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Electromagnetic Fields and Antenna Impedance Analysis of an RF Ion Source at HUST

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INTRODUCTION

◆ Studying the RF characteristics of the source is necessary for understanding the basic physics in the RF ion source.

◆ Conventional EM simulations of the ICP sources usually exclude Faraday screen for simplifying analysis, which can not reflect the key features of the EM fields in the source and the coupling configuration between the antenna and plasma.

◆ The matching network plays a big role in the RF system for maximum power transmission to the driver. It is available to adjust matching by adjusting the circuit components and operating frequency.

◆ Improving the power absorbed by the plasma is a main concern of the RF system. Many studies have proposed good approaches to improve the power coupling efficiency, one of which is the ferromagnetic enhancement (FRE) technique.

THE SIMULATION MODEL

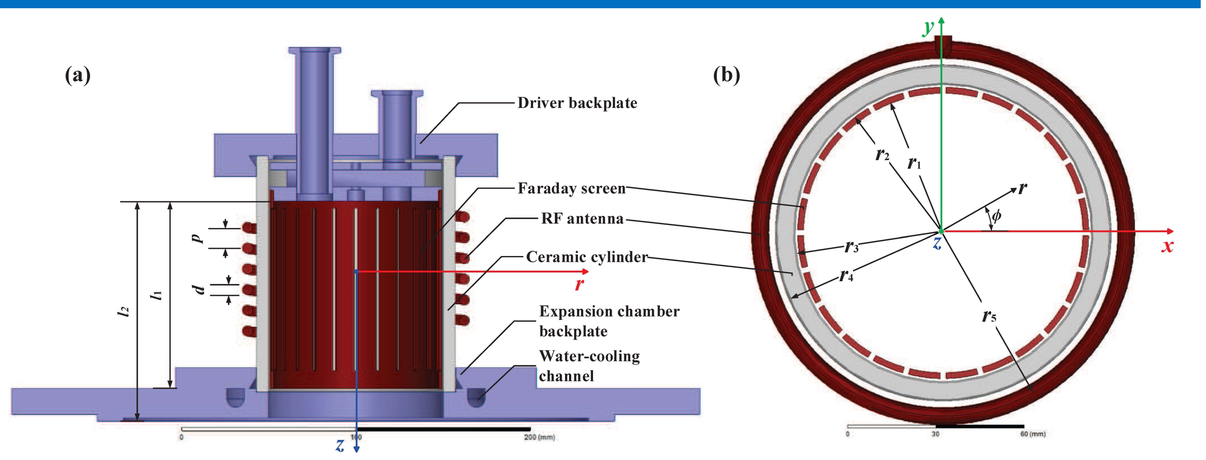


Figure 1. Cross section views of the RF driver: (a) lateral view, (b) front view (z direction)

◆ **Simulation tool:** ANSYS HFSS

◆ **Solution type:** Driven modal

◆ **Excitation:** Current, Icoil_peak=20A /1 MHz

◆ **Material:** FS & coil are assigned infinite electric conductors which have infinite conductivity and zero skin depth; The plasma is defined as a homogeneous electric conducting medium with σpl= 10~2000 S/m.

◆ **Boundary:** A finite conductivity boundary is assigned on the conductor surfaces to simulate the surface losses on the FS and coils.

