【Grant-in-Aid for Scientific Research (S)】

Research on a high-power magnetic nozzle plasma thruster

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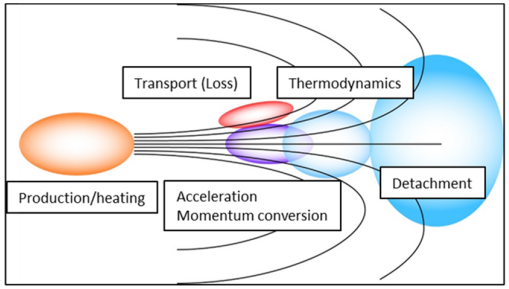
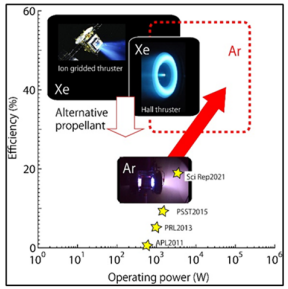
Purpose and Background of the Research

●Outline of the Research

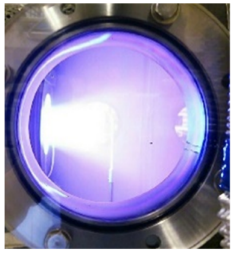
Low-cost and massive space transportation is one of fundamental technologies for future space development and industry; a high-power electric propulsion system providing high specific impulse is required. Electrodeless magnetic nozzle plasma thruster is an attractive and important technology providing a long lifetime even for a high-power operation. In the present study, comprehensive understanding of the plasma dynamics in the magnetic nozzle, including the plasma production, transport, acceleration, momentum conversion, and plasma detachment from the magnetic nozzle. The performance improvement of the 10-20kW class high power magnetic nozzle plasma thruster will open a door for a future space transportation technology.

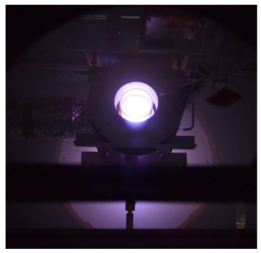


Schematic of the magnetic nozzle plasma thruster



Target of the performance improvement





Photographs for the laboratory model

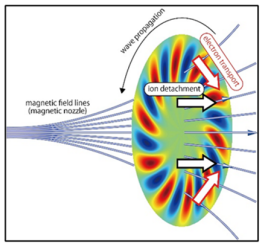


Image for the plasma detachment

Figure 1. Schematic and images of the magnetic nozzle plasma thruster, the performance improvement, the laboratory experiments, and the plasma detachment phenomenon.

●Performance of the magnetic nozzle plasma thruster

The thruster performance is gradually increasing based on the fundamental physics, while it is still developing issue compared with the mature electric propulsion devices. Most of the rf power is consumed to heat the electrons in the plasma and the generated plasma is lost to the source wall, causing the poor efficiency. Hence, inhibition of the plasma loss to the wall is an important research topic.

●High-power operation of the plasma

Thermal problems and novel physical phenomena will appear when extending the operation power up to 10-20 kW level. Therefore, assessment of the thermal issues will identify engineering subjects and novel plasma dynamics will be focused on, by which the scientific and academic base will be established over the wide range of the power.

●Waves-driven electron transport for plasma detachment

Plasma detachment from the magnetic nozzle is the final stage of the thruster operation; detachment of the magnetized electrons is indeed desired to be induced and understood. Various scenarios have been proposed before, while a laboratory demonstration has not been performed yet and it remains an important scientific issue. A preliminarily experiment has suggested that an inward electron transport can be induced by a spontaneously excited plasma wave. Understanding the detailed physical mechanism of the wave-induced transport will be required for the comprehensive study.

Expected Research Achievements

●Scientific and engineering topics

Here is the topics toward a laboratory demonstration of a high-power plasma thruster and the experimental devices can be found in Figs.2 and 3.

1- Performance improvement

Magnetic field structure confining the plasma and inhibiting plasma loss to the wall will be designed and tested, while maintaining the magnetic nozzle downstream of the source. By considering the system efficiency including the electricity for the solenoids, a permanent magnet array providing the confinement will be performed and the thruster efficiency will be improved.

2- High-power operation

By extending the operational power range up to 10-20 kW, the thermal characteristics and newly appearing physical phenomena will be investigated, establishing the scientific base over the wide range of the operational power.

3- Waves-, instabilities-, and turbulence-induced transport for detachment

Unmagnetized ions are expected to be detached from the magnetic. On the other hand, wave-induced cross-field electron transport induced by waves will be investigated in the laboratory plasmas with a help by a particle-in-cell simulation. Especially, the study will be focused on the inward electron transport contributing to the plasma detachment from the magnetic nozzle. Plasma researches over the past 50 years have focused on inhibition of instabilities as it causes a significant plasma loss from the core, as in fusion plasmas. The present study will find an engineering utilization of the plasma instabilities for electric propulsion and open a door for new perspective of the role of the plasma waves.

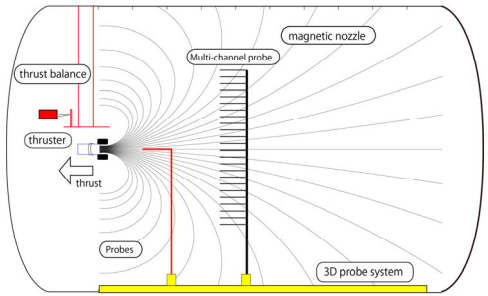


Figure 2. Schematic of typical experimental setup.

Figure 3. Representative photos of the experimental devices.

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