J. Plasma Fusion Res. SERIES, Vol.1 (1998) 239–242

High Ion Temperature Mode in CHS Heliotron/Torsatron Plasmas

IDA Katsumi*, NISHIMURA Shin, MINAMI Takashi, TANAKA Kenji, OKAMURA Shoichi, OSAKABE Masaki, IDEI Hiroshi, KUBO Shin, TAKAHASHI Chihiro and MATSUOKA Keisuke

National Institute for Fusion Science, Toki 509-5292, Japan

(Received: 30 September 1997/Accepted: 21 January 1998)

Abstract

High ion temperature mode (high T_i mode) is observed for neutral beam heated plasmas in Compact Helical System (CHS) Heliotron/torsatron plasmas. The high T_i mode plasma is characterized by a peaked ion temperature profile and is associated with a peaked electron density profile produced by neutral beam fueling. The reduction of ion thermal diffusivity is observed at the plasma core ($\rho=0.1$) in the high T_i mode by a factor of two. The high T_i mode discharge is observed only in the low density and the upper limit of n_e (critical n_e) for the high T_i mode depends on the density peaking factor.

Keywords:

high T_i mode, Compact Helical System, improved mode, density peaking, radial electric field, charge-exchange spectroscopy

1. Introduction

The high T_i mode plasma is one of the improved modes in Heliotron/torsatron and in stellarator[1]. It has many similar characteristics to that observed in super shots in TFTR [2], hot ion modes in JET and in JT-60 [3,4]. The high T_i mode is characterized by a high central ion temperature and low central ion thermal diffusivity, associated with a peaked electron density profile produced by neutral beam (NB) fueling with low wall recycling[5]. Characteristics and operation regime of the high T_i mode discharges in CHS are studied. The electron density and its profiles are measured with scanning 3 chord FIR interferometer, 24 points, YAG Thomson scattering, while the ion temperature and its profiles are measured with 30 points charge exchange spectroscopy (CXS) using fully stripped carbon[6]. The radial electric field profiles are derived from poloidal rotation velocity profile and carbon pressure profile measured with CXS.

2. Characteristics of High T_i Mode Discharges

Figure 1 shows the time evolution of the central electron density, density peaking factor, $n_e(0)/<n_e>$, where $< >$ denotes volume average, central ion and electron temperature for the discharges without gas puff (high T_i mode[7]) and with gas puff (L-mode). Electron cyclotron resonance heating (ECH) pulse produces a target plasma for 14–40 ms and neutral beam is injected for 40–140 ms with the energy of 37 keV, the beam current of 46 A, the injected power of 900 kW. The NB is tangentially injected to the plasma, where the magnetic axis of plasma is 0.921 m and the tangential radius of NB is 0.87 m. The helical magnetic field is 1.76 T. When the electron density increases in time with gas puffing (t=20–100 ms), the ion temperature stays almost constant in time (~0.4 keV) in the L-mode discharges. However, when the gas puff is turned off at t=40 ms after the neutral beam injection, both central electron density, $n_e(0)$, and central ion

