§ 17. 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.

It is also important in other applications to control the balance between particle thermal energy and flow energy. One of the key technologies is ion heating of a fast flowing plasma by using radio frequency(RF) waves. Though ion heating in a magnetically-confined plasma has been precisely investigated both theoretically and experimentally in many researches, few attempt of a direct ion heating for fast flowing plasmas by RF waves has been done. Ion heating in a fast flowing plasma is difficult because of the short transition time for ions passing through a heating region only once and of the modification of ion cyclotron resonance due to the effect of Doppler shift.

The purpose of this research is to investigate effective methods of ion heating 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 with a non-axisymmetric azimuthal mode near the ion cyclotron frequency (f_{ci}= $\omega_{ci}/2\pi$=20kHz at B_z= 526G) is launched by a pair of loop-type antennas in an argon plasma. Figure 1 shows schematic of the antenna, which is set at Z=1.03m downstream of the MPDA. The wave with an azimuthal mode number of m=0, ± 1, ± 2 can be excited by adjusting the combination of the antenna current and orientation. The antenna current is supplied by a pulsed oscillation power-supply, which consists of a condenser and a gap-switch.

An axial profile of the magnetic field is set as a magnetic beach configuration so that the wave is excited in $\omega/\omega_{ci} < 1$ region and propagates downward approaching to the region of $\omega/\omega_{ci} = 1$. Figure 2 shows typical waveforms of the discharge current I_d, the antenna current I_{RF} and an observed diamagnetic signal $W_\perp$. Though the antenna current damps rapidly due to the lack of power supply capability, the diamagnetic coil signal, which is measured by a diamagnetic loop coil located at Z=2.23m, increases during the excitation. We also confirmed the ion heating from the data of an increase in ion temperature T_i measured by an electrostatic energy analyzer.

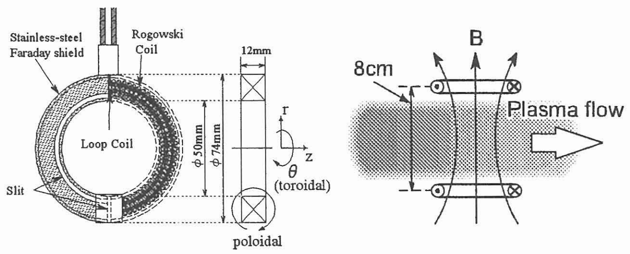

Fig.1. Schematic of RF-Antenna and setting of a pair of antennas to excite m=$\pm$1 mode.

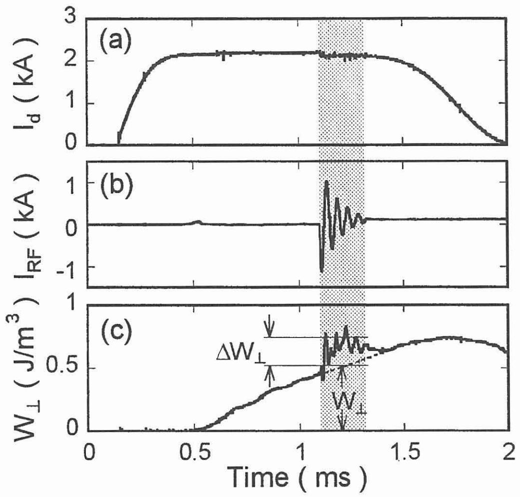

Fig.2. Typical time evolutions of the discharge.

We have varied an azimuthal mode number of the excited waves, m=0, ± 1, ± 2, by changing the loop coil arrangement. An increment ratio of the thermal energy $\Delta W_\perp / W_\perp$ is the largest in the case of m=$\pm$1.

Experiments are performed in various magnetic field configurations. The heating efficiency is large in a magnetic beach configuration, though the dependence on the magnetic field strength shows no clear indication of the ion cyclotron resonance region of thermal ions. It should be caused by the Doppler effect of fast flowing ions.

References

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