Formation of Microwave Spherical Torus on LATE

H. Tanaka, T. Maekawa, M. Uchida, T. Yoshinaga, S. Nishi, K. Komiya, W. Hamada, Y. Matsumoto, Y. Yamahana, Y. Kawazu, K. Kurata, T. Takeuchi
Graduate School of Energy Science, Kyoto University, Kyoto 606-8502, Japan

Removal of central solenoids (CS) from the fusion reactor based on Spherical Tokamak (ST) concept is essential and expected to reduce the construction cost greatly. Start-up with electron cyclotron heating (ECH) is promising because breakdown and current initiation can be fulfilled simultaneously and the required equipment for microwave power injection is only a small launcher remote from the plasma.

The purpose of the LATE device is to demonstrate the formation of ST plasmas by ECH/ECCD without CS and to establish the physical bases. Three 2.45 GHz magnetrons (< 45 kW in total, ≤ 2 s) and a 5 GHz klystron (< 130 kW, ≤ 0.1 s) are used for ECH. The microwave power is injected through cylindrical antennae set at radial ports with small injection angles (about 15 degree) from normal to the toroidal field, to aim the effective mode conversion to electron Bernstein wave (EBW) by the O-X-B process.

Under a weak steady vertical field (Bv ~ several tens of Gauss) and at low gas pressure (≤ 1 x 10^{-2} Pa), breakdown takes place at the fundamental EC resonance layer and a weak plasma current Ip appears. Then, Ip increases rapidly in several milliseconds, resulting in the spontaneous formation of closed flux surfaces. This current jump bridges the gap between the open field equilibrium maintained by a pressure-driven current and the closed field equilibrium at a larger current, and may be due to the efficient current generation by the asymmetric confinement of electrons along the field line appearing upon the transition of field topology [1].

After the current jump, Ip is ramped up by increasing both the microwave power P_{inj} and Bv for equilibrium at larger plasma current. By injecting a 2.45 GHz microwave pulse up to 35 kW for 2 seconds, Ip = 8.1 kA is obtained at the final stage. With short but high power microwave pulse of 5 GHz, 130 kW, 60 ms, Ip reaches 12 kA at the end of the microwave pulse. These values of Ip amount to 13.5 % of the total toroidal coil current and the magnetic field line on the last closed flux surface has a large pitch angle, showing the characteristics of the ST configuration. The profiles of plasma current, visible light emission and soft X-ray emission encompass the multi EC harmonic resonance layers from the 2nd to the 4 th. The bulk electron density is more than the plasma cutoff density. These facts suggest that the injected microwave is mode-converted to EBW and then absorbed at EC harmonic resonances. The current ramp-up rate is ~1kA/10ms. It seems to be limited by the increasing rate of Bv ~ 8G/10ms, which is the maximum value by the present power supply. From the magnetic measurement, a reverse voltage (-0.025V) at the plasma current center is observed during the current ramp. Temporal evolution of hard X-ray energy spectra shows that high energy tail electrons are produced and build up during the current ramp-up and at the final stage their maximum energy reaches ~100 keV. Coincidentally, a hot spot appears on one edge side of the limiter inserted from the outboard side. The glowing side is just that high energy tail electrons carrying the plasma current would hit on. These facts suggest that a directional high energy electron tail is developed as plasma current increases, which may be generated by the EBW heating with high refractive indices along the magnetic field ($N_{//}$).

[1] T. Yoshinaga, M. Uchida, H. Tanaka, T. Maekawa, *Phys. Rev. Lett*. **96** (2006) 125005.