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H-MODE STUDY IN CHS

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ABSTRACT

In CHS rapid H-mode transition is observed in NBI heated deuterium and hydrogen plasmas without obvious isotope effect, when a net plasma current is ramped up to increase the external rotational transform. The H-mode of CHS has many similarities with those in tokamaks. Recent measurement with fast response Langmuir probes has revealed that the rapid change in floating potential occurs at the transition, but the change follows the formation of edge transport barrier. The presence of $\iota/2\pi = 1$ surface near the edge and sawtooth crash triggered by internal modes may play an important role for determining the H-mode transition in CHS.

Keywords: L-H Transition, Edge Transport Barrier, Heliotron/Torsatron,
Collapse of Magnetic Island, Radial Electric Field

I. INTRODUCTION

Recent confinement study in toroidal magnetic systems such as tokamak or helical system (stellarator or heliotron/torsatron) is addressed to enhanced confinement regimes, because they have a potentiality for minimizing a fusion-reactor size. Discovery of the H-mode in ASDEX accelerated the confinement study in tokamaks[1]. At present, radial electric field shear Er' or ExB sheared flow near the edge is thought to be a key factor for the L-H transition and confinement improvement[2]. However, a cause and effect relationship between ExB sheared flow and the transition has not been established yet. In helical plasmas several experiments for controlling Er or Er' externally were carried out in order to improve the plasma confinement, but no H-mode transition was observed so far. A different approach controlling the rotational transform profile was started since 1991 in the CHS heliotron/torsatron, and the H-mode was immediately achieved[3]. The spontaneous H-mode was also observed in W7-AS stellarator[4]. This paper describes the characteristics of the H-mode achieved in CHS along this approach[3,5,6].

II. EXPERIMENTAL SET-UP AND RESULTS

In CHS the H-mode study is carried out on deuterium and hydrogen plasmas heated with co-injected neutral beams (NBI), at the toroidal magnetic field Bt=1.2 T and 1.4 T. A net plasma current is induced up to 50 kA mostly by a toroidal inductive voltage. Line averaged electron density just before the transition is adjusted from 1.5 to 3×10^{13} cm^{-3}, and increases up to 3 to 5 $\times10^{13}$ cm^{-3} in the H-phase. In this experimental series, the external rotational transform is about 0.25 at the magnetic axis and 0.9 at the last closed flux surface(LCFS).

Figure 1 shows a typical H-mode discharge obtained in NBI heated deuterium plasma. In this discharge the plasma current is ramped up to ~35 kA in 100 ms by a loop voltage of about 2 V, to increase the external rotational transform. Hα/Dα emission is depressed within 0.2 ms, which is much shorter than the global energy confinement time(~2-3 ms). The line averaged electron density (n_e) continuously rises during the H-phase till the gas puff is turned off. At the transition edge electron density measured with thermal Li beam probing(LIBP) just inside LCFS is suddenly raised (in 50 to 100 μs) and that just outside LCFS is suddenly reduced, as shown in Fig.1(b). This clearly indicates a rapid formation of edge transport barrier.

Figure 2 shows time evolution of electron temperature and density profiles obtained with YAG Thomson scattering. At ~5 ms after the transition electron temperature near the edge remains unchanged or slightly increases compared with that in L-phase, while electron density is considerably increased there. In the deep H-phase (~25 ms after the transition), the electron temperature exhibits a pedestal near the edge and electron density profile evolves to the hollow one.
The ion temperature profile also becomes broad. Poloidal rotation of C^{+6} ion is increased in the electron diamagnetic drift direction [6]. The radial electric field is estimated to be ~100 V/cm near the edge.

At the L-H transition electron density fluctuations measured with LIBP are clearly suppressed at very near and just outside LCFS. Magnetic fluctuations with various low mode numbers are excited throughout the H-mode discharges. About 10-20 ms before the transition m/n=1/1 mode is excited presumably due to appearance of the $\iota/2\pi=1$ rational surface just inside LCFS. The m/n=1/1 mode is thought to be the resistive interchange mode. As shown in Fig.3 this mode amplitude is clearly reduced at the transition, although the $\iota/2\pi=1$ surface still resides just inside LCFS. Increase in electron temperature at $\iota/2\pi=1$ rational surface through the increase of $\iota(a)/2\pi$ in time and a heat pulse due to internal modes may play an important role on suppression of the m/n=1/1 mode.

