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Measurement of potential distribution by a heavy ion beam probe in a microwave spherical torus on LATE

重イオンビームプローブによる LATE マイクロ波球状トーラスの静電ポテンシャル分布計測

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A heavy ion beam probe (HIBP) system have been developed to measure the electric potential distribution and to investigate confinement and transport characteristics in the low aspect ratio torus plasma which is produced and maintained by electron Bernstein (EB) wave heating and current drive on LATE. The 2.45 GHz microwave noise has been reduced completely by inserting the cutoff section in front of the energy analyzer. By injecting Rb^+ ion beam of ~100 μA with energy of 14 keV into the plasma produced by EB wave with Ip ~ 5 kA, the secondary beam of ~7 nA is detected at the energy analyzer. The electric potential deduced from the difference between the split plates currents is 40 ~ 50 V, which is positive to the grounded vacuum vessel.

1. Introduction

Non-inductive startup of spherical tokamak (ST) by electron cyclotron (EC) heating and current drive (ECH/ECCD) has been investigated in the LATE device [1,2]. Recent experiments show that overdense ST plasmas with more than 7 times the plasma cutoff density are produced and maintained by electron Bernstein (EB) waves [3]. Here, the plasma current is carried by high energy electrons with energy up to ~100 keV and the bulk electrons with temperature of ~70 eV are confined in the last closed flux surface.

A heavy ion beam probe (HIBP) system have been developed to measure the electric potential distribution and to investigate confinement and transport characteristics in the ST plasma produced by EB waves. The target plasma parameters are as following: plasma current Ip ≦ ~12 kA, electron density $n_e = 10^{11} \sim 10^{12}$ cm^{-3}, electron temperature Te = 40 ~ 100 eV, toroidal field Bt = 480 ~ 750 Gauss and vertical field Bv ≦ ~ 130 Gauss.

2. HIBP System on LATE

Figure 1 shows the overall HIBP system on LATE. Alkali metal ions (Na^+, K^+ or Rb^+) with energy up to 20 keV are used as the primary beam ion. The primary beam from ion gun with acceleration voltage V_{GUN} is focussed by quadrupole lenses in toroidal and poloidal directions and changed directions by toroidal and poloidal sweepers. The secondary beam ions which are generated in the plasma and reach the bottom port are guided by poloidal and toroidal deflectors to the energy analyzer. The energy analyzer consists of entrance slits, parallel electrodes and split plates detectors. The electric potential in the plasma is measured by the difference between the secondary beam currents of upper and lower split plates.

In order to reduce the noise from the 2.45 GHz

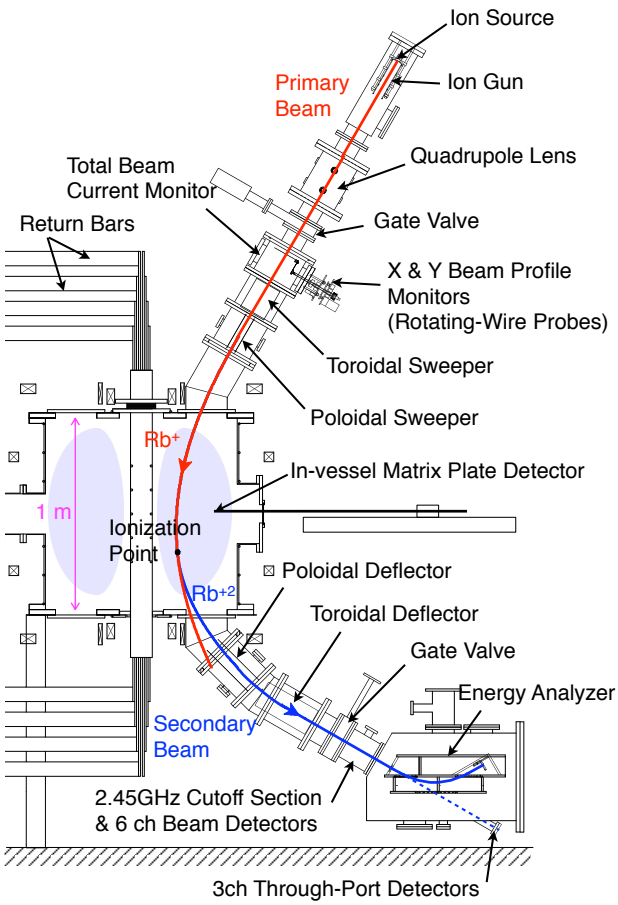

Fig.1. HIBP system on LATE

microwave, the cutoff section with 4.7 x 2.7 cm rectangular cross section and 12 cm long has been installed in front of the energy analyzer. The RF noise is removed completely and the minimum current detection level becomes ~0.1 nA which is caused by the electric noise from the current amplifiers.

