論文の内容の要旨

論文題目

Numerical Analysis on Discharging Characteristics in Microwave-excited Surface Wave Plasma Apparatus with Self-consistent Simulation Method
（セルフコンシステントシミュレーションによるマイクロ波励起表面波プラズマ装置の放電特性解析）

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Microwave-excited surface wave plasma (SWP) is one of the most important discharging methods to generate uniform and dense plasma in a large-area. On the contrary to this high applicable possibility, the design of microwave-excited SWP apparatus is not facile because of the strong coupling between the plasma parameters and microwave propagation characteristics. This characteristic makes it difficult to design a SWP apparatus and optimize it for achieving expected plasma parameters.

A simulation technique is expected as one of the solutions for overcoming the difficulties on designing a SWP apparatus. In many conventional simulations to analyze the microwave propagation modes in a SWP apparatus, the plasma region is usually assumed to have uniform parameters. This method is very useful to evaluate the dependences of plasma parameters on the structural characteristics of a SWP apparatus. However, it is impossible to calculate the parameter distributions of discharged plasma in the apparatus. In order to calculate the distributions of plasma parameter in a microwave-excited SWP apparatus, it needs to calculate the microwave propagation mode and the plasma parameters simultaneously in a self-consistent method.

In this study, a three-dimensional self-consistent simulation tool for a microwave-excited plasma apparatus with considering the chemical reactions for metastable atoms has been developed. Using the simulation tool, the propagation characteristics of electromagnetic wave and the distribution of plasma parameters such as electron density and electron temperature have been calculated in ring dielectric line typed SWP (RDL-SWP) apparatus. And the results obtained by the self-consistent simulation have been compared to the experimental results to confirm the validity of the simulation tool.

In chapter 2, the self-consistent simulation tool which consists of the microwave model and the plasma model was explained. The governing equations and their discretized equations for each calculation model were presented and the boundary conditions and the stabilization condition were explained. The chemical reactions which were taken into account in the simulation and the rate coefficients for each reaction were indicated. In the last section of this chapter, the 3D cell arrangement for combining the microwave model and the plasma model was explained.

In chapter 3, the propagation characteristics of the electromagnetic wave were investigated in RDL-SWP apparatus with assuming uniform and time-independent plasma parameters. From the simulation results, it was confirmed that the propagation characteristics of the electromagnetic wave is influenced strongly by the electron density than the electron temperature or the Ar gas pressure in plasma. And the limitation of the electron density which could be generated in the apparatus was evaluated. From the simulation results, the limitation of generated plasma's electron density was thought to be around 2.8×10^{17} m^{-3} in RDL-SWP apparatus. On the condition over that electron density, the electromagnetic wave did not propagate sufficiently into the center of the apparatus and the incident power was not absorbed efficiently by plasma. This discharging characteristic was explained with comparing to the experimental results.

In chapter 4, a self-consistent simulation was performed in an imaginary simple model, which consists of a waveguide and a plasma discharging box, to evaluate the validity of the simulation tool qualitatively. From the simulation results, it was confirmed that the evolutions on the distributions of the plasma parameters such as electron density and electron temperature were well simulated by introducing the microwave into the plasma discharging chamber. Furthermore, it was also confirmed that the evolutions on the propagation characteristics of the electromagnetic wave were well updated by the evolution of the plasma parameters. Although these simulation results could not compare to the experimental results directly, the validity of this simulation tool have been confirmed conceptually and quantitatively in this chapter.

In chapter 5, using the self-consistent simulation tool developed in this study, the propagation characteristics of electromagnetic wave and the distributions of electron density and electron temperature in RDL-SWP apparatus were calculated at the Ar gas pressures of 10 and 30 m Torr with the incident microwave power of 1.5 kW. And the validity of this simulation tool was confirmed by comparing the vertical profiles of electron density and electron temperature obtained by simulation to those of the experimental results. The discharging characteristics of surface wave plasma were well described in the simulation results but the electron temperature at the Ar gas pressure of 10 mTorr was ~0.5 eV higher in all vertical space than the experimental results. The distributions of electric field intensity, power absorption, electron density and electron temperature which were obtained through the self-consistent simulation were indicated and the reasons of the mismatches on the electron temperature with the experimental results were also discussed in this chapter. And a designing direction to achieve high and uniform electron density with low electron temperature in a large-area was proposed on the basis of the simulation results

In chapter 6, the conclusion of this thesis was given.