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리소그라피를 위한 새로운 가스젯 방식의 Z방전 극자외선 광원

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A new gas jet type Z-pinch extreme ultraviolet light source for next generation lithography

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Abstract - A new gas jet Z-pinch EUV light source having double gas jet electrodes has been developed. It has two nozzles and two diffusers. The EUV beam is collected from the side of pinch plasma, generated in between the inner nozzle and corresponding diffuser. A cylindrical shell of He gas curtain produced by the outer nozzle is specially designed for shielding the debris and suppressing the inner gas expansion. We have succeeded in generating EUV energy of 1.22 mJ/sr/2%BW/pulse at 13.5 nm. The estimated dimension of EUV source is to be FWHM diameter of 0.07 mm and length of 0.34 mm, and FW 1/e2 diameter of 0.15 mm and length of 1.2 mm.

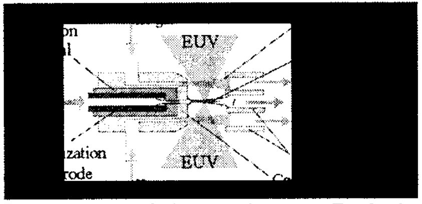
1. Introduction

The extreme ultraviolet (EUV) light source, the most critical component of the EUV lithography, plays a decisive role for early implementation of this tool in commercial scale production of chips at the 45 nm technology and beyond that [1]. Two major techniques, based on discharge produced plasma (DPP) and laser produced plasma (LPP), are currently under intense investigations and these are still to compete for fitting into the EUV lithography tool. The DPP sources using Xe appear to have energy conversion efficiency of 0.6 % in 2 % bandwidth at 13.5 nm into 2 sr relative to the energy dissipated into the plasma [2]. The electrical input power requirement of DPP is, therefore, about 100 kW in order to obtain100 W of clean light at the intermediate focus (IF) of EUV lithography tool, taking into account the optical requirements such as system etendue and cleanliness of the whole imaging system. Due to constraint in the electrode shape, the DPP sources normally emit usable light into the forward direction. The light from these sources emerges out in a solid angle typically smaller than 2 sr. On the contrary, in case of the LPP sources, the laser and the gas/solid target injection apparatus are located at a relatively large distances from the plasma generation point and, hence, the light can be collected in a solid angle equals to 4 sr [3]. In order to improve the EUV power of DPP light source, further development in collection angle is needed. Another challenge of DPP EUV light source is to generate the debris-free light. A region of high-speed gas flow, named as gas curtain, is currently under development to slow down or stop the highly energetic debris. The gas curtain must have a high cross section for scattering of debris particles. Nevertheless, the gas curtain arrangement is not easy to design and install in DPP source [4].

The aforementioned challenges of designing a debris free EUV source having wider collection angle prompt us to propose and develop a new DPP source, named as a gas jet type Z-pinch that meets both the issues simultaneously. Our approach not only promises a solid angle close to that of LPP source and a simple gas curtainbut also keeps the characteristics of low cost and high efficiency of DPP sources. In this article, we report the preliminary results obtained from our innovative gas jet type Z-pinch EUV source.

2. The gas jet type Z-pinch

The new gas jet type Z-pinch source has two nozzles and two diffusers. The inner nozzle (cathode) is used to create Xe gas jet in a gap between the inner nozzle and corresponding diffuser. The diffuser (anode) controls the vacuum inside the chamber for reducing the EUV absorption. The outer nozzle produces an annular cylindrical He gas jet, which acts as a gas curtain. This design assures that the entire EUV emission path is covered by the gas curtain. The axes of both the gas jet and curtain are on the axis of device (Z-axis) as shown in Fig. 1. The preionization of the working Xe gas is spatially separated from the main discharge region. A low-density cold plasma comes out from the preionization region due to continuous flow of Xe gas. Thus, Xe ion stream together with neutral Xe atoms flows towards the anode as shown in Fig. 1. A pulsed high current, applied between electrodes, ignite Xe jet to form main plasma. The self generated azimuthal magnetic field owing to the high current compresses the main plasma to form a hot and high-density pinch plasma column. This high-temperature plasma mainly radiates light at around 13.5 nm in full solid angle.



