Control Of Spatial Plasma Profile In Slot-Excited Microwave Discharges By Using Inverse Simulation

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It is known that plasma uniformity of a plasma device in plasma-aided manufacturing is one of the most important parameters in determining qualities of processing, especially for large wafers. Precise control of the edge-to-center density ratio is now being required. We here introduce a novel method of controlling the spatial plasma density profile by using an inverse simulation that gives operating conditions to the plasma device that produce desired radial density profiles. It is noted that the inverse simulation has the inputs and outputs just opposite to conventional simulations.

The inverse simulation is based upon a 3D fluid finite difference formulation that models a cylindrical chamber of $500\phi\times150\ell$ with a quartz glass plate on the top, a multi-slot planar (MSP) antenna above the glass plate and a microwave feeder. Maxwell equations are solved in time domain and power absorption of the plasma p_{abs} is obtained. We also use the equations of continuity and energy conservation to relate the plasma density n_e and the electron temperature T_e with the diffusion coefficients D, ionization rate ν_i thermal conductivity K, and electron collision rate ν_j with V_j being the threshold energy of j-th type inelastic collision. We set the desired (target) density profile n_{eT} as the input of the inverse simulator. We specify the profile only in the radial direction and the rests remains the same as a reference profile that is obtained by a usual direct simulation. The inverse simulator calculates ν_i from the equation; $\overleftrightarrow{D}\cdot n_{eT} = n_{eT}\nu_i$, with $\overleftrightarrow{D}$ and n_{eT} being the $m\times m$ matrix operator related to D and the vector of size m, respectively (m is the number of spatial divisions). Then, T_e can be obtained from ν_i. This procedure is repeated until T_e converges. Using the equation; $\overleftrightarrow{K}\cdot T_e = p_{abs}/e - n_{eT}\sum V_j\nu_j$, in which the operator $\overleftrightarrow{K}$ is actually related to K, D and n_{eT}, the inverse simulator finally generates p_{abs}, which is necessary to produce n_{eT}.

In order to reflect p_{abs} to the discharge device with the MSP antenna operating at 2.45 GHz, we divide the antenna slot plate into radially inner and outer segments driven by separate magnetrons, and change the power of the two magnetrons so that the antenna radiates electric fields with a radial profile similar to that of p_{abs}.

Combining these techniques, we establish an advanced control system, by which one can obtain a desired edge-to-center density ratio suitable for each process.