Formation of a magnetized plasma jet by the pseudo-spark discharge

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1. Introduction

The behaviour of a magnetized plasma jet generated by the modified pseudo-park discharge (PSD) [1,2] has been investigated. The PSD is a one of the high current hollow cathode discharge. The cathode of the PSD has a cylindrical cavity, and the both electrodes has a small circular hole on the same axis as shown in Fig.1(a). The PSD can be formed under the condition of the low-pressure region. In general discharge, the breakdown property obeys the Paschen's relation. The breakdown of the PSD is also a function of a working pressure and a length of the discharge path. Figure 2 shows the experimental plots of the breakdown voltage as a function of the initial gas pressure. In the low-pressure region, the breakdown voltage rapidly increases with decreasing the pressure. The minimum break down voltage is over the 800 V in this experiment. On the left hand side of the minimum point of the Paschen's curve, the breakdown voltage along the long discharge path is smaller than that along the short one. This result indicates that the discharge has a tendency to occur along the long discharge path through the electrode holes. The length of the discharge path depends on the space distribution of the applied electric field. The penetration of the electric field through the electrode holes depends on the size of electrode holes, thickness, the anode-cathode distance and so on [3].

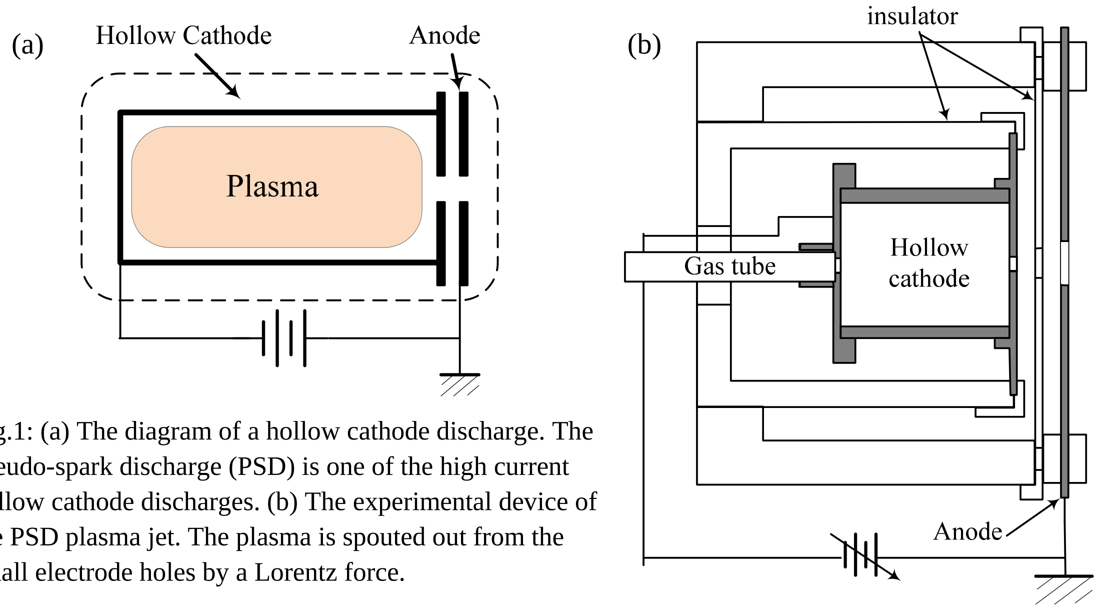

Fig.1: (a) The diagram of a hollow cathode discharge. The pseudo-spark discharge (PSD) is one of the high current hollow cathode discharges. (b) The experimental device of the PSD plasma jet. The plasma is spouted out from the small electrode holes by a Lorentz force.

Consequently, the property of the breakdown in the PSD becomes very complex and the length of the discharge path becomes an uncertain parameter. In this low-pressure region, the breakdown voltage also rapidly increases with decreasing the pressure, resulting that a high current discharge can be easily formed. Since the PSD keeps the diffused arc mode and the interaction between the discharge and electrode in not point but the surface of the electrodes, the damage (erosion) on the electrode will be relatively small and the metallic impurity from the heated electrode is regarded as low.

Figure 1(b) shows the schematics drawing of the experimental device for plasma jet electrodes. The working gas is directly injected into the hollow cathode cavity and the electric discharge occurs between the cathode and anode holes. To accelerate the plasma cluster from the electrode hole, the diameter of the anode hole is enlarged as compared with that of the cathode (see in Fig.1(b)). The force of the plasma acceleration is caused by a combination of a Lorentz force and a thermodynamic force inside the cathode cavity, that is similar to MPD and arc jet thrusters. The electromagnetic force, due to the radial component of the discharge current and the azimuthal self-magnetic field, accelerates the plasma from the electrode hole.