**Corresponding author's e-mail: ida@nifs.ac.jp*

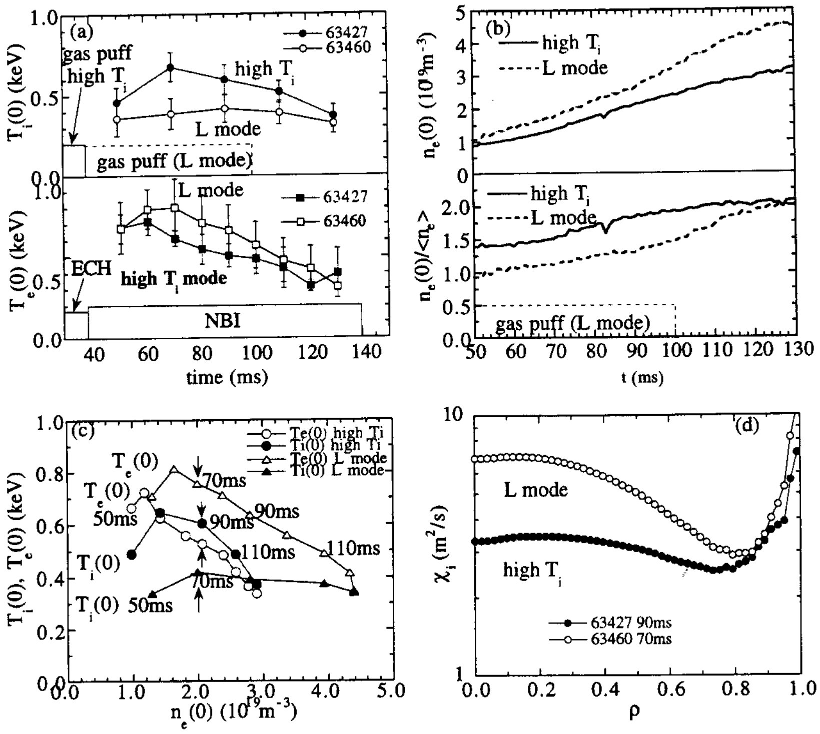

Fig. 1 Time evolution of (a) central ion and electron temperature, (b) central electron density and its peaking factor $n_e(0)/<n_e>$ and (c) the central ion and electron temperature as a function of central electron density (d) radial profiles of ion thermal diffusivity for high T_i mode and L-mode discharges. The arrows in Fig.(c) stand for the time sliced data used in the transport analysis for χ_i profiles in Fig.(d).

temperature, $T_i(0)$, increase in time and the central ion temperature reaches 0.7 keV at t=70 ms then decreases to the L-mode levels (0.4 keV) as the electron density is increased. The transition between the high T_i mode and the L-mode is sensitive to the fraction of beam fueling to the gas puff fueling, and a small amount gas puff or high wall recycling due to insufficient Titanium flash will prevent the discharge from getting into the high T_i mode.

The absolute value of $n_e(0)$ in the high T_i mode is similar to that in the early phase of the L-mode discharge. For example, $n_e(0)$ at t=70 ms in the L-mode discharge is almost identical to the $n_e(0)$ at t=90 ms in the high T_i mode discharge. On the other hand, a clear difference in the n_e profiles is observed between the high T_i mode discharge and the L-mode discharges. In the high T_i mode discharge, the electron density profile is peaked (~1.5), while it is flat (~1.0) in the L-mode during gas puff (t<100 ms). Although the electron density profiles in the L-mode also become peaked after the gas puff is turned off, the electron density seems to be too high for the transition to the high T_i mode late in the discharges. One of the characteristics of high T_i mode is high ion temperature (low ion thermal diffusivity, χ_i). Although the two third of the neutral beam power deposits to electrons, the ion temperature is higher than the electron temperature due to the reduction of χ_i. The transport analysis has been done for the time sliced data at t=90 ms for the high T_i mode discharge and at t=70 ms for the L-mode discharge to compare the L-mode and the high T_i mode plasmas with similar electron density $n_e(0)$. The reduction of ion thermal diffusivity in the high T_i mode is observed at the plasma core of $\rho<0.8$ and the central $\chi_i(\rho=0.1)$ is smaller than that in the L-mode by a factor of two.

Figure 2 shows radial profiles of electron density, temperature, ion temperature and radial electric field for one high T_i mode discharge and for three L-mode discharges with various gas puff rate. In the L-mode discharges, ion temperature has weak dependence on electron density as $T_i(0)\propto n_e(0)^{-0.67}$. However, at the boundary between the the high T_i mode and the L-mode, even small increase in electron density, $\Delta n_e(0)$=15%, results in the large drop of ion temperature by 30% and plasma shows transition to the

