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Particle Simulation Of RF H⁻ Source Including Coulomb Collision Process
高周波放電型水素負イオン源粒子シミュレーションにおけるクーロン衝突のモデリング

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In order to evaluate Electron Energy Distribution Function (EEDF) for RF-ICP negative ion source plasmas more correctly, the Electromagnetic Particle-In-Cell model has been improved by taking into account electron-electron Coulomb collision. Binary collision model is employed to model Coulomb collision process. The preliminary calculation of RF plasma including Coulomb collision has been done and it is shown that Coulomb collision doesn't have significant effect under the condition: electron density $n_e \sim 10^{18}$ m^{-3} and high gas pressure p_{H_2} = 3 Pa, while it is needed to include Coulomb collision under high electron density (> 10^{19} m^{-3}) and low gas pressure (i.e. ~0.3 Pa) calculation.

1. Introduction

We have developed a numerical simulation code [1] based on the Electromagnetic Particle in Cell (EM-PIC) model with Monte Carlo method for Collision process (MCC) to understand the RF-ICP plasma. This code has been applied to the numerical analyses of Linac4 H⁻ Source plasma. In these numerical studies of Linac4 source plasma, the some effects have been studied[2].

One of the purposes of these studies is to make clear the relationship between the electron density, electron energy distribution function (EEDF), and the RF input parameters. The dissociation rate of hydrogen molecule (H_2) reaction, which produces hydrogen atoms (H), depends on EEDF and electron density, and the flux of H atoms on the plasma grid surface produces hydrogen negative ions (H⁻) by surface production. In order to estimate the H⁻ production, we have to evaluate EEDF and electron density. However, it is generally difficult to understand the relation between EEDF and electron density experimentally, thus numerical simulation plays a key role.

In previous analyses, most of important collision processes between electrons and neutrals have been taken into account by MCC as mentioned above, but the code doesn't include electron-electron (e^--e^-) Coulomb collision process which has to be modeled in order to estimate accurately EEDF in RF H⁻ Source. Therefore we decided to add Coulomb collision process to our RF simulation for our final goal. As the first step, e^--e^- collision calculation model has been implemented into EM-PIC code described above, and some preliminary test calculations have been done.

2. Simulation Model

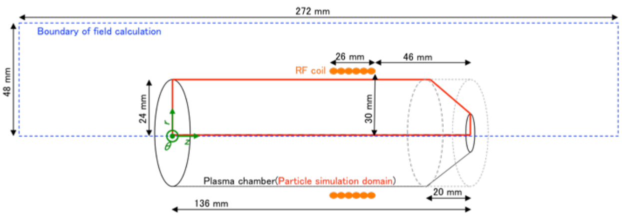

Fig.1. Model geometry of the numerical simulation

Our EM-PIC MCC model consists of mainly two parts. One is the 2D model of RF electromagnetic field produced by external RF-coil and plasma. We have solved Maxwell equations using Finite Difference Time Domain (FDTD) method [2] and assumed axial symmetry. The other part is 3D3V particle dynamics model, where the equations of motion for the charged particles are numerically solved. The Boris-Buneman version of leap-flog method [3] has been used to solve them. The important collision processes between electron and neutral particles are taken into account by Monte Carlo method. Coulomb collision process between two electrons is modeled using binary collision model [4]. For simplicity, in this preliminary calculation two electrons involved in Coulomb collision event are picked up from entire volume of source chamber. The code is parallelized via the Message Passing Interface (MPI) interface.

3. Results and Discussion

3.1 *Test simulation for the binary collision model*

Before proceeding to implementation of the e^--e^- collision model into EM-PIC MCC code, a basic and separate check of the algorithm has been done. Figure 3 shows the results of this test calculation. As seen in Fig. 2, the box-type initial velocity distribution has been relaxed to Maxwellian distribution.

