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Calculation of two-dimensional electromagnetic fields in a Cylindrical Inductively Coupled Plasma

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Inductively coupled plasmas (ICPs) are widely used in etching processes due to their relatively high electron density at low pressures and the ability to independently control ion bombardment energy [1]. As a result, extensive research has been conducted to better understand the underlying mechanisms of ICPs.

A well-known electromagnetic (EM) model of ICPs uses the plasma dielectric constant, derived from the perturbed momentum equation including electron-neutral collisions to calculate the electric and magnetic fields (**E** and **B**) inside the plasma [2]. These calculated fields can then be used to calculate the energy dissipated through electron-neutral collisions.

Although this widely accepted model captures the general behavior of **E** and **B** fields and power dissipation as a function of plasma density, it assumes a uniform plasma density, making it difficult to directly compare to experimental measurements under varying conditions.

In this study, the **E** and **B** fields of a cylindrical ICP with radial and axial plasma density gradients are calculated. This study focuses on the axial B-fields generated from the antenna of the ICP and induced azimuthal E-fields.

The inclusion of axial and radial density gradients introduces steady-state terms into the momentum equation which is discussed in this work. Since the obtained differential equation of the fields is not analytically solvable, finite element method (FEM) is employed to numerically solve the partial differential equation.

The plasma density profiles used in this work are obtained using Langmuir and cutoff probes, and electron temperature values are measured with a Langmuir probe.

Using the calculated **E** and **B** fields, the divergence of the Poynting vector is calculated and compared to that in the uniform density case.

References

[1] J. Hopwood, Plasma Sources Sci. Technol. 1(2), 109 (1992)
[2] M. A. Lieberman and A. J. Lichtenberg, Principles of Plasma Discharges and Materials Processing (John Wiley & Sons, 2005)