Time evolution of ion saturation current and floating potential across the L-H transition has been measured with Langmuir probes having good time (2 μs sampling) and spatial resolutions (~ 1 mm). Floating potential just outside LCFS, which gradually evolves from positive to negative for 10-15 ms before the transition, is suddenly (~ 100-200 μs) raised at the transition (Fig.4(a)). On the other hand the potential just inside LCFS is suddenly decreased, as shown in Fig.4(b). It is thought that a strong negative Er is generated at the transition near the edge and presumably Er' is also enhanced. Note that the change in Hα/Dα emission is usually slow and often small, because of an integral effect along the line of sight. Most significant point is that in these shots the potential change follows the rapid reduction of ion saturation current which indicates the formation of edge transport barrier. Namely, the strong Er or Er' is developed as a result of the L-H transition, not a cause. Above mentioned temporal evolution of floating potential across the transition may be interpreted with the reduction of electron loss enhanced during the L-phase instead of enhanced ion loss. One of possible interpretations of these observations at the transition is collapse of magnetic islands or healing of braised magnetic surfaces near the edge.

There is an obvious threshold for the plasma current depending on Bt, that is, Ip ~30 kA at Bt=1.2 T and ~38 kA at Bt=1.4 T. The threshold current also depends on the external $\iota(a)/2\pi$. These results suggest the transition closely correlates with the presence of $\iota/2\pi=1$ surface just inside LCFS. It should be noted that a sawtooth crash initiated by internal MHD mode also plays an important role on the transition. The threshold heating power is within twice of the ITER scaling law[7]. So far we have not recognized obvious isotope effect on the transition character.

III. SUMMARY

The H-mode is achieved in CHS, exhibiting rapid formation of edge transport barrier. Although improvement of global energy confinement is not significant so far, i.e., ~20 %, the H-mode in higher beta plasma may provide a route for further improvement of plasma confinement in the heliotron/torsatron through self-stabilization effect. Fast-response Langmuir-probe with good spatial resolution has revealed the generation of enhanced edge radial electric field and Er' as a result of the formation of edge transport barrier. The cause of generation of enhanced edge Er or Er' is under investigation. Collapse of magnetic islands or healing braised magnetic surfaces near the edge may have close connection with the H-mode transition in CHS, through a preferential improvement of edge electron confinement. We are also studying how thus enhanced Er' contributes to boost a frail transition to more robust one.

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Figure Captions

Fig.1(a) Time evolution of Hα/Dα emission, line averaged electron density at the central and edge chords(<r>/<a>~0 and 0.77), and plasma current in a typical deuterium H-mode discharge, where Bt=1.2 T. Two solid vertical lines denote the first and second L-H transition, and dotted ones the H-L transition.

(b) Time behaviors of LIBP signals which is roughly proportional to local electron density near the edge, where Li8 is the signal from just outside LCFS and Li6 just inside LCFS.

Fig.2 Time evolution of electron temperature and density profile measured with YAG Thomson scattering in the cross-section horizontally elongated, where solid circles, open circles and diamonds denote the profiles at t=80ms, 100ms and 120 ms respectively. The L-H transition occurs at t ~ 95 ms.

Fig.3 Time evolution of magnetic fluctuation amplitude in the range of 5 to 11 kHz. The fluctuations are dominated by m/n=1/1 mode activity. The transition is seen from LIBP signal from just outside LCFS.

Fig.4(a)Time evolution of ion saturation current(Iis) and floating potential(ϕ_{fl}) measured just outside LCFS, together with Hα/Dα emission, where these data are averaged over 20 μs and the L-H transition occurs at 97.05 ms.

(b)Time evolution of Iis and ϕ_{fl} just inside LCFS, when the L-H transition occurs at 97.38 ms.