<Fig. 1> Schematic of the gas jet type Z-pinch source

3. The gas jet type Z-pinch

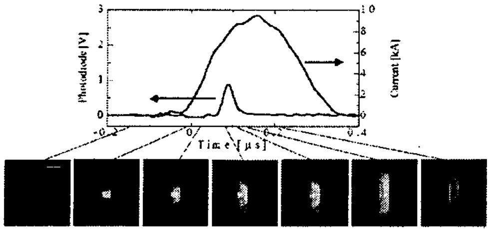
The electrodes (nozzles and diffusers) of the source are made of stainless steel. The inner nozzle having 2 mm orifice diameter is used to form the Xe jet. A cylindrical type opening, which has 0.2 mm width, is used as an outer nozzle and this nozzle assists to form the He gas curtain. The diameter of inner diffuser is 6 mm, whereas the maximum and minimum diameters of outer diffuser are 20 mm and 24 mm, respectively. The preionization plasma is first created in the Xe gas jet by applying 6 kV pulse between preionization electrode and cathode and, subsequently, the main plasma is formed by delivering a 9.5 kA current pulse to the preionized plasma.

The framing photographs in visible region were taken with a high-speed camera (10 ns resolution) to study the discharge dynamics. An EUV photodiode (AXUV-100) coupled with Zr/C filter was employed. An EUV mini calorimeter consisting of a Zr filter, a Mo/Si multi-layer mirror and a photodiode, was also employed and was mainly used for the measurements of absolute in-band EUV energy. The spectral emission of the source in the visible region was analyzed by employing a multi-channel spectroscope. The EUV pinhole camera that consists of 50 m pinhole, Zr filter and X-ray CCD (DO434) was employed to estimate the size of EUV emission plasma.

4. Results and discussion

4.1 Plasma dynamics of gas jet type Z-pinch

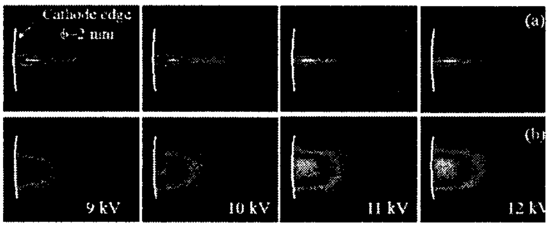
The plasma dynamics of gas jet type Z-pinch was observed from the radial position (perpendicular to the axis of device). A typical set of framing photographs together with the main discharge current and photodiode signal recorded at Xe pressure of 10 Torr, is illustrated in Fig. 2. As the main discharge current grows, the main plasma starts appearing between the electrodes. The evidence of pinch plasma is prominent in the framing photo taken at a time around 80 ns. In fact, the maximum pinch of plasma occurs just before the maximum of discharge current pulse. The plasma is enough heated to have copious amount of Xe ions in higher ionization state as clearly shown by the photodiode output. An intense EUV photon signal appears after about 60 ns of the initiation of discharge and it reaches its peak value during the pinch of plasma. The pinching action may last for a few tens of nanoseconds and the plasma, after the pinch, expands in the radial direction.



<Fig. 2> Time-resolved framing photographs

4.2 EUV pinhole images at different input energy and pressure

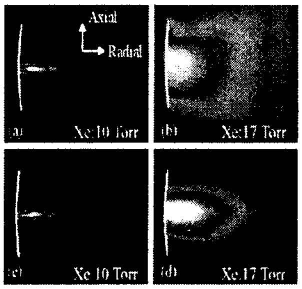
EUV pinhole images recorded in radial position for various input energies and Xe gas supplying pressures were shown in Fig. 3. In the case of Xe pressure of 10 Torr, the EUV plasma images, shown in Fig. 3(a), are found to have extremely narrow ellipsoidal shapes, which are fairly symmetrical with respect to the axis. However, a look at the images recorded at 17 Torr, shown in Fig. 3(b), indicates that the shape of the EUV plasma is blunted and the EVU radiating plasma seems to be located at the upstream inside the cathode nozzle. The effect of input energy on EUV intensity is easily seen in those images shown in Fig. 3and it is noticed that the intensity increases linearly with the increase of input energy.



<Fig. 3> EUV pinhole images for 10 pulses superimposed at different input energy: (a) Xe 10 Torr; (b) Xe 17 Torr

4.3 Effects of gas curtain on EUV plasma

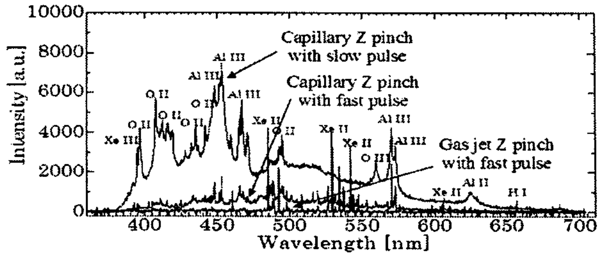
Figure 4 shows the EUV plasma images taken with and without He gas curtain. The He gas flow rate is 12 sccm and the charging voltage of main capacitor is 12 kV. The FWHM radius of the EUV source at Xe 10 Torr with and without He gas curtain are 0.13 and0.10 mm, respectively. Especially at Xe 17 Torr, the FWHM radial length with He gas curtain is 0.48 mm, which is 56 % less value in comparison with 1.10 mm without He gas curtain. This illustrates that the He gas curtain has an additional function of limiting the radial expansion of Xe gas. EUV plasmas with gas curtain are found narrower and brighter than those without gas curtain.



