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Enhancement of Ion Current in a Magnetron Ion Source for an Inertial Electrostatic Confinement Fusion Device
慣性静電閉じ込め核融合駆動用マグネトロン放電イオン源の大電流化

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A newly developed IEC device driven by a ring-shaped magnetron ion source showed a neutron yield proportional to the square of the IEC grid current in low pressure D_2 gas operation. However, the IEC grid current in the RIS-IEC is limited to ~1 mA at 5 mPa. In order to study the new regime in the RIS-IEC in a higher IEC grid current range, application of a thermal electron emitter to the magnetron ion source is studied. Numerical simulations suggested a linear increase of the IEC grid current up to ~150 mA, which meets our requirement, as the thermal electron current increases to 120 mA. This thermal electron current can be provided by use of commercially available thermal electron emitters.

1. Introduction

An Inertial Electrostatic Confinement (IEC) fusion device [1] is expected to be a compact neutron source. A conventional IEC driven by a typically 0.1-5 Pa glow discharge consists of a grounded spherical vacuum chamber and a central spherical cathode grid (an IEC cathode, hereafter). An IEC device can accept larger input power than existing D-D or D-T neutron generators because the target of accelerated fusing ions is mainly neutral gas or plasma in IECs, unlike the solid metal target in the neutron generators. However, the ratio of fusion output to input power is quite low in IECs, and fusion output is limited by the capacity of the power supply.

An IEC device newly developed at Kyoto University aims at an operation under a reduced D_2 gas pressure of units of mPa with the aid of a ring-shaped magnetron ion source. This device employs a negatively biased ring-shaped array of permanent magnets between the IEC cathode and the anode, to produce ions in the vicinity of the anode by a magnetron discharge [2]. In this ring-shaped ion-source driven IEC (referred to as a RIS-IEC), the experimental neutron yield was found to be proportional to the square of the IEC cathode current, unlike the linear dependence in any experimental IEC devices so far. One possible explanation for this newly observed phenomenon might be fusion reactions between energetic ions (so-called a "beam-beam" fusion regime), which is expected to increase the neutron output drastically, thanks to the current-square dependence.

Through a comparison between the neutron yields by the RIS-IEC mode and the glow-driven mode in the present device, it is found that the neutron yield in the new RIS-IEC mode would exceed that of the conventional glow-driven mode if the IEC cathode current would increase to 4 mA. The IEC cathode current in the RIS-IEC mode is, however, limited to 1 mA in the present device. Also, a stable glow-mode operation can hardly be maintained below 10 mA, which makes a direct comparison of neutron yields between the two modes at the same IEC cathode current difficult.

In this paper, we discuss an upgrade of the RIS-IEC device to meet the IEC cathode current requirement in order to make clear the possible fusion rate enhancement by the new IEC regime.

2. Theory

The present self-sustained operation of the magnetron ion source in the RIS-IEC can be described as follows. The ring-shape array of magnets induces orthogonal magnetic and electric fields between the anode and the negatively biased magnet array.

Either thermal electrons, electrons by field-emission or secondary electrons due to ions' impact on the magnet array tend to drift because of the cyclotron motion in the crossed electric and magnetic fields. The electrons thus collide to the background neutral molecules many times and produce ions and electrons by ionization, before reaching the anode. The produced ions are accelerated toward the negatively-biased magnets. Some of them go through the spacing of the magnets and are accelerated toward the IEC cathode to gain a fusion relevant energy. The other ions hit the magnets to emit secondary electrons. The electron and ion currents are thus multiplied through the ionizations and the secondary emissions, and a magnetron discharge will start up.

In the present magnetron discharge, the chain-reaction ionization by the electrons, and the secondary electron emission by the ion collision to the magnets balance, to lead to a specific steady-state IEC cathode current dependent on the applied bias voltage and the gas pressure.

We plan to place a thermionic electron emitter attached to the magnet array to provide a much higher electron current, e.g. 100 mA, than in the present self-sustained magnetron discharge. Numerical simulations are presented in the next section, to see if this system can lead to an enhanced IEC cathode current and to meet the requirement of 10 mA.

3. Simulation

We carried out trajectory simulations of ions and electrons in the present magnetron discharge in a cylindrically symmetric system, by use of a 2-dimendional code [3]. This code is a particle-in-cell code based on the Finite Element Method taking the space-charge effect into account self-consistently. It also handles atomic and molecular collisions among electrons, ions and background neutrals.

In this study we neglected the secondary electron emission from the magnet array (the magnetron cathode), though the code can handle it. Instead, we gave constant electron currents of 0.1, 0.3, 1.0 and 100 mA from the magnetron cathode surface as the input conditions of the simulations, which is thus regarded as the sum of thermal and secondary electron emission currents. We fixed the gas pressure and the applied bias to the magnet array to 5 mPa He and -10 kV, respectively.

The simulation results are summarized in Table 1, showing the incident electron currents from the magnet array and the resultant He^+ ion current to the magnetron cathode. The ratio of electron and ion current is found to be roughly 3:10 independent of the incident electron current. The ratio is found to be reasonable as the secondary yield coefficient ranges 0.3-0.5 in the present energies of He^+ ion impact on stainless steel (the magnets in the experimental device are covered by stainless steel for shielding from the incident ions).

An important suggestion from the simulation results is that a linear increase of the ion supply is expected up to an incident thermal electron current of 120 mA. With an incident thermal electron current of 120 mA, the resultant ion current and the total magnetron discharge current of 310 mA and 430 mA, respectively as shown in the table. Though the present simulations do not handle the ion current extraction from the magnetron ion source, the expected IEC cathode current turns out to be ~150 mA, according to the experimental ratio of the magnetron discharge current and the extracted IEC cathode current.

4. Conclusions

In order to enhance the IEC cathode current in the RIS-IEC device, the application of thermal electron emitter to the magnetron ion source is discussed in this paper. Numerical simulations suggested a linear increase of the IEC cathode current up to ~150 mA by the use of a thermal electron emitter, where the current-square dependent neutron yield in the RIS-IEC regime is expected to exceed that in the glow-driven mode.

We plan to introduce an electron emitter to the experimental RIS-IEC device. As a candidate emitter, a directly heated tungsten dispenser cathode is under consideration, which is commercially available and can provide a thermal electron current of ~20 A in a vacuum. The fundamental electron emission characteristics measured in helium, hydrogen and deuterium gases as well as in a vacuum will be presented in the conference.

References

[1] R. L. Hirsch: J. Appl. Phys. **38** (1967) 45422.

[2] K. Masuda, T. Nakagawa, J. Kipritidis, T. Kajiwara, Y. Yamagaki, H. Zen, K. Yoshikawa and K. Nagasaki: Plasma Phys. Control. Fusion **52** (2010) 095010.

[3] K. Masuda and K. Yoshikawa: Fusion Science and Tech. **52** (2007).

Table 1. Currents of incident electrons and resultant ions.

Incident electron current I_e [mA]	0.11	0.33	1.11	120
Resultant ion current I_i [mA]	0.37	1.13	3.92	310
$I_e : I_i$	3: 10	3 : 10	3 : 10	4 : 10