A 3D Hybrid Model of a Helicon Source[+]

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51st Gaseous Electronics Conference
October 1998

+ Work supported by Semiconductor Research Corp. and AFOSR/DARPA.
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Agenda

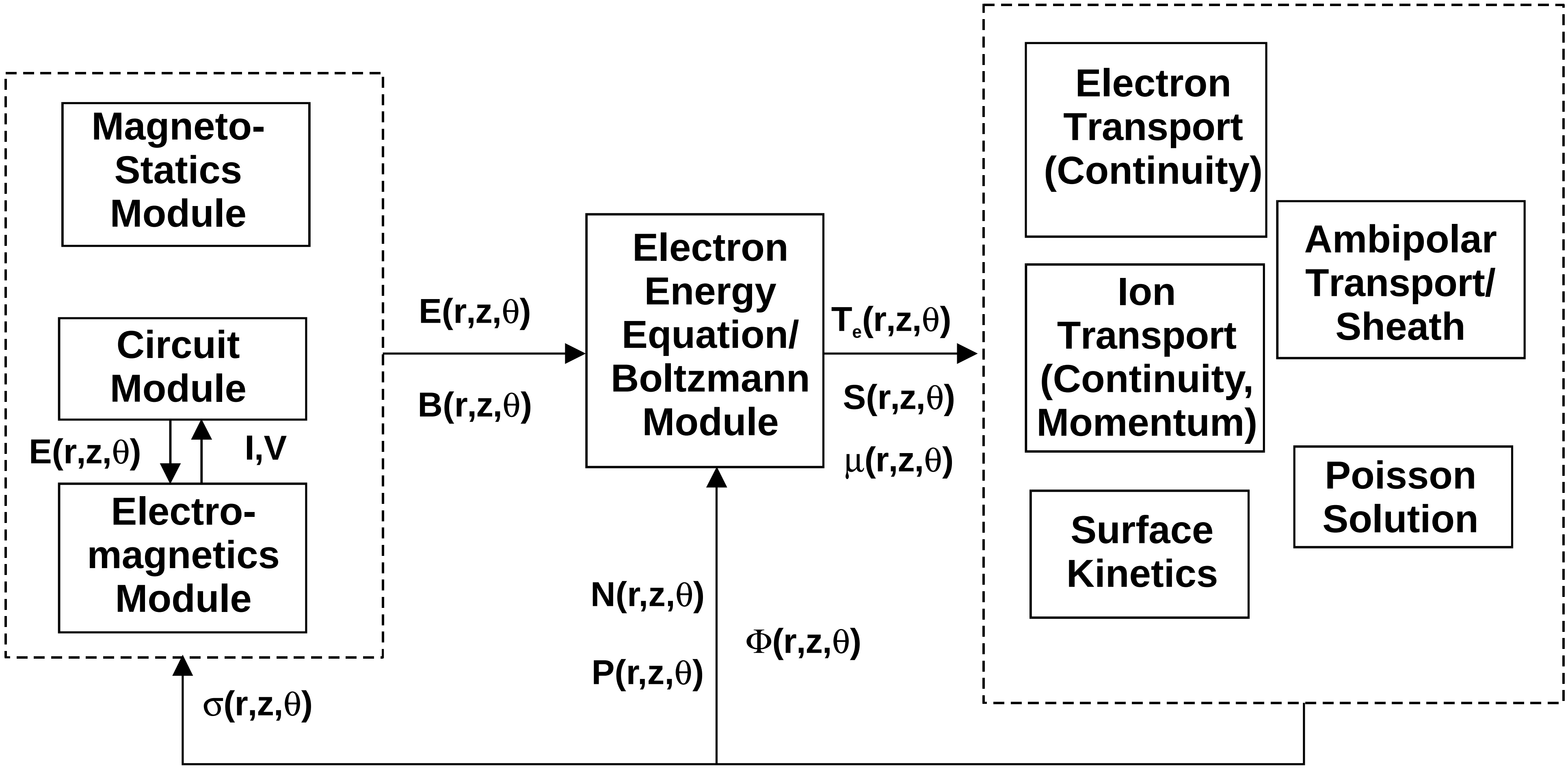
- Abstract
- Model Description
  - wave equation
  - tensor conductivity
- Results, Nagoya Type III coil
- Results, M=0 Coil
- Conclusions

