ANTENNA ANALYSIS IN MAGNETIZED PLASMA VIA PARTICLE-IN-CELL SIMULATIONS

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1. Introduction

Antenna properties in plasma have been investigated by many scientists [1][2][3]. However, the analysis of the antenna impedance is very complex because the plasma is a dispersive and anisotropic medium. In the previous theories, approximations in the current distribution along the antenna or the sheath structure around the antenna were hired. Meanwhile, recent progress of computer facilities enables us to analyze the antenna properties in vacuum with the FDTD (Finite Difference Time Domain) method which solves the Maxwell equations with spatial and temporal grid points. By using the FDTD method with a dielectric tensor obtained under the cold plasma approximation, we can basically analyze the antenna impedance in plasmas.

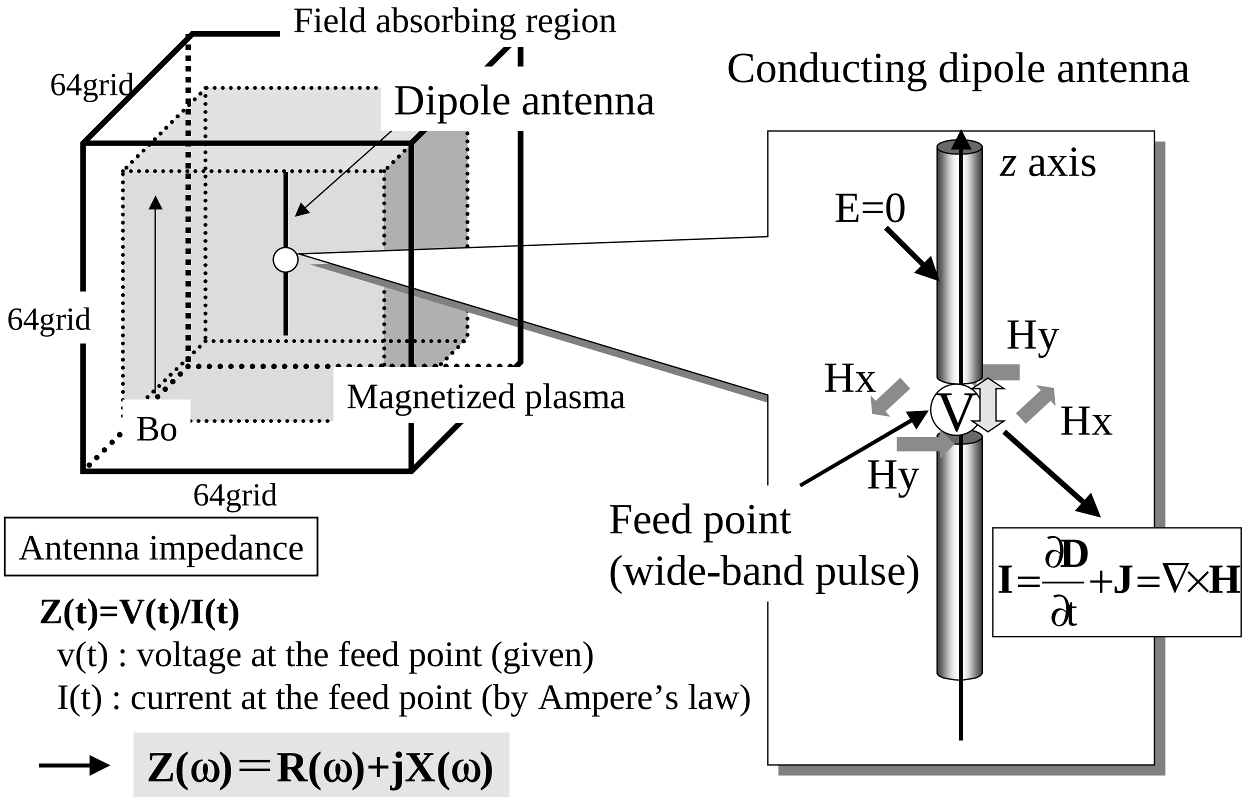


Fig.1 Simulation model

However, in order to include the plasma kinetic effects in the antenna impedance such as temperature and sheath around the antenna, we need to treat the plasma as particles in the simulations. To treat the plasma dynamics, we apply the PIC (Particle-In-Cell) method to the FDTD field solving simulations. In the PIC method, we solve the equation of motion for each particle with the field components obtained at grid points with the FDTD method. To obtain the plasma density and current at each grid point, we use the area sharing method.

In the present paper, we will report preliminary results of the antenna impedance obtained in the PIC simulations. We particularly focus on the dependence of antenna resonance on the plasma temperature and sheath size around the antenna.

