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Observation of Ion and Electron Flows across Magnetic Field Driven by Space Potential Gradient in Simple Toroidal ECR Plasmas

単純トロイダルECRプラズマにおける空間電位勾配により駆動される磁場を横切るイオンと電子流の観測

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Suppose an electron cyclotron resonance (ECR) plasma immersed in a simple toroidal field. The electrons drift downward while the ions drift upward due to the field gradient and curvature. A vertical electric field arises and the radial E × B drift might sweep the plasma away but ECR plasma is stably maintained as long as the microwave is incident. We observed the plasma in the low aspect ratio torus experiment (LATE) device using a 2.45 GHz microwave power around 1 kW. We found a potential hill on the poloidal cross section to adjust the flow of the plasma.

1. Introduction

Suppose an electron cyclotron resonance (ECR) plasma immersed in a toroidal field. The electrons drift downward while the ions drift upward due to the field gradient and curvature (B_ϕ>0 is assumed), being referred to as vacuum toroidal field (VTF) drift. A vertical electric field arises and the radial E × B drift might sweep the plasma away and terminate the discharge. Many experiments in past decades, however, showed that ECR plasmas were easily initiated and maintained by the microwave power. This result indicates that steady flows of electrons and ions from the source to the surrounding conducting walls are always realized.

2. Experiment

In order to find in what way the electrons and ions flow we have done experiments in the low aspect ratio torus experiment (LATE) device using a 2.45 GHz microwave. Four different ECR discharges, hydrogen discharges by microwave injection power of Pinj=0.5, 1.0 or 1.9 kW and an argon discharge by Pinj=1.2 kW have been done. We have set the top and bottom panels in the cylindrical vessel, which and the vessel wall constitute the conducting boundary, and fabricated electrode arrays, an ion energy analyzer and Langmuir probes for diagnostics. Fig.1

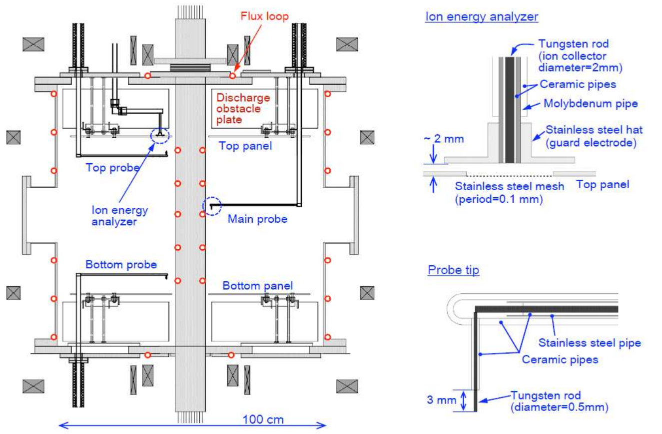

Fig.1. Side view of LATE discharge chamber for present experiment with enlargement of the ion energy analyzer and the probe tip.

3. Experimental results and analysis

A CCD plasma image and profiles of the electron pressure (pe) and space potential (Vs) on the poloidal cross section during the steady duration of the 1.9 kW hydrogen discharge are shown in Fig.2.

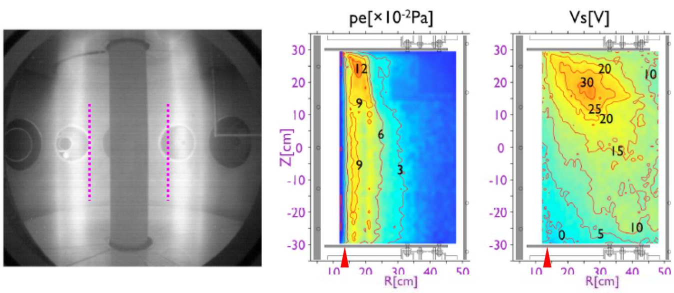

Fig.2. A CCD plasma image and plasma profiles of hydrogen discharge by microwave power of 1.9 kW

We have found that a vertically uniform ridge of electron pressure that also constitutes the source belt of electron impact ionization is formed along just lower field side of the ECR layer and a cross-field potential hill (Vs~=30 V while Te~ =10eV), eccentrically shifted toward the corner formed by the top panel and the ECR layer, arises. In order to analyze the electron and ion flows due to the VTF and E×B drifts on the poloidal cross section we first have done profile-smoothing for the profiles using appropriate polynomialexpressions for coordnates R and Z to fit the smoothed profiles to the measurement results. Figure.3 show the flows using blue arrows for the local flux density vectors, $\Gamma_{E\times B}$, Γ_{eVTF} and $\Gamma e = \Gamma_{E\times B} + \Gamma_{eV\,TF}$, respectively, where the vectors are weighted by 2πR

