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Plasma-surface interactions in plasma etching processes for nanometer-scale microelectronic devices

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Chlorine- and bromine-based plasmas have been used for plasma etching processes in semiconductor industry, and a better understanding of plasma-surface interactions is indispensable for nanometer-scale control of sidewalls and bottom surfaces of the feature being etched. This paper presents our recent numerical and experimental study of plasma-surface interactions in Cl- and Br-based plasma etching of Si and other new materials. First, a Monte Carlo-based atomic-scale cellular model (ASCeM) was developed to simulate the feature profile evolution on nanometer scale during Si etching, including surface oxidation, inhibitor deposition, and ion reflection and penetration on surfaces. A classical molecular dynamics (MD) simulation was also developed with an improved Stillinger-Weber interatomic potential model, to clarify surface reaction kinetics on atomic scale during Si etching, and then to simulate the feature profile evolution on atomic scale. The numerical results reveal the origin of profile or surface anomalies such as microtrench, roughness, and residue, and also the etching fundamentals such as etch yield, product stoichiometry, and atomistic surface structures; and a comparison is made with etching experiments and surface diagnostics for further modeling. Moreover, the etching of high-k dielectric and metal electrode materials was investigated to gain an understanding of the etch mechanisms for anisotropy and selectivity. As compared to Si, a competition between etching and deposition is significant and crucial in etching of these materials.