Present status of laser-produced plasma EUV light source

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ABSTRACT

The development status of key technologies for a HVM laser-produced plasma EUV light source is presented. This includes the high-power RF-excited CO_2 laser, the Sn droplet target and the collector mirror lifetime enhancement technology. In this paper, we mainly discuss countermeasures for Sn ions and neutrals which cause mirror reflectivity degradation. The effectiveness of ion mitigation by a strong magnetic field was measured. We also observed that Sn neutrals were removed by etching gases and that the etching process did not degrade the effectiveness of the ion mitigation by the magnetic field. A part of this work was supported by the New Energy and Industrial Technology Development Organization (NEDO), Japan.

Keywords: EUV light source, Laser-Produced Plasma, Sn, Debris, Magnetic field ion guiding

1. INTRODUCTION

A CO_2 laser produced Sn plasma is finally the solution for the 13.5nm light source for extreme ultraviolet lithography (EUVL). One of the technical challenges is the requirement of high average in-band power at the intermediate focus[1], together with the cleanness of the plasma chamber. Theoretical[2] and experimental[3] data have clearly demonstrated the advantage of the combination of a CO_2 laser with Sn to achieve a high conversion efficiency (CE) from laser pulse energy to EUV in-band energy. High average laser power due to high amplification efficiency and superior beam quality is readily available by short pulse CO_2 laser technology[4]. The CO_2 laser is based on industrial high average power cw CO_2 laser modules.

1.1 System of Laser-produced plasma light source and Magnetic field ion guiding

Figure 1 shows the fundamental laser-produced plasma (LPP) EUV light source system. The LPP EUV light source system mainly includes a CO_2 laser, a Tin droplet target supply, a EUV collector mirror, and a magnet for plasma guiding to fully recover the injected fuel.

Liquid micro-droplets, generated by the Sn droplet target supply, are synchronously irradiated by CO_2 laser and the generated EUV light is collected at the intermediate focus (IF) by a EUV collector mirror.
It is very important to remove Sn debris, generated with the Sn plasma, because Sn debris causes serious damage of the multilayer EUV collector mirror placed inside the vacuum chamber near the plasma. Because our LPP EUV system has the magnetic field ion guiding system with a superconducting magnet, it is possible to collect the Sn ions effectively, and prevent the degradation of the EUV collector mirror.

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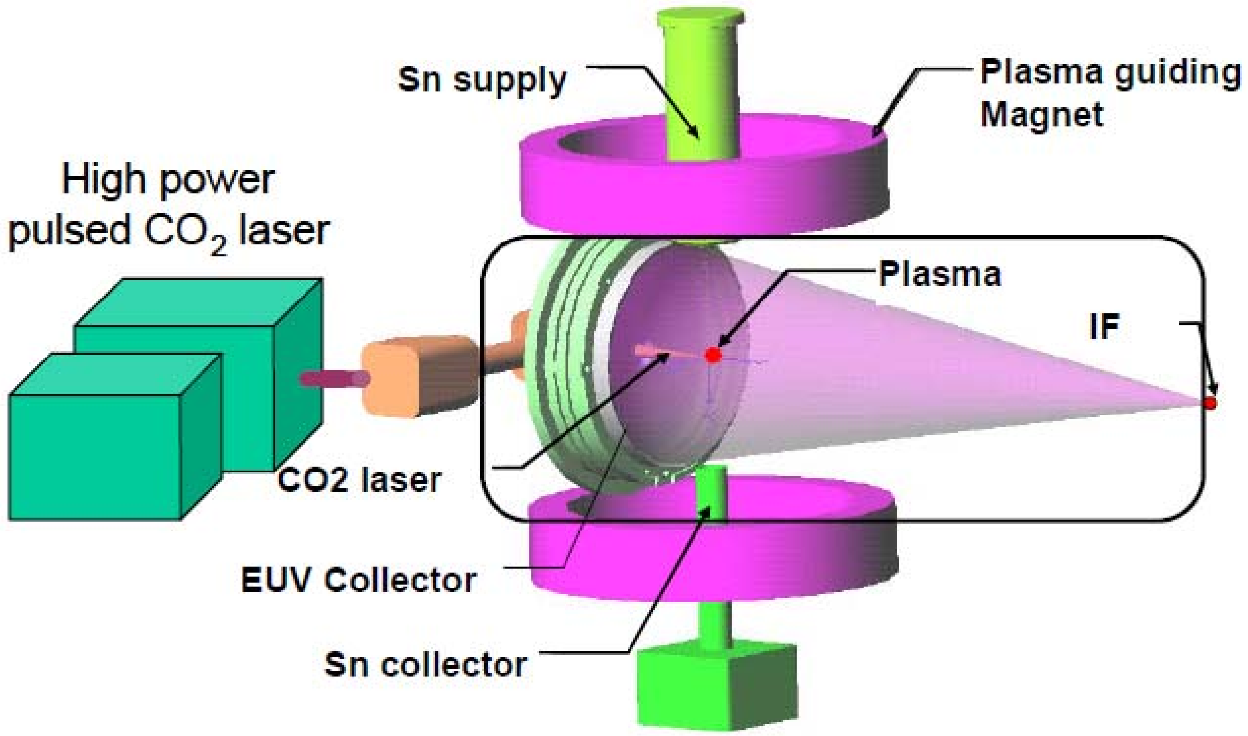


