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# OPPORTUNITIES AND CHALLENGES IN LOW-TEMPERATURE PLASMA SCIENCE FOR ATOMIC-LAYER PROCESSING

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**Abstract.** Plasma processing technologies, which are widely used for semiconductor device manufacturing, are now facing a paradigm shift as Moore's law of device-scale shrinkage is near its end and new three-dimensional structures and nonconventional materials are employed in advanced semiconductor devices. As the complexity of structures increases and more unconventional materials are used, semiconductor manufacturing technologies, including plasma processing, also require further innovations. One of the most promising semiconductor technologies that have contributed significantly to the fabrication of such device structures with atomic-scale accuracy is atomic-layer processing (ALP) (K. Arts, et al. 2022) such as atomic-layer deposition (ALD) and atomic-layer etching (ALE). Unlike conventional chemical/physical vapor deposition (CVD/PVD) or reaction ion etching (RIE), ALP deposits or etches materials layer by layer. In this presentation, the author first discusses the necessity of ALP in modern semiconductor process technologies. In ALP, "self-limiting" surface reactions play key roles in achieving layer-by-layer processes. Plasmas are often used to allow self-limiting surface reactions to take place at relatively low surface temperatures. Therefore, second, the author presents atomic-scale numerical simulation as a means to analyze the fundamental reaction mechanisms in plasma-enhanced and thermal ALP techniques, using examples of plasma-enhanced ALE of Si-based materials (Tinacba, E.T.C. et al., 2021; Hirata, A. et al., 2023; Tercero, J. U. et al., 2024) and thermal ALE of metals (Basher A.H. et al., 2020; 2020; 2021) and discusses the nature of self-limiting reactions in such processes.

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