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協同的トムソン散乱法によるレーザー生成EUVプラズマの電子密度・電子温度・イオン温度計測

Measurements of Electron Density, Electron Temperature and Ionic Charge of Laser Produced EUV Plasmas using Collective Thomson Scattering

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Extreme ultraviolet (EUV) lithography with wavelength of 13.5 nm is a promising technology for next-generation microprocessors whose node size is less than 22 nm. For the practical use of EUV lithography, an improvement of output power and efficiency of EUV light source is indispensable, and measurements of their fundamental plasma parameters, such as electron density (n_e), electron temperature (T_e) and ionic charge (Z) are prerequisite to control and improve EUV plasmas.

In order to achieve precise measurements of these plasma parameters, we have applied collective Thomson scattering technique to laser-produced EUV light source plasmas. When the second harmonics of Nd:YAG laser (λ = 532 nm) is used as the light source, LTS spectra observed from EUV plasmas ($n_e = 10^{24} - 10^{25}$ m^{-3}, T_e = 30 - 50 eV) are in the collective regime and they consist of the electron term and the ion term. In this study, only the ion term were focused, because the electron term was easily overwhelmed by plasma emission when the energy of the probing laser is set to be small to avoid plasma perturbations.

Figure 1 shows a schematic of the LTS system. Three lasers were used in this study: a driving laser to produce plasmas (fundamental of Nd:YAG laser, λ = 1064 nm, 10 ns pulse width, laser energy E_p = 40-260 mJ), a probing laser for LTS measurements (the second harmonics of Nd:YAG laser, λ = 532 nm, 10 ns pulse width, laser energy E_L = 5-15 mJ, spectral width<0.1 pm), and a heating laser to heat plasmas (fundamental of Nd:YAG laser, 10 ns pulse width, laser energy E_H = 0-440 mJ). The driving laser was injected perpendicular to a target, which has 0.5 mm width and is located in a vacuum chamber (<10^{-2} Torr). The probing laser was injected perpendicular to both the driving laser and the target as shown in Fig. 1. The heating laser was injected into the same axis and the same time as those of the probing laser. Typical spot size of the two lasers at the focusing point was 50 μm. LTS signals were collected by achromatic lenses (f = 300 mm, effective diameter 46 mm) and focused on an entrance slit of a triple grating spectrometer (TGS). The TGS has three gratings and reduces stray lights efficiently. Scattered lights dispersed by the TGS were detected by an intensified-CCD (ICCD) camera (Princeton, PI-MAX UNIGENII, 1024×1024 pixel, 10 ns gate width). To determine n_e, calibration of the absolute value of the LTS signals was performed by using Rayleigh scattering measurements. Rayleigh scattering lights from atmospheric pressure nitrogen gas were observed in the same experimental condition.

Thomson scattering measurements were performed at a position of 200 μm from the surface of the carbon target and at a time of 15 ns after the plasma production. From the observed ion term spectrum, n_e, T_e, T_i and Z were evaluated to be 1.5×10^{25} m^{-3}, 14 eV, 11 eV and 3.8, respectively. In order to heat plasmas, the other laser (the fundamental of Nd:YAG laser, power density (0-2.3) $\times10^{16}$ W/m^2) was injected to the LPP, and it was found that n_e, T_e, T_i and Z changed in the ranges of (0.4-1.5) $\times10^{25}$ m^{-3}, 14-53 eV, 11-24 eV, 3.8-4.1, respectively. The measurement error was estimated to be ±10%. Referring these results, a new LTS system for Sn plasmas has been designed.

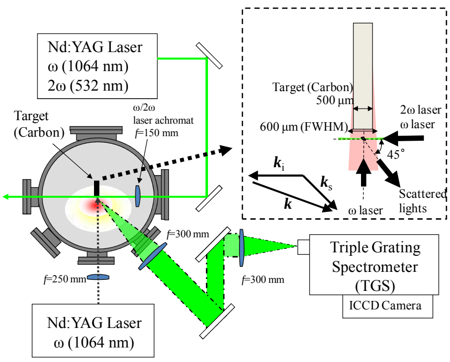

Fig. 1. The schematic of the collective Thomson scattering system for laser produced plasmas. The inset shows the detailed diagram around the target. $\boldsymbol{k}_i$ and $\boldsymbol{k}_s$ mean the wave-numbers concerning the probing laser and scattering angle, respectively. $\boldsymbol{k}$ means the differential wave-number.