Figure 1. Concept of Laser-produced plasma light source and Magnetic field ion guiding.

1.2 Sn debris

Figure 2 shows a schematic of the materials generated from a laser-produced plasma with a Sn droplet target which consist of energetic plasma ions, neutrals and fragments.

The ions are mainly emitted anti-parallel to the laser incident direction, while the neutrals are emitted in all directions from the Sn droplet. The fragments are ejected into the same direction as the laser pulse[5].
Figure 3 and figure 4 show the velocity distribution and the peak velocity angular distribution of the ions, neutrals and fragments, respectively[5]. The velocity of the fragments is very low due to their large mass, while the ion velocity is fast.
From these characteristics, we have to optimize the configuration of the incident laser direction and the EUV collector mirror position.

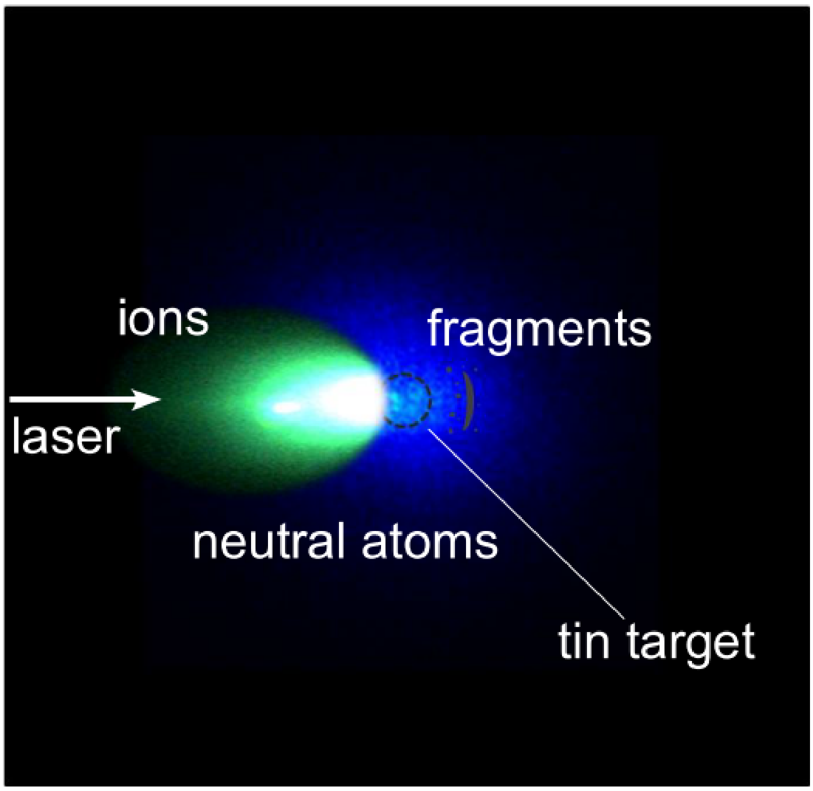


Figure 2. Schematic of the materials from the laser produced plasma with Sn droplet target.