2. Model

Three-dimensional simulation model is shown in Figure 1. In the simulation space with 64×64×64 grid points a number of electrons is uniformly distributed. In the center, dipole antenna with the length of 32 grid points is set. We assume that the antenna is a pure conductor, which implies that the electric field inside the antenna is assumed to be zero. To feed the power to the antenna, we adopted the delta gap feeding method. At one grid point which is located in the middle of the antenna, we provide voltage as a function of time. To obtain the wide-band characteristics of frequency with one simulation run, we utilize a Gaussian-type pulse for the voltage at the feed point. The current is obtained by the rotational field around the feed point. The antenna impedance is calculated as the ratio of the voltage to the current. By taking its Fourier transformation, we obtain the antenna impedance in frequency domain.

3. Dependence of antenna impedance on plasma temperature

Figure 2 shows the antenna impedance with different plasma temperature. The upper and lower panels indicate the real and imaginary parts of the impedance, respectively. The dashed line corresponds to the impedance for the vacuum case. As clearly shown, there is a big change of impedance at the Upper-Hybrid resonance frequency ω_{UHR}. The real part of the impedance takes large values at peaks in comparison with the vacuum case, which implies that the minimum power is radiated in plasma from the antenna at ω_{UHR}. The interesting feature we should mention is that the peaks found in the real part of the impedance shift toward higher frequency as the plasma temperature increases. This tendency is not observed when no external magnetic field is included in the simulation model. Therefore, we speculate that specific plasma wave mode is closely related to the shift of the impedance resonance. Although not displayed here, we found the slow-X mode branch is responsible for the impedance resonance at ω_{UHR}. If we focus on the frequency at the wave number corresponding to the half-wave antenna, the resonance frequency on the slow-X mode increases as the plasma temperature becomes high.　This explains the shift of the resonance frequency as shown in Figure 2.

