Study of transition mechanism based on poloidal ion viscosity using biasing electrode in Heliotron J

H. Takahashi[1], S. Kitajima[2], K. Ishii[2], Y. Sato[2], J. Tachibana[2], S. Koike[2], T. Oku[2], M. Yokoyama[1], Y. Suzuki[1], S. Satake[1], S. Yamamoto[3], S. Ohshima[3], H. Okada[3], K. Nagasaki[3], S. Kobayashi[3], T. Minami[3], T. Mizuuchi[3], F. Sano[3]

[1]*National Institute for Fusion Science, Toki, Japan*

[2]*Department of Quantum Science and Energy Engineering, Tohoku Univ., Sendai, Japan*

[3]*Institute of Advanced Energy, Kyoto Univ., Uji, Japan*

Abstract.

An improved confinement could be successfully achieved by an electrode biasing in the Heliotron J. The increases of n_e and n_eT_e, the decrease of the potential fluctuation and the formation of strong negative E_r were observed. The nonlinearity in the plasma resistance was found in the transition region and the clear hysteresis was observed. An intermittent transition phenomenon was found in the marginal-biasing condition. In the discharge, forward and backward transition repetitively occurred. This is considered due to the spontaneous change of the normalized poloidal torque around the transition threshold.

1. Introduction

The neoclassical theory points out the criterion of LH transition from the viewpoint of the ion viscosity. In this theory, the ion viscosity has local maxima against the rotation velocity [1,2]. When the driving force in poloidal direction exceeds a critical value, the poloidal rotation velocity increases rapidly and the plasma makes transition to the H mode. It means that LH transition mechanism is the bifurcation phenomena originated from the existence of the local maxima in the ion viscosity. The electrode bias experiment has the advantage of ability to control radial electric field externally by controlling the electrode voltage and/or the electrode current and to estimate the driving force from the electrode current. So far, electrode bias experiments were carried out in many tokamaks and helical devices [3-7]. In these experiments, confinement improvement with the formation of strong radial electric field was observed.

Motivated by the background mentioned above, electrode biasing experiments has been carried out in Heliotron J in order to investigate the role of the poloidal ion viscosity on the confinement transition to an improved mode. The present paper shows the achievement of the improved confinement mode in Heliotron J using the biasing electrode and the nonlinear phenomena observed in the transition phase.

2. Experimental Setup

Heliotron J is a medium-sized helical-axis heliotron device with R = 1.2 m, a = 0.1-0.2 m, and $B(0) \leq 1.5$ T [8, 9]. The confinement magnetic configuration is produced using an $L = 1/M = 4$ helical coil, 16 toroidal field coils and 3 pairs of the vertical field coils. The target plasma in biasing experiments is produced using 2.45 GHz ECRH with the injection power into the vacuum vessel of 10-20 kW and the plasma is sustained at most 4 s. He was used as the working gas for the experiments. The electrode made of LaB_6 is inserted horizontally from the low magnetic field side. The relation between the electrode and the poloidal magnetic surface is shown in Fig. 1. The electrode is biased against the vacuum vessel negatively by a voltage control power supply with the maximum voltage and current are 650 V and 23 A, respectively.

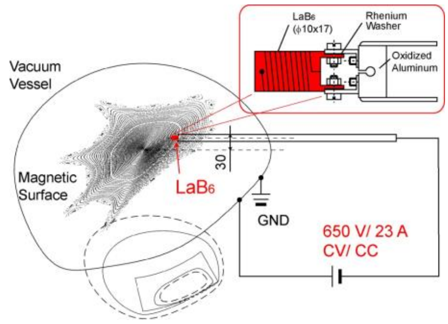

Figure 1. The relation between the electrode and the poloidal magnetic surface

3. Improved Plasma Confinement Triggered by Electrode Biasing

The temporal behaviours of plasma parameters during a helium discharge and the relation between the bias voltage V_E and the electrode current I_E are shown in Fig. 2. V_E was ramped up to -300 V and was ramped down to 0 V. As can be seen in Fig. 2 (b) there were points, where the electrode current rapidly changed both in ramp-up/down phases. At the timing of t = 1.1 s, the electron temperature T_e decreased to half, averaged electron density n_e increased by seven times, the plasma space

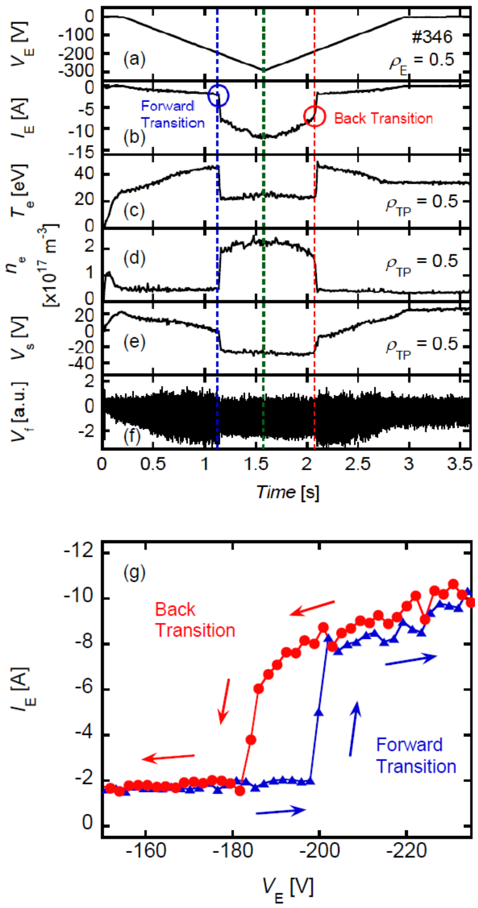

Figure 2. The time evolution of plasma parameters and the dependence of I_E on V_E.

