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回転磁場プラズマ加速を用いた無電極電気推進におけるイオン流速評価

Evaluation of ion flow velocity in electrodeless electric propulsion using the rotating magnetic field plasma acceleration

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Electrodeless radio frequency (RF)/helicon plasma thruster[1] is a promising way to realize further away space probes and manned missions in the future. This is because plasma acceleration grids do not directly contact plasma in the thruster system and a longer operation lifetime is expected than that of practical electric propulsion, e.g., ion gridded engine.

We are proposing the rotating magnetic field (RMF) plasma acceleration method[2,3] for enhancement of the plasma acceleration in the RF thruster. The RMF current drive has been utilized to maintain a field reversed configuration in the field of magnetically confined plasma fusion research.[4] In this RMF scheme under the divergent magnetic field configuration, electrons are additionally accelerated by the electromagnetic force given as a cross product of the driven azimuthal current and a radial component of the external diverging magnetic field (magnetic nozzle), as shown in Fig. 1. Afterwards, ions are accelerated by a bipolar electric field caused by the axial transit of electrons, and a net plasma flow is evacuated downstream of the magnetic nozzle region.

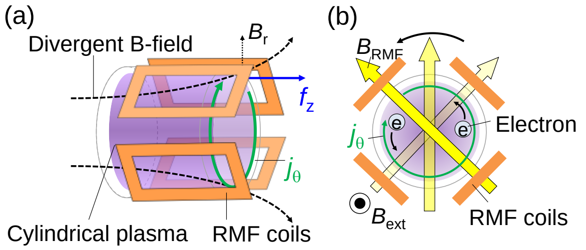

Fig. 1: Schematic of RMF acceleration method [(a) side view of the RMF antennas and (b) cross-sectional view of the azimuthal current generation].

To estimate the net plasma acceleration, the ion flow measurement is important. We previously measured the ion Mach number using a Mach probe and a qualitative evaluation of the spatial profile of the ion flow was conducted.[3] Laser-induced fluorescence (LIF) velocimetry is a suitable method to quantitatively check the ion flow in detail. The LIF method yields absolute ion velocity based on the theories of the Doppler shift and ion velocity distribution function (IVDF). In our Ar-II LIF measurement, a three-state scheme was adopted. The Ar-II $3d^4F_{7/2}$ metastable state is optically pumped by 668.63 nm (in vacuum) laser light to $4p^4D_{5/2}$ state decaying to $4s^4P_{3/2}$ state by emission at 442.73 mm.[5]

Figure 2 shows two-dimensional (2D) spatial profiles of electron density, n_e, and ion flow near the RMF antenna region. The velocity increased and the flow direction was slightly shifted to the axial direction, compared to the 2D profiles without the RMF application shown in Fig. 2(a).

We also investigated radial profiles of the 3V components in the axial middle of the RMF antenna. We will report the 2D-3V (three-velocity) characteristics of the ion flow measured by the LIF method, and discuss the acceleration effect using the RMF method.

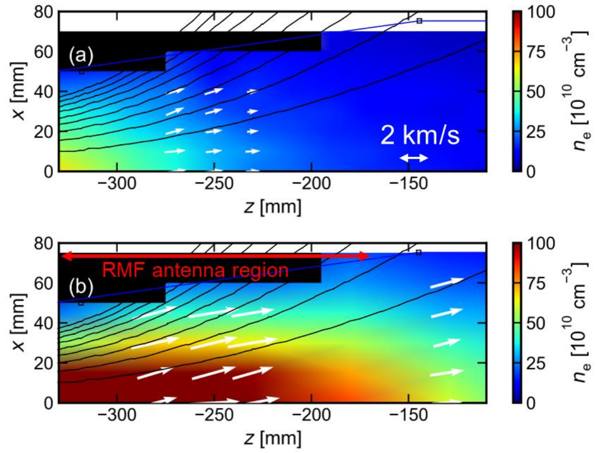

Fig. 2 Ion flow vectors and contours of n_e with the DC magnetic field lines [(a) RF discharge at the RF power of 3 kW and (b) the RMF operation at the total power of 3 kW (RF: 1 kW, RMF: 2 kW)].

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