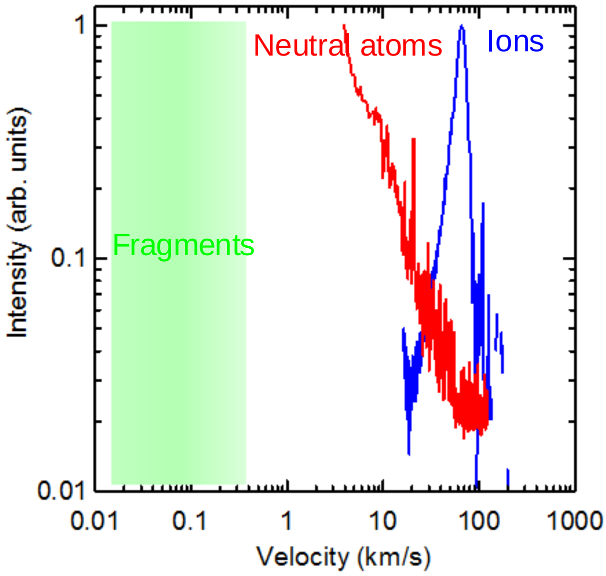


Figure 3. Velocity distribution of ions, neutrals and fragments.

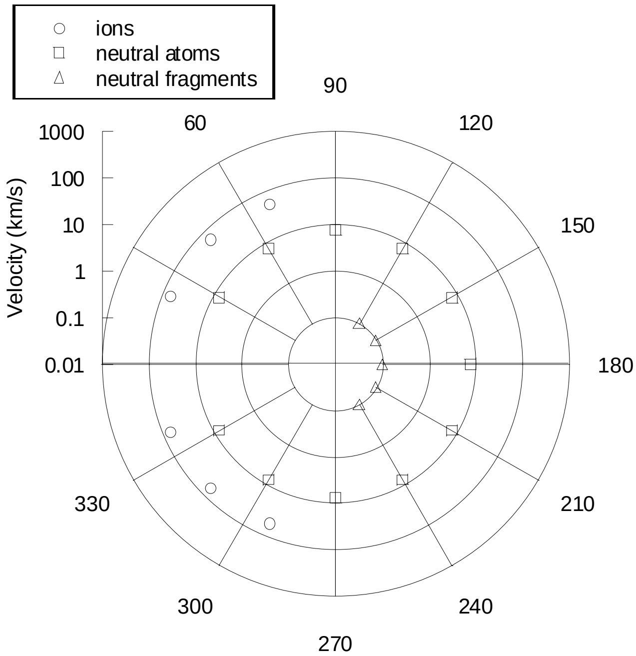


Figure 4. Peak velocity angular distribution of ions, neutrals and fragments.

2. EXPERIMENTAL RESULT

2.1 Magnetic field ion guiding

The most important technical challenge is the debris mitigation from a Sn plasma to extend the EUV collector mirror lifetime.

The fast ions from a laser produced plasma are controlled by a magnetic field[6,7]. We evaluated the effect of a magnetic field with the experimental setup shown in figure 5. A Faraday cup which detects ion signals is placed at an angle of 52.5 degrees horizontally and 30 degrees vertically from the laser direction. Figure 6 shows a Faraday cup signal with and without magnetic field. The Faraday cup signal decreased below the detection limit by applying a magnetic field.

To evaluate the dependence of the Sn deposition rate on the magnetic field intensity, we measured the thickness of Sn deposition on witness plates placed near the EUV collector mirror inside the vacuum chamber. The experimental setup is shown in figure 7. Micro Sn droplets are introduced into the vacuum chamber and the CO_2 laser is irradiated to them from the back side of the EUV collector mirror. A witness plate is placed at an angle of 52.5 degrees from the laser direction, and we measured the thicknesses of Sn deposition on the witness plate at several intensities of the magnetic field.

Figure 8 shows the result of the experiment. The Sn deposition rate decreases as the intensity of the magnetic field increases. At strong magnetic field intensity, the effect of magnetic field ion guiding is constant, and the Sn deposition rate reduces to about 1/4, compared to the Sn deposition rate without magnetic field. This remaining part, not collected by the magnetic field ion guiding, is considered to be Sn neutrals.

