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Dispersion relation of helicon waves in a non-uniform cylindrical plasma

ISAYAMA, Shogo[1*], HADA, Tohru[1], TANIKAWA, Takao[2], Shunjiro Shinohara[3]

[1]Graduate School of Engineering Sciences, Kyushu University, [2]Research Institute of Science and Technology Tokai University, [3]Tokyo University of Agriculture and Technology

Electric thrusters, characterized with high specific impulse, are considered to be useful for long term space missions such as those to outer planets. On the other hand, the performance of many of the conventional electric thrusters (e.g., ion engines) is limited by electrode wastage. In order to overcome this difficulty, we have initiated the HEAT (Helicon Electrode less Advanced Thruster) project[1], in order to pursue research and development of completely electrodeless (i.e., no direct contact of electrodes with plasma) thrusters.

The electrodeless thrusters are comprised of a plasma generation part and the plasma acceleration part. Understanding of these parts is a challenging issue both from the plasma physics and technology points of view. While efficient plasma production using a "helicon wave" is well established experimentally, there still remain a number of unsolved issues regarding how the plasma is generated using the helicon wave. This is due to the complexity of the problem: one needs to understand how the helicon waves propagate in the plasma, how electrons are accelerated by the waves, how neutrals are ionized, how the wave dispersion relation is modified as the ionization rate is increased, and how these processes interact with each other.

As a first step to solve this problem, we studied what kind of electric field can be generated when the helicon wave propagates into a non-uniform plasma and how it accelerates the electrons. Previous studies show that an electrostatic wave called TG wave is excited as the helicon wave propagates into the non-uniform plasma, and that these TG waves accelerates the electrons efficiently and plays a crucial role in the plasma production[2]. Depending on the propagation/evanescence of the helicon and the TG waves, the plasma can be divided into three distinct regions (Fig.1). We analyzed detailed wave properties of both the helicon and the TG waves in the three regions within the approximation of the WKB. To be exact, on the other hand, since the helicon wavelength can be comparable or longer than the density gradient scale, and since the non-uniform background makes the Fourier formulation inapplicable, propagation of the waves has to be treated as an eigenvalue problem.

Considering the above, we solved the propagation, damping, and mode conversion of the helicon and the TG waves in a non-uniform plasma, numerically using the shooting method. Radial and anti-radial propagating waves of both the helicon and the TG waves co-exit in the system. Energy loading (wave damping) due mainly to the TG waves is analyzed for varying external parameters including the electron-neutral collision frequency.

Keywords: Electric thrusters, The electrodeless thrusters, Helicon plasma, Helicon wave, TG wave, Dispersion relation

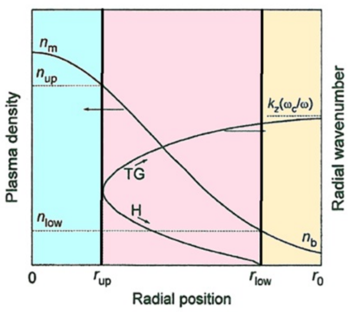

Fig.1 Density profile and solutions of Helicon and TG
・Domain a($n>n_{up}$) : Helicon wave and TG wave can't propagate.
・Domain b ($n_{low}<n<n_{up}$) : Helicon wave and TG wave can propagate.
・Domain c ($n<n_{low}$) : Helicon wave can't propagate, TG wave can propagate.