Characteristics of EUV emission from CO_2 laser-produced plasma with a punch-out target

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INTRODUCTION

Research of Extreme UltraViolet (EUV) light source is attractive as a light source for next generation microprocessors. A EUV light source is required mitigation of debris, having high energy conversion efficiencies from laser to EUV (EUV-CEs), and high-repetition operation. " A punch-out target (POT) method " has been proposed as the one of the solutions for debris mitigation and high repetition operation [1, 2].

The POT uses tin (Sn) layer coated on a glass plate. A punch-out laser is irradiated from a glass plate side and generates plasma between Sn layer and a glass plate. Then, Sn layer is propelled toward due to pressure of plasma. The flying Sn target is heated with a heating laser to generate EUV light. As a divergence angle of propelled target is within 5 degrees, spattering or deposition on Mo/Si multilayer mirror for focusing EUV will be negligible because the mirror is located at 90 degrees difference from Sn target flight direction [3]. Furthermore, a POT method has a potential of high repetition operation with providing new surface of the glass plate.

Sn is promising target because of having strong characteristics of EUV emission [4]. However, since it has high optical absorbance of EUV, low density plasma is required to make optical thin conditions. To perform the above condition, a carbon dioxide (CO_2) laser is suitable as a heating laser compare with an Nd:YAG laser because of low cut-off density (10^{18}-10^{19} cm^{-3} in general) of plasma. The POT with CO_2 laser-heating method is effective in terms of high EUV-CEs.

In this report, we reported the dependence on pulse duration of CO_2 laser in terms of EUV spectra and laser pulse - EUV emission timing to investigate the optimum condition of laser irradiation.

EXPERIMENTAL CONFIGURATION

Schematic diagram of this experiment is shown in Fig. 1. POTs and BULKs were used. There are two types of POTs. One is a coated Sn, the other one is a round-shape coated Sn (Sn dot target) on a glass plate. Fig. 2 shows a picture of Sn dot targets. Dot thickness and diameter were 10 μm^t and 500 μm^ϕ, respectively. If the coated Sn target were used as a POT, targets flew as if the shape of a temple bell. On the other hand, the Sn dot target flew on a straight line and kept enough density to absorb CO_2 laser energy [5, 6]. Therefore, targets were used Sn dot targets as a POT in this experiments.

Of the two lasers, the one was a Q-switch Nd:YAG laser to punch out Sn dot targets (Punch-out laser). The other was CO_2 laser to heat targets (Heating laser). Punch-out laser was 1.064 μm wavelength and 13 ns pulse duration. The laser was focused on Sn dot targets through a glass plate with a F/28.5 lens, whose spot size was 700-800 μm^ϕ larger than the dot diameter. The laser intensity was 0.9-2 $\times$ 10^9 W/cm^2. Heating laser was 10.6 μm wavelength and 90 or 40 ns pulse duration. In the case of 90 ns pulse duration, the main pulse dragged on low intensity tail of $\geq$ 500 ns, whose energy included about 30 % of all energy separately from the main energy. 40 ns pulse duration was made with plasma shutter technique. There was no long tail. The laser was focused on 5 mm from the target surface in the case of POTs with a ZeSe lens of F/16, whose spot size was 300 μm^ϕ. The laser intensity was 8 $\times$ 10^9 W/cm^2 (90 ns pulse duration) and 1-2 $\times$ 10^9 W/cm^2 (40 ns pulse duration).

EUV spectra measured with Grazing Incidence Spectrometer (GIS [7]) installed at 45 degrees from normal incident angle of the heating laser. The device for measuring the relation between laser pulse and EUV emission timing (EUV timing detector) was installed at 45 degrees of the other side from GIS with respect to the target normal. Targets were used BULKs to observe the dependence of laser pulse durations. The detector consists of a Zr filter, a mesh, and a Al rod. It was measured with a photoelectric effect of EUV light through a Zr filter.

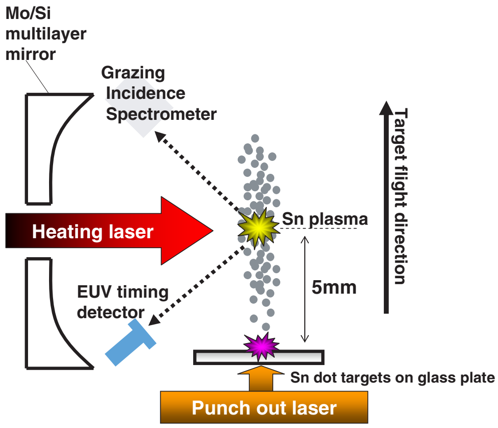

Fig. 1 Experimental setup.

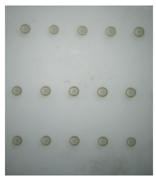

Fig. 2 Sn dot targets.