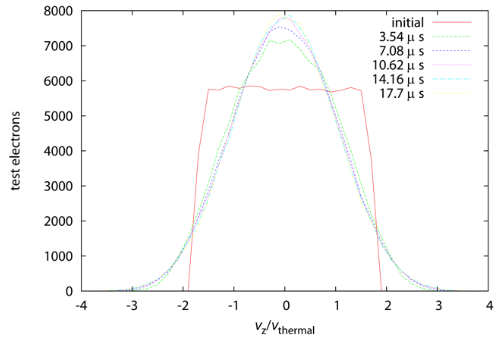

Fig.2. Electron velocity relaxation by Coulomb Collision

3.2 *Preliminary results with Coulomb Collision*

We have implemented the algorithm in our EM-PIC MCC code as a subroutine and performed some simulations to compare the results between the cases with and without Coulomb collision under the following condition; Coil current amplitude: 70A, H_2 gas pressure: 3Pa, RF frequency: 2MHz. Figure 3 shows the time evolution of electron density and average electron energy for each case. Figure 4 shows the comparison of EEDFs at 0.5 μs and 2.0 μs. Almost no differences are observed in these figures.

Figure 5 shows the comparison between total collision frequency with neutral particles ν_m and Coulomb collision frequency ν_e . Coulomb collision frequency ν_e depends on electron density and average electron energy while ν_m depends on the density of neutral particles which is given as gas pressure. As far as this density range and gas pressure, ν_m is greater than ν_e by 1-2 order so Coulomb collision doesn't have significant effects on electron energy relaxation. On the other hand, it is also indicated that Coulomb collision should have some effects in lower gas pressure (i.e. ~0.3 Pa) or higher electron density (> 10^{19} m^{-3}) condition.

4. Conclusion

Coulomb collision process between two electrons has been modeled using the binary collision model and implementation of this algorithm into EM-PIC code for RF-ICP plasma has been started. Initial calculation successfully has been done and it is shown that Coulomb collision should have some effects in lower gas pressure (i.e. ~0.3 Pa) or higher electron density (> 10^{19} m^{-3}) condition.

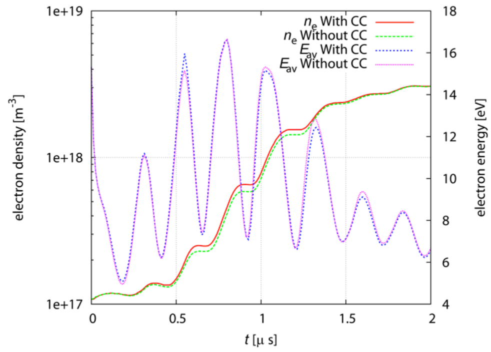

Fig.3. Time evolution of electron density n_e and average electron energy E_{av}.

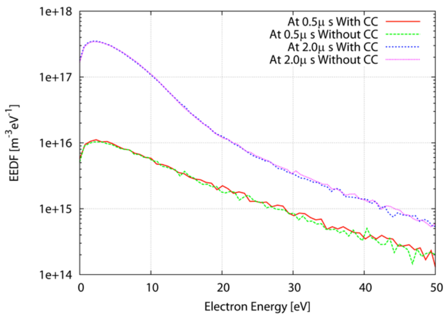

Fig.4. EEDFs compared between with and without Coulomb collision at t = 0.5 μs and 2.0 μs.

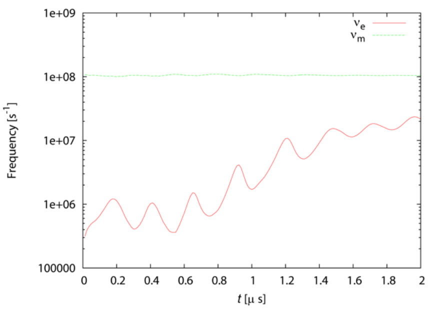

Fig.5. Time evolution of frequencies of Coulomb collision ν_e and collision with neutral particles ν_m.

References

[1] M. Ohta, S. Mattei, M. Yasumoto, A. Hatayama and J. Lettry, Rev. Sci. Instrum. **85**, 02B113 (2014)

[2] S. Mattei, M. Ohta, A.Hatayama, J. Lettry, Y. Kawamura, M. Yasumoto and C. Schmitzer, AIP Conf. Proc. **1515**, 386 (2013)

[3] K. Yee, Antennas and Propagation, IEEE Transactions on **14**, 302–307 (1966), ISSN 0018-926X

[4] C. Birdsall, and A. Langdon, Plasma Physics via Computer Simulation, (2004)

[5] T. Takizuka and H. Abe, J. Comput. Phys. **25**,205-219 (1977)