RF EM FIELDS ANALYSIS

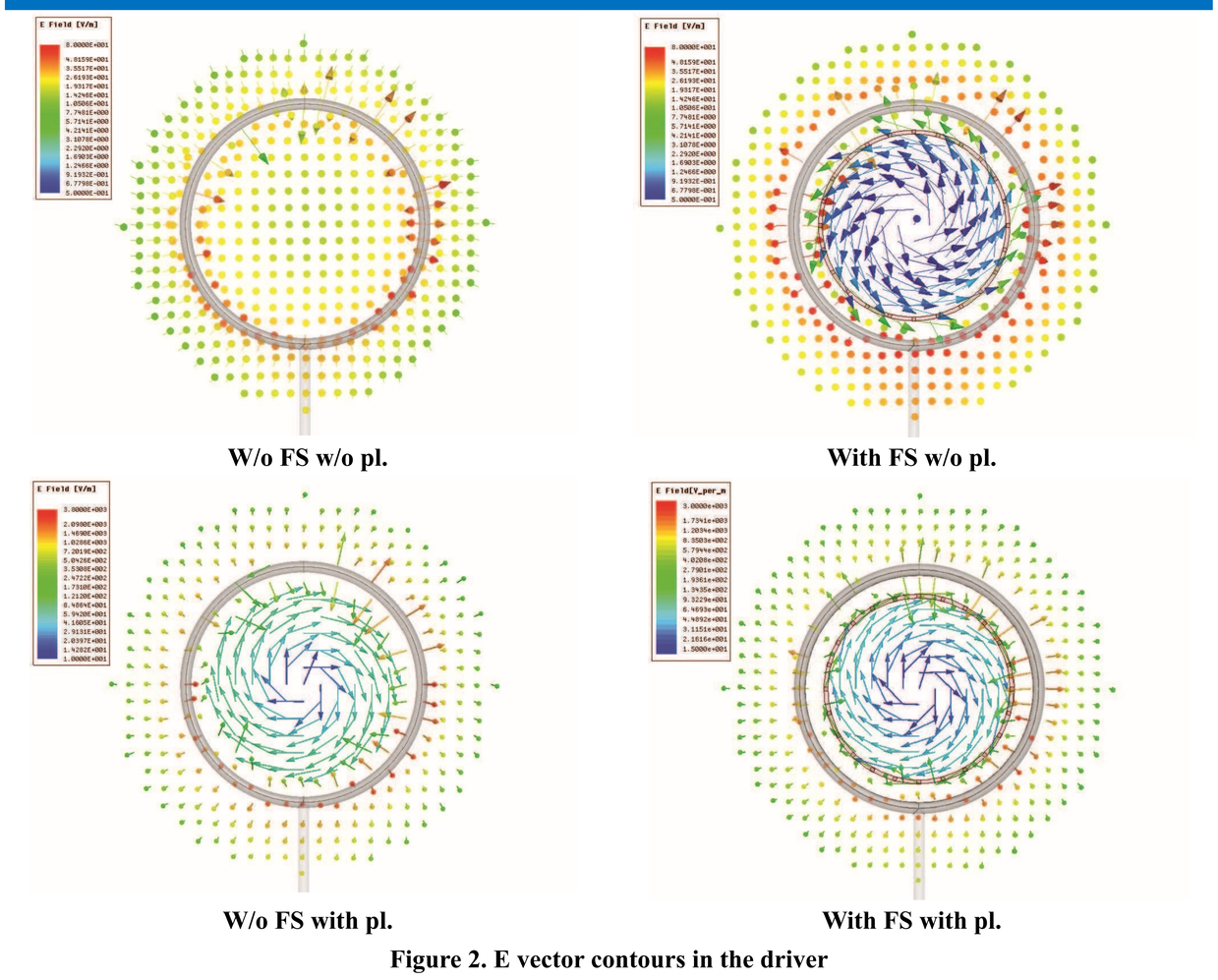
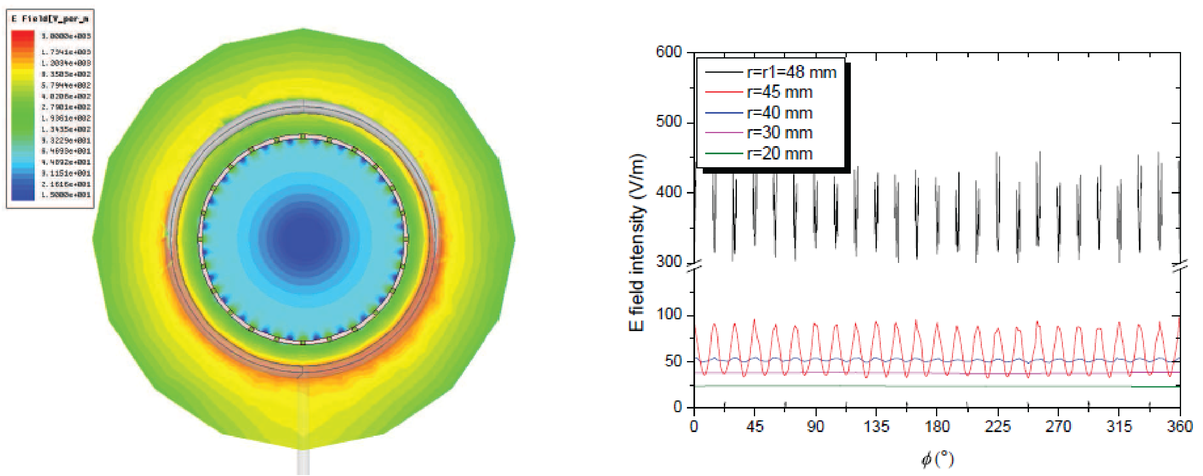


Figure 2. E vector contours in the driver

◆ The FS suppresses effectively the axial electric field in the discharge zone, therefore diminishes the capacitive coupling between the antenna and the plasma;