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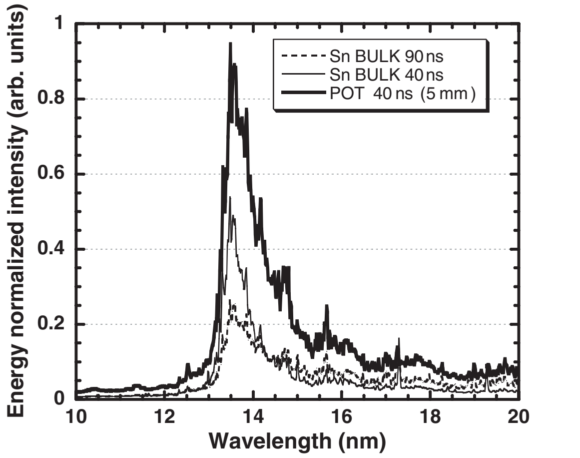

Fig. 3 Spectral comparisons in case of changing targets and heating laser pulse durations.

RESULTS AND DISCUSSION

Figure 3 shows spectra as compared with changing targets and heating laser pulse durations. These spectra were normalized by a heating laser energy. The dotted line and the fine solid line show spectra irradiated by 90 ns and 40 ns pulse duration of a heating laser, respectively. Both targets were used BULKs, and then they were irradiated by the laser only once. The bold solid line show the spectrum irradiated by 40 ns pulse duration of a heating laser, whose target was used a POT.

In the beginning, it is compared with spectra in the case of using a BULK target to observe the dependence of pulse durations. The spectral shape of 40 ns pulse duration was sharper than it of 90 ns pulse duration. This result shows that EUV-CEs become high by irradiating Sn targets with a short pulse duration and non-tail laser. Secondly, it is compared the spectrum of POT with it of BULK in the case of using a 40 ns pulse duration as a heating laser. EUV energy of POTs increased about twice as much as it of BULKs. These differences depend on each initial density. The length of optimum density with POTs is longer than it with BULKs because the density of POTs at 5 mm from the target surface is about 10^{19} cm^{-3} [5, 6].

The relation between laser pulse and EUV emission timing are shown in Fig. 4. The dot line and solid line are laser pulse and EUV emission, respectively. In the case of 90 ns pulse duration, the peak of EUV emission was earlier than it of the laser pulse, whose shape was attenuated faster than laser pulse. On the other hand, both the peak and the shape of EUV emission and the laser pulse in the case of 40 ns pulse duration was almost same. This reason is thought that EUV emission irradiated with the laser of 90 ns pulse duration is absorbed in the tail region of laser pulse because the plasma scale length is long, whose opacity is large.

CONCLUSION

Spectra and the incident laser - EUV emission timing were measured with GIS and EUV timing detector. The spectrum sharpened by changing from 90 ns pulse duration to 40 ns pulse duration. Moreover, EUV energy increased about twice by changing from BULK to POT as a target.

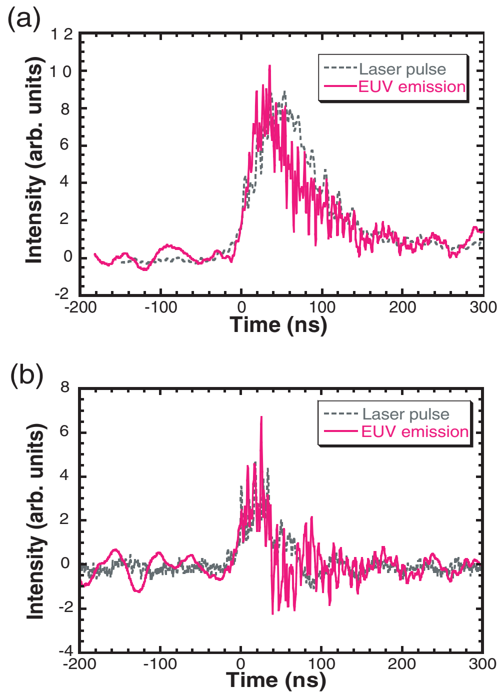

Fig. 4 The relation between laser pulse and EUV emission timing. Heating laser pulse duration and intensity are, respectively, (a) 90 ns, 8×10^9 W/cm^2. (b) 40 ns, 2×10^9 W/cm^2.

Laser pulse and EUV emission profiles were almost same in the case of 40 ns pulse duration. However, the peak of EUV emission was earlier than it of the laser pulse, whose shape was attenuated faster than laser pulse in the case of 90 ns pulse duration.

In the case of using CO_2 laser as the heating laser, a short pulse duration without tail is effective in order to increase EUV-CEs. Furthermore, EUV-CEs of POTs are higher than it of BULKs because of the initial density to be low.

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