§16. Study on Electron Bernstein Wave Heating and Current Drive in High Density Plasmas

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Electron Bernstein wave (EBW) is an electrostatic wave near the electron cyclotron (EC) range of frequency and has distinct features compared to the electromagnetic waves. It is excited by mode-conversion at the upper hybrid resonance from the injected electromagnetic waves, and can propagate into a high density plasma core without density limit. It can heat the plasma and drive plasma currents by EC damping at EC harmonics even in a low temperature plasma. It is very important to use EBW for heating and current drive of over-dense plasmas where the conventional method with electromagnetic waves is incapable. The purpose of this study is to establish the physical basis of mode-conversion, EC heating and current drive with EBW in torus plasmas through experiments on the LATE device[1], and to research application to the LHD plasma.

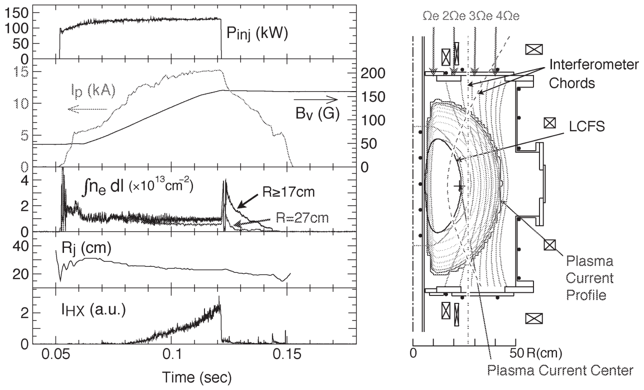

Fig. 1. Discharge waveforms and contour plotting of poloidal flux and plasma current density when the plasma current is ramped up to 15.3 kA.

By injecting a 5GHz, 130 kW, 70 ms microwave pulse under a toroidal field of 624 G and a vertical field of 50 G, breakdown occurs at the fundamental EC resonance layer and a small initial toroidal current appears. Then, the current increases rapidly in about 6 ms and the closed flux surfaces are formed spontaneously (Fig. 1). After the formation of the closed flux surfaces, plasma current increases as the vertical field strength is increased. The plasma current Ip reaches 15.3 kA at the end of the microwave pulse with the vertical field of 160 G[2], which amounts to ~20% of the total toroidal coil current. The last closed flux surface has an aspect ratio of ~1.7 and the spherical tokamak equilibrium is formed.

The electron density is ~ 4 x 10^{17} m^{-3} and exceeds the cutoff density for the 5 GHz microwave. The plasma current center and the strong soft X-ray emission region locate near the second and the third EC harmonic layers. These facts show that the heating and the current drive is brought about by the mode-converted EBW.

During the current rise, strong X-ray emission with photon energy of ~ 100 keV is observed. X-ray energy spectra are obtained by pulse height analysis (PHA) systems with Cd-Te detectors. The each line-of-sight is shown in Fig. 2. One of the angles to the magnetic field line at R = 25 cm is 0˚ (denoted by "forward") and the other is 180˚ ("backward"). In Fig. 3, X-ray energy spectra obtained during the 0.2 sec flat top period at Ip = 5 kA are shown. The photon count in the "forward" direction is two or three times larger than that in the "backward" direction. This result means that the number of electrons moving in the opposite direction to the plasma current is at least 5 times larger than that of electrons moving in the reverse direction, and then, an anisotropic velocity distribution of high energy tail electrons along the magnetic field is formed by EBW heating.

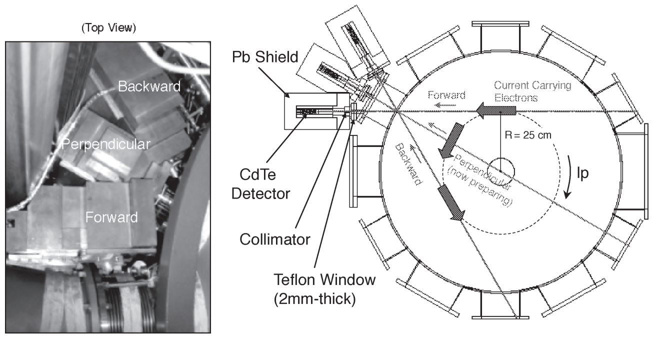

Fig. 2. X-ray PHA system with Cd-Te detectors.

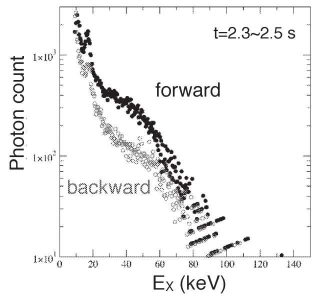

Fig. 3. X-ray energy spectra during the 0.2 sec flat top period at Ip = 5 kA.

The plasma current may be carried by these high energy tail electrons. The reason is that the mean drift speed of current-carrying electrons is estimated to be about one third of the thermal speed, which is too large to attribute the plasma current to bulk electrons. While, the high energy tail electron density estimated from X-ray PHA is ~ 2 % of bulk electrons and that is reasonable. The magnetic measurement shows that the electric field at the current center is negative during the current rise. From these facts, it is concluded that the plasma current is driven and ramped up by directional tail electrons produced by EBW.

Reference

1) H. Tanaka et al., J. Plasma Fusion Res., **82**, (2006) 526.
2) H. Tanaka et al., Proc. 21st IAEA Fusion Energy Conf. (2006) IAEA-CN-149, EX/P6-6.