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Studies of EUV light source plasmas based on measurements of electron temperature and electron density

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1. Introduction

Extreme-ultraviolet (EUV) sources at wavelength of 13.5 nm 2% bandwidth, have been studied for the application of semiconductor lithography light sources [1]. For the EUV light sources, (i) an improvement of so called "in-band" EUV power and (ii) suppression of debris, are important issues which should be solved for future systems. Regarding the theme (i), in-band EUV power (power at the wavelength of 13.5 nm 2% bandwidth) collected at an intermediate focus point, is a result of radiation transport inside the EUV light source plasmas, which consists of multi-ionized tin ions having highly complex atomic configurations. Manly, 4d-4f transitions of ionic charge (Z) of 8-12 ions emit many spectral lines at around in-band EUV, which is called unresolve transition array (UTA). Collisional Radiative Equilibrium (CRE) model, which may include adequate energy levels of Sn ions for EUV radiation, provides radiation transport coefficient (emissivity W/cm^3 and opacity cm^{-1}) at the EUV region as functions of electron temperature (T_e) and ion density ($n_i=n_e/Z$, n_e: electron density) [2]. The accuracy of the radiation transport coefficient is an important factor to ensure the accuracy of the plasma dynamics predicted by simulation. Validation and verification of the CRE model and radiative-fluid simulations, both of which need plasma parameters such as Te and ne.

Regarding the theme (ii), the debris properties are generally specified by ion energy distribution function (IEDF). For the simple production scheme (ex., single, Gaussian shaped laser irradiation with plane-solid target), IEDFs are well explained by One-dimensional isothermal expansion model. In this model, IEDFs are scaled by $Z\kappa T_e$, where κ is Boltzmann constant. However, in the case of so-called "double-pulse" scheme, which has been usually used for industrial system, no adequate model has explained the IEDF profiles yet, in our best knowledge. Generally, fluid model indicates that the electric field in the plasma is expressed as $1/n_e \nabla p_e$, where p_e is electron pressure [3]. Recent PIC simulations also concluded that $1/n_e \nabla p_e$ is a main parameter for ion acceleration in laser-produced EUV sources. Therefore, measurements of n_e and T_e are also important for controlling of the IEDF.

2. Experiment

Figure 1 shows experimental setup for the theme (ii). In this system, we have measured ne, Te, and angle dependencies of the IEDFs (ionic charges are not resolved, however) of laser-produced Sn plasmas for EUV light sources.

A driving laser (λ=1064 nm, pulse width 10ns, laser intensity 10^9-10^{10} W/cm^2) irradiate plane solid Sn target, which is mounted in the vacuum chamber. Then, Thomson scattering probe laser (λ=532 nm, pulse width 6ns with injection seeding) passes through perpendicular to the driving laser. Thomson scattering signal is collected by lenses at the angle of 135 degree from probe-laser direction and is analyzed by custom-made spectrometer having 6 reflected gratings (2400 lines/mm) and an ICCD camera (gate width: 2 ns) [4]. For the measurements of the IEDF, the probe for Thomson scattering is not used. We also performed the double-pulse scheme for plasma production. In this case, the wavelength for the two lasers for plasma production were 1064 nm.

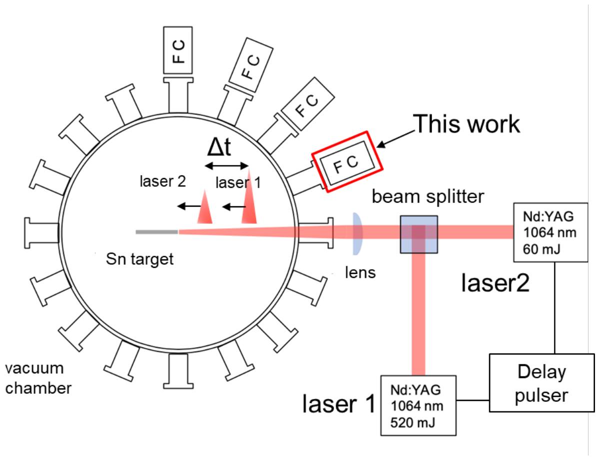

Fig.1 experimental setup

3. Results

When the plasma was produced with the double-pulse scheme, the IEDFs were clearly different from the single-laser production scheme. Now we are investigating the reason of the different results.

References
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