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§10. Measurement of EUV Out-of-Band Spectra in Laser Produced Sn Plasmas

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The hot dense plasmas created by intense laser pulses have been extensively studied for various applications, such as next generation extreme ultraviolet lithography (EUVL), x-ray microscopy, and absorption spectroscopy. Especially, in order to realize the next generation semiconductors with a node < 45 nm, the development of EUV light source suitable for the lithography has been considered to be one of the urgent issues[1]. For the purpose of this, xenon and tin plasmas produced by a high-intensity laser and z-pinch have been used so far.

On the other hand, a Mo/Si multilayer mirror used for focusing and transmitting EUV light, which has maximum reflectivity around 13.5 nm in wavelength, suffers from heat load caused by intense emission radiated from high-density laser plasma, resulting in the deformation of the mirror surface. Moreover, since the Mo/Si mirror has also high reflectivity above 100 nm in wavelength, the unnecessary light for the lithography (out-of-band) as well as EUV emission could be transferred and exposed on the wafer. Consequently, the resolution of EUVL system becomes drastically worse. Therefore, the measurement of absolute emission intensity from UV to the infrared region provides essential information to enhance the miniaturization.

In this study, we measured the EUV out-of-band spectra in the wavelength region of 200-750 nm emitted from a laser produced Sn plasma to elucidate the spectral distribution.

The experiments were carried out by using a YAG laser (wavelength: 1064 or 355 nm). The target was tin plate (purity 99.9 %) mounted on the *x-z* state to irradiate the fresh tin surface for each laser pulse. Spectroscopic investigations were performed using time- and spatial resolved optical system. For the measurement of spatial intensity distribution along the direction parallel to the laser incidence, the emission was collected by a lens onto an optical fiber with 48 cores. The spatial resolved spectra were measured by a spectrometer coupled with a CCD camera with an image intensifier. The whole optical system was relatively calibrated by D_2 and Xe lamps.

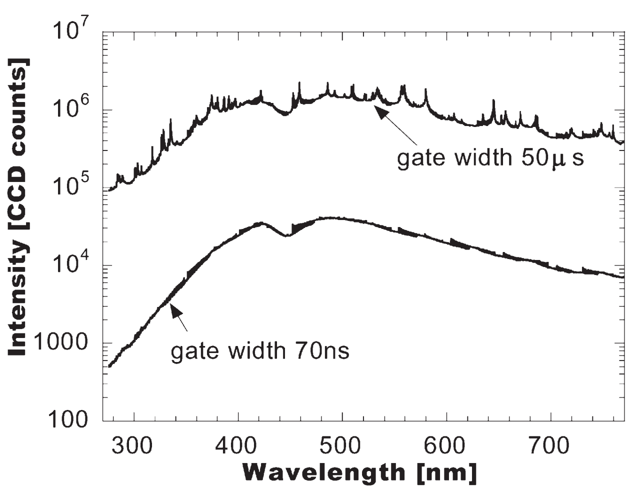

Fig.1. Out-of-band spectra for exposure times of 70 ns and 50 µs.

Figure 1 shows the spectral distribution between 280 and 780 nm under the experimental condition of 1064 nm, pulse width of 10 ns, and intensity of ~7×10^{10} W/cm^2. The exposure times for CCD camera were set to 70 ns and 50 µs. As is clearly seen, the continuum emission dominates over the line emissions. The calibrated spectral intensity for 70-ns exposure is shown in FIG. 2 with solid curve. The dotted curve represents the Planck distribution corresponding to plasma temperature of 17 eV. The good agreement between experimental and Planckian curves was obtained. The out-of-band spectra, therefore, can approximately be regarded as the blackbody radiation.

The measurement of UV spectral region above 180 nm was also carried out using laser pulses with 355 nm, ~5 ns pulse, ~7×10^9 W/cm^2. The experimental curve can be reproduced by Planckian of ~10 eV.

In general, the high Z atoms such as tin have many, complicated excited levels. Realistically, it is impossible to calculate the all optical transition which contributes to the out-of-band emission. However, the fact that the spectral distributions can approximately be expressed by Planckian with the certain plasma temperature makes the estimation of out-of-band spectra much simple, since we can neglect a great number of line emissions.

In future, we will measure the out-of-band spectrum in VUV region (100~200 nm). For calibration of optical system, the atomic branching ratio method will be employed to obtain the absolute intensity [2].

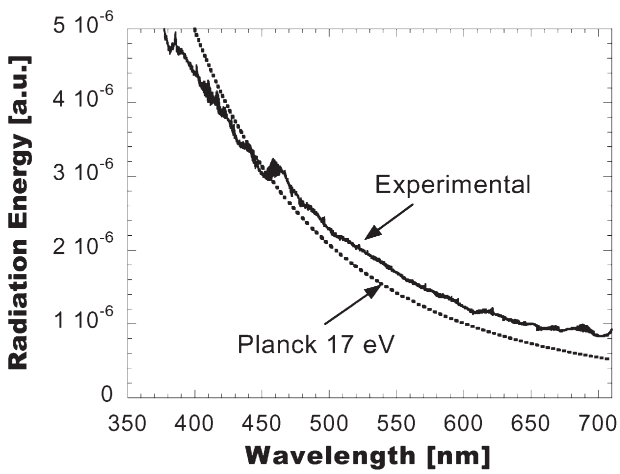

Fig. 2. Calibrated experimental spectrum. The Planckian curve with a plasma temperature of 17 eV is also shown.

References

[1] Namba, S., et al., Appl. Phys. Lett. **88**, 171503 (2006).

[2] Sato, K., et al., Appl. Opt. **23**, 3336 (1984).