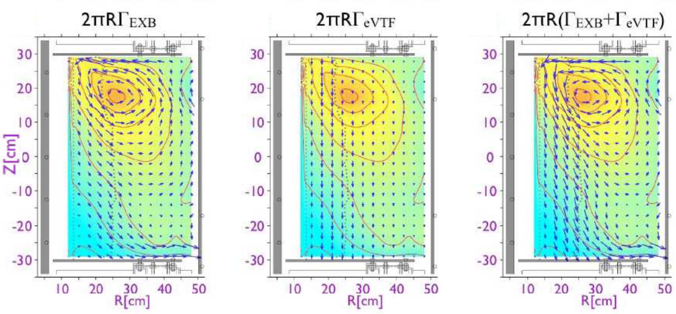

Fig.3. flux flows on the smoothing space potential. Analyses for the 1.9 kW hydrogen plasma.

Combination of electron production and ECR-driven VTF drift of these electrons along the pressure ridge is the primal engine and maintains the plasma with the potential hill. Combination of the hill-driven E×B drift and the VTF drift realizes steady flows of electrons and ions from the source to the boundary. In particular, the ions, of which VTF drift velocity is much lower than the electron VTF drift velocity near the source belt, are carried by the E×B drift around the hill to the vicinity of the top panel, where the ion VTF drift is enhanced on the steep down slope of potential toward the top panel. On the other hand the electron temperature strongly decreases in this area. Figure.4 shows calculated result of numerical simulation based on the single particle motion of ions. the result suggest the carrier of VTF drift current is replaced from the electrons to the ions before the top panel, enabling the current circulation through the top and bottom panels and the vessel (electrons mainly to the bottom and ions mainly to the top) and keeping charge neutrality very high. The deviation of the electron charge density from the ion density is as low as ~ 10^{-3}%.

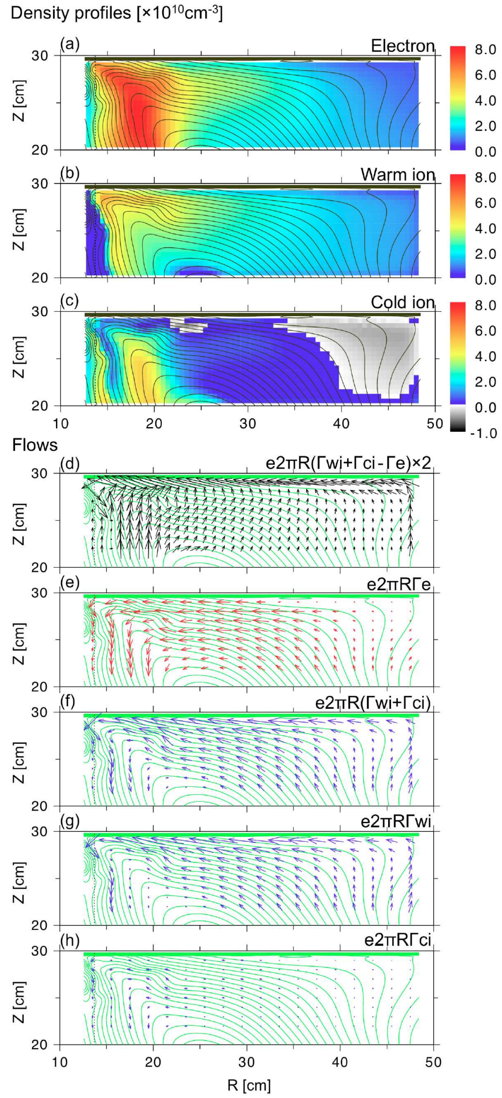

Fig.4. Simulation results for ion enhanced drift toward the top panel driven by the cross field potential hill. (a) electron density profile, (b) and (c) density profiles of warm and cold ions, respectively, flow patterns of (d) electric current, (e) electrons, (f) ions, (g) warm ions and (h) cold ions. Analyses for the 1.9 kW hydrogen plasma. Density and flow of warm ion are calculated from a large number of ions that start from starting line from R=27.9 cm to 48.1 cm on Z=20 cm, where ion have a Maxwellian velocity distribution with a same temperature $T_{i\text{-}ini}$=2 eV on the starting line with the starting density set to be the density given in (a). Density of cold ion is difference of electron density and calculated density of warm ion which may correspond to the density of low temperature ion just produced via electron impact ionization.