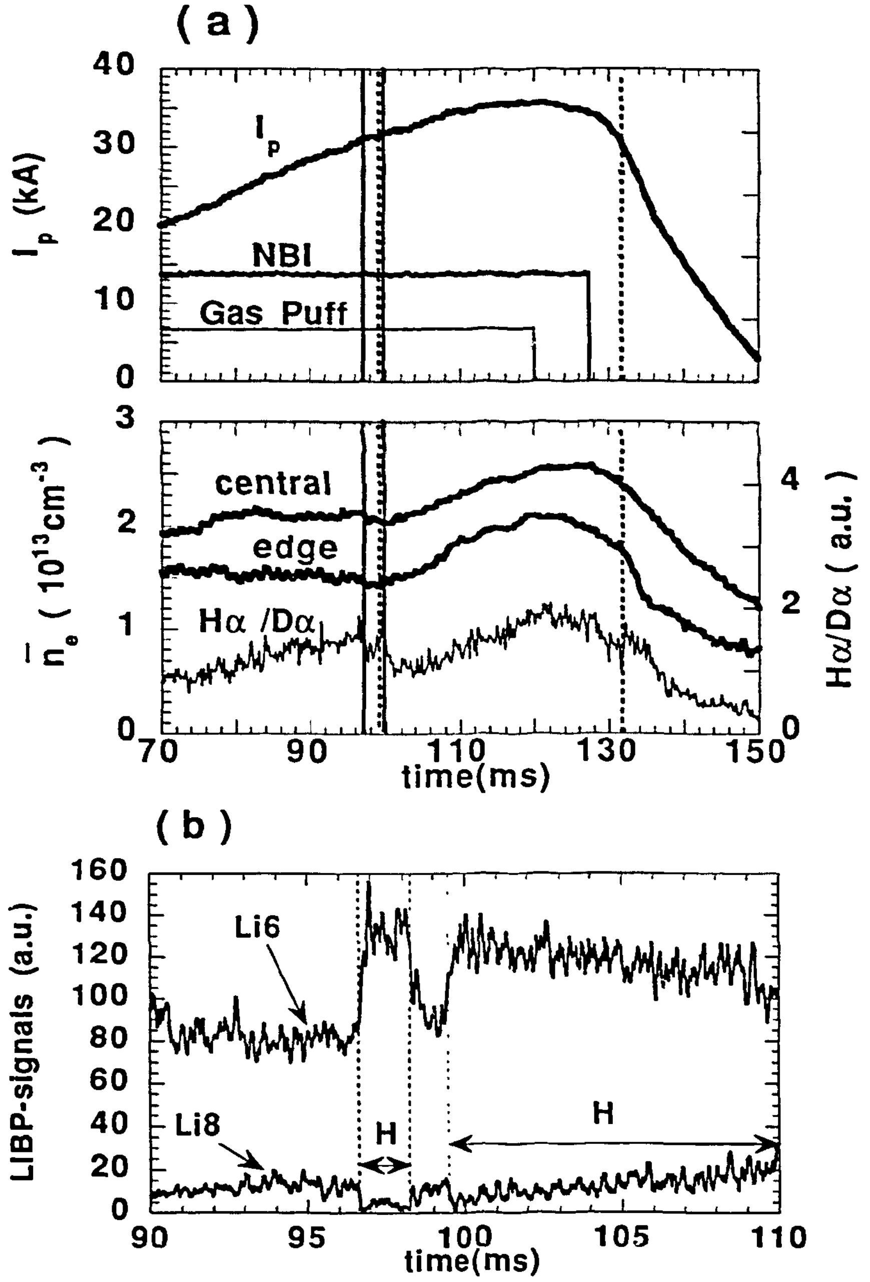

Fig.1 K. Toi et al.

