

## §14. Ion Heating in a Supersonic Plasma Flowing 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 an ion cyclotron heating and a magnetic nozzle, where a flowing plasma is heated by ICRF (ion cyclotron range of frequency) power and the plasma thermal energy is converted to flow energy via a magnetic nozzle.

The purpose of this research is to investigate effective methods of wave excitation and to establish an ion heating technology in a fast flowing plasma for the 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 a right-handed helically-wound antenna in a helium plasma. This antenna is set at  $Z=0.6\text{m}$  downstream of the Magneto-Plasma-dynamic Arcjet (MPDA) and excite RF waves with an azimuthal mode number of  $m=-1$ . The RF frequency can be changed from 100kHz to 500kHz with an input power up to 15kW.

When RF waves excited in a flowing plasma with a density around  $1 \times 10^{13} \text{cm}^{-3}$ , we observed an increase of plasma stored energy  $W_{\perp}$  measured by a diamagnetic coil located at  $Z=2.23\text{m}$  downstream from the MPDA. Ion temperature  $T_i$  also increased during the RF pulse. However, no clear indication of the cyclotron resonance is observed, because the ion-ion collision frequency  $\nu_{ii}$  is larger than the ion cyclotron frequency  $f_{ci}$  in the high density region and the waves are damped not by cyclotron resonance but by collisional damping. We decreased a plasma density from  $1 \times 10^{13} \text{cm}^{-3}$  to  $5 \times 10^{11} \text{cm}^{-3}$  so that the cyclotron heating phenomena appeared and a diamagnetic coil signal  $W_{\perp}$  increases drastically as shown in Fig.1. It is also observed that the peak position is shifted to lower magnetic field than that corresponding to  $\omega/\omega_{ci}=1$ , i.e.  $\omega/\omega_{ci}$  higher than 1. This is due to the Doppler effect caused by the fast plasma flow.[4]

Figure 2 shows a dependence of  $W_{\perp}$  on the RF input power  $P_{RF}$ . It linearly increases with  $P_{RF}$ . We have also measured ion temperature by an electrostatic energy analyzer, of which collection surface faces to perpendicular direction to the plasma flow. The perpendicular component of ion temperature  $T_{i\perp}$  can be obtained. When  $P_{RF}$  increases,  $T_{i\perp}$  increases almost linearly as shown in Fig.3.

Experimental researches on the energy conversion from thermal energy to flow energy by a magnetic nozzle should be pursued further.

### Reference

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- 2) M.Inutake, et al.: Proc. of 26th ICPIG, Vol.1, (2003), p.127.
- 3) A.Ando, et al.: Advances in Applied Plasma Science, 4 (2003) 193.
- 4) A.Ando, et al.: Proc. the 7th APCPST, (Fukuoka, 2004), A2 (2004) 45.

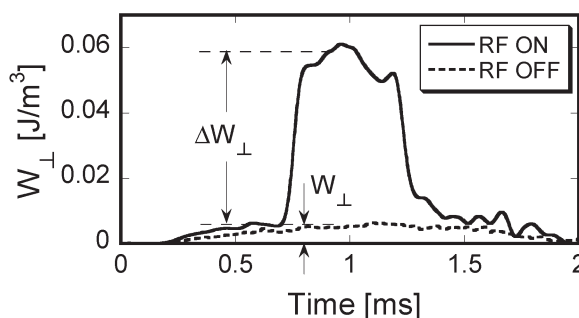


Fig.1 Time evolutions of diamagnetic coil signal  $W_{\perp}$ .  $f_{RF}=236\text{kHz}$ ,  $P_{RF}=15\text{kW}$ .

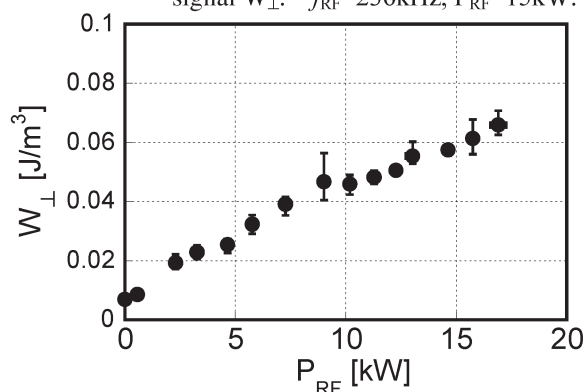


Fig.2 Dependence of diamagnetic coil signal  $W_{\perp}$  on input RF power  $P_{RF}$ .  $f_{RF}=236\text{kHz}$ .

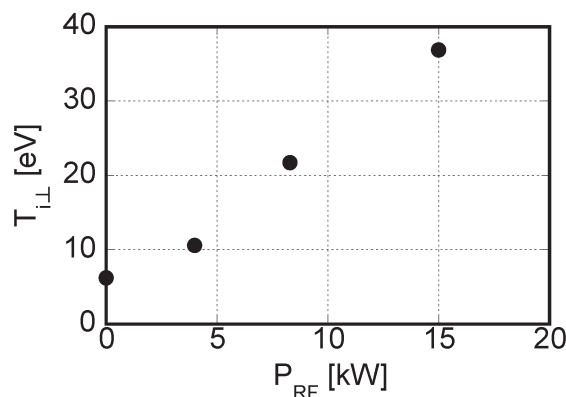


Fig.3 Dependence of perpendicular component of ion temperature  $T_{i\perp}$  on input RF power  $P_{RF}$ .  $f_{RF}=236\text{kHz}$ .