To magnetize the plasma jet, the external magnetic field is directly induced nearby the electrode holes. The external magnetic field is generated by using a ring neodymium magnet. This neodymium magnet is located between the electrodes and excites the dipole magnetic field B_z through the electrode holes. The plasma jet with the self-azimuthal magnetic field B_θ was accelerated under the externally-induced dipole magnetic field in this experiment.

2. Experimental device and setup

The geometrical parameters of electrodes are as follows: the anode-cathode gap distance is 12 mm, a diameter of the cathode and anode holes are 5 mm and 10 mm respectively. The cathode and anode are made of a stainless steel. To prevent the discharge between opposite surfaces of

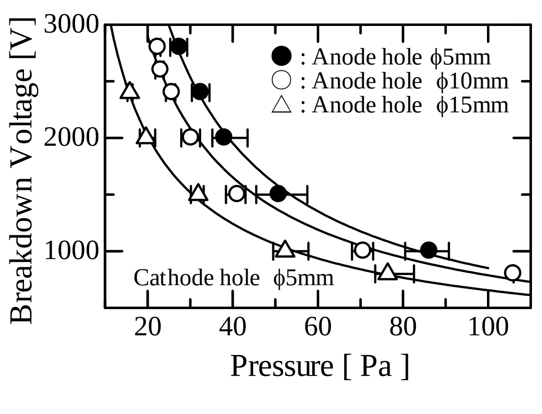

Fig.2: The experimental plots of the breakdown voltage as a function of the initial gas pressure.

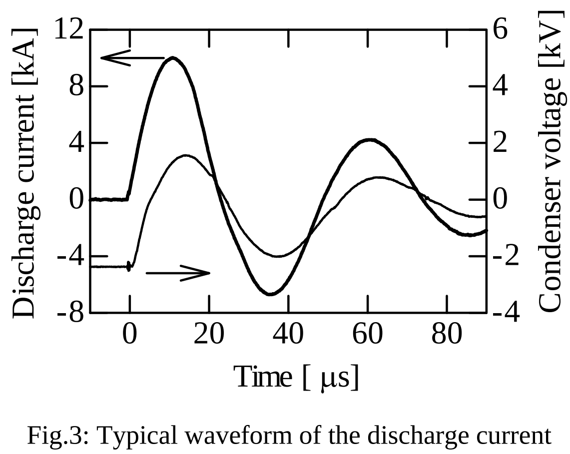

Fig.3: Typical waveform of the discharge current and the voltage between the condenser bank.

the cathode and anode, an intermediate insulator is inserted between them. The diameter of the intermediate insulator hole is 10 mm. The base pressure of vacuum chamber is in the order of 10^{-3} Pa and the discharge working pressure is in the order of 10 Pa as shown in Fig.2. The discharge is formed by using a condenser bank of 40 μF. After the evacuation by an oil diffusion pump, the cathode is slowly charged through the condenser bank. After then, the hydrogen gas directly injects into the hollow cathode cavity and the plasma jet is formed. The Rogowskii coil measures the discharge current and the high voltage meter measures the breakdown voltage. The electron temperature and density of the plasma jet is measured by using an electric double and triple probes technique.

3. Experimental results and discussions

Figure 3 shows the typical waveforms of the discharge current and the voltage between the condenser bank. The breakdown voltage is 2.8 kV and the maximum discharge current is approximately 10 kA. The discharge is dumped oscillation and the half period of the discharge current is about 20 μs. The discharge characteristics were almost same with or without the external magnetic field.

The time response of the temperature and the density of the plasma jet with the external magnetic field are shown in Fig. 4. The strength of the external magnetic field is approximately 0.53 T around the small electrode holes. The temperature and density also oscillates synchronized with the discharge current, because the Lorentz force increases with increasing the product of the discharge current multiply by the self-magnetic field. The temperature and the density were around 5 eV and in the order of 10^{19} m^{-3} at the distance from the electrode hole of 10 cm. The direction of the plasma acceleration is the same during the oscillating discharge.

