Two-Dimensional PIC/MCC Simulation of EUV-Induced Argon Plasma: Cumulative Effects under Repetitive Pulsed Irradiation

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The rapid advancement of semiconductor technology has established extreme ultraviolet (EUV) lithography as a critical process in fabricating advanced integrated circuits (ICs).[1] The interactions between EUV-induced plasma and optical components are complex, especially under repetitive pulsed irradiation. Understanding these dynamics is crucial for enhancing the precision and stability of lithography processes.[2]

In this study, we present a comprehensive numerical investigation of EUV-induced argon plasma dynamics using a two-dimensional implicit electrostatic Particle-in-Cell/Monte Carlo Collisions (PIC/MCC) model. The model includes photoionization, the photoelectric effect, electron-neutral collisions, and secondary electron emission. The algorithm employs a direct implicit momentum conservation approach, enabling large-scale, long-term simulations with high numerical stability and efficiency.

We verified the single-pulse model by comparing the simulated and experimental electron densities[4] at 5 Pa under different EUV pulse energies, as shown in Figure 1(a). The simulation accurately captured the two-phase decay of electron density: an initial rapid radiative decay (Phase I) dominated by energy loss, followed by an exponential decay (Phase II) governed by ambipolar diffusion and wall recombination. The agreement between simulation and experimental results confirms the model's reliability for studying plasma dynamics under repetitive pulses.

As depicted in Figure 1(b), at 5 Pa, the potential distribution exhibited a transient negative potential near the reticle surface during early plasma formation, attributed to electron accumulation from the photoelectric effect. When electron density near the surface exceeds ion density, an inverse sheath forms, generating a negative potential that repels electrons. Over time, energy dissipation through collisions and ambipolar diffusion results in a more uniform potential distribution.

Comparative analysis of electron density evolution at different pressures, as shown in Figure 1(c-d), reveals significant pressure-dependent characteristics. At low pressure (1 Pa), the lower collision frequency leads to a rapid decline in electron density. Electrons quickly reach the wall and are absorbed, resulting in a negligible plasma accumulation effect. At higher pressures (5 Pa), the increased collision frequency significantly slows down plasma decay and promotes a notable accumulation effect.

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References

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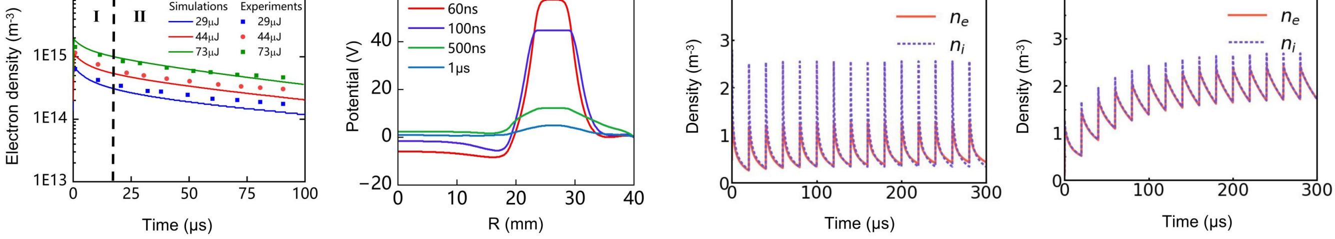

Figure 1. (a) Simulated and experimental electron densities at 5 Pa under different EUV pulse energies;[4]
(b) Spatial-temporal evolution of the potential near the reticle surface at 5 Pa;
(c) Evolution of electron density at 1 Pa;
(d) Evolution of electron density at 5 Pa.