Three-Dimensional Fields and Temperatures in a Squat Helicon Reactor

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***Abstract*—Magnetically enhanced inductively coupled plasmas (MEICP) and helicons have complex plasma electric-field coupling between the electric field and the plasma due to the tensor conductivity and multiple-dimensional antenna segments. Computed three-dimensional electric fields and electron temperatures are presented for a helicon reactor demonstrating azimuthal asymmetries and rotations of the electric field. The electron temperature peaks near the axial antenna segments upstream and aligns with the azimuthal electric field downstream.**

***Index Terms*—Electromagnetic propagation in plasma media, glow discharge devices, plasma applications.**

MAGNETICALLY enhanced inductively coupled plasma (MEICP) and helicon reactors are of interest for their ability to deposit power in the volume of large systems [1]. When using these sources for plasma material processing, fluxes of ions and radicals must be uniform over wafer diameters up to 300 mm. With, for example, $m = \pm 1$ antennas, there are inherent azimuthal asymmetries which could impact the uniformity of processing. To investigate properties of MEICP and helicon reactors, the three-dimensional (3-D) Hybrid Plasma Equipment Model (HPEM) has been improved [2]. The model is now functionally equivalent to the two-dimensional (2-D) model described in [3] with the addition of a sparse matrix solver for the wave equation, a full tensor plasma conductivity and energy equations for neutrals and ions. The following are the physics options:

1) electron energy equation;
2) momentum, continuity and energy for ions and neutrals;
3) drift–diffusion for electrons.

The numerical grid (r, θ, z) was 55 × 30 × 110.

The images here are for a squat, helicon plasma etching tool modeled after the Trikon M0RI using a Nagoya Type III $m = +1$ coil which has azimuthal and axial antenna segments. The antenna surrounds a quartz bell jar positioned between a pair of solenoids producing a flared magnetic field, as shown in Fig. 1. The magnetic field is 100 G at the reference point. The plasma is sustained in 10 mtorr of Ar powered at 800 W at 10 MHz. The resulting azimuthal electric field, E_θ and electron temperature, T_e, are shown in Fig. 2. The individual subimages were produced using Tecplot v8 [4] and combined using Adobe Photoshop v5 [5]. In the 3-D images, radial slices expose planes through the coils on the right side and through the gap in the coils on the left side. The 2-D circular images are axial slices at the locations noted in Fig. 1. The plasma density is 2×10^{12} cm^{-3} in the dome and 5×10^{11} cm^{-3} 5 cm above the substrate.

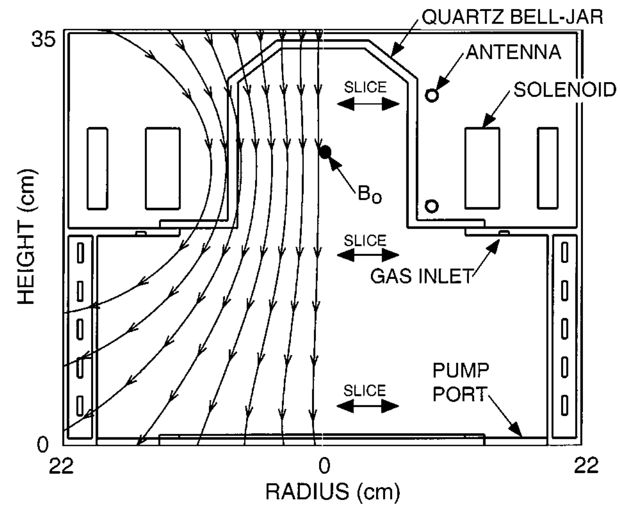

Fig. 1. Schematic of the squat helicon reactor. The streamlines show the magnetic field (azimuthally symmetric), 100 G at B_o. The double arrows show the heights of the axial slices in Fig. 2.

E_θ is maximum in the quartz dome aligning with the azimuthal segments of the antenna. On the right side, E_θ has two maxima with opposite polarities around the top and bottom coil segments. On the left side, there is a single peak. As the wave propagates downstream, E_θ rotates executing approximately a 90° turn before reaching the substrate. In the bell jar, the largest component of the electric field is actually E_z, aligning with the vertical segments of the antenna, thereby producing the peak electron temperature of 4.6 eV adjacent to those segments. The high electron thermal conductivity along the magnetic field lines convects the temperature downstream. There is an azimuthal rotation of T_e to align with E_θ, the largest component of the field downstream.

