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Measurements of electron density, electron temperature, and velocity field in laser-produced EUV source plasmas using collective Thomson scattering

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Measurements of electron and ion dynamics are essential to diagnose laser-produced multi-ionized light source plasmas. Generally, these plasmas are based by plasma physics, atomic physics, and radiation hydrodynamics. Therefore, measurements of plasma parameters, such as electron density (n_e), electron temperature (T_e), and averaged ionic charge (Z) are important. In addition, measurements of plasma flow velocity fields (v_{flow}) may give us significant findings to know plasma dynamics.

However, it is highly challenging to observe such local plasma parameters due to their small (< 0.5 mm) scale and short (<50 ns) lifetime. Here, we report time-resolved two-dimensional profiles of T_e, n_e, Z, and v_{flow} of laser-produced Sn plasmas for extreme-ultraviolet (EUV) lithography light sources using a collective Thomson scattering (CTS) measurements.

Figure 1 shows schematics of the plasma generation system. For plasma generation, a pre-pulse laser (14 ps pulse) and the main laser (CO_2 laser with a 15 ns pulse width, 100 mJ energy) irradiated droplet tin target [1]. The CTS system with custom-build spectrometer (not shown in the Fig.1) was used to measure the ion-term spectra, with which time-resolved (5 ns resolution) local values of n_e, T_e, Z, and v_{flow} of the Sn plasmas were revealed. To measure v_{flow}, Doppler shift of the ion-term spectra observed from two scattering angles were analyzed [2]. Detailed procedures to determine v_{flow} field are described in Ref. [2]. The way to determine n_e, T_e, Z from the shape, spectral width, and absolute intensity of the ion term spectra is shown in Ref. [1].

Figure 2 shows an example of two-dimensional profiles of v_{flow} and pressure P, which was calculated using measured n_e, T_e, and as $P=n_e\kappa\,(T_e+T_i/Z)$, where κ is Boltzmann constant and T_i is ion temperature (T_i is assumed to be same as T_e in this study). Regarding Fig. 2, two points should be emphasized, (i) both the direction and magnitude of v_{flow} varied with positions, (ii) there exist the plasma flows toward the central plasma axis (x-axis).

After further analyses, we found that the plasma inflows exceeding 10^4 m/s toward a plasma central axis play an important role in improving the total EUV light emission, i.e., the plasma inflows maintain the EUV source at a temperature suitable for EUV light emission for a relatively long time and at a high density.

References

[1] K. Tomita *et al.*, "Time-resolved two-dimensional profiles of electron density and temperature of laser-produced tin plasmas for extreme-ultraviolet lithography light sources", *Scientific Reports* 12328, **7** (2017).

[2] K. Tomita *et al.*, "Observation of plasma inflows in laser-produced Sn plasma and their contribution to extreme-ultraviolet light output enhancement", *Scientific Reports* 1825, **13** (2023).

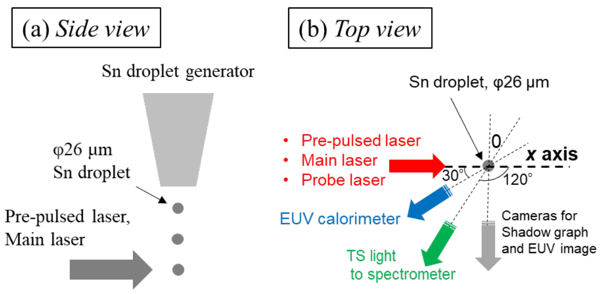

Fig. 1. (a) Side view and (b) top view of experimental layout.

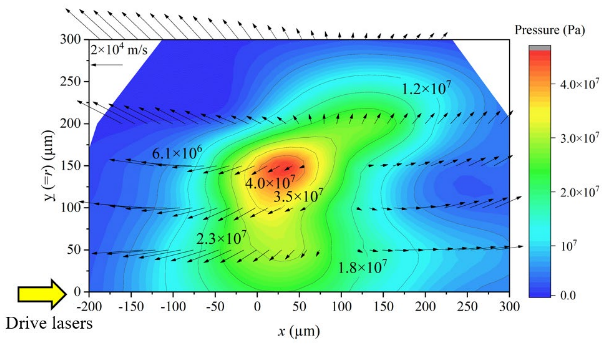

Fig. 2. 2D-profiles of pressure and plasma flow-velocity field (vflow)