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Improvement of Neutron Production Rate at Inertial Electrostatic Confinement Fusion by Use of a Multi-Stage Feedthrough

多段電圧導入端子を用いた慣性静電閉じ込め核融合装置の中性子発生率の向上に関する研究

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In our inertial electrostatic confinement fusion (IECF) device, the maximum applied voltage was limited to -80 kV. In order for an enhancement fusion rate, we have designed a 5-stage feedthrough aiming at applying higher voltage up to -200 kV as well as at modifying spherical symmetry of the electric field in the device, by numerical simulations. Based on the numerical design, we have constructed the experimental IEC device employing a 5-stage feedthrough. We successfully applied a voltage exceeding the maximum voltage of the original single-stage device, and have achieved -180 kV so far.

1. Introduction

In a conventional glow-driven IEC devices, the range of typical operating gas pressure ranges are several tens of mPa to 1 Pa. In those devices, the ion energy is rapidly lost by charge exchange collisions with background neutral gas molecules. To cope with this problem, we have developed a new IEC scheme driven by a built-in ring-shaped magnetron ion source. This device can provide a new IEC operation mode driven by the ion source (RS-MIS), which extended the accessible low pressure limit very much down to 5 mPa, as well as the conventional glow mode under several hundreds mPa [1].

For both the operation modes in this newly developed IEC device, the maximum applied voltage is limited to -80 kV. Especially in the glow mode, the averaged energy of ions is known to have about one third of applied voltage because of the frequent collisions with the background neutrals. In this every range, i.e. 20-30 keV, the cross section of D-D fusion increases rapidly as the ion energy increases. So we can expect a significant enhancement of fusion rate by increasing the applied voltage. In this research, our aim is to apply -200 kV.

Meanwhile, the importance of ion beam optics in terms of ion recirculation was increased in the ion-source driven mode, because, for tens keV and 5 mPa, the mean free path for deuterium ion charge exchange is of order of 10 m, which is much longer than the anode diameter. Therefore, unlike the glow mode where charge-exchange loss of ion is significant, field asymmetry induced by the high-voltage feedthrough to the central cathode grid may limit the ion recirculation (oscillatory motion of ions within the anode, prior to striking the feedthrough rod).

In order to cope with these two requirements, a 5-stage high-voltage feedthrough to be employed in the IEC device was designed. Figure 1 shows the schematics. The numerical simulations of the ion trajectories showed that, the averaged recirculation number of injected ions is 3 times as large as that in the present experimental device [2]. Also the design showed that the maximum electric field at the central cathode bias of -40 kV on each electrode surfaces to be less than 9 MV/m, within the acceptable electric field limit [2].

We have then developed a 5-stage feedthrough based on this design. In this paper, we describe the IEC device employing the new feedthrough system and the preliminary experimental results.

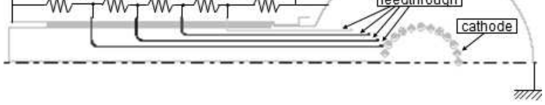


Fig.1. Schematics of the 5-stage feedthrough device

2. Experimental Device

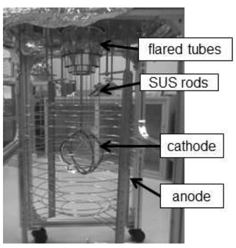
Figure 2 shows photos of the experimental IEC device employing the 5-stage feedthrough. The diameters of the original device were 445 mm and 80 mm, respectively. In this research, we expanded the size of both the anode and the cathode, i.e. the diameters of the new anode and cathode are 560 mm and 200 mm.

The anode is made of 15 rings made of SUS316. Diameters of these rings are decides to make the diameter of anode 560 mm (see Fig.2.a).

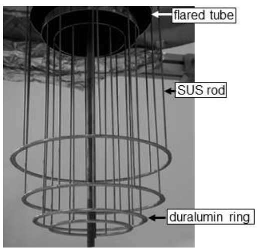
The cathode is made from molybdenum. This cathode and the anode are set concentric. This cathode is also connected to a cylindrical feedthrough rod. The diameter of this rod is 10 mm, which is to be biased at a high negative voltage up to -200 kV.

Each of the 4 intermediately biased electrodes consists of 4 parts, namely ring-shaped plates made of alloy of ferrous, nickel and cobalt, a stainless flared tube, 6 stainless rods and a duralumin rings. The flared tube is connected to the alloy plates. 6 stainless rods are set on the end of the flared tube inside the chamber. The duralumin ring is put on the terminations of the 6 stainless rods (see Fig.2.a and b).

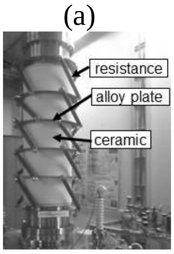
The 4 intermediately biased electrodes and the central feedthrough rod are insulated from each other by 5 cylindrical ceramics. The diameter of these ceramics is 200 mm and the length is 120 mm. The alloy plates of the intermediately biased electrodes are fixed between these ceramics. We put 4 resistances between every intermediately biased electrode outside the vacuum in order to divide the applied bias voltage equally into the 4 intermediate biases to the electrodes (see Fig.2.c).



(a)



(b)



(c)

Fig.2. Photos of the IEC device employing the 5-stage feedthrough:
(a) the anode, the cathode and the intermediately biased electrodes, (b) the intermediately biased electrodes, (c) the ceramic tubes and the resistances.

3. Result of Experiment

We applied a high negative voltage to the device in a vacuum. Figure 3 shows the relation between the condition time and the applied voltage. We have operated the device about 80 hours so far. The dotted line shows the maximum applicable voltage in the original single-stage device. In the newly developed device, we could reach this voltage very quickly in less than 1 hour. And so far we have reached temporarily -180 kV. This is 90% of the target voltage of -200 kV.

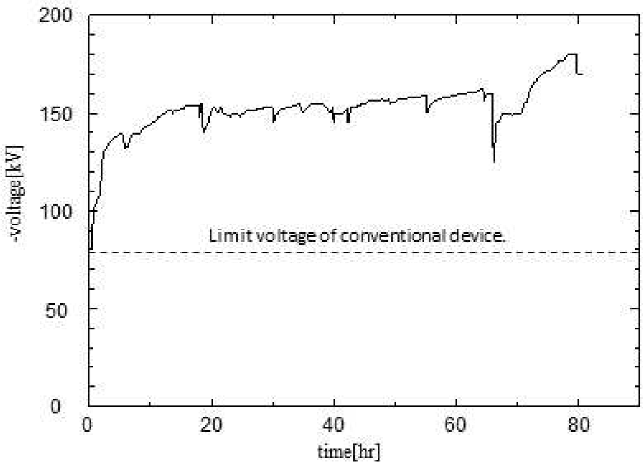


Fig.3. Conditioning Data

4. Summary and Conclusion

We constructed an IEC device employing a newly designed 5-stage high voltage feedthrough in order for an improved fusion rate by applying a high bias voltage up to -200 kV and by modifying spherical symmetry of the electric field. We have conducted a high-voltage conditioning of the developed device under a vacuum. So far, we successfully achieved a bias of -180 kV, which is much higher than the maximum limit of -80 kV by the use of the original single-stage feedthrough. In the near future, we plan to apply a high voltage under the glow mode by feeding a fuel deuterium gas.

References

[1] K. Masuda et al., Plasma Phys. Control. Fusion, 52, 095010 (2010).
[2] Kai Masuda et al., Fusion Science and Technology, vol.60, 2011, p.625