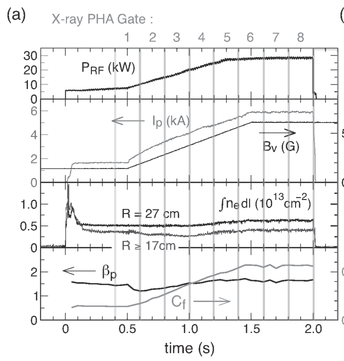
§9. Study on Electron Bernstein Wave Heating and Current Drive in High Density Plasmas

Tanaka, H., Maekawa, T., Uchida, M., Nishi, S. (Grad. School of Energy Science, Kyoto Univ.), Nagasaki, K. (IAE, Kyoto Univ.), Kubo, S., Shimozuma, T., Yoshimura, Y., Igami, H., Notake, T., Yanagi, N.

Electron heating and current drive (ECH/ECCD) in a over-dense plasma is not possible by using conventional electromagnetic waves, but becomes possible when the injected electromagnetic wave is converted at the upper-hybrid resonance layer to an electrostatic mode, i.e., electron Bernstein wave (EBW). It can propagate into a high density plasma core without density limit and can be absorbed by electron cyclotron (EC) damping even in a low temperature plasma. The purpose of this study is to establish the physical basis of mode-conversion, ECH/ECCD with EBW in torus plasmas through experiments in the LATE device[1)], and to research application to the LHD plasma.

On the LATE device, microwaves at 2.45 GHz and/or 5 GHz are injected through circular waveguide-type antennas obliquely to the toroidal magnetic field, expecting mode-conversion to EBW via O-X-B scheme. By applying a weak vertical magnetic field, toroidal plasma current starts up and ramps up as the vertical field is increased, resulting in formation of a spherical tokamak equilibrium without ohmic heating. In Figure 1 (a), the typical time evolution of plasma current and density are shown for the 2.45 GHz microwave injection. The electron density exceeds the plasma cutoff density. Plasma current Ip = 5.9 kA is sustained for 0.5 sec with 28 kW microwave power. The poloidal beta βp is about 1.5 and is due to the high energy electrons carrying Ip. Such high energy electrons emit bremsstrahlung hard X-rays strongly in their moving direction by relativistic effect. Figure 1 (b) shows the time evolution of X-ray energy spectra obtained in each 0.2 sec gate duration. X-ray emission detected in the forward direction of electron drift is more intense and with higher energy than that in the backward direction. The velocity distribution of the high energy electrons is searched by fitting the obtained energy spectra, including βp = 1.5 from magnetics. It is shown that a uni-directional electron tail with energy up to 250 keV and pitch angles to the magnetic field from 0˚ to 75˚ is produced when Ip = 5.9 kA.



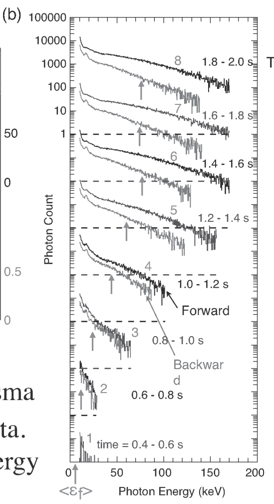


Fig.1 (a) Time evolution of plasma current, density and poloidal beta. (b) Time evolution of X-ray energy spectra.

A new hard X-ray pulse height analysis system is constructing. It has a vertical line-of-sight. Combining three energy spectra, it is expected that more detailed and reliable distribution function of high energy electrons can be estimated. In addition, the detector can be moved along the major radius and the spatial profile of hard X-ray will be obtained.

The spacial distribution of high energy electrons are estimated from 4 soft Xray cameras with CT method. Improving the microwave shielding in the vacuum chamber, the noise level is reduced greatly and most of signals are obtained in good S/N ratio. The reconstruction of emission profile is carried out by maximum entropy method as well as quad-ellipse method. The obtained results show that the emission profile extends over multi-EC resonance layer and the peak position moves according to the position of EC resonance layer as the toroidal magnetic field is changed.

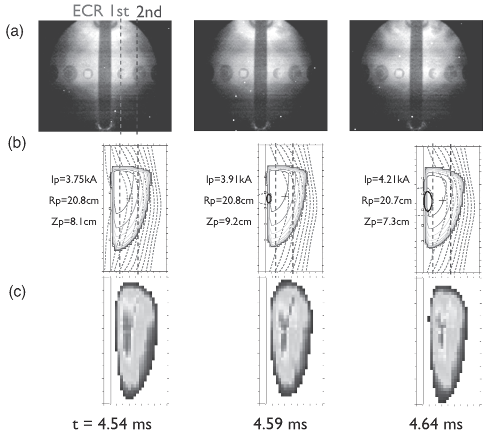


Fig.2 (a) Plasma image by the fast CCD camera, (b) plasma current distribution and poloidal flux contour, (c) soft X-ray emission profile during "current jump".

A new fast CCD camera has been installed to watch a whole plasma image with visible light in every 50 μs interval to observe fast change of plasma shape. Figure 2 shows the CCD camera image, plasma current distribution and poloidal flux contour, and soft X-ray emission profile during "current jump", when Ip increases rapidly under a steady weak vertical field and the initial closed flux surfaces are formed. In this case, a 190 kW, 5 GHz microwave pulse is injected under 960 G toroidal field and 50 G vertical field. Plasma current increases from 3.75 kA to 3.91 kA during time t = 4.54 ms ~ 4.59 ms and a closed flux surface appears on the surface of the center post near the midplane. It is seen that the emission near the second EC resonance layer becomes intense at the formation of closed flux surfaces.