3. Detection of the Secondary Beam Current

Preliminary result of detection of the secondary beam current is shown in Fig. 2, where the injected microwave power $P_{inj} \leqq 24$ kW, Ip ≦ 5 kA at Bt = 720 Gauss, primary beam is Rb^+ with V_{GUN} = 14 kV and the poloidal deflector voltage V_{PD} is varied from 1.05 to 1.65 kV in 20 ms while the poloidal sweeper voltage V_{PS} is kept constant at 1.0 kV. The secondary beam current is observed when V_{PD} is around ~1.2 kV. The sum of upper and lower split plates currents reaches ~7 nA, while the primary beam current is ~100 μA. The ratio of the secondary current to the primary one is less than 10^{-4}. The stray beam current monitors are set around the side walls of the cutoff section and they show signals as V_{PD} becomes ~1.2 kV, which implies that the beam spreads more than 4.5 cm in the toroidal direction in front of the energy analyzer. Although focusing adjustment by quadrupole lenses help increasing the secondary beam current at the energy analyzer, more focusing in the toroidal direction is necessary.

The electric potential in the plasma is calculated as 40 ~ 50 V, which is positive to the grounded vacuum vessel.

4. Determination of Position of Measurement Point

The position of measurement point is calculated by a numerical program which calculates ion trajectories by using Runge-Kutta-Fehlberg method. In order to confirm the calculation results, the primary beam position is measured by a in-vessel matrix-plates detector (MPD) which consists of 11 plates with each plate size of 1 cm in the radial direction and 1.5 cm in the toroidal direction and is moved radially at Z = 1.5 cm above the mid-plane [4]. Figure 3 shows comparison of the observed radial position versus applied poloidal sweeper voltage and the calculated one. The observed radial position and calculated one are nearly the same as R = 26 cm in the cases of V_{PS} = 0.95 kV for V_{GUN} = 14 kV and V_{PS} = 0.15 kV for V_{GUN} = 8 kV. However, difference between them become large at inboard side. This discrepancy may cause 3 ~ 4 cm errors in calculation of position of measurement point at inboard side. The errors at outboard side (R > 20 cm) may be much less, but other confirmation is needed for assurance.

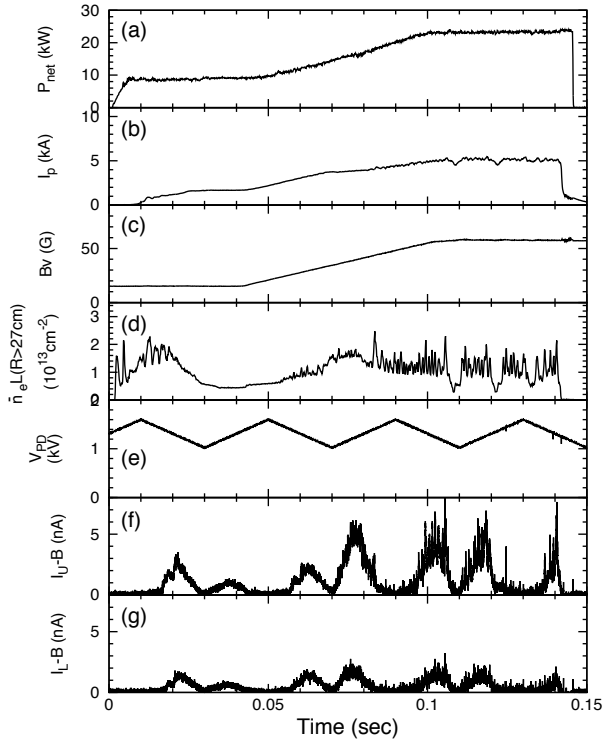

Fig.2. Waveforms of (a) injected microwave power, (b) plasma current, (c) vertical field strength at R = 25 cm, (d) line-integrated electron density along the oblique chord (R > 27cm), (e) poloidal deflector voltage, (f) and (g) secondary beam currents detected by the upper and the lower split plate, respectively.

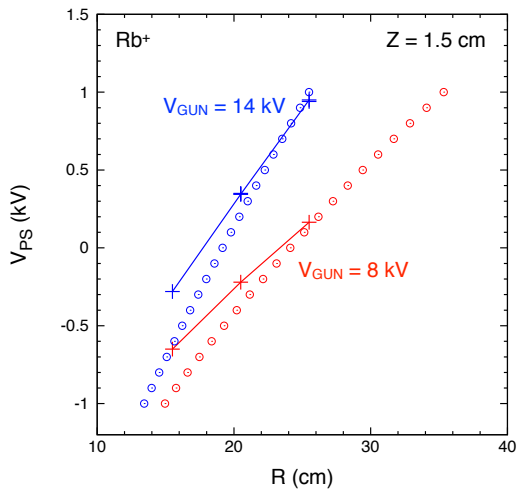

Fig.3. Primary beam position vs poloidal sweeper voltage. Crosses are observed ones and circles are calculated ones.

References

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