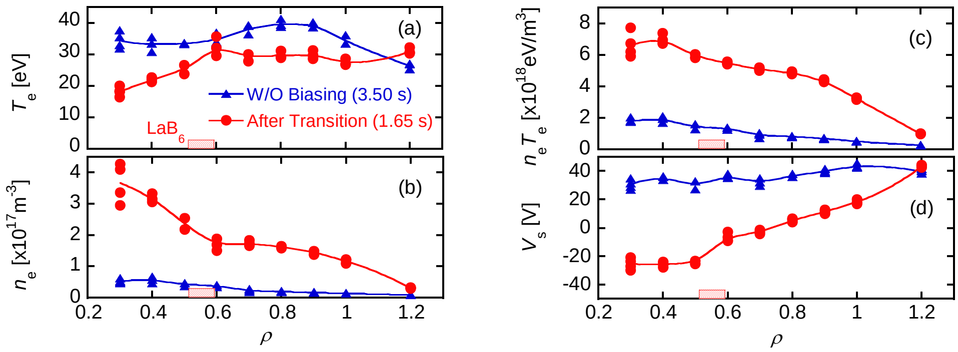

Figure 3. The radial profiles of (a) T_e, (b) n_e, (c) electron pressure n_eT_e and (d) V_s when V_E = 0 V and -300 V.

potential V_s changed from positive to negative and the fluctuation of the floating potential V_f suppressed. Although T_e decreased after the transition, the plasma pressure n_eT_e increased by 3.5 times. These results indicate that the plasma made a transition to the improved confinement mode and the non-linearity of the plasma resistance can be considered as an indication of transition. As can be seen from Fig.2 (g), I_E shows clear hysteresis and had multi value against V_E in transition region that means bifurcation. The characteristic curve was similar that observed in TU-Heliac [6,7]. Figure 3 shows the radial profiles of (a) T_e, (b) n_e, (c) electron pressure n_eT_e and (d) V_s when V_E = 0 V and -300 V. Here the radial derivative of V_s corresponds to the radial electric field E_r. The hatched rectangle indicates the position of the LaB_6. Although T_e decreased after the transition, n_e and n_eT_e greatly improved in the plasma whole region with the formation of the negative E_r. In the vicinity of the electrode, steep gradient of T_e, n_e and the strong shear of E_r were found to be formed.

In the recent experiments, the intermittent transition phenomena, when the plasma repeated the transition between low and high confinement in a discharge, was found. Figure 4 shows the behaviour of the plasma parameters under the marginal biasing condition. In the discharge, forward and backward transition repetitively occurred. Similar results have been observed in CHS [10]. The observation in CHS was the repetitive transition of the plasma confinement in the ECRH plasma and the mechanism was explained as the bifurcation of E_r due to the spontaneous change of n_e. Figure 4 (f) illustrates the trajectory of the density-normalized poloidal driving force on V_s in one cycle of the repetitive transition. The normalized torque spontaneously changed in the discharge. This indicates that the normalized torque increased (decreased) and exceed the local maximum (fall down to the local minimum) of the poloidal ion viscosity, then the plasma make a transition to the high (low) confinement mode with increase (decrease) of negative E_r (decrease (increase) of V_s). These results support the scenario of LH transition mechanism [1,2,7].

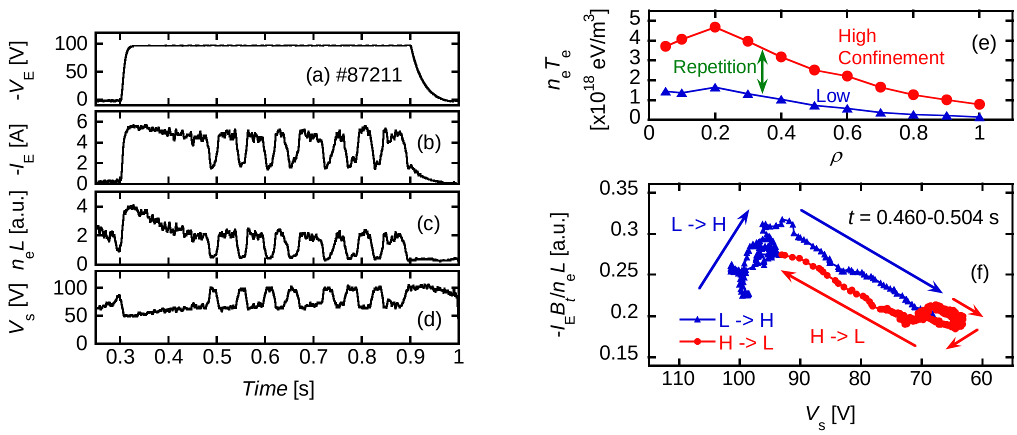

Figure 4. The behaviour of the plasma parameters under the marginal biasing condition.

4. Summary

Electrode biasing experiments were carried out in the Heliotron J in order to investigate the role of a poloidal ion viscosity on a transition to an improved confinement regime. An improved confinement could be successfully achieved using biasing electrode. The increases of n_e and $n_e T_e$, the decrease of the potential fluctuation and the formation of strong negative E_r were observed in the high confinement mode. The nonlinearity in the plasma resistance was found in the transition region both in the discharge of V_E ramped up/down and the clear hysteresis was observed. An intermittent transition phenomenon was found in the marginal-biasing condition. In the discharge, forward and backward transition repetitively occurred. This is considered due to the spontaneous change of the normalized poloidal torque, namely the normalized torque spontaneously decreases after the transition to the high confinement mode and that increases after the backward transition.

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