Abstract

As the semiconductor industry moves to larger wafer sizes ($>$300mm) effecient new plasma sources which are capable of maintaining process uniformity at large scale will be needed. Helicon sources have been proposed as a possible alternative to inductively coupled plasma sources, due to high efficiency, and the power deposition not being limited to a skin depth. Additionally, helicon plasmas operate at very low pressure, so particulate contamination is minimal. In this paper, we present results from a numerical study of a helicon source. The three dimensional hybrid plasma equipment model(HPEM3D) has been extended to include a cold plasma tensor conductivity in the electromagnetics(EM) module. A static magnetic field is generated by a solenoid which surrounds the cylindrical reactor geometry and is simulated by solving for the vector potential. Transport of charged and neutral species is handled with a fluid simulation. By varying parameters such as the static magnetic field magnitude, reactor geometry, and coil configuration, we are able to modify the power deposition profile. This in turn determines the downstream ion and neutral flux uniformity. We find that for larger magnetic fields, the power deposition penetratesmoredeeply into the bulk plasma.

Scehmatic of 3D Hybrid Plasma Equipment Model (HPEM-3D)

- HPEM-3D combines modules which address different physics or different timescales.



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Electric Field Module: Wave Equation

- The electric field module of the HPEM-3D is responsible for solving the 3D frequency domain wave equation:

$$\nabla \times \nabla \times \boldsymbol{E} = \mu_0 \varepsilon_0 \omega^2 \boldsymbol{E} - i\mu_0 \omega \boldsymbol{J}_{ant} - i\omega\mu_0 \sigma \boldsymbol{E}$$

- The left hand side is replaced by: $\nabla \times \nabla \times \boldsymbol{E} = \nabla(\nabla \cdot \boldsymbol{E}) - \nabla^2 \boldsymbol{E}$ where the first term is neglected.

- The conductivity, σ, is the cold plasma tensor conductivity (see next slide)

- The finite difference form of the wave equation results in a large matrix equation, which is solved using a generalized minimum residual method.

- The Helicon wavelength can be estimated by $\lambda_{\|} = 1.0x10^{20} \dfrac{B}{\omega r n}$

- If λ is small compared to reactor size, the numerical solution of the wave equation is difficult, as the problem is less well conditioned.

- The matrix problem is solved using the generalized minimum residual method.

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Conductivity Tensor

- The plasma current in the wave equation is handled by a cold plasma tensor conductivity:

$$\sigma = \sigma_0 \frac{m v_m}{qa} \frac{1}{\left(\alpha^2 + |\boldsymbol{B}|^2\right)} \begin{bmatrix} \alpha^2 + B_r^2 & \alpha B_z + B_r B_\theta & -\alpha B_\theta + B_r B_z \\ -\alpha B_z + B_r B_\theta & \alpha^2 + B_\theta^2 & \alpha B_r + B_\theta B_z \\ -\alpha B_\theta + B_r B_z & -\alpha B_r + B_\theta B_z & \alpha^2 + B_z^2 \end{bmatrix}$$

$$\alpha = \frac{\left(i\omega + v_m\right)}{q / m} \qquad \sigma_0 = \frac{q^2 m}{m v_m}$$

- The addition of the static magnetic field results in a larger, less well conditioned matrix problem.

