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Kinetic Modeling of Low-Pressure Multi-Frequency Capacitively Coupled Plasmas

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Low pressure (<20 mTorr) capacitively coupled plasmas (CCP) are widely used for dielectric etching in the semiconductor industry. These plasma discharges are often used with multiple radio frequency (RF) generators and RF power can be high. Kinetic effects dominate the behavior of these discharges due to the low gas pressure and high voltages. This paper focuses on particle-in-cell modeling of low-pressure multi-frequency CCPs. A combination of 1-dimensional (1D) and 2-dimensional (2D) models in both Cartesian and cylindrical geometry are used to understand the physics of these plasmas and examine technological issues. 2D model of the Gaseous Electronics Conference (GEC) reference cell is first used to validate the underlying model using experimental measurements of electron density and DC self-bias voltage at 100 mTorr. The plasma density peaks at the electrode edge at 100 mTorr in the GEC reference cell. The model is then extended to lower pressures and it is shown that enhanced diffusion leads to the peak in plasma density moving to the chamber center at pressures below 50 mTorr. A larger plasma system is next modeled with a combination of very high frequency (VHF) and medium frequency (MF) RF sources. As expected, application of the MF voltage increases the ion energy at the substrate. However, the MF source also influences plasma density and uniformity. 1D models are used to understand some of the kinetic effects that dominate the operation of low pressure CCPs. 1D model of a single frequency discharge is first used to illustrate the transition of electron transport from fluid-like at 100 mTorr to fully ballistic at sub-25 mTorr pressures. 1D models of multi-frequency discharges are then used to examine issues related to ion energy distribution function (IEDF) control. The use of non-sinusoidal MF voltages for IEDF control is also studied.