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Two-dimensional Profiles of Electron Density and Temperature in Laser-produced Sn Plasmas for Extreme-ultraviolet (EUV) light sources

K. Tomita[1], Y. Sato[1], R. Fukada[1], H. Ito[1]. Uchino[1], K. Kouge[2], H. Tomuro[2], T. Yanagida[2], Y. Wada[2], M. Kunishima[2], G. Soumagne[2], T. Kodama[2], H. Mizoguchi[2], A. Sunahara[3], K. Nishihara[4]
[1] Interdisciplinary graduate school of engineering sciences, Kyushu University, [2] Gigaphoton Inc., [3] Purdue University, [4] Osaka city University
e-mail: tomita@ence.kyushu-u.ac.jp

Extreme-ultraviolet lithography (EUVL) is a promising technology for high-volume manufacturing of next-generation semiconductor devices. Laser-produced Sn plasma, which shows a sharp and strong spectrum at λ=13.5 nm, has attracted considerable attention as a candidate of the EUVL light sources (only 2% bandwidth at 13.5 nm wavelength is useful because of the reflection characteristics of Mo/Si multilayer optics in the EUVL system). The modeling of atomic processes has found that efficient EUV emission is obtained from 4d-4f and 4p-4d transitions of Sn plasmas with average Z~10 [1)]. Therefore, in order to obtain higher output and better conversion efficiency (CE, efficiency between input laser power and output EUV power) of EUV, it is necessary to control average ionic charge Z (i.e., control electron temperature T_e). Furthermore, larger ion density (n_i) is desirable within the etendue limit. Therefore, time- and spatial resolved measurements of these parameters (Z, T_e and n_i) are essential to optimize EUV source. However, a small size (~0.5 mm diameter) and short lifetime (~20 ns) of the plasma make it difficult, and the precise measurements were never performed.

For this challenging research theme, we have tried to apply collective Thomson scattering (CTS) technique to the EUV light source plasmas. CTS is a non-intrusive method and it can measure electron density (n_e), T_e, and Z with excellent time (< 5 ns) and spatial (< 50 µm) resolutions [2)]. The CTS technique has been already applied to laser-produced plasmas. However, a special challenge for the EUV light source plasmas is the very small wavelength separation of the ion component of ~100 pm from the probe-laser wavelength: λ_0 = 532 nm, which also means that the ion component is very close to the probe laser wavelength λ_0 (i.e., 50 pm). Therefore, very high spectral resolution and stray light reduction are essential. Triple grating spectrometers are widely used for collective and noncollective Thomson scattering. However, they block a wavelength range of approximately1 nm at λ_0 to reduce stray light (i.e., the ion component in our application is also blocked). Therefore, we built a custom-made spectrometer [3)]. This spectrometer has six gratings with 2400/mm grooving. Four gratings are used for stray light reduction, while the other two gratings are utilized for wavelength dispersion. Using this special system, the ion components from the Sn were successfully observed.

Figure 1 shows a schematic view of the experimental layout. A Sn-droplet with a diameter of 26 µm was selected as a target material for EUV source. A CO_2 laser was used as a driving laser. As the probing laser, the second harmonic (wavelength: 532 nm) of the Nd:YAG laser was used. As the result of the CTS measurements, clear two-dimensional profiles of n_e and T_e were observed [4)]. An interesting structure of ne were obtained from the plasmas, whose conversion efficiency (CE) was highest (4%) in this study, i.e., a characteristic hollow-like density profile was formed only for the highest-CE plasma. We also clarified significant amount of “useless” Sn ions within the limited etendue, whose temperature was too low to contribute EUV emission. These structures were pointed out for the first time.

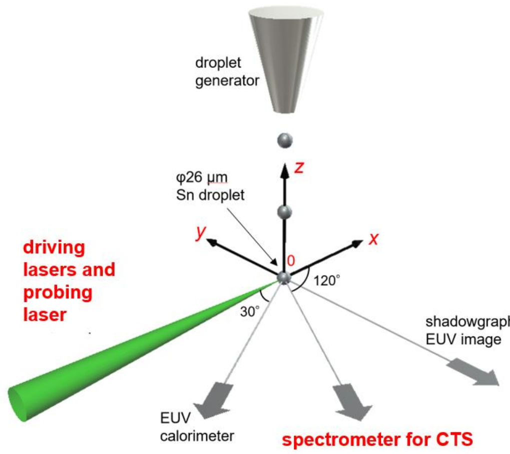

Fig. 1. Schematic view of the experimental layout.

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