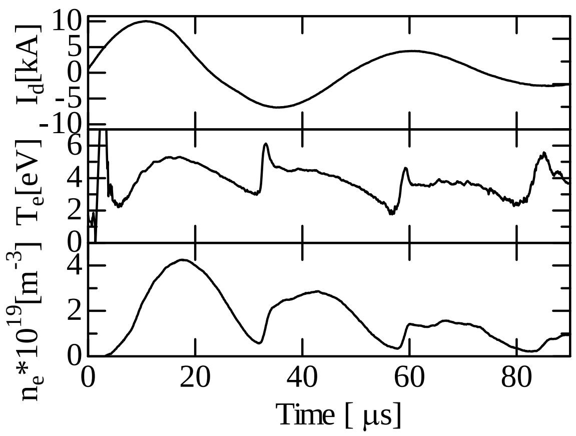

Figure 4 : This figure shows the time variation of the discharge current, the temperature and the density of the plasma jet. The temperature and density were around 4eV and in the order of 10^{19} m^{-3} .

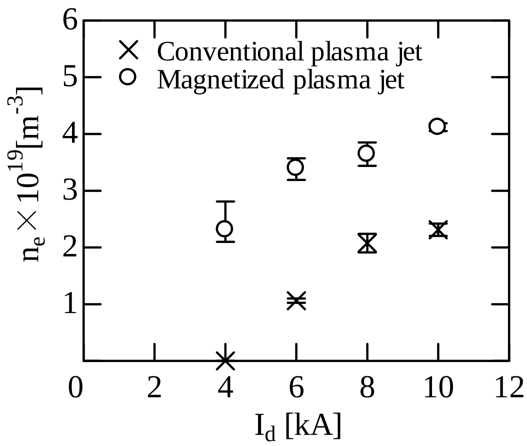

Figure 5 : The dependence of the electron density of the plasma jet on the discharge current w/o the applied magnetic field.

Figure 5, 6 shows the dependence of the density and the temperature on the discharge current with or without the external magnetic field. We can see the density and the temperature increase with increasing the discharge current. It is clear that the plasma density with the external magnetic field becomes higher. The plasma jet density increased several times with the external magnetic field. This result supports that the some magnetic confinement effect acts on the plasma jet. The plasma jet temperature was, however, almost same with or without the external magnetic field. This result will be due to the same input power into the plasma jet with or without the external magnetic field when the maximum discharge current is same.

Figure 7 shows the dependence of the density on the distance between the electric probe and electrode holes with or without the external magnetic field. The density decreases with the distance between the electrode and the probe. The magnetic diffusion will be strong due to the low temperature of the plasma jet.

4. Conclusions

The behaviour of a magnetized plasma jet generated by the modified PSD has been investigated. The plasma accelerates due to the Lorentz force and the thermodynamic force, that is similar to MPD and arc jet thrusters. With the external magnetic field, the temperature and the density of the plasma jet were around 5 eV and in the order of 10^{19} m^{-3} at the distance of 10 cm from the electrode hole. The plasma jet density increased several times with the external dipole magnetic field. This result indicates that the magnetic confinement effect acts on the plasma jet.

References

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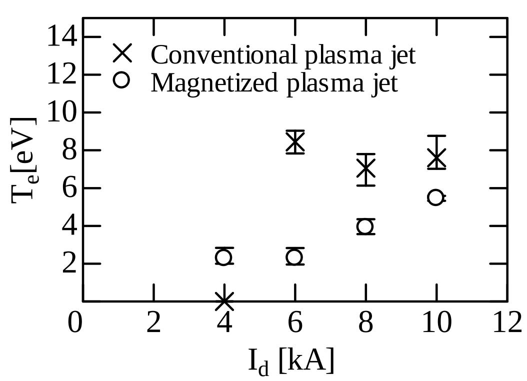

Figure 6 : The dependence of the temperature of the plasma jet on the discharge current w/o and without the applied dipole magnetic field.

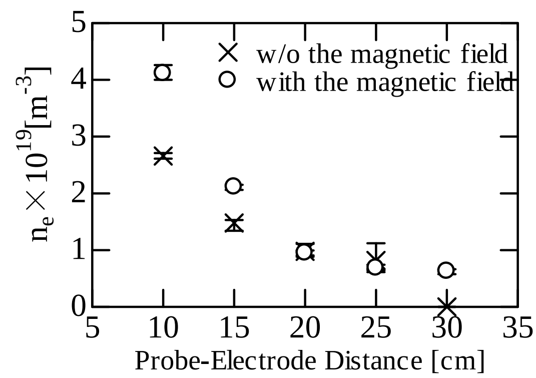

Figure 7 : The dependence of the density of the plasma jet on the distance of the probe and the electrode w/o the applied dipole magnetic field.