8th Asia-Pacific Conference on Plasma Physics, 3-8 Nov, 2024 at Malacca

A Pathway to Tin Contamination Cleaning in Extreme Ultraviolet Lithography Source with Photoionized Plasma

N. Tanaka[1], J. E. Hernandez[1], Y. Wang[1], K. Nishihara[1,2], A. Sunahara[1,3], T. Johzaki[1,4], Kyung Sik Kang[5], S. Ueyama[6], S. Fujioka[1,7]
[1]Institute of Laser Engineering, Osaka University, [2]Osaka Metropolitan University, [3]Purdue University, [4]Hiroshima University, [5]Mechatronics Research, Samsung Electronics Co. Ltd., [6]Samsung Device Solutions R&D Japan, Samsung Japan Corporation, [7]National Institute for Fusion Science
e-mail (speaker): nozomi.tanaka.ile@osaka-u.ac.jp

First projected and predicted in 1965, Moore's Law [1] states that the number of transistors in semiconductors doubles every two years. This empirical law has been a significant driving force in the development of the semiconductor industry. As the feature sizes of transistors continue to shrink, the need for shorter wavelength light in photolithography processing has become more critical. The transition to extreme ultraviolet lithography (EUVL) has been pivotal in this regard. Tin target laser produced plasma (LPP) EUV source is employed for its high power output and there has been continuous progress in the source development. Since the start of mass production using EUV lithography in 2018, the semiconductor industry has been able to continue following the law. As of 2024, a critical requirement is increasing the EUV power to support further mass production and its expansion to mid- to low-end devices. Surface contamination of the first collector mirror in the EUV source by tin debris is a critical bottleneck for maintaining or increasing the throughput. Not only does the deterioration of EUV reflectivity, but the need for *ex-situ* mirror cleaning also greatly reduces the duty cycle.

Mitigation of tin debris and *in-situ* cleaning are effective approaches to solve this issue. First, mitigation of tin debris by controlling the target mass [2] or applying a magnetic field to dump ion debris [3] prevents tin from contaminating the mirror surface. Second, in-situ cleaning of the tin contamination layer includes methods such as reactive ion etching by energetic ions [4], the utilization of hydrogen radicals, which chemically react with tin atoms to form a volatile stannane that can be pumped out, and a plasma produced in RF plasma induced by the mirror itself [5], among other methods. Due to engineering limitations for implementing additional mechanical systems in the EUV source, the current standard design of the EUVL source incorporates hydrogen buffer gas to mitigate the tin debris and clean the contamination layer with XUV-induced hydrogen radicals simultaneously [6]. However, no study has reported the number density characteristics and production of hydrogen radicals in the photoionized plasma itself.

We have revealed the characteristics and production mechanism of photoionized hydrogen plasma and hydrogen radicals using an intense pulsed LPP wideband extreme ultraviolet (XUV) source equipped with a set of XUV focusing optics. The electron temperature and density were obtained from the visible spectrum of the hydrogen plasma. The photoionized plasma showed electron temperature of $T_e = 1.0 \pm 0.2$ eV and electron density of $n_e = (2.0 \pm 0.4) \times 10^{13}$ cm^{-3} at a hydrogen gas pressure of 5.0 ± 0.1 Pa and XUV irradiation intensity of $8.00 \pm 1.47 \times 10^8$ W/cm^2. Our findings indicated that both ionization and recombination contributed to the population of hydrogen radical density, and the plasma was in quasi-steady-state by a collisional radiative model [7].

The number density of hydrogen radicals in the photoionized hydrogen plasma was measured for the first time. We have implemented laser induced fluorescence (LIF) method to detect the ground state population density of hydrogen radicals. Excited hydrogen radicals at upper states (p=3, 4, 5) were obtained from the Balmer series spectrum, where p is the principal quantum number. The total hydrogen radical density was 4×10^4 cm^{-3}. The experimental results were well described with a relatively simple equation consisting of XUV photon flux, XUV spectrum, cross section, and gas pressure. The XUV intensity and hydrogen radical density are expected to be 6–7 orders smaller than those in our experiment due to the absence of the XUV focusing optics [8]. Thus, great enhancement of radical production is required, and an actively controlled hydrogen radical production method that utilizes longer wavelength emission in vacuum ultraviolet emission was suggested to maximize the hydrogen radical density, leading toward an efficient contamination cleaning [9].

References

[1] G. E. Moore, Electron Devices Meeting, **21**, 11 (1975).
[2] M. Shimomura *et al*., Appl. Phys. Express, **1**, 056001 (2008)
[3] H. Mizoguchi *et al*., Proc. of SPIE, **11609**, 1160919 (2021)
[4] D. Qerimi *et al*., J. Vac. Sci. Technol. B **38**, 052601 (2020)
[5] D. T. Elg *et al*., Plasma Chem Plasma Process, **38**, 223 (2018)
[6] Ma Y, Labetski D, LaForge AD (2021) US20210325791A1.
[7] C. Liu *et al*., Appl. Phys. Express. **15**, 036002 (2022)
[8] N. Tanaka *et al*., Appl. Phys. Lett., **124**, 152113 (2024).
[9] J. E. Hernandez *et al*., Appl. Phys. Lett., **124**, 012101 (2024)