- If the static magnetic field is predominantly in the z-direction, the (3,3) term of the tensor dominates

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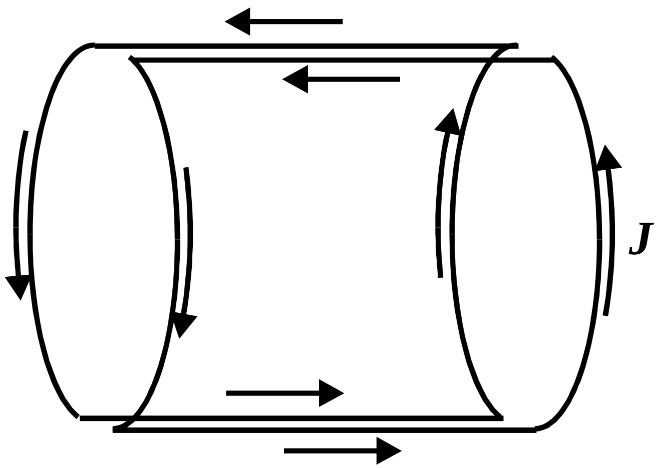
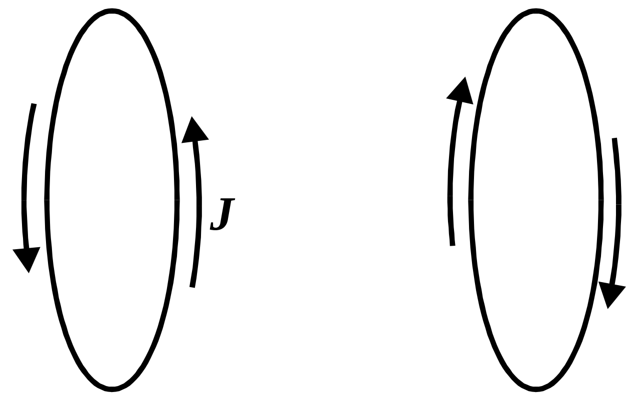
Antenna Configuration

- Two different antenna configurations were used:





- The Nagoya Type III is commonly used in laboratory Helicon plasmas, where it has been shown to produce an m=1 mode under the right conditions.

- The Double Ring configuration was tested here to see if using it would result in a m=0 Helicon mode.

