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# Research on Advanced Electrodeless Plasma Rocket: HEAT (Helicon Electrodeless Advanced Thruster) Project

# 先進的無電極プラズマロケットエンジンの研究：HEAT (Helicon Electrodeless Advanced Thruster) Project

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Electric thrusters can provide high specific impulse; therefore, they are suited for long time missions. However, many of conventional plasma thrusters suffer from the life-time limitation due to the electrode erosion, and the electrodeless configuration is one solution for the problem. We have initiated the HEAT (Helicon Electrodeless Advanced Thruster) project to develop an advanced plasma thruster using a helicon plasma source and RF-based electrodeless plasma acceleration schemes. We have been conducting experimental, numerical and theoretical studies, and our research activities are reviewed in this paper.

## 1. Introduction

Electric propulsion can provide significantly higher specific impulse ($I_{sp} = v_e/g$; $v_e$ and $g$ are the exhaust velocity and the gravitational acceleration, respectively), that is, higher velocity increment of a spacecraft can be obtained. The successful mission of HAYABUSA, which utilized ion engines, shows the effectivity of electric propulsion in a long time space mission. However, many of conventional electric propulsions have a problem in life time due to the electrode erosion in plasma production and acceleration processes. The electrodeless configuration is a promising solution, and development of electrodeless plasma thruster is one of the important issues. Several electrodeless thruster concepts have been investigated worldwide (for example, see [1]), and we have initiated HEAT (Helicon Electrodeless Advanced Thruster) project to investigate our original idea of electrodeless plasma thruster. Our concept is based on the utilization of a helicon plasma source (high density up to $10^{19}$ m$^{-3}$) and RF (Radio-Frequency) based plasma acceleration schemes. In this paper, as a review of our project, the development of a helicon plasma source and current research status of the plasma acceleration schemes are presented.

## 2. Thruster Concept

Figure 1 shows the schematic of our thruster concept. In the plasma production part, dense plasma is produced using helicon waves. In the downstream of the plasma source, additional input of RF power accelerates the plasma to high velocity in the static divergent magnetic field. We consider three acceleration schemes: 1) a Rotating Magnetic Field (RMF) acceleration, 2) a Rotating Electric Field (REF) acceleration, and 3) the ion cyclotron resonance (ICR) acceleration with a ponderomotive force acceleration (PA).

## 3. Helicon Plasma Source

Helicon plasma source can efficiently produce dense plasma with a wide-range of the control parameters; therefore, it is suited for the application to plasma thrusters. We have developed helicon plasma sources of various sizes (from 2.5 cm to 74 cm in diameter), and successfully produced dense plasma ($n_e$ up to $10^{19}$ m$^{-3}$) which is applicable to various-scaled plasma thruster (from laboratory small models to high power large thrusters) [2].

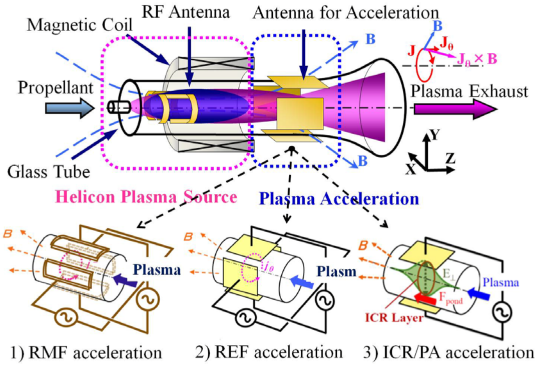


Fig.1. Thruster and plasma acceleration schemes.

### 4. Rotating Magnetic Field Acceleration

This idea is originated from the Field-Reversed Configuration concept [3]. The azimuthal electron current ($j_\theta$) driven by the RMF is a source of the electromagnetic force accelerating the plasma; i.e. $j_\theta \times B_r$ in the static divergent magnetic field, where $B_r$ is the radial component of the field. The theoretical estimation shows several tens mN of thrust, which is enough for a thruster, can be obtained in our typical experimental condition. The initial RMF experiments have been conducted using the Large Mirror Device at Kyushu Univ. Almost full penetration of RMF into plasma was confirmed using a magnetic probe, and a small increment of the Mach flow velocity was measured by an axial probe. Further experiments have been conducted at Tokyo Univ. of Agriculture and Tech. (TUAT).

### 5. Rotating Electric Field Acceleration

In this scheme, the $j_\theta$ is driven by the REF; the E×B drift gyration motion of electrons at the REF frequency is a source of $j_\theta$ [4]. Feasibility study is under way using several approaches. Theoretical thrust model has been developed and the analysis shows that several mN thrust can be obtained in our typical experimental condition. The REF experiments have been conducted at TUAT, and a small velocity increment has been observed by a Mach probe (Fig. 2). We are trying to optimize the experimental condition with the aid of the theoretical and numerical analysis. Direct thrust measurement has been started at ISAS/JAXA, and several mN thrust force without REF was successfully measured by a thrust stand, where $I_{sp}$ is about 100-200 s.

### 6. ICR/PA Acceleration

In this acceleration scheme, ions are heated by the ICR, and their perpendicular energy is converted into the parallel energy while ions travel through the divergent magnetic field. Additional acceleration by the pondermotive force [5] can be expected, when the resonance point corresponds to the peak of the RF wave energy density. In this scheme, the ICR and the PA are inseparable, but the PA is preferred because this scheme has less effect of the wall interaction. We have conducted test particle simulations, and the ICR/PA acceleration mechanism through the resonance point was clarified (Fig. 3 shows a typical result of the particle simulation). Now, we have initiated a proof of principle experiment at Tokai University.

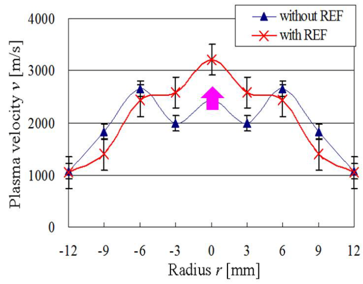


Fig.2. REF experiment; radial distribution of the plasma velocity in the plasma plume.

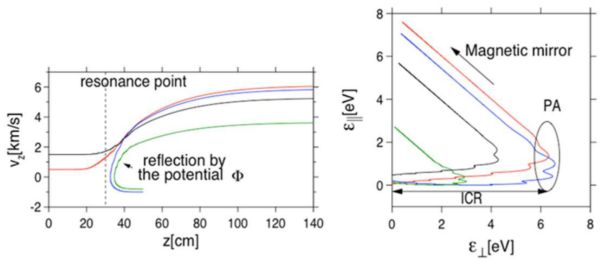


Fig.3. Particle simulations; (left) ion trajectory, (right) perpendicular energy vs. parallel energy.

### 7. Summary

In order to develop the electrodeless plasma thruster, we have initiated the HEAT project. helicon plasma sources of various sizes have been successfully developed. We have proposed three types of plasma acceleration schemes (RMF, REF and ICR/PA), and feasibility studies are under way using theoretical, numerical and experimental approaches.

### References


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