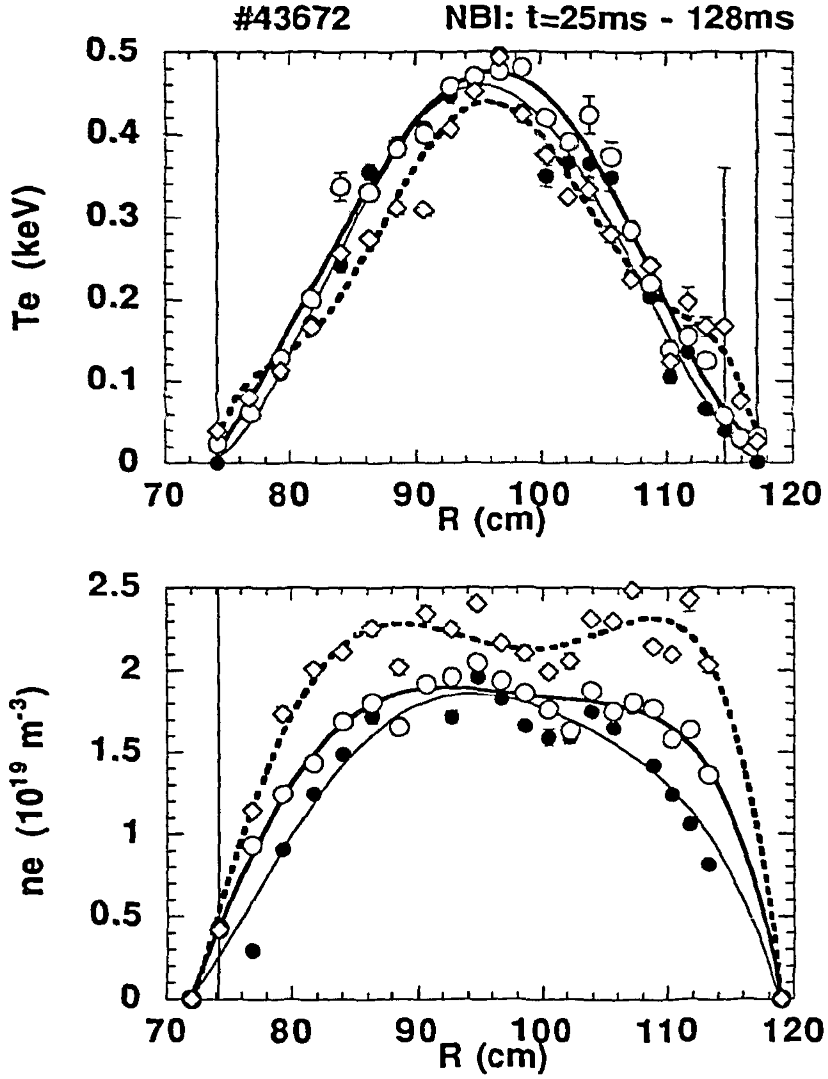

Fig.2 K. Toi et al.

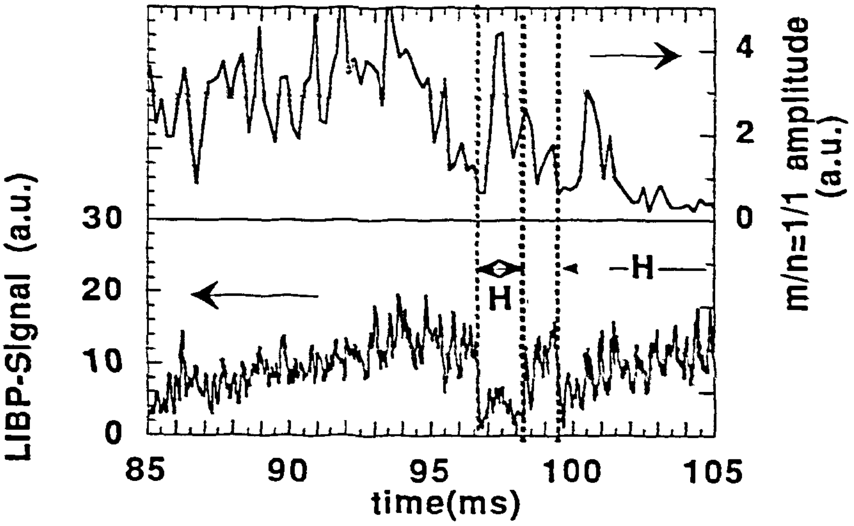

Fig.3 K. Toi et al.

