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Radiofrequency plasmas in a magnetic nozzle: fundamental physics and applications

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Low-pressure radiofrequency discharge under magnetic fields can provide highly ionized dense plasmas approaching 10^{19} m-3, where the rf power is coupled with electrons via capacitive-, inductive-, and wave-modes. In a magnetic nozzle configuration, the high-density plasma is transported along the field lines and expands along the magnetic nozzle; the electron thermal energy is converted into the plasma flow energy via electrostatic or electromagnetic acceleration processes. An electric space propulsion device utilizing this acceleration process has recently been investigated from the viewpoint of fundamental physics and development. A brief overview of the magnetic nozzle rf plasma thruster R&D will be shown in the presentation [1-5]. We have also demonstrated that the thruster can be applied for contactless removal of space debris by having two open exits, where one plasma plume impinges and decelerates the debris, leading a re-entry to the Earth atmosphere by lowering their altitude. Another plasma plume ejected in the opposite direction to the debris is used to maintain zero net thrust exerted on the thruster [6]. A recent fundamental experiment for mounting the thruster for debris removal will also be shown.

Interestingly, although the instability generally induces a performance degradation of plasma devices, a beneficial influence of a plasma instability/wave has been discovered in a recent experiment, where anomalous transport induced by the wave provides an inward electron transport leading to an electron detachment from the magnetic nozzle structure. This finding will open a new perspective for the role of waves and instabilities in plasmas [7].

Regarding the electric propulsion devices, the development of peripheral components such as gas supply system and the rf generator are also required to minimize size and weight and to maximize efficiency. These technologies can also be used for industrial plasmas represented by a plasma etching device. Here a helicon-based minimal plasma etching device developed in Tohoku University is presented, where a scallop-free Bosch process for silicon etching has been tested by using pulsed gas valves and automatically and fast-controlled rf generator [8].

References

[1] K. Takahashi, Reviews of Modern Plasma Physics, **3**, 3 (2019).
[2] K. Takahashi, Scientific Reports, **11**, 2768 (2021).
[3] K. Takahashi, Scientific Reports, **12**, 18618 (2022).
[4] K. Takahashi, C. Charles and R.W. Boswell, Physical Review Research, **5**, L022029 (2023).
[5] K. Takahashi and S. Sumikawa, Plasma Physics and Controlled Fusion, **66**, 015012 (2024).
[6] K. Takahashi, C. Charles, R.W. Boswell, and A. Ando, Scientific Reports, **8**, 14417 (2018).
[7] K. Takahashi, Christine Charles and Rod W. Boswell, Scientific Reports, **12**, 20137 (2022).
[8] K. Takahashi, R. Imai, and K. Hanaoka, Frontiers in Physics, **9**, 639010 (2021).

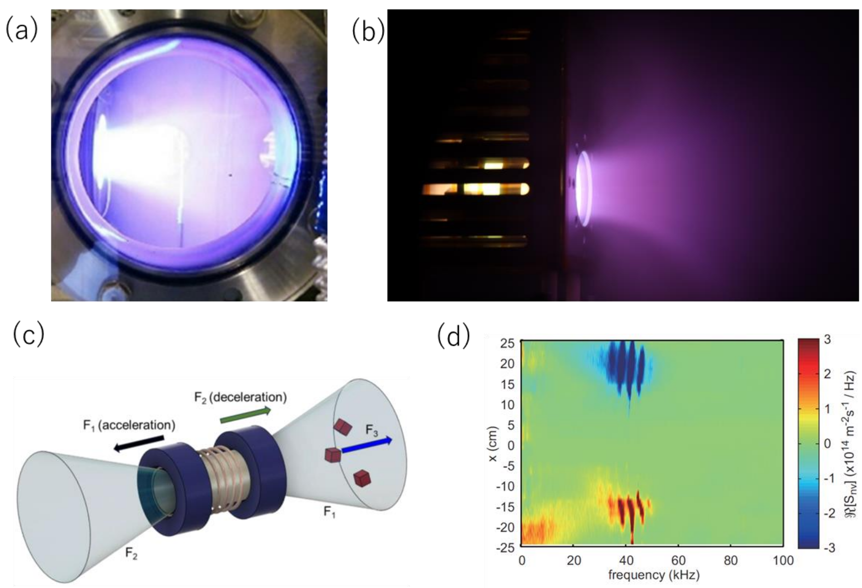

Fig.1: Operations of the (a) 5-kW and (b) 100-W class thrusters. (c) Concept of the active debris removal by using the helicon thruster. (d) Observation of the anomalous cross field electron transport directing to the main axis.