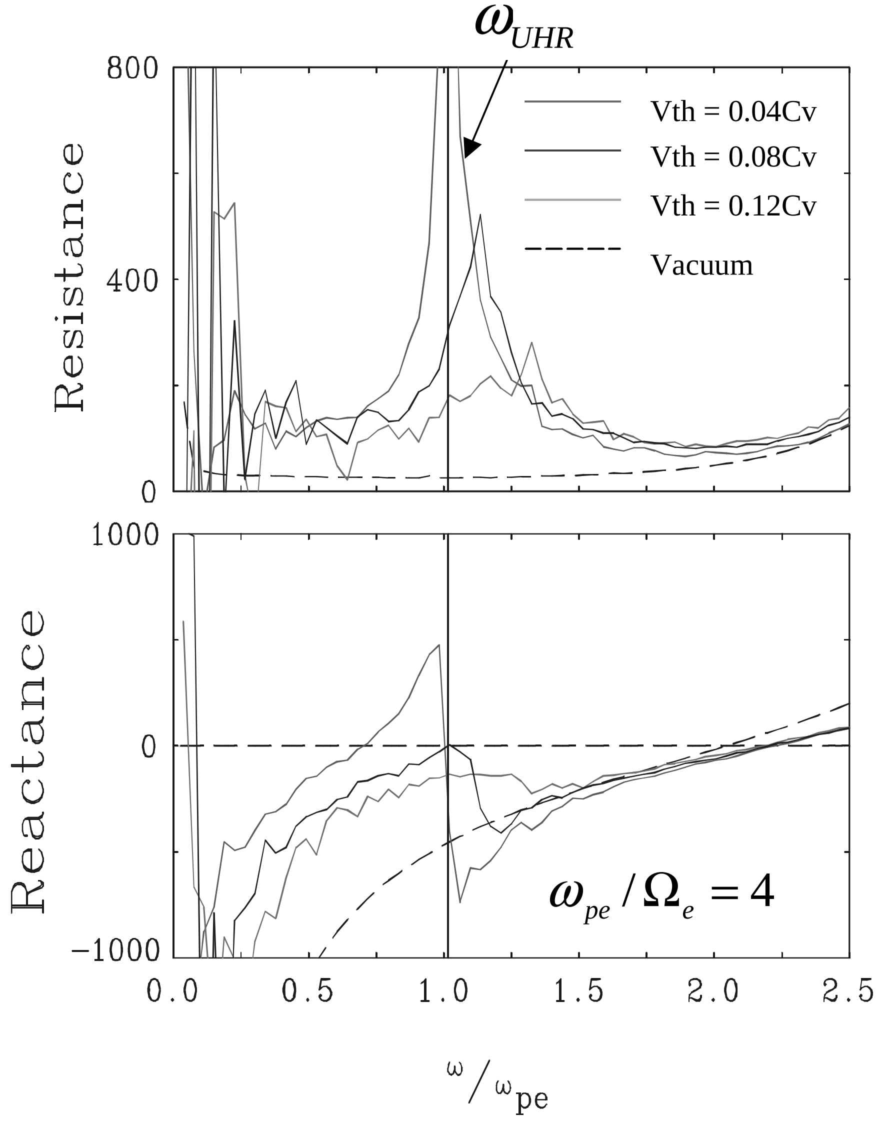
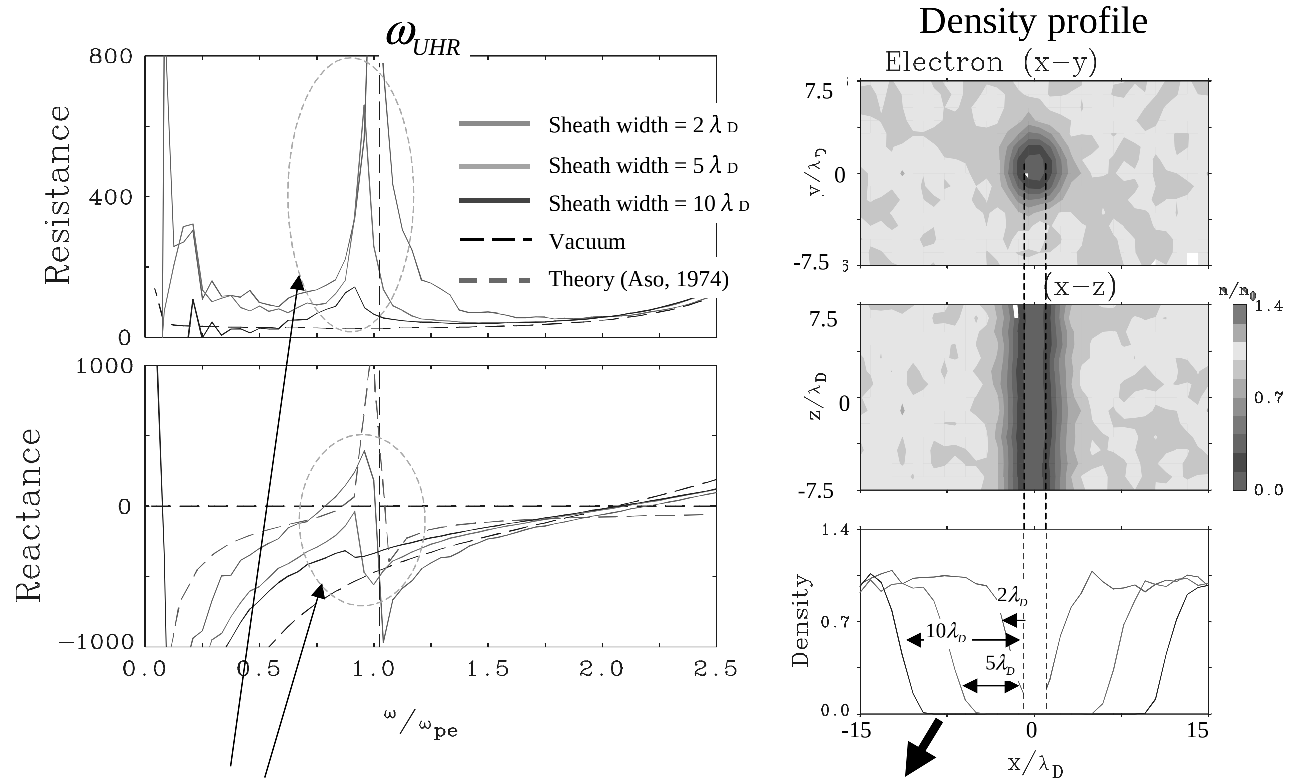


Fig2　Antenna impedance with different plasma temperature.

3. Sheath effect on the resonance

Figure 3 shows the dependence of the antenna impedance around ω_{UHR} on the sheath size created around the antenna. The right panels depict the profiles of the sheath around the antenna. By changing the parameters, sheath with different size is created. At each case, we examined the antenna impedance as shown in the left panels in Figure 3. It is obviously shown that the resonance at ω_{UHR} is sharp for the small sheath while the profiles of the impedance approach to those of vacuum case as the sheath becomes large. It is because the vacuum region around the antenna expands for the larger sheath. The resonance frequency also decreases because the plasma density also decrease in the vicinity of the antenna. It is theoretically examined that the impedance will be affected by the sheath



- Resonance frequency decreases
- Profiles approach to the vacuum case

Vacuum (ion sheath) region expands

Fig.3 Sheath profiles (right panels) and corresponding antenna impedance (left panels).

resonance, which we could not confirm in the present simulations. It is also reported that sheath waves which propagate along the antenna surface may affect the antenna impedance. Currently we have been working on the properties of the sheath waves. We will examine the effect of the sheath waves on the antenna impedance with the larger scale of simulation model, which is left as a future work.

Reference

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