6th Asia-Pacific Conference on Plasma Physics, 9-14 Oct, 2022, Remote e-conference

Actively controlled radical production in a photo-ionized hydrogen plasma for tin contamination cleaning

[1] N. Tanaka, [1] Y. Wang, [1] K. Nishihara, [1] S. Fujioka, [1,2] A. Sunahara, [1, 3] T. Johzaki, [4] Kyung Sik Kang, [4] Youngduk Suh, [4] Jeong-Gil Kim, [5] S. Ueyama, [5] K. Ozawa
[1] Institute of Laser Engineering, Osaka University, [2] Purdue University, [3] Hiroshima University, [4] Mechatronics Research, Samsung Electronics Co. Ltd., [5] Samsung R&D Institute Japan
e-mail (speaker): tanaka.nozomi.ile@osaka-u.ac.jp

Extreme ultraviolet light lithography (EUVL) is a technology for the manufacture of semiconductor devices that uses extreme ultraviolet (EUV) light. Laser-produced tin plasma is known as an intense EUV source. However, tin atoms and neutrals emanated from the EUV source plasma significantly contaminate mirrors in the EUVL system resulting in reduction of through-put and duty cycle. Thus, cleaning of the contamination is one of the key issues that must be solved for the long-term and stable operation of the EUVL system. The chemical reaction between tin atoms and hydrogen atoms, as known as “H-radicals”, can be used to remove the tin [1,2]. To date, in-situ H-radical production in photo-ionized plasma by EUV irradiation has been attracting much attention [3-5], but the sufficient density of H-radicals has not been obtained due to its passive operation. Active control and optimization of radical production in the EUV source environment is thus very important to maximize the cleaning efficiency. We have successfully obtained the H-radical density as well as the EUV photoionized plasma properties.

The experiments were conducted in a separated test-bed device. It consists of a solid xenon EUV source [6], EUV focusing optics [7], and the target hydrogen gas cell. With measurement of hydrogen plasma spectrum, Balmer series, and H-radicals in ground state, we have found that the photo-ionized plasma has electron temperature and density at $T_e = 1 \pm 0.2$ eV and $n_e = (2 \pm 0.4) \times 10^{13}$ cm^{-3} at a hydrogen gas pressure of 5 Pa and EUV irradiation intensity of $8 \pm 1.47 \times 10^8$ W/cm^2. The total H-radical density was in the order of 10^{14} cm^{-3}. It was shown that both ionization and recombination contributed to the population of H-radical density, and the plasma was in semi-steady-state by a collisional radiative model [8]. The results also suggested that the operation parameter, such as EUV spectrum, intensity, or gas pressure strongly controls the H-radical density.

To enhance the H-radical production efficiency, the controllable parameters would be the hydrogen pressure, radical production cross section, and the EUV irradiation intensity. We will present our results of parametric study on the factors in the talk.

References

[1] Dujardin G, Besnard M, Hellner L and Malinovitch Y 1987 Physical Review A 35 5012
[2] Chung Y, Lee E M, Masuoka T and Samson J A 1993 The Journal of chemical physics 99 885–889
[3] N. Faradzhev and V. Sidorkin, J. Vac. Sci. Technol. A 27, 306 (2009)
[4] R. Van Der Horst et al., J. Phys. D: Appl. Phys. 49, 145203 (2016)
[5] J. Beckers, T. Van de Ven, C. De Meijere, R. Van der Horst, M. Van Kampen, and V. Banine, Appl. Phys. Lett. 114, 133502 (2019)
[6] M. Masuda, N. Tanaka, K. Hane, A. Sunahara, S. Fujioka, and
H. Nishimura, Appl. Phys. B 119, 421 (2015)
[7] N. Tanaka, N. Wada, Y. Kageyama, and H. Nishimura, High Energy Density Phys. 37, 100865 (2020)
[8] C. Liu et al., Applied Physics Express 15, 036002 (2022)

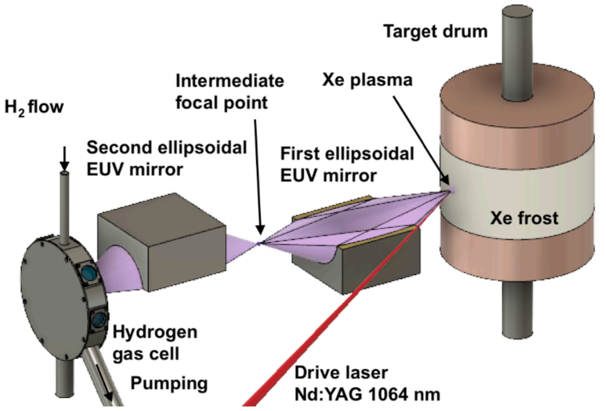

Figure 1 The Xe EUV source, EUV focusing optics and the hydrogen radical production target gas cell [6,7,8].