EUV Emission Study of a 600 Joules Small Plasma Focus Device

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Abstract. A small plasma focus with electrical input energy of 600 joules has been developed as a radiation source. Radiation from argon discharge is being investigated. X-Ray Diode (XRD) is employed to measure the ultra-soft radiation while Extreme Ultraviolet (EUV) radiation at 13.5 nm wavelength has been investigated by a SXUV5A photodiode with integrated filter. The relation of the intensities of the EUV and ultra-soft X-ray with the operating pressure will be discussed. The average total EUV energy and the average EUV energy conversion efficiency are found to vary from 7.8 mJ to 275 mJ and 0.0013 % to 0.046 %, respectively.

Keywords: EUV Emission, Argon Plasma and EUV Detector.

INTRODUCTION

The plasma focus device is capable of producing high density high temperature plasma that emits intense hard and soft X-rays, UV and extreme ultraviolet (EUV) [1-3]. The radiation output and the emission spectra depend on the operating parameters of the plasma focus discharge, which include the discharge energy, operating pressure and electrode geometry [4-5]. The application of a dense plasma focus pinch discharge as a light source for extreme ultraviolet lithography (EUVL) has been investigated [5]. We developed a low energy plasma focus aims to produce pinch plasma with ion temperature of several tens of eV. The intense radiation output if optimally tuned into the EUV region will make the plasma source as a potential light source for EUVL. EUVL being the most promising technologies for Next-Generation Lithography (NGL) technology is demanded for High-Volume Manufacturing (HVM) [6] at the 22 nm half-pitch node in the Semiconductor industry in near future. However SEMATECH reported [7] various optical components for EUVL industry are at good status but the EUV sources remain one of the main concern.

Solution to the intense EUV light source includes Discharge Produced Plasma (DPP) or Laser Produced Plasma (LPP), where intense pulsed EUV radiation can be produced. EUVL by using radiation sources of 13.5 nm EUV with up to 180 W at intermediate focus (IF) in a bandwidth of 2 eV is the next milestone of semiconductor industries [7]. DPP based EUV source gives several advantages than the immense, complex and high cost of ownership (CoO) synchrotron. Plasma focus discharge is believed to be the one of the DPP system capable of producing pulsed EUV emission for EUVL [4-5].
EXPERIMENTAL SETUP

The plasma focus system used was as described in our earlier paper [8]. It consists of a set of coaxial electrodes with lengths of 50 mm. The inner electrode is surrounded by six symmetrically and coaxially arranged copper rods acting as the outer electrodes with diameter of 47.5 mm. The cathode base has been shaped into knife-edge profile to ease the current breakdown. In addition, a set of six coaxial plasma guns is used to enhance the current sheath formation between the electrodes.

This discharge system is driven by a capacitor bank with a total capacitance of 3.7 µF and charged to 18 kV. The discharge current and voltage are measured by using a Rogowski coil and a resistive voltage divider respectively. X-ray diode (XRD) is used as broadband X-ray detector. It is mounted at a side-on view port 550 mm from the anode tip. The temporal evolution of the ultra-soft radiation emitted from the plasma is registered by the XRD. It has a spectral sensitivity range from UV to soft X-ray. The cathode of the XRD is connected to a negative biased voltage of 100 V. This biased voltage is sufficient to collect all electrons emitted by the cathode in response to the incident photon flux.

The radiation at the EUV region in the range of 11 to 18 nm is measured by using a filtered photodiode SXUV5A with integrated thin film filters of 100 nm Si/ 200 nm Zr. It is mounted on another side-on view port, at a distance of 550 mm from the anode tip. A pinhole is installed before the detector which allows it to be aligned to the tip of the anode. This diode is biased at negative 100 V. The sensitivity of the SXUV5A at wavelength 13.5 nm is 0.194 A/W.

RESULTS AND DISCUSSION

Experiments were carried out for the range of operating pressure from $1.4 \times 10^{-2}$ mbar to $2.2 \times 10^{-2}$ mbar with argon as a working gas. At this pressure range, focusing action was observed with good reproducibility with reference to the XRD and EUV signals. Typical sets of the current and radiation emission signals obtained for discharges at the pressures of $1.5 \times 10^{-2}$ mbar and $1.7 \times 10^{-2}$ mbar are shown in Figures 1(a) and 1(b) respectively. Pinching is observed to occur for these discharges as evident from the electrical signals (current dip and voltage spike). The EUV and XRD signals are observed to coincide with the voltage spike, indicating that the EUV radiation is emitted during the radial compression phase of the plasma focus discharge. Stronger pinching with higher voltage spike and larger current dip are observed at lower pressure. The stronger pinching is believed to lead to high temperature plasma which causes a stronger XRD signal but weaker EUV emission. On the other hand, weaker pinching is observed at higher pressure causing stronger EUV emission. However, no good focusing discharge was observed at pressure above $2.0 \times 10^{-2}$ mbar.
The emission spectrum of the plasma is strongly dependent on the plasma electron temperature. The temperature of the plasma with peak of the plasma emission continuum at the wavelength of 13.5 nm is expected to be around 46 eV. Assuming the argon plasma produced by this device is of low density plasma so that Coronal Equilibrium model (CE model) is applied. Figure 2 represents the fraction of argon ionization distribution with the function of electron temperature calculated from the CE model. Based on this model, at an electron temperature of around 30 to 100 eV the dominating species are the Ar-VII, Ar-VIII, Ar-IX, Ar-X and Ar-XI. From the NIST atomic spectra database [9], these species emit intense spectral lines at wavelength at or near to 13.5 nm. Thus, it is believed that for the case of discharge at lower pressure shown in Figure 1(a), a higher electron temperature is reached and hence the plasma emission is more intense at the wavelength shorter than 11 nm, which is beyond the range of response of the SXUV5A. Whereas for discharge at higher pressure, the electron temperature may be in the range of 30 to 100 eV, where more intense emission at wavelength in the range of 11 - 18 nm is produced.
EUV energy emitted is found to vary from 7.8 mJ to 275 mJ, corresponding to a conversion efficiency of 0.0013 % to 0.046 %. Figure 3 shows the variation of EUV energy measurements at different pressures. The average optimum EUV energy output of 275 mJ is obtained at the pressure of $1.6 \times 10^{-2}$ mbar.

![EUV Energy emitted from Plasma at Different Pressure](image)

**FIGURE 3.** Variation of EUV energy at argon pressure of $(1.4 - 2.2) \times 10^{-2}$ mbar.

**CONCLUSIONS**

Argon plasma produced in 600 joules small plasma focus was tested for emission of EUV radiation. From the current and voltage waveforms it can be confirmed that focusing shots have been obtained. The time resolved EUV and XRD signals are obtained simultaneously and the peak of both the EUV and XRD signals correspond to the voltage spike. The EUV energy estimated from the SXUV5A photodiode is in the range of 7.8 mJ to 275 mJ. The corresponding energy conversion efficiency is in the range of 0.0013 % to 0.046%. Further work is being carried out to measure the 13.5 nm in-band EUV emission.

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**REFERENCES**