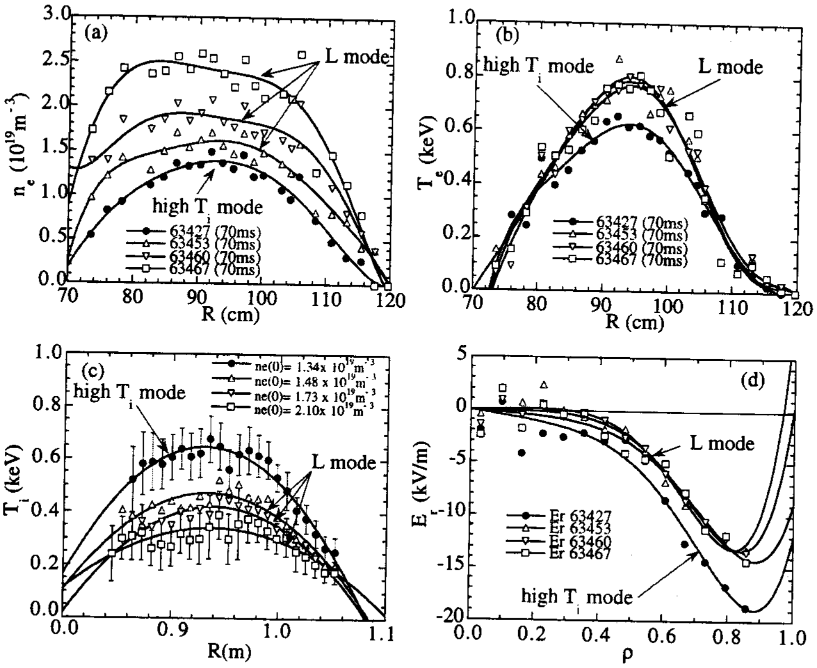

Fig. 2 Radial profiles of (a) electron density, (b) electron temperature, (c) ion temperature, and (d) radial electric field for various rate of gas puffing (one is high T_i mode discharge and three are L-mode discharges).

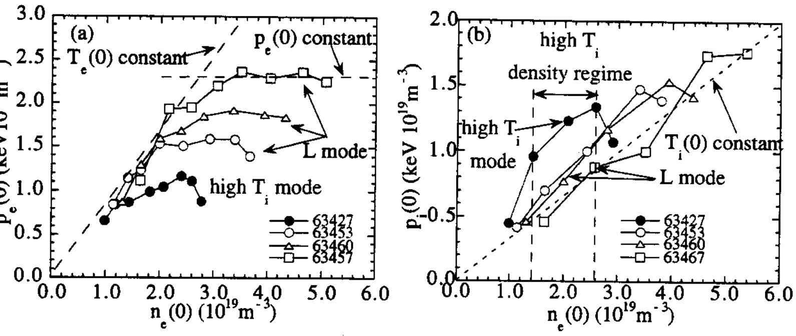

Fig. 3 Central (a) electron and (b) ion pressure as a function of central electron density for various rate of gas puffing (one is high T_i mode discharge and three are L-mode discharges).

L-mode. Clear differences between in the high T_i mode discharge and three L-mode discharges are also observed in the electron temperature and radial electric field profiles. The tiny change in T_e profiles in L-mode is due to the fact that increase in n_e is compensated by the increase in NB deposition power in the low density region. In the high T_i mode, the radial electric field is more negative and radial electric field shear is also larger than those in L-mode. These characteristics suggest the hypothesis that radial electric field and shear improve ion transport but not electron transport.

At the low density region, the fraction of beam deposition power to the injected power strongly depends on the electron density, while the ion temperature shows no dependence on the electron density as seen in Fig. 2(b). In order to study the difference of density dependence between ion and electron temperature, the central plasma ion and electron pressure are plotted as a function of central electron density for the constant injected power in Fig. 3. The electron pressure shows linear density dependence at the low density $n_e(0) < 2.0 \times 10^{19}$ m^{-3}, which is partly due to the change in deposition power of neutral beam, while the electron pressure shows saturation for higher density of $n_e(0) > 2.0 \times 10^{19}$ m^{-3}. On the other hand, the ion pressure shows linear density dependence even at the higher density.