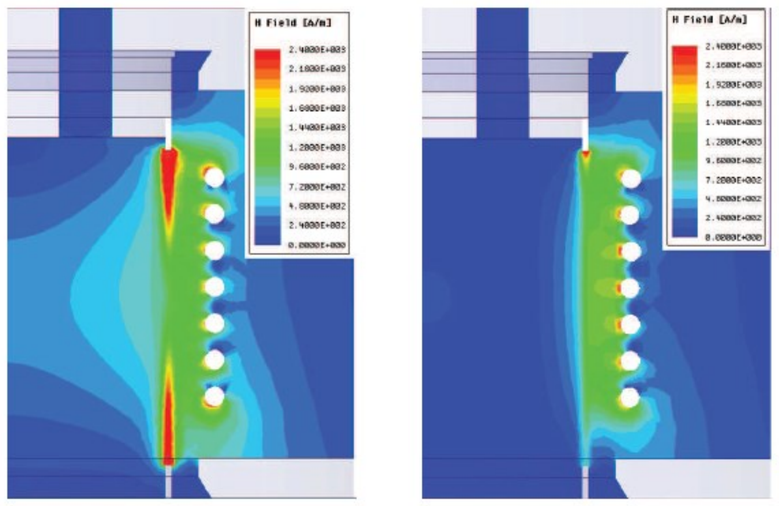
◆ The existence of plasma intensifies the induced azimuthal electric field in the plasma chamber and further enhances the inductive coupling between the antenna and plasma.



(a) E field magnitude contour (b) E field distribution from the FS inner wall to driver center region

Figure 3. Electric field in the driver with FS with pl. ($\sigma_{pl} = 500S/m$)

◆ The E field adjacent to the slits is much stronger than elsewhere in the plasma volume and it drops sharply away from the slits.



(a) $\sigma_{pl} = 100S/m$ (b) $\sigma_{pl} = 1000S/m$

Figure 4. Magnetic field in the driver at different σ_{pl}

◆ The H field is expulsed to the plasma surface at high plasma conductivity due to the skin effect on the plasma surface, which results in EM field shielded from the plasma volume and power absorption of the plasma suppressed.

ANTENNA IMPEDANCE ANALYSIS

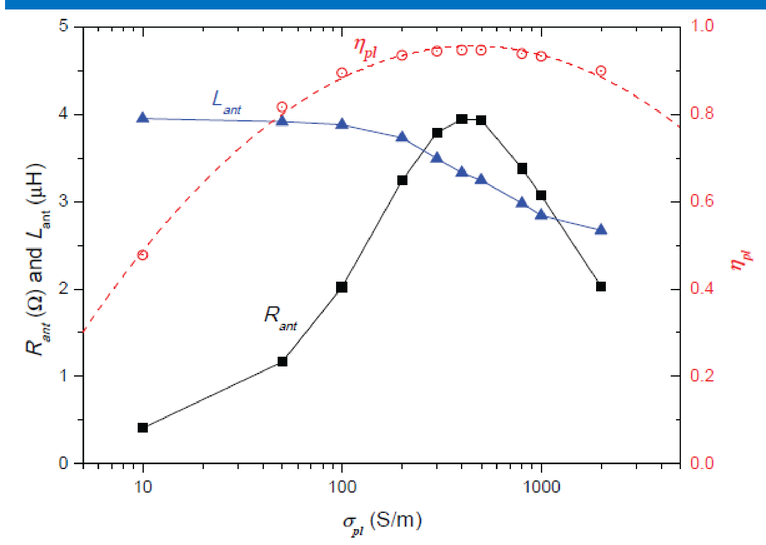


FIGURE 5. R_{ant}, L_{ant} and η_{pl} against the plasma conductivity

$$R_{ant} = \frac{V_p cos\varphi}{I_p}$$

$$L_{ant} = \frac{V_p sin\varphi}{\omega I_p}$$

$$P_{pl} = \oint E \cdot J dv$$

$$P_D = \frac{1}{2} V_p I_p cos\varphi$$

$$\eta_{pl} = P_{pl} / P_D$$

SUMMARY

◆ Numerical simulations have been performed on the small RF ion source at HUST through finite element analysis. A complete 3D model containing Faraday screen is employed to exhibit the EM field inside the plasma chamber.

◆ Clear physics images depict that the FS suppresses the capacitively axial electric field while the plasma enhances the inductively azimuthal electric field in the plasma volume. Both of them benefit the inductive coupling between the RF antenna and plasma.

◆ The antenna impedance analysis shows that the resistance and the RF power transfer efficiency firstly rises as the plasma conductivity increases, and then drops due to the skin effect when the plasma conductivity reaches high values. This may be the reason why the plasma density in many studies tends to saturate at high input power.

◆ The plasma is considered as a homogeneous electric conducting medium in the analysis, which is not true if considering the complex plasma dynamics, however, this method is helpful for understanding the basic physics in the source and providing support for the engineering design of the source, such as the matching network design. Further work will be focused on finding the effective plasma conductivity for balancing the simulation and experimental results .