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Research on Completely Electrodeless Electric Thrusters using High-Density Helicon Plasmas - the HEAT Project and Related Topics

高密度ヘリコンプラズマを用いた完全無電極電気推進研究 －HEATプロジェクトを中心に

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Although high specific impulse can be provided by electric propulsion systems, many of conventional electric thrusters suffer from a problem of finite lifetime due to the electrode wastage. To solve this problem, we have executed the HEAT (Helicon Electrodeless Advanced Thruster) project to develop completely electrodeless advanced-concept electric thrusters. The entire process, i.e., a high-density (up to 10^{13} cm^{-3}) plasma production by helicon waves and its electromagnetic acceleration by novel proposed methods, can be achieved without using any eroding electrodes. Here, as a review in our project, some experimental and theoretical approaches to realize this concept along with related topics are presented.

1. Introduction

Higher specific impulse I_{sp} can be provided by electric propulsion systems compared to chemical ones. However, present-time electric plasma thrusters suffer from a problem of finite lifetime due to the erosion of various electrodes that are in direct contact with plasmas. In order to solve this problem, several novel methods, e.g., VASIMR concept [1], are proposed, mostly using helicon plasma sources [2,3].

Here, helicon plasmas have been proven to be very effective for use in fundamental research as well as in a variety of additional applications. This is because that the helicon sources can produce high-density (~ 10^{13} cm^{-3}) plasmas with a broad range of external operating parameters.

In this paper, we discuss the applicability of our helicon sources with new electrodeless acceleration schemes as the Helicon Electrodeless Advanced Thruster (HEAT) project [4,5].

2. High-Density Helicon Plasma

We have examined up to eight high-density helicon plasma sources with various external parameters. High-density plasmas were successfully produced with a diameter ranging from 0.5 [5] to 74 cm [4] as well as with an axial length from 5.5 to 486 cm [4], which enabled to predict the excellent scalings of the plasma production efficiency [4]: total number of produced electron-ion pair divided by electron density vs. input radio frequency power. Furthermore, the selective excitation of the azimuthal mode number was also demonstrated [5,6].

This makes these sources promising for use in the development of the next generation electrodeless thrusters, as well as for fundamental research and industrial applications.

3. Electrodeless Acceleration Schemes

We have proposed and examined many acceleration methods [5] by external means, such as the Rotating Magnetic Field (RMF), Rotating Electric Field (REF) and Ponderomotive Acceleration (PA) with Ion Cyclotron Resonance (ICR) acceleration schemes, along with sole, simple high-density helicon acceleration. In these concepts, as shown in Fig. 1, the acceleration electrodes (and production antennas) are indirect contact with the plasma, leading to a longer lifetime operation because of the reduction in the strong plasma–wall interactions. In these schemes, the axial component of the magnetic field B_z is necessary.

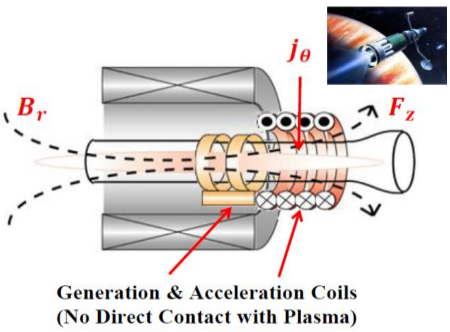

Fig.1. Conceptual idea of electrodeless helicon thruster.

In addition, the RMF and REF schemes require the radial component of the magnetic field B_r, because the B_r and the induction of the azimuthal current density j_θ in the two schemes create the axial thrust F_z by the electromagnetic (EM) force, $j_\theta \times B_r$.

Here, by the RMF method, the increase in the flow velocity by ~ 15 % was ascertained experimentally. Although the increase in this velocity was also found, further studies are necessary in the REF method, choosing operational parameters: Numerical calculations of the REF and PA/ICR methods have been carried out to derive optimal operational windows.

Simple helicon discharge using a target thrust stand [7] showed that in the middle sized helicons, diameters of 5 and 10-15 cm (tapered discharge tube), I_{sp} were 840 and 2,000 s, respectively, for Ar plasmas. The ratio of the thrust to rf input power was 8.5 and 16 mN/kW, respectively, for Ar and Xe discharges. Here, the maximum thrust was 41 mN for 3 kW input power for Xe plasmas. Small diameter of 2 cm case using SHD [8] showed that the lighter ions have higher velocity: hydrogen case showed the ion velocity was up to ~ 30 km/s (I_{sp} ~ 3,000 s) by Mach probe measurements.

4. Conclusions

We have reviewed our recent studies that were performed within the HEAT project, on high-density (~ 10^{13} cm^{-3}), helicon plasma production and its acceleration schemes.

Here, the availability of the helicon plasmas, which can accept various external parameters with a good production efficiency, to electrodelss thrusters was discussed.

Next, the proposed acceleration schemes, such as the RMF, REF and PA/ICR along with sole, simple helicons, were discussed from the viewpoint of their application in the development of advanced electrodeless plasma thrusters.

To verify and improve these schemes, further studies are required to extend our understanding on the related physical phenomena and to specify the most appropriate parameter ranges

Acknowledgments

The author would like to acknowledge the great contributions made by late Prof. K. Toki and late Dr. K. P. Shamrai. Members of the Heat project are also acknowledged.

This work was supported in part by the Grant-in-Aid for Scientific Research (S: 21226019) from the Japan Society for the Promotion of Science.

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