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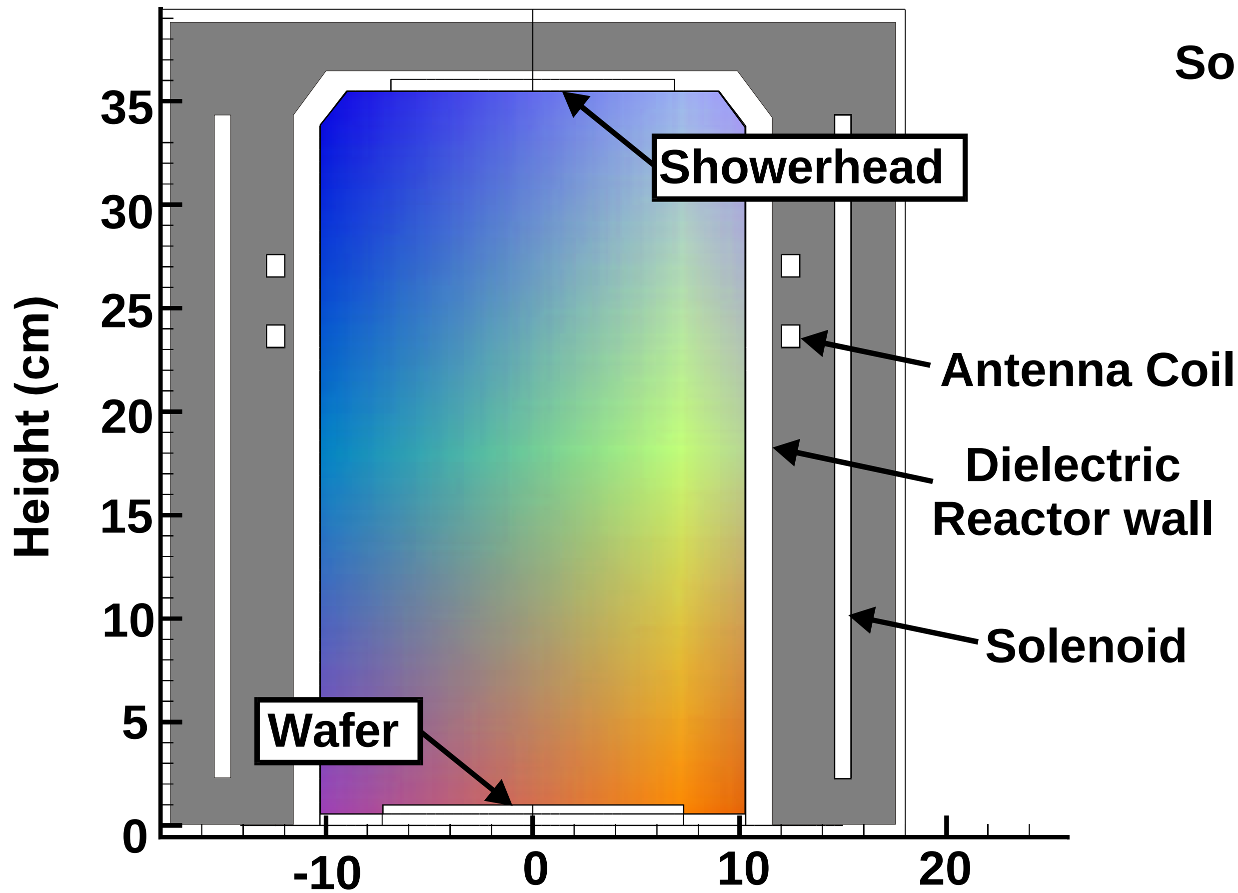
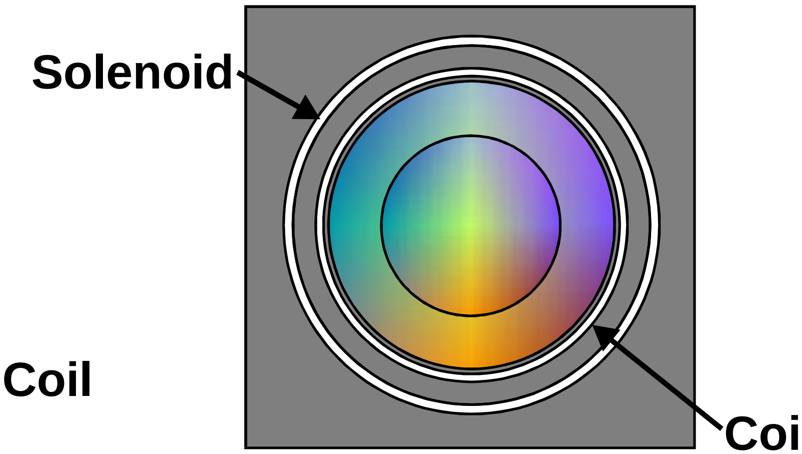
Reactor Geometry

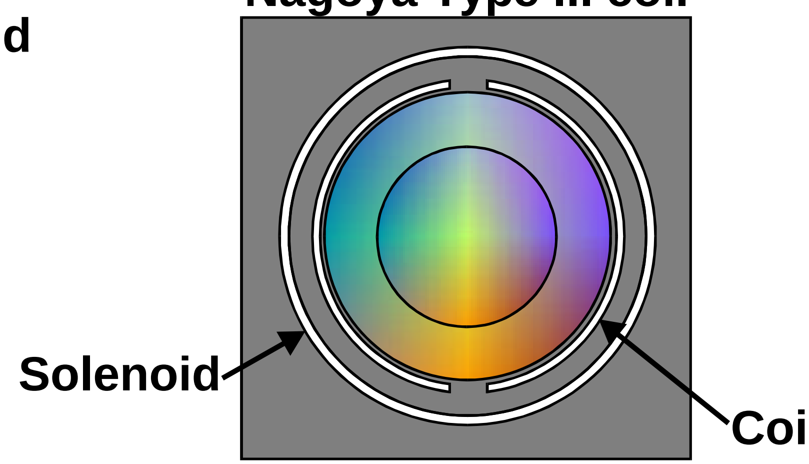
Side (r,z) view



Top (r,θ) view, m=0 coil



Top (r,θ) view,
Nagoya Type III coil



- Antenna coil can either be the m=0 or Nagoya Type III configuration

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