§13. Ion Heating Experiment in a Supersonic Plasma Flow Passing Through a Magnetic Nozzle

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Recently a plasma flow has been recognized to play an important role in space and fusion plasmas. Intensive researches to develop a fast flowing plasma with high particle and heat fluxes are required for the purpose of basic plasma researches as well as various wall material researches and space applications.

A magnetic nozzle acceleration and ion heating in a fast flowing plasma attracts much attention in an advanced electric propulsion system. In the Variable Specific Impulse Magnetoplasma Rocket (VASIMR) project, it is proposed to control a ratio of specific impulse to thrust at constant power.[1] This is a combined system of the ion cyclotron heating and the magnetic nozzle, where a flowing plasma is heated by ICRF (ion cyclotron range of frequency) power and the plasma thermal energy is converted to a flow energy via a magnetic nozzle.

The purpose of this research is to investigate effective methods of wave excitation and to establish the ion heating technology in a fast flowing plasma for an advanced plasma thruster and other applications.

We have performed an ion heating experiment in a supersonic plasma flow produced in the HITOP device.[2,3] RF waves are launched by two types of a helically-wound antenna in a helium or argon plasma. One is a right-handed helically-wound antenna, which is called a right helical antenna, shown in Fig.1. The other is a left-handed one, which is called a left helical one. These antennas can excite RF waves with an azimuthal mode number of $m=-1$ and $+1$, respectively. One of the antennas is set at Z=0.6m downstream of the MPDA. The antenna current is supplied by an inverter-type power-supply operated with a pulsed mode. The oscillating frequency can be changed from 20kHz to 160kHz by controlling an external oscillator.

Figure 2 shows typical waveforms of the discharge current I_d, the antenna current I_{RF} and an observed diamagnetic signal $W_\perp$. The diamagnetic coil signal, which is measured by a diamagnetic loop coil located at Z=2.23m, apparently increases during the RF excitation.

To confirm the ion heating we have measured an ion and electron temperature and density spatial profiles. The ion temperature T_i increases from 3.9eV to 6.3eV and also electron temperature T_e from 1eV to 1.5eV. The electron density is $1\times10^{19}\mathrm{m}^{-3}$ and slightly decreases during the RF excitation. The measurement time is just after RF- pulse-off time to eliminate the RF effect in the probe measurement. The increment value of $W_\perp$ is quantitatively agrees with the increment of T_i and T_e.

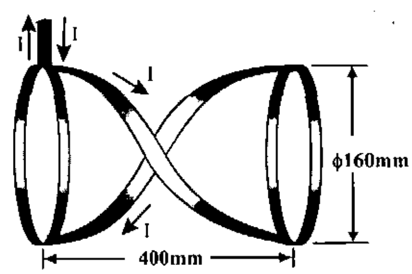

Fig. 1 Schematic of the right helical antenna.

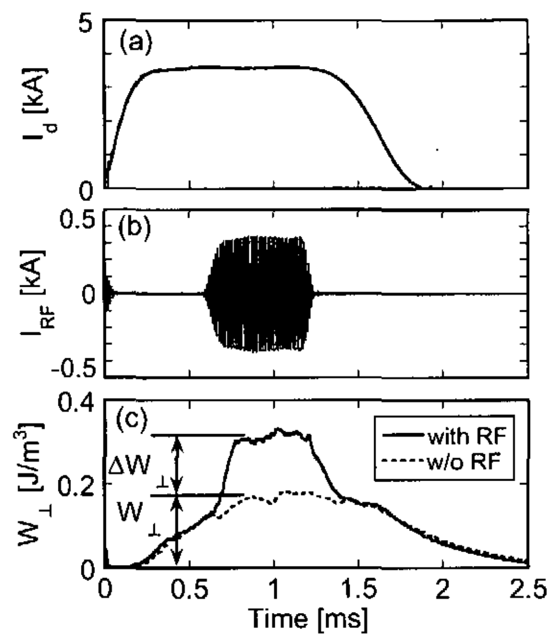

Fig.2 Temporal evolutions of (a) I_d, (b) I_{RF} and (c) $W_\perp$. Helium plasma. B_Z=0.7kG(uniform). f_{RF}=80kHz (ω/ω_{ci}=0.3).

A heating efficiency is compared for various cases of the magnetic field configuration and strength. There are no difference caused by the magnetic field configuration, and no clear indication of the cyclotron resonance of thermal ions is observed. The reason is that the ion-ion collision frequency ν_{ii} is larger than the ion cyclotron frequency f_{ci} under the experimental conditions and the waves are damped not by cyclotron resonance but by collisional damping. This damping mechanism should play an effective role in an MPD thruster operation with a high density plasma and a lower magnetic field. This heating scenario is feasible in space applications. Heating experiments in a lower-collisionality plasma are under preparation.

References

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2) M.Inutake, *et al.*: Proc. of 26th ICPIG, (2003). Vol.1, p.127.
3) A.Ando, *et al.*: Advances in Applied Plasma Science, 4 (2003) 193.