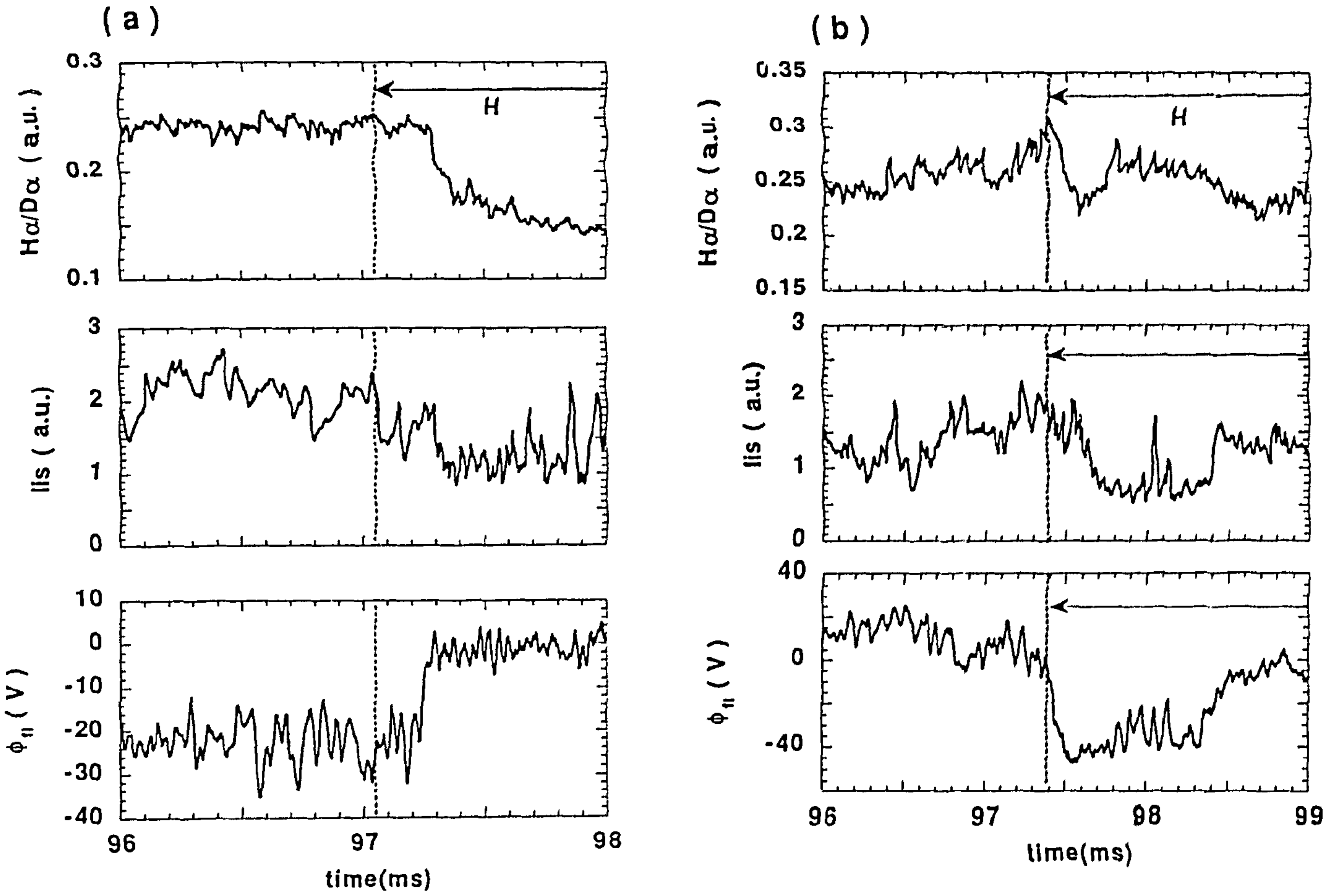

Fig.4 K. Toi et al.

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