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Investigation on a momentum of the charged particles in permanent-magnets-expanded plasma

永久磁石利用発散プラズマ中の荷電粒子モーメントの検討

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An electron pressure and a momentum of a supersonic ion beam downstream of the permanent-magnets-expanded plasma source are experimentally investigated using a retarding field energy analyzer and a Langmuir probe. As the previously reported thrust from a magnetically-expanding or simple rf plasma thruster can be well explained by the electron pressure force inside the source tube, the present measurements downstream of the source are compared with the upstream electron pressures. There are significant disagreement between the upstream electron pressure and the total momentum from the electron and drifting ions downstream of the source; it is discussed from the viewpoint of the ion-neutral charge-exchange collision and the radially non-uniform electron energy distribution.

1. Introduction

Conventional electric propulsion devices, e.g., ion engines, hall thrusters, and magneto-plasma-dynamic thrusters, require electrodes for ion accelerations and/or plasma productions. In these types of propulsion devices, the electrodes are damaged by thermal loads and ion bombardment; the development of the long-lived thruster has been progressed so far. One of the candidates for the long-lived propulsion devices is an electrodeless system such as helicon thruster including ion accelerations by ambipolar or double-layer (DL) electric fields [1,2]. More recently, the permanent-magnets helicon source has been developed in order to reduce the consumed electric power by the solenoids [3].

The investigation on the thrust generation mechanisms in the helicon-type plasma thrusters are now vigorous topic in experiments and theories [4-7]. A directly measured thrust from the permanent-magnets-expanded plasma source (custom built in Iwate Univ. and operated in the Australian National Univ.) has been about 3-4 mN for rf power of about 800 W, which are well explained by the electron pressure force inside the source tube. In the present study, the density and velocity, i.e., a momentum of the ion beam induced by the DLs are experimentally investigated using a Langmuir probe (LP) and a retarding field energy analyzer (RFEA). A total momentum from the ion beam and the electron pressure downstream of the source tube are compared with the upstream electron pressure.

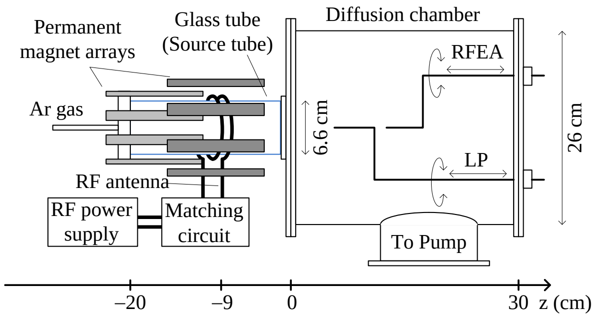

Fig.1. Schematic of the *PMPI* machine.

2. Experiment Setup

Experiments are performed in *P*ermanent *M*agnets expanding *P*lasma machine at *I*wate University (*PMPI*) shown in Fig.1. The machine has a 20-cm-long and 6.6-cm-diameter source tube contiguously connected to a 30-cm-long and 26-cm-diameter stainless steel diffusion chamber, where z = 0 cm is defined as the source exit. Permanent magnet arrays surrounding the source tube provide a constant magnetic field of about 100 G inside the source and an expanding field decreasing to 10 G at the middle of the diffusion chamber. A double-turn rf loop antenna winding the source tube at z = – 9 cm is powered from a 13.56 MHz rf power supply, and an argon plasma is produced by an inductively-coupled mode discharge. The rf power is varied in the range of 100-800 W. The flow rate of the argon gas is chosen as 4.5 sccm giving the argon gas pressure of about 0.75 mTorr, where the gas pressure is measured by an ionization gauge connected to a side port of diffusion chamber. Then the DL structure is formed near the plasma source exit, and the supersonic ion beam is generated downstream of the source exit [3].

3. Experimental results

Fig. 2(a) shows the radial profile of the upstream plasma density $n_{\text{p-up}}$ at z = – 11.5 cm for an rf power of 250 W. This axial position gives the maximum electron pressure along z, and the previous experiments have shown the thrust from the DL source can be given by the maximum pressure [6,7]. Fig. 2(b) shows the radial profiles of the downstream plasma density $n_{\text{p-down}}$ and ion beam density n_{beam} measured at z = 3 cm. It is found that both n_{beam} and $n_{\text{p-down}}$ are radially non-uniform. The momentums from the electron pressure and the drifting ion beam can be described by the integration in the cross section as

$$T_{e(pressure)} = 2\pi \int_0^{\infty} n_p(r) k_B T_e r dr \,, \qquad \cdots \quad (1)$$

$$T_{i(beam)} = 2\pi \int_0^{r_{beam}} m_i n_{beam}(r) v_{beam}(r) r dr \,, \cdots \quad (2)$$

At the axial position of the maximum electron pressure, it is assumed that the ions are not accelerated and its drift velocity is zero. Then the total momentum at this position corresponds to the electron pressure; it can be obtained as ~0.75 mN. On the other hand, the downstream momentum is due to both the thermal electrons and the drifting ions. The total momentum downstream of the source exit (z = 3 cm) can be estimated as ~0.2 mN, where $T_{\text{e(pressure\_down)}}$ and $T_{\text{i(beam)}}$ are ~0.1 mN and ~0.09 mN, respectively. Even if the contribution from the neutral beams produced through the charge-exchange collisions, it is still ~0.3 mN. Now the electron temperature is assumed to be uniform in the system. However, the previous studies have shown the presence of the energetic electrons both inside and outside the source. These energetic electrons would also contribute to the total momentum. Detailed measurements will be reported in the presentation.

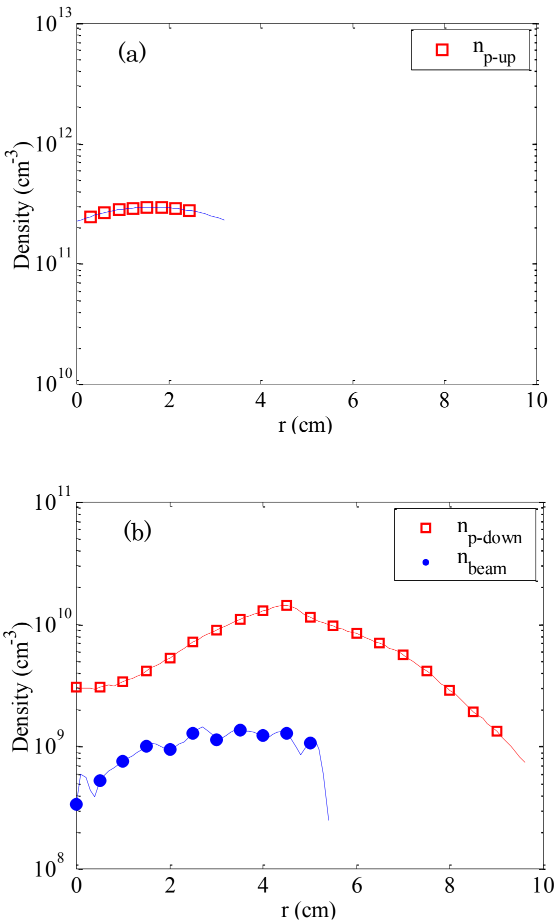

Fig.2. Radial profiles of (a) the plasma density at z = – 11.5 cm, and (b) the plasma density and ion beam density at z = 3 cm.

4. Conclusion

The total momentums both inside and outside the source tube are experimentally investigated in the permanent-magnet plasma source. The results show a significant disagreement and discussed from the viewpoint of the charge-exchange collisions and the radially non-uniform electron energy distributions.

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