Manuscript received June 26, 2001. This work was supported in part by the National Science Foundation (CTS-9974962) and by the Semiconductor Research Corporation.

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Publisher Item Identifier S 0093-3813(02)03066-7.

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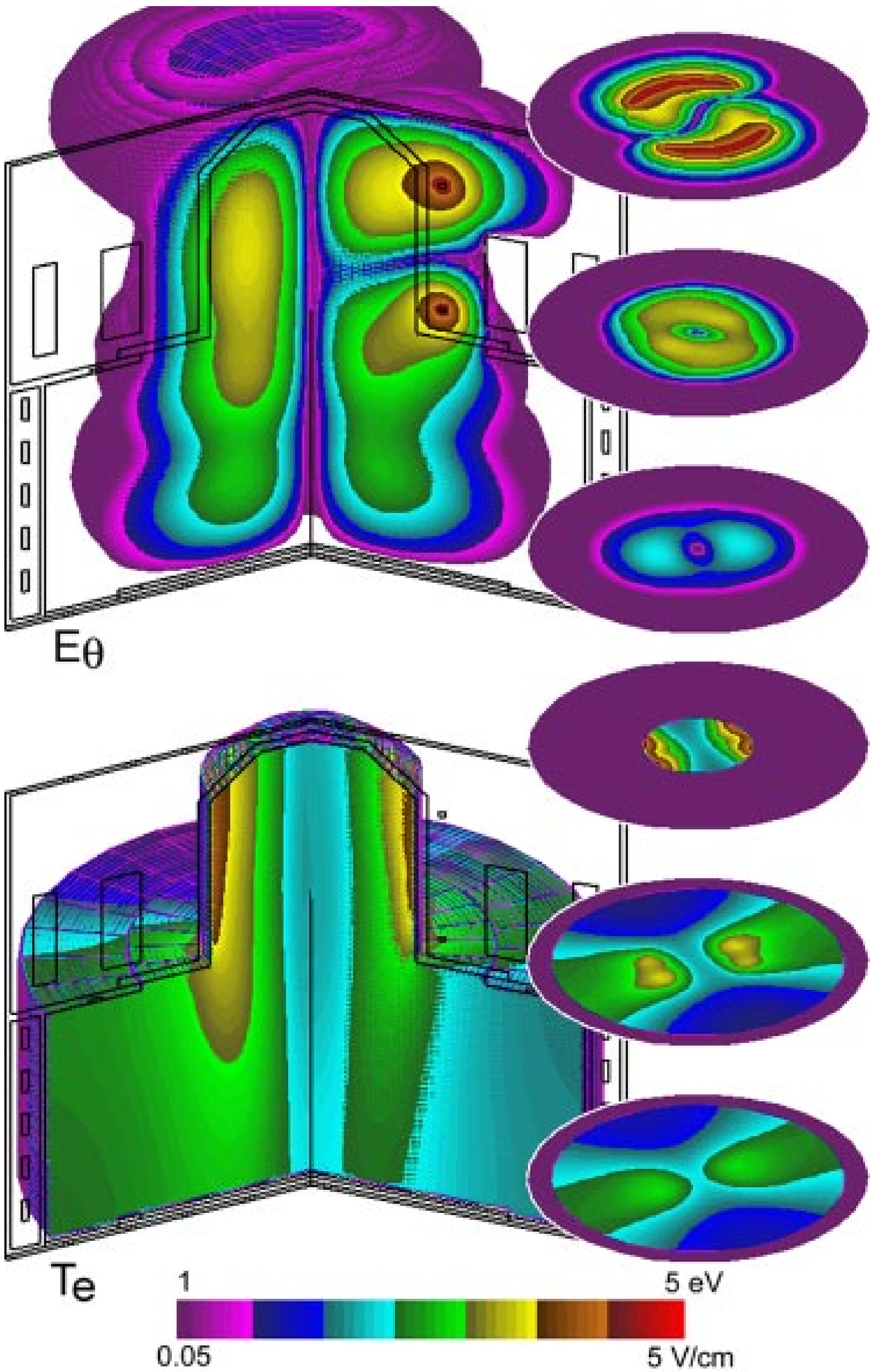

Fig. 2. Azimuthal electric field (top) and electron temperature (bottom). The radial slices through the 3-D images are through the antenna (right) and through the gap in the coils (left). The axial slices are at the heights noted in Fig. 1.