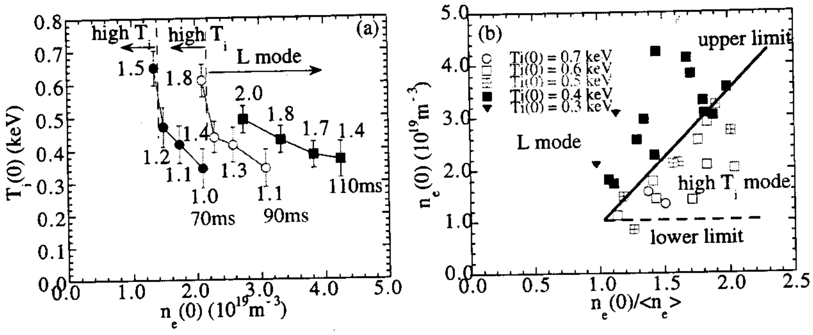

Fig. 4 (a) Central ion temperature as a function of central electron density and (b) operation regime of high T_i mode discharges. The values of peaking factor $n_e(0) < n_e >$ are also plotted in Fig. 4(a).

Fig. 3(b) also shows the density regime for the high T_i mode discharge for this discharge is $1.5-2.5\times10^{19}$ m^{-3}, where the ion pressure is higher but the electron pressure is even lower than that in L-mode discharges. These data show that the ion confinement is improved but the electron confinement is degradated in the high T_i mode.

3. Operation Regime of High T_i Mode Discharges

Fig. 4(a) shows ion temperature as a function of central electron density for various gas puff at $t=70$, 90, 110 ms. At the low density regime ($t=70$ and 90 ms), there are sharp change in $T_i(0)$ at $n_e(0)=1.4\times 10^{19}$ m^{-3} ($t=70$ ms) and $n_e(0)=2.2\times10^{19}$ m^{-3} ($t=90$ ms), which indicates the transition from L-mode to high T_i mode. The density peaking factor in the high T_i mode are 1.5 ($t=70$ ms) and 1.8 ($t=90$ ms). However, there is no sharp change (transition to the high T_i mode discharge) observed at $t=110$ ms because the electron density exceeds the upper limit for the high T_i mode. The high T_i mode is observed at only low density plasma and the upper limit of the electron density for the high T_i mode increases as the peaking factor of electron density is increased. The dependence of critical $n_e(0)$ on the peaking factor is more clearly seen in Fig. 4(b) which shows operation regime of high T_i mode discharges. $T_i(0)$ at the boundary between the high T_i mode and L-mode is roughly 0.5 keV as seen in Fig. 4(a). The discharge with the ion temperature higher than 0.5 keV (high T_i mode plasma) are restricted in the lower $n_e(0)$ and higher $n_e(0)/<n_e>$.

There is a minimum $n_e(0)$ for the high T_i mode discharges. This is mainly due to the lack of enough beam deposition and fueling at the very low density. The transition from L-mode to high T_i mode is observed in the range of central electron density of 1×10^{19} m^{-3} to 3×10^{19} m^{-3} and the upper limit of electron density increases as the density peaking factor is increased.

When the recycling is high due to the poor wall condition, the central electron density increases without gas puff but the density peaking factor is low (<1) then the plasma is always in the L-mode. To achieve high T_i mode discharge, the peaking factor should increase as the central electron density increases. Therefore the central fueling by neutral beam is key for the high T_i mode. The high T_i mode due to pellet injection[8] observed in Heliotron-E also suggests that central fueling is important for the high T_i mode. The upper limit of electron density should depend on neutral beam heating power, magnetic field as well as peaking factor. Since the high T_i mode is observed only in the high field of >1.7 T and with high power NBI>0.8 MW with low recycling wall condition in CHS so far, the dependence of the upper limit on heating power and magnetic field is not clear yet.

References

[1] A. Iiyoshi, Fusion Energy (*Proc. 16th Int. Conf. on Fusion Energy,* Montréal, 1996) IAEA Vienna Vol.**1**, 113 (1997).

[2] R. J. Fonck *et al.*, Phys. Rev. Lett. **63**, 520 (1989).

[3] H. Weisen *et al.*, Nucl. Fusion **29**, 2187 (1989).

[4] Y. Koide *et al.*, Nucl. Fusion **33**, 251 (1993).

[5] K. Ida *et al.*, Phys. Fluids **B4**, 1360 (1992).

[6] K. Ida and S. Hidekuma, Rev. Sci. Instrum. **60**, 867 (1989).

[7] K. Ida *et al.*, Phys. Rev. Lett. **76**, 1268 (1996).

[8] K. Ida *et al.*, Plasma Phys. **38**, 1433 (1996).