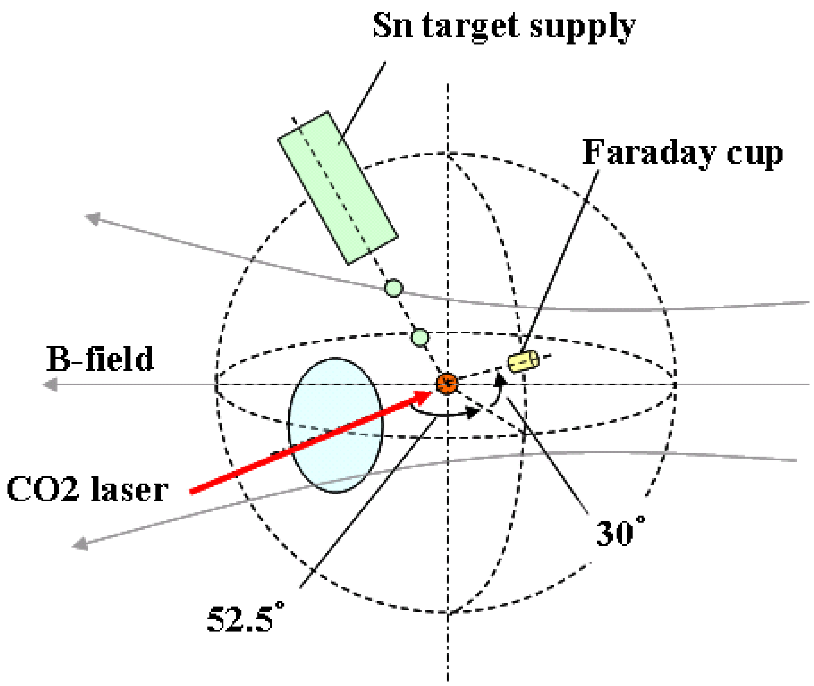


Figure 5. Experimental setup for ion mitigation measurement.

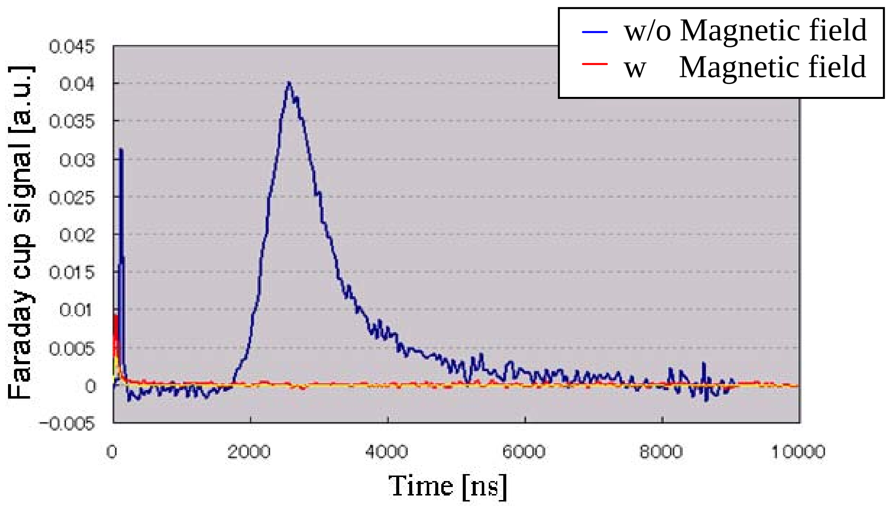


Figure 6. Faraday cup signal with and without magnetic field.

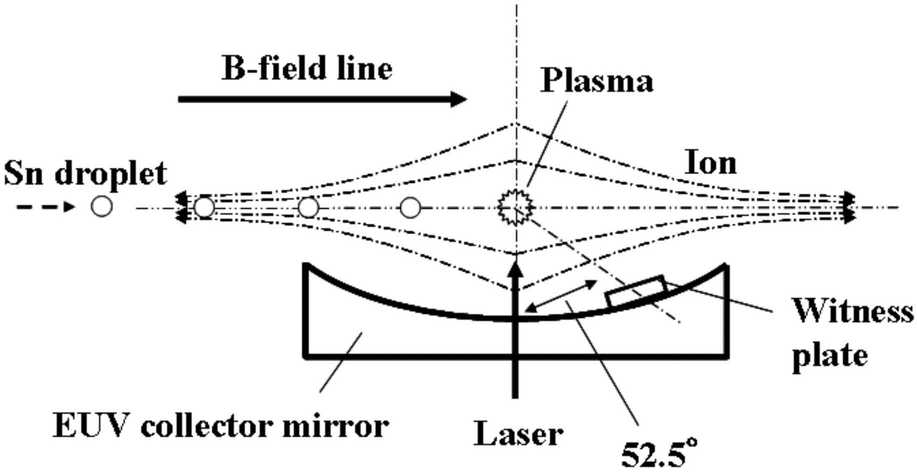


Figure 7. Experimental setup of dependence of magnetic field intensity.

