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

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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 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.

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 require 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 a 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)-3)] Figure 1 shows typical magnetic field configuration and locations of a magneto-plasma-dynamic arcjet (MPDA), RF antenna and diagnostics. 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 $10^{18}\mathrm{m}^{-3}$.

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. The plasma potential was measured by an emissive probe in the diverging field downstream. As shown in Fig.2, an electric field in the direction of ion acceleration was generated with RF excitation. It was caused by the ambipolar effect along the magnetic field, and the potential profile well corresponded to the Boltzman's equation considering the density decrease.

In order to investigate the effect of higher power RF excitation, we have raised the RF power P_{RF} by adding a FET stage of the inverter power supply. The plasma thermal energy $W_{\perp}$ measured by a diamagnetic coil increased almost linearly with P_{RF} below 20kW. However, it tends to saturate in higher P_{RF} region. The ion Larmor radius becomes larger and attained to several cm, which is same as a plasma radius. The saturation occurred because loss of higher energetic ions with 100eV became large. Higher magnetic field is necessary to avoid the loss of these energetic ions.

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

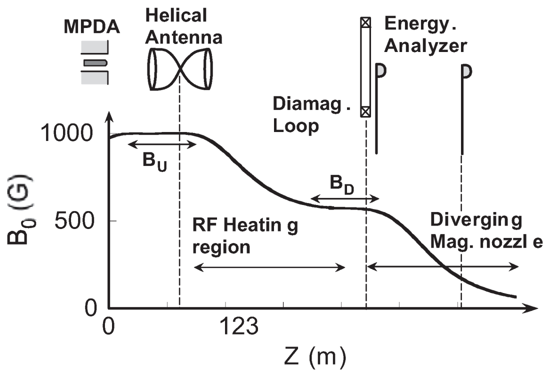

Fig. 1 Magnetic field configuration and locations of a helical antenna, a diamagnetic loop and electrostatic energy analyzers (Faraday Cup).

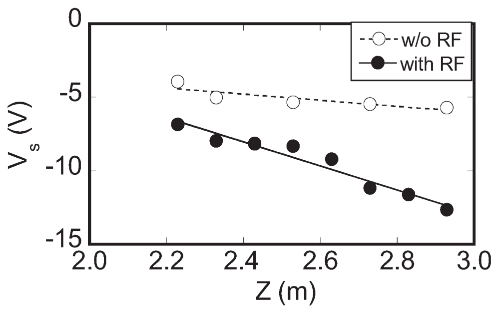

Fig. 2 Axial profile of plasma potential with or without RF excitation. He plasma.

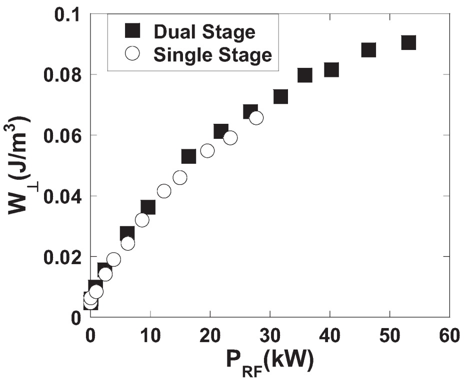

Fig. 3 Dependence of $W_{\perp}$ on input RF power P_{RF} by using single and dual stage of FET inverter power supply. He plasma.