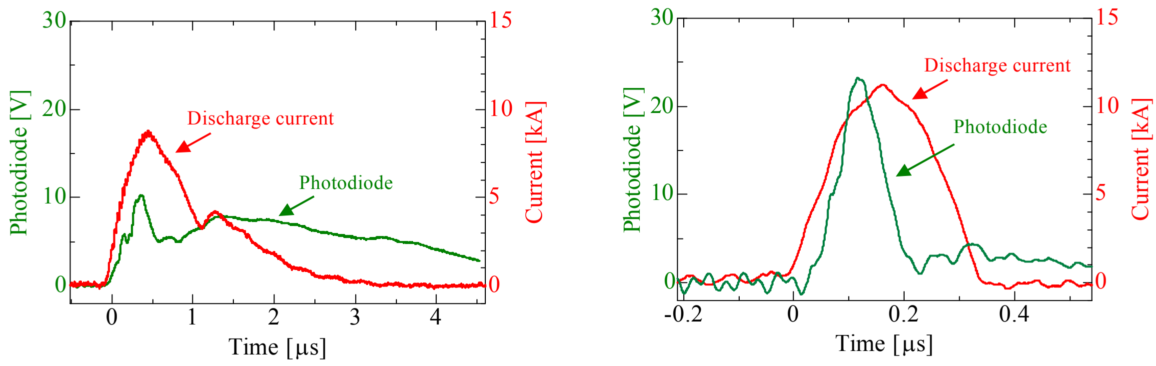
(a) Slow pulse power supply



(b) Fast pulse power supply.

Fig. 4. Streak images of capillary discharge

Waveforms of the discharge current as well as photodiode output are presented in Fig. 5. Each EUV photodiode signal appears first (around 40 ns in short pulse power supply) after the initiation of the discharge inside the capillary and it reaches a maximum at the time of maximum compression of the plasma. The maximum compression time was inferred from Fig.4. During the early phase of discharge, EUV output energy of fast pulse power supply is larger than that of Fig. 5 (a). And the photodiode signal of slow pulse power supply only lasted after the peak of the discharge current.



(a) Slow pulse power supply (b) Fast pulse power supply.

Fig. 5. Measured discharge current and photodiode signal waveform

4. Summary

Experimental study of Xe-filled capillary Z-pinch discharge plasma has been conducted. A streak camera and photodiode measurements are performed. Our experiments and comparisons of slow and fast pulse power system show that fast rising time and short pulse width are best for producing peak EUV output and low spectra impurities and low debris. A high repetitive experiment and development of debris mitigation system will be future works.

Acknowledgements

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References

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