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Atomic Precision Plasma Processing – Modeling Investigations

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Sub-nanometer precision is increasingly being required of many critical plasma processes in the semiconductor industry. Some of these critical processes include atomic layer etch and plasma enhanced atomic layer deposition. Accurate control over ion energy and ion / radical composition is needed during plasma processing to meet the demanding atomic-precision requirements. While improvements in mainstream inductively and capacitively coupled plasmas can help achieve some of these goals, newer plasma technologies can expand the breadth of problems addressable by plasma processing. Computational modeling is used to examine issues relevant to atomic precision plasma processing in this paper. First, a molecular dynamics model is used to investigate atomic layer etch of Si and SiO_2 in Cl_2 and fluorocarbon plasmas. Both planar surfaces and nanoscale structures are considered. It is shown that accurate control of ion energy in the sub-50 eV range is necessary for atomic scale precision. In particular, if the ion energy is greater than 10 eV during plasma processing, several atomic layers get damaged near the surface. Low electron temperature (T_e) plasmas are particularly attractive for atomic precision plasma processing due to their low plasma potential. One of the most attractive options in this regard is energetic-electron beam generated plasma, where T_e <0.5 eV has been achieved in plasmas of molecular gases. These low T_e plasmas are computationally examined in this paper using a hybrid fluid-kinetic model. It is shown that such plasmas not only allow for sub-5 eV ion energies, but also enable wider range of ion / radical composition. Coauthors: Jun-Chieh Wang, Jason Kenney, Ankur Agarwal, Leonid Dorf, and Ken Collins