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Spatiotemporal Emission Spectra from Laser-Produced Tin Plasma in a Hydrogen gas Atmosphere

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1. Introduction

Extreme Ultraviolet (EUV) lithography using 13.5-nm wavelength light source is a critical technology for mass production of state-of-the-art semiconductors with a circuit width resolution of 22 nm or below. However, the EUV system faces the issue of debris generated by the laser-produced tin (Sn) plasma process, particularly highly charged ions. These debris particles can damage the expensive and large EUV collecting mirror (C1 mirror), which is one of the crucial problems for the EUV lithography. One approach to mitigating this issue is by introducing hydrogen gas into the Sn plasma [1-3]. Our experiment aims to clarify the spatiotemporal behaviors of Sn and H plasmas in a H_2 gas atmosphere, focusing on the interaction processes between Sn ions and H/H_2 particles, particularly how H radials react with Sn ions and then they form gaseous SnH_4. To identify the complicated mechanism in Sn and H plasma, emission spectroscopy of visible wavelengths was conducted in this study.

2. Experimental setup

Figure 1 shows a schematic diagram of the experimental setup. An Nd:YAG laser irradiated a Sn target to generate laser plasma. A pinhole camera captured two-dimensional EUV emision image. EUV spectra were analyzed using a grazing incidence spectrometer (GIS) with a flatfiled grating of 1200 grooves/mm and a toroidal mirror for collecting plasma emission, while visible light spectra were measured with a visible spectrometer coupled to an ICCD detector. Hydrogen gas introduced into the chamber to keep the constant pressure of 100 Pa, and its chamber pressure was monitored with an absolute pressure gauge.

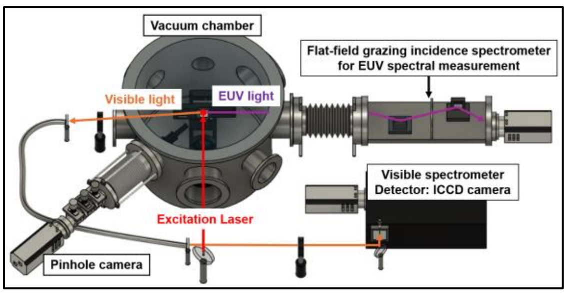

FIG. 1: Schematic of the experimental setup for visible and EUV emission spectroscopies.

3. Results and discussion

Figure 2 shows the spatiotemporal spectral distributions of neutral Sn I (452.4 nm) and Sn II (458 nm) under vacuum and 100-Pa H_2 atmosphere. In vacuum, the results show that intense Sn I emission is observed only near the target surface (0~2 mm), while the radiation attributed to Sn II extends to 15 mm from the target. In the H_2 atmosphere, however, the emission area of Sn I is broadened spatially and temporally, whereas for Sn II the intense emission region is restricted within 50 ns and 5 mm. This behavior can be explained by the electron cooling due to interaction between Sn plasma and H_2, resulting in the rapid recombination (three-body collisional recombination). More details will be reported in the presentation.

Measurements of electron temperature and density were also conducted by analyzing the H_β spectral profile, showing that our interpretation of the above result is reasonable.

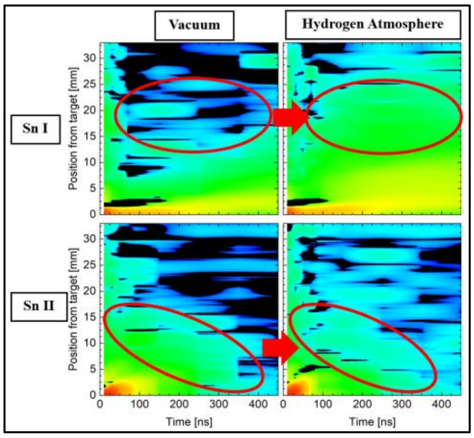

FIG. 2: Spatiotemporal distributions of emission from Sn I and Sn II in vacuum and H_2 environments.

References

[1] H. Komori, "Ion damage analysis on EUV collector mirrors", SPIE 5374, pp. 710-719 (2000)

[2] P. Mirkarimi, Applied Optics **39** (10), pp.1617-1625 (2000).

[3] V. Bakshi, "EUV Sources for Lithography," SPIE Press, Bellingham, WA (2006).