

## Direct measurement of the plasma momentum in a magnetic nozzle helicon plasma for electric propulsion

TAKAHASHI, Kazunori<sup>1\*</sup> ; CHARLES, Christine<sup>2</sup> ; BOSWELL, Rod<sup>2</sup> ; CHIBA, Aiki<sup>1</sup> ; ANDO, Akira<sup>1</sup>

<sup>1</sup>Department of Electrical Engineering, Tohoku University, <sup>2</sup>Space Plasma, Power and Propulsion Laboratory, The Australian National University

The ion and electron energy distribution functions of a low-pressure, current-free helicon plasma in a magnetic nozzle configuration are experimentally investigated by electrostatic Langmuir probes including a radiofrequency compensated probe and a retarding field energy analyzer; the ions are electrostatically accelerated by a spontaneous potential drop of a double layer and/or ambipolar electric field, and only the energetic electrons can overcome the potential structure. The results indicate that the accelerated ions are spontaneously neutralized by the energetic electrons. These findings propose that the source system is applicable to an electrodeless and neutralizer-free plasma thruster.

Momentum of the plasma flow is one of essential physical parameters dominating the particle acceleration in both laboratory and space. Especially their interaction with magnetic fields have been significant subject associated with natural plasmas (astrophysical jets, magnetospheric physics, solar dynamics, aurora dynamics, etc.) and artificial plasmas (thermonuclear fusion devices, electric propulsion systems, plasma devices for material processing, etc.). The plasma momentum is equal in magnitude and opposite in direction to a thrust imparted from a plasma thruster for the electric propulsion device. The direct measurement of the thrust imparted from a magnetic nozzle helicon plasma thruster is successfully measured by using a pendulum thrust balance immersed in vacuum, where the thrust components arising from the presence of the physical boundaries and magnetic nozzle are also independently measured by attaching each component to the thrust balance. Further a laboratory experiment of a helicon plasma thruster is established to control only a plasma cross-field diffusion in a rapidly-divergent magnetic nozzle while maintaining a constant plasma injection into a magnetic nozzle. The thrust component due to a plasma pressure force inside the source cavity is constant and that due to the magnetic nozzle increases when inhibiting the cross-field diffusion in the nozzle. The latter force is well explained by an electron-diamagnetic-induced plasma momentum derived from two-dimensional momentum equations and approaches the theoretical limit derived from a one-dimensional model assuming an ideal magnetic nozzle with no plasma loss. Further a new source system approaching the ideal magnetic nozzle and the recent progress of the thruster performance will also be shown. It is noted that the above-described phenomena are occurring in current-free source system. These insights into the plasma thruster dynamics might include a common physics relating to the plasma acceleration in a non-uniform magnetic field in both the laboratory and space.

Keywords: plasma momentum, magnetic nozzle, helicon plasma, electric propulsion