Numerical simulation of a large scale magnetizedinductively coupled plasma generator using COMSOL

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Abstract

In this study, we simulated a large scale magnetized (static magnetic field) inductively coupled plasma generator filled with argon to study the effect of the magnetic field on inductively coupled plasma discharges. In fact, before the static magnetic field is applied, the electron transport mobility is isotropic; and after the static magnetic field is applied, the electron transport mobility is anisotropic. Distributions of the number density and temperature of electrons were obtained for various input powers, pressures, and magnetic field configurations. In addition, the macro-gas temperature distribution was obtained for different magnetic field configurations. There are four multi-physics coupling interfaces in our simulation model, namely the ICP discharge interface, static magnetic field interface, Laminar Flow interface, and Heat transfer in Fluids interface, they achieve the mutual coupling via the related physical quantities. We conclude that the distributions of the number density of the electrons can be improved by the addition of a static magnetic field.

Introduction

And in our MICP model, a static magnetized field is applied to the inductively coupled plasma (ICP) discharge, and the electromagnetic field equations for the static magnetized field are

$$\nabla \times H = J \qquad \nabla \times A = B \qquad B = \mu_0 H$$

The electron transport mobility and diffusion coefficient is isotropic; and after the static magnetic field is applied, the electron transport mobility and diffusion coefficient become is an anisotropic. As shown below

$$D_e = \begin{pmatrix} D_{\parallel} \bullet \sin^2\varphi + D_{\perp} \bullet \cos^2\varphi & \sin\varphi \bullet \cos\varphi \bullet (D_{\parallel} - D_{\perp}) \\ \sin\varphi \bullet \cos\varphi \bullet (D_{\parallel} - D_{\perp}) & D_{\parallel} \bullet \cos^2\varphi + D_{\perp} \bullet \sin^2\varphi \end{pmatrix}$$

The electron density is computed by solving the drift-diffusion equation for the electron density.

$$\frac{\partial n_e}{\partial t} + \nabla \bullet \Gamma_e = R_e - (u \bullet \nabla) n_e$$

For non-electron species, the following equation is solved for the mass fraction of each species.

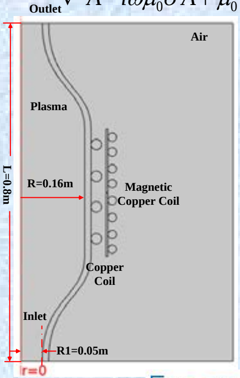
$$\rho \frac{\partial}{\partial t}(w_k) + \rho (u \bullet \nabla) w_k = \nabla \bullet j_k + R_k$$

In our model, the electron energy is given by

$$\frac{\partial n_\varepsilon}{\partial t} + \nabla \bullet \Gamma_\varepsilon + E \bullet \Gamma_e = R_\varepsilon - (u \bullet \nabla) n_\varepsilon$$

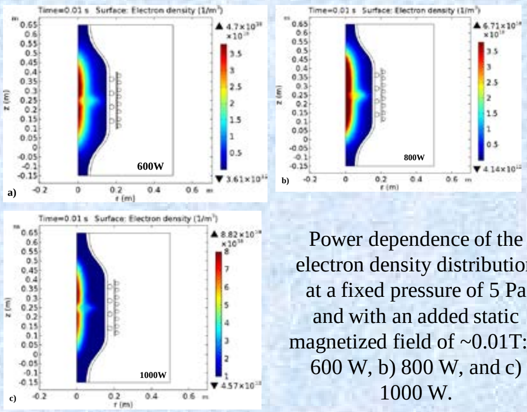
In the two-dimensional axisymmetric MICP model, the Maxwell electromagnetic field equation is

$$\nabla^2 A - i\omega\mu_0\sigma A + \mu_0 j_{coil} = 0 \qquad \sigma = \frac{q^2 n_e}{m_e(v_e + j\omega)}$$

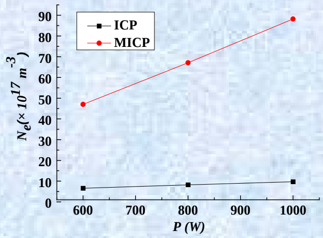


In this study, three sets of conditions were used in the simulations: 1) a fixed pressure of 5 Pa and a variable input power (600 to 1000 W); 2) a fixed power input of 800W and variable pressure (2 to 10 Pa);and 3) a fixed power input of 1000W, a fixed pressure of 5 Pa, and a static magnetized field varying from ~0.01 to ~0.1 T.

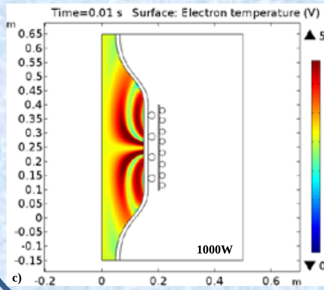
Results



Power dependence of the electron density distribution at a fixed pressure of 5 Pa and with an added static magnetized field of ~0.01T: a) 600 W, b) 800 W, and c) 1000 W.



Comparison diagram of electron density changing trend between MICP and ICP with different power supplies



Distribution of the various parameters of the static magnetized field at ~0.1T at a fixed input power of 1000 W and a pressure of 5Pa: electron temperature distribution

Conclusion

The physical properties of a two-dimensional axisymmetric MICP model were studied using COMSOL software with different static magnetized field, different power, and pressure settings. To gain a better understanding of the dynamics in an argon MICP generator, the electron density, electron temperature, and macro-gas temperature were calculated inside an argon MICP generator with a frequency of 440kHz. The static magnetized field added in the ICP generator improves the electron density in this simulation, and the electron density increase with increasing static magnetized field strength. Finally, we can add the static magnetized field to conduct some related experiments and use those experimental results to verify the accuracy of our simulation in the future.

References

[1]A. F. Gibson, R. E. Burgess, P. Aigrain, C. Kittle, "Progress in Semiconductors," Physics Today, 1960, 11(6): 35-36.