§1. Control of Ion Acceleration by RF Waves in a Fast-flowing Plasma

Ando, A., Jo, S. (Dept. Electrical Eng. Tohoku Univ.)

Ion heating and magnetic nozzle acceleration in a fast-flowing plasma attracts much attention as a new control method of flow energy in various applications. Especially, an advanced electric propulsion system requires a control method of plasma exhaust energy. In the Variable Specific Impulse Magnetoplasma Rocket (VASIMR) project, it is proposed to control a ratio of specific impulse to thrust at constant power. This is a combined system of an ion cyclotron heating and a magnetic nozzle, where flowing plasma is heated by ICRF (ion cyclotron range of frequency) power and the plasma thermal energy is converted to flow energy by passing through a magnetic nozzle.

The purpose of this research is to investigate an ion heating and acceleration phenomena in a fast-flowing plasma in order to control the flow energy.

We have successfully demonstrated the ion heating and acceleration in a magnetic nozzle using helium and hydrogen gases in the HITOP device.[1),2)] A magneto-plasma-dynamic arcjet (MPDA) was utilized as a plasma source, and RF waves in the frequency range of 0.1MHz to 1MHz were launched by the right-hand helically wound antenna set at Z=0.6m downstream of the MPDA. Plasma thermal energy and ion temperature were clearly increased when n_e was below 10^{18}m^{-3}.[3),4)]

The increased thermal energy was converted to flow energy by passing through the diverging magnetic nozzle. The energy conversion occurred so as to keep the magnetic moment μ constant. Additionally, we found an electric field appeared along the diverging magnetic field.

When the RF power P_{RF} increased, the plasma thermal energy $W_\perp$ measured by a diamagnetic coil at Z=2.33m increased almost linearly with P_{RF}. However, it tends to saturate in higher P_{RF} region more than 20kW as shown in Fig.1. The saturation was caused by the loss of higher energetic ions with 100eV, where the ion Larmour radius becomes larger and attained to several cm, which is same as a plasma radius.

In order to confirm the effect of large Larmour radius, directional electrostatic energy analyzers were installed at different radial positions. Figure 2 shows the energy analyzer signals measured at each radius, where the direction of correction orifice was faced upward and downward. At the center position (X=0) the signals were similar to each other and show the existence of higher energetic ions. At the peripheral region, higher energetic components were detected in one direction only, which corresponds to the direction of Larmour motion of ions in the magnetic field. As a consequence of high power ICRF heating, ion Larmour radius becomes large and comparable to the plasma radius, which results in the loss of the energetic ions.

It suggests that higher magnetic field should be necessary to avoid the loss of these energetic ions.

1) H. Tobari, et al., Physics of plasmas, **14** (2007) 093507.
2) M. Inutake, et.al., Plasma Phys. Cont. Fusion, **49** (2007) A121.
3) A.Ando, et.al., Physics of Plasmas, **13** (2006) 057103.
4) A.Ando, et.al., Transaction of Fusion Science and Technology, **51** (2007) 72.

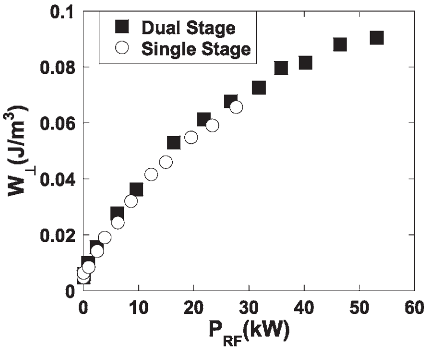

Fig. 1 Dependence of $W_\perp$ on input RF power P_{RF} by using single and dual stage of FET inverter power supply. He plasma.

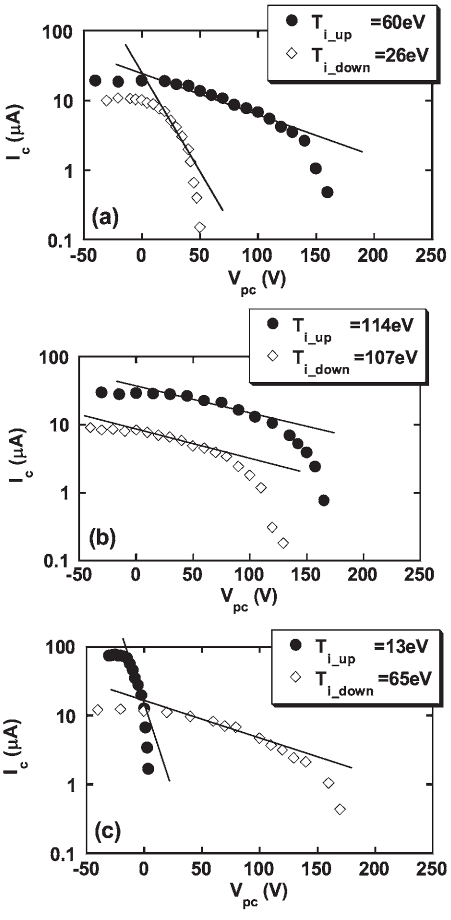

Fig.2 Electrostatic energy analyzer signals measured at different radial positions (a)X=+10cm, (b)X=0cm, (c)X=-10cm. Z=2.33m. Correction orifice was faced to upward (closed circles) and downward (open diamonds).