<Fig. 4> EUV pinhole images at 12 kV without gas curtain (a,b) and with gas curtain, He 12 sccm (c,d)

4.4 Spectra in visible region

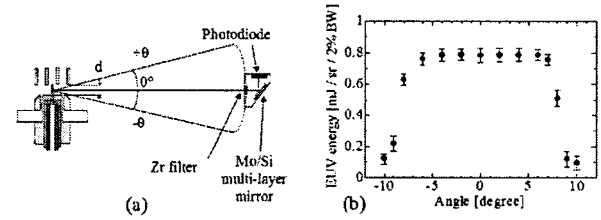
As mentioned earlier, the main interest in developing this gas jet type Z-pinch EUV source is to reduce the debris substantially by innovative configuration. It is, therefore, interesting to study the spectral emission in visible region at first to have an idea about impurities emerging out of the source in radial direction. The visible spectrum recorded in radial position is shown in Fig. 5. In the figure, other spectra obtained in our work based on capillary discharge EUV plasma source are also shown for comparison of debris generation in both schemes. The detail of the capillary discharge work is found in Ref. 5. No significant impurity contribution from the electrode materials is marked in the gas jet type Z-pinch discharge. Since the impurity lines together with Xe lines of lower ionization state affect the spectral purity of a EUV lithography source, the spectral purity of EUV source is one of the factors, which influences the lifetime of collecting mirror. The measurement of visible spectrum establishes that our gas jet type Z-pinch source radiates very clean EUV light with minor contamination in low ionization state of Xe and the prospects of radial extraction of EUV light seems to be fruitful.



<Fig. 5> Visible spectra of capillary discharge and gas jet type Z-pinch at the same input energy

4.5 Spectra in visible region

The schematic view of the mini calorimeter setup is shown in Fig. 6(a) and the measured angular distribution of in-band EUV radiation at 9 kV charging voltage and Xe 10 Torr is illustrated in Fig. 6(b). The EUV output in 2% bandwidth at 13.5 nm is 0.78 mJ/sr/pulse. Currently the small available observation angle (8 degree) may lead to partial obscuration of the source and thus by dropping the output power. In spite of the low output energy, we believe that increasing the discharge current and improving the present nozzle design can achieve the higher EUV yield.



<Fig. 6> A schematic view of the EUV mini calorimeter setup (a) and angular distribution of in-band EUV (b)

5. Summary

The concept of radial extraction of clean EUV light has been successfully demonstrated by our new gas jet type Z-pinch discharge. At Xe pressure of 10 Torr, the EUV plasma has extremely narrow ellipsoidal structure with 0.07 mm FWHM diameter and 0.34 mm FWHM length. The He gas curtain has an additional function of limiting the radial expansion of Xe gas. With the help of it, narrower and brighter EUV plasma can be generated. No significant impurity spectra in visible region are marked in this source. Protection of condenser optics is probably easier in a gas jet type Z-pinch source by using cylindrical annular He gas flow. The characteristics attained with gas jet type Z-pinch source such as a small pinch plasma, large solid angle and an opportunity to reduce the effects of debris make such source the subject of great interest.

[References]

[1] V. Banine and R. Moors,Proceedings of SPIE, Vol.4343 (2001), pp.203-214.

[2] R. Lebert, K. Bergmann, L. Juschkin, O. Roiser and W. Neff, Proceedings of SPIE, Vol.4343 (2001), pp.215-225.

[3] P. Marczuk and W. Egle, Proceedings of SPIE, Vol.5533 (2004), pp. 145-156.

[4] E.V. Lopez, B.E. Jurczyk, M.A. Jaworski, M.J. Neumann and D.N. Ruzic, Microelectronic Engineering, Vol. 77, Issue 2 (2005) pp.95-102.

[5] I. Song, K. Iwata, Y. Homma, S.R. Mohanty, M. Watanabe, T. Kawamura, A. Okino, K. Yasuoka,K. Horioka, E. Hotta, Jpn. J. Appl. Phys., Vol.44 (2005)