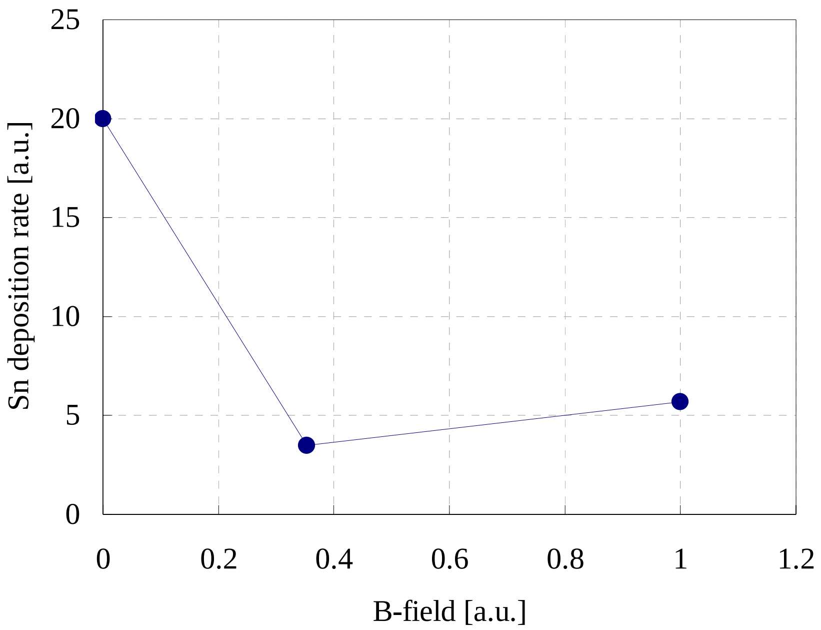


Figure 8. Dependence of Sn deposition rate on magnetic field intensity.

2.2 Sn neutrals etching by gases

Because Sn neutrals, not collected by the magnet field, deposit on the EUV collector mirror, we need to introduce gases into the vacuum chamber, which etch the deposited Sn. The relationship between the Sn etching rate and the the flow of etching gases is shown in figure 9. It has to be verified that the gas flow, indicated by “A” in figure 9, is sufficient to fully etch the Sn neutrals deposited on the mirror.

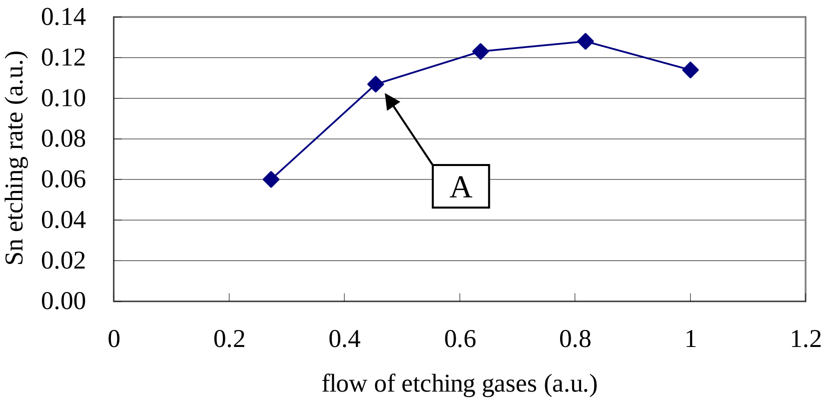


Figure 9. Dependence of Sn etching rate on etching gas flow

2.3 Influence of Etching gases on Magnetic field ion guiding

Sn neutrals, deposited on the EUV collector mirror, are etched by etching gases. However, there is a possibility that the directions of the ions, collected by the magnetic field ion guiding, get scattered due to collisions with the etching gases, and then the ions may also deposit on the EUV collector mirror.

To evaluate the influence of the etching gases on ion diffusion, we measured the ion number, using Faraday cups, at condition “A” shown in figure 9, i.e. at sufficient gas flow to etch the Sn neutrals deposited on the mirror. The experimental setup is shown in figure 10. There are three Faraday cups placed at the magnetic field at an angle of 0, 10 and 20 degrees, respectively. The edge of the EUV collector mirror that must be protected from Sn debris is at the angle of about 10 degrees. The experimental result is shown in figure 11. Without any Sn etching gases, only an ion signal of the Faraday cup placed at an angle of 0 degree was detected, due to the collection of Sn ions by the magnetic field, while no ion signal were detected at an angle of 10, 20 degrees (figure 11 (a)). With some Sn etching gases, the ion signal was still only detected at an angle of 0 degree, i.e. the same result as without etching gases (figure 11 (b)).This result means that the influence of ion diffusion by etching gases is not big enough to degrade the effectiveness of the magnetic field ion guiding, and that the magnetic field ion guiding and the etching of Sn are compatible. The difference between the Faraday cup signals at 0deg, see figure 11 (a) and (b), shows that the ion energy decreased due to the etching gases.

