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Monte-Carlo Simulation of glow discharges in magnetic field
粒子モンテカルロ法による磁場中グロー放電の挙動解析

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A Monte-Carlo based simulation code is applied to glow-discharge, especially high frequency glow discharge (HF-GD), in magnetic fields. Both electric and magnetic fields are provided externally and are not adjusted self-consistently. We have tried to examine the pre-breakdown phenomena and found that the orbiting electrons would play an important role in the uniformity of HF-GD plasma in magnetic fields.

1. Introduction

It is well-known that the wall surface conditions of fusion devices are directly related to plasma performance. Thus, from the operational point of view, it is quite important to keep the wall surfaces clean. The way to clean up the wall surfaces is often regarded as **wall conditioning** or **discharge cleaning**, wherein plasma is used to remove impurities from wall surfaces. In ITER, the next generation experimental fusion reactor, the wall conditioning method would be very limited due to the presence of strong magnetic fields. High frequency glow discharge cleaning (HF-GDC) is one of the candidates for wall conditioning in superconducting devices, like ITER. Although, it has been shown that HF-GDC works well in some superconducting devices [1, 2], including EAST and HT-7, the performance of HF-GDC in other devices is unclear. Furthermore, the basic mechanism of HF-GDC in magnetic fields has not been explained theoretically yet. Therefore, to apply this technique to ITER, we have to reveal the basic mechanism of HF-GD and evaluate its future performance in ITER.

2. Background

Glow discharge is the most common plasma and is widely used for many purposes including glow discharge cleaning (GDC) of tokamak wall surfaces. It is sometimes used within magnetic fields, e.g. Penning discharges, and its characteristics in magnetic fields are well examined. However, when it comes to strong magnetic fields, plasma become very unstable and sometimes cannot ignite. Unfortunately, this is the case in GDC in future superconducting devices wherein magnetic fields are always present. By contrast, it is reported that HF-GD plasma within magnetic fields is uniform and stable. HF-GD plasma also shows similar characteristics with those of GD plasma without magnetic fields [1].

3. Objectives

The objectives of this study are to reveal the basic mechanism of HF-GD and to make a reasonable model for it. First of all, we focused on the pre-breakdown phase, since it is much easier to analyze and it would be attributed to the shape of plasma.

4. Methodology

In order to simulate the glow discharge at the very beginning, we traced the trajectory of fast electrons emitted from wall surfaces and introduced collision effects based on Monte-Carlo method. For simplicity, we choose Ar gas as background and assume that following atomic processes are dominant in inelastic collisions and ignored others.

Ionization: $e^- + Ar \to e^- + Ar^+ + e^-$

Excitation: $e^- + Ar \to e^- + Ar^*$

Thus, in our case we accounted for N = 3 collisional events (elastic collision, excitation, ionization) by using Nanbu method [3]. Firstly, we generate a random number U (0, 1) and obtain the integer i form i = [NU+1], where [ ] is Gauss's symbol. Then the reaction probability for the specified reaction is calculated at every time step.

$$P_i = N_{Ar} c \sigma_i(\varepsilon)\Delta t\,,\ \ (i = 1, N) \tag{1}$$

where N_{Ar} is the number density of Ar gas, c is the electron speed, ε is the energy of electron, and σ_i is the cross section of i-th event.

Secondly, we generate another random number U' (0, 1) and check whether U' satisfies $U' > (i/N) - P_i$ or $U' \le (i/N) - P_i$. In the former case, i-th collision occurs while the latter case causes no collision.

5. Summary

The experiments in EAST showed that HF-GD plasma becomes more uniform at lower filling pressure [1]. This means that the mechanism of its uniformity can become clear at lower pressure, which then indicates that collision-less electron trajectories are important. Firstly, we carried out simulation to examine the collision-less electron trajectory in magnetic and/or electric field. The impact of electric field can be found in the different electron trajectories with and without electric field (See Fig.1 (a) and (b)). The electric field is calculated from the electric potential shown in Fig. 1 and the magnetic field only includes the toroidal component without any ripples.

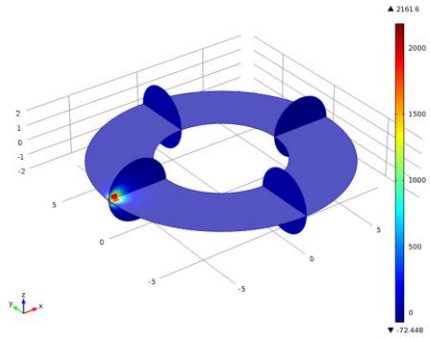

Fig. 1 electric potential

The impact of electric field can be found in the different electron trajectories with and without electric field (See Fig.2 (a) and (b)).

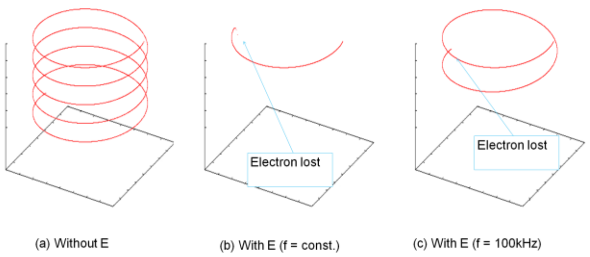

Fig. 2. A particle trajectory in B_t = 1.0 [T], (a) without E, (b) with E (f = const., U = 2 [kV]), and (c) with E (f = 100 [kHz], U = 2 [kV])

Without electric field, electrons continue the circular motion inside the torus (see Fig. 2 (a)), whereas electrons under electric field fall into the electrode as shown in Fig. 2 (b, c). Secondly, we calculated the energy change of an electron for different frequencies. For constant electric field, electrons are always accelerated toward the electrode. Thus when they are approaching to the electrode their speed will increase, but they will soon be in touch with electrode. Therefore, energetic electrons can only exist near the electrode. By contrast, with alternating electric field, a part of accelerated electrons can survive and continue circular motion with higher energy (see Fig. 3).

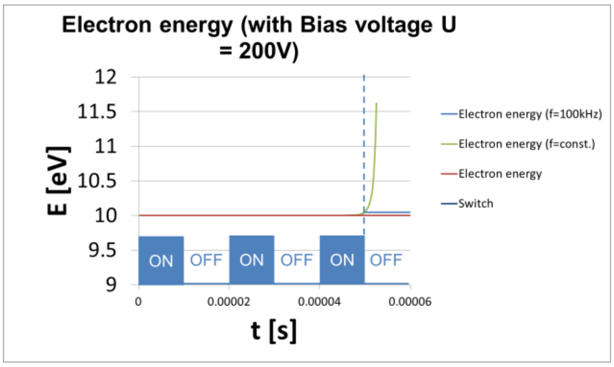

Fig. 3. Time evolution of single electron energy

6. Future works

We are planning to introduce collisions of ions and examine their behavior. The second step is to add the self-consistent effect to our model with PIC method.

References

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