Rapid Communications

Development of a Gas Jet-Type Z-Pinch EUV Light Source for Next-Generation Lithography

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A new gas jet-type Z-pinch EUV light source having double gas jet electrodes has been developed. It has two nozzles and two diffusers. A xenon Z-pinch plasma that emits EUV light is produced between the inner nozzle and the corresponding diffuser. A cylindrical shell consisting of a 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/pulse (2% in-band at 13.5 nm) and EUV emitting plasma of 0.07 mm FWHM diameter and 0.34 mm FWHM length by using this He gas curtain.

Keywords:

EUV light source, double gas jet, Z-pinch, radial collection, He gas curtain

The semiconductor industry is aiming at the next generation lithography (NGL) to achieve a structure size of less than 45 nm and thereby realize higher storage density and switching speed. After the start of the International SEMATECH, the NGL was narrowed down to EUV lithography [1]. The application of extreme ultraviolet (EUV) lithography to semiconductor manufacture requires a high power and long lifetime EUV source that emits mainly at 13.5 nm. Discharge produced plasma (DPP) and laser produced plasma (LPP) are currently under investigation as possible radiation sources.

The DPP sources normally emit usable light in the axial direction due to the constraint on the electrode shape. The light from these sources emerges in a collection angle typically smaller than 2π sr. In contrast, in the case of LPP EUV sources, the light emerges in a collection angle equal to 4π sr [2]. The large collection angle means that higher EUV power can be obtained at intermediate focus. Nevertheless, DPP light sources have been widely developed due to their advantages in efficiency, low cost and compactness [3]. Further development of the collection angle of the DPP source is needed to satisfy the demands of high-volume manufacturing. Another challenge of the DPP light source is debris mitigation. The gas curtain arrangement, which uses a region of high-speed gas flow to remove the debris, is installed in front of the electrode [4], and is not easy to adapt this arrangement to a large collection angle electrode in the DPP source.

The developed xenon (Xe) gas jet-type Z-pinch source has a provision for the extraction of EUV light in the radial direction with respect to the pinch axis, and thus it has a larger collecting angle than the general DPP sources. Also, the helium (He) gas jet from the outer nozzle removes the debris and suppresses the radial expansion of Xe the discharge gas. At the same time, this light source retains the characteristics of small size, low cost and high efficiency of DPP sources. In this article, we report the results of our preliminary investigations of this innovative gas jet-type Z-pinch EUV source.

Figure 1 shows the schematic of the gas jet-type Z-pinch used for generating the EUV radiation. It is comprised of coaxial stainless steel nozzles (cathode) and diffusers (anode). The inner nozzle ejects a Xe gas jet and the outer one forms a He gas curtain. The inner nozzle diameter is 2 mm and the outer nozzle of cylindrical type has an opening of 0.2 mm width. The Xe gas jet is positioned centrally between the cathode and anode via the action of the inner nozzle. The preionization is spatially separated from the main discharge region and a high voltage applied between a preionization electrode and the cathode initiates the preionization of Xe

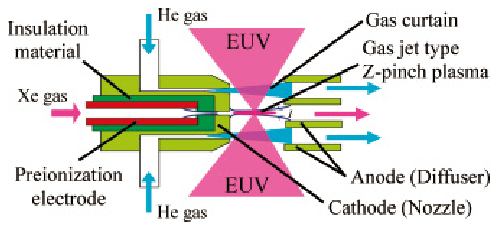

Fig. 1 Schematic of the gas jet-type Z-pinch source.

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gas. The low-density cold plasma thus formed emerges from the preionization region due to the continuous flow of Xe gas. After a brief preionization discharge, a pulsed high current is delivered from a pulsed power supply to ignite the cold plasma Xe 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 at around 13.5 nm with in a full solid angle [5].

Figure 2 shows EUV plasma images recorded with a pinhole camera at 90° with respect to the electrode axis. The pinhole camera consists of a pinhole, a Zr filter with 12 nm ~ 18 nm bandpass and an X-ray CCD camera. The images illustrated in Fig. 2 are indicative of a strong contraction of the main plasma at Xe 10 Torr and EUV emission in the radial direction. EUV plasma generated with a gas curtain is found to be narrower (FWHM diameters with and without the gas curtain were 0.07 mm and 0.09 mm, respectively), longer (FWHM lengths with and without gas curtain were 0.34 mm and 0.32 mm, respectively) and brighter (5% increase in the peak intensity of the images). These result show that the He gas curtain has an additional function of limiting the radial expansion of Xe gas and increasing the emission intensity [6]. An EUV mini calorimeter calibrated by E-Mon [7] was used to measure the absolute 2% in-band EUV energy at 13.5 nm and showed 1.22 mJ/sr/pulse with the He gas curtain.

As mentioned earlier, the main reason for developing this gas jet-type Z-pinch EUV source was to reduce the debris by means of an innovative configuration. We therefore considered that it would be of interest to investigate the spectral emissions in the visible region to gain some idea of the impurities emerging from the source. In Fig. 3, spectrum is superimposed on another spectrum that we obtained using a capillary discharge EUV plasma source in order to compare the debris generation between the two sources. It appears that the capillary discharge generates far more impurity lines in the visible region than the gas jet-type Z-pinch. No significant impurity contribution from the capillary is marked in the case of the gas jet-type Z-pinch discharge or from the electrode material in either case. The visible spectrum establishes that our gas jet-type Z-pinch source radiates clean EUV light with minor contamination in the low ionization state of Xe.

In conclusion, we have developed a gas jet-type Z-pinch EUV light source for use in lithography. The new source has a large collection angle for picking up debris-free EUV light. The concepts of radial extraction of EUV light and cylindrical gas curtain were successfully demonstrated. We will continue to study the EUV emission characteristics under various conditions. The characteristics attained with our gas jet-type Z-pinch source, such as a small pinch plasma, large collection angle and a combination of debris shielding, indicate that it has potential as EUV light source.

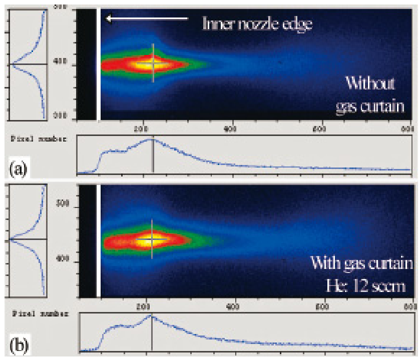

Fig. 2 EUV pinhole images without gas curtain (a) and with gas curtain (b) at charging voltage of 12 kV and 10 Torr Xe supplying pressure.

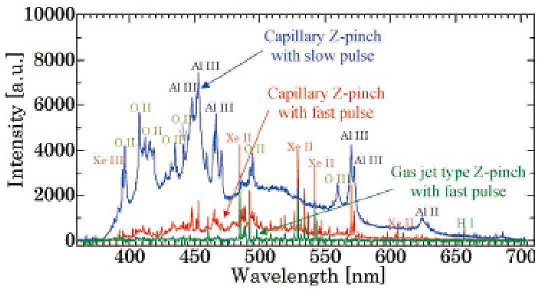

Fig. 3 Visible spectra of capillary and gas jet type Z-pinch at the same input electrical energy.

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