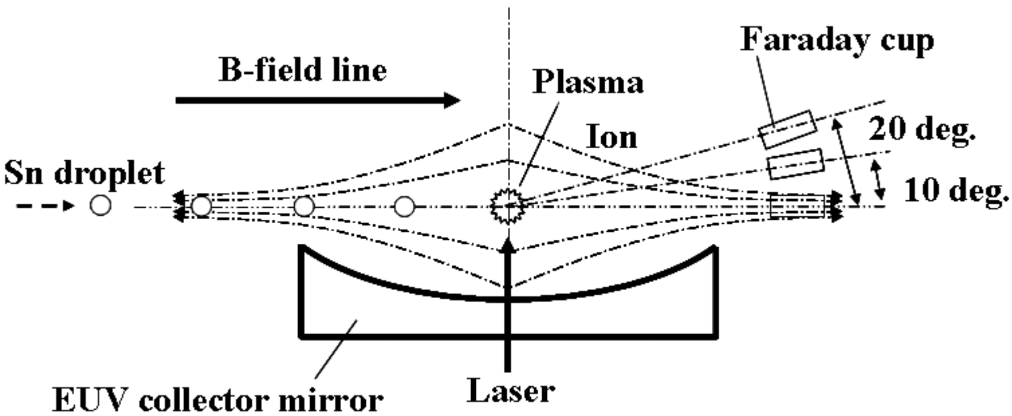
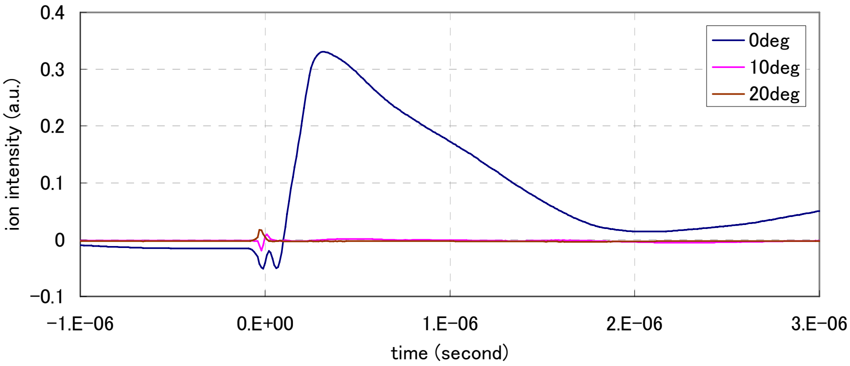


Figure 10. Experimental setup for angle distribution of ions.

(a)



(b)

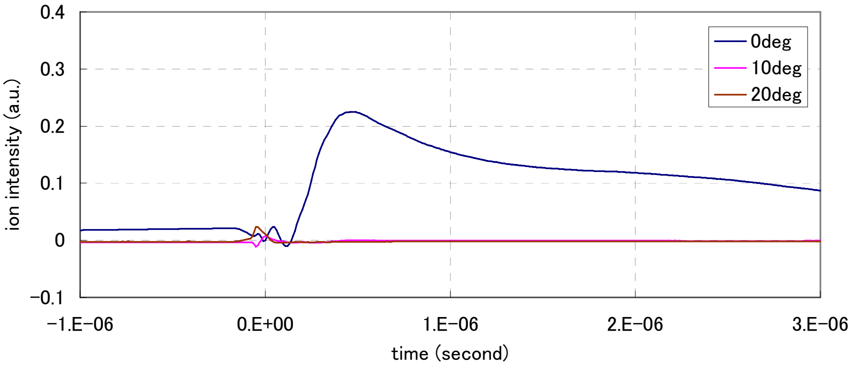


Figure 11. Faraday cup signal (a) without and (b) with etching gases

3. SUMMARY

We are developing a LPP source for high volume manufacturing EUV lithography that is based on a high power CO_2 laser and a tin droplet target. The effectiveness of the magnetic ion guiding as Sn ion mitigation is examined by monitoring the ion signals of Faraday cups with and without magnetic field. Sn neutrals are not collected by the magnetic field, but they can be removed from the EUV collector mirror, by etching with some gases. Because we examined that those gases do not degrade the effectiveness of the magnetic field ion guiding, it is possible to use the magnetic field and the Sn etching gases at the same time to remove ions and neutrals.

ACKNOWLEDGEMENTS

This work was partly supported by the New Energy and Industrial Technology Development Organization (NEDO), Japan.

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