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Development of an Improved Numerical Methodology for Design and Modification of Large Area Plasma Processing Chamber

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The present work proposes an improved numerical simulator for design and modification of large area capacitively coupled plasma (CCP) processing chamber. CCP, as notoriously well-known, demands the tremendously huge computational cost for carrying out transient analyses in realistic multi-dimensional models, because electron dissociations take place in a much smaller time scale (Δt≈10-8∼10-10) than time scale of those happened between neutrals (Δt≈10-1∼10-3), due to the rf drive frequencies of external electric field. And also, for spatial discretization of electron flux (Je), exponential scheme such as Scharfetter-Gummel method needs to be used in order to alleviate the numerical stiffness and resolve exponential change of spatial distribution of electron temperature (Te) and electron number density (Ne) in the vicinity of electrodes. Due to such computational intractability, it is prohibited to simulate CCP deposition in a three-dimension within acceptable calculation runtimes (<24 h). Under the situation where process conditions require thickness non-uniformity below 5%, however, detailed flow features of reactive gases induced from three-dimensional geometric effects such as gas distribution through the perforated plates (showerhead) should be considered. Without considering plasma chemistry, we therefore simulated flow, temperature and species fields in three-dimensional geometry first, and then, based on that data, boundary conditions of two-dimensional plasma discharge model are set. In the particular case of SiH4-NH3-N2-He CCP discharge to produce deposition of SiNxHy thin film, a cylindrical showerhead electrode reactor was studied by numerical modeling of mass, momentum and energy transports for charged particles in an axi-symmetric geometry. By solving transport equations of electron and radicals simultaneously, we observed that the way how source gases are consumed in the non-isothermal flow field and such consequences on active species production were outlined as playing the leading parts in the processes. As an example of application of the model for the prediction of the deposited thickness uniformity in a 300 mm wafer plasma processing chamber, the results were compared with the experimentally measured deposition profiles along the radius of the wafer varying inter-electrode gap. The simulation results were in good agreement with experimental data.

Keywords: numerical modeling, simulation, capacitively coupled plasma, plasma enhanced chemical vapor deposition, plasma enhanced atomic layer deposition