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Transport Analysis of High Ion Temperature Mode in CHS Heliotron/Torsatron Plasmas

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Abstract

The high ion temperature mode for neutral beam heated plasma is observed in CHS heliotron/torsatron device. Transport analysis for this mode shows that increase in ion temperature is due to improvement of ion heat transport. On the other hand, electron diffusivity in the high ion temperature mode is larger than that in the L-mode. There is a correlation between thermal diffusivity and density gradient.

Keywords:
compact helical system, transport analysis, PROCTR-MOD, thermal diffusivity,
high ion temperature mode, improved confinement mode, YAG Thomson scattering,
charge exchange spectroscopy

1. Introduction

The improved confinement regime that is correlated with density peaking has been observed in many tokamaks such as TFTR [1] and ASDEX [2]. The characteristic of these regimes is that high ion temperature is realized. Recently similar regime that is called high ion temperature (HIT) mode has been observed in heliotron/torsatron devices such as Heliotron-E [3,4] and CHS [5]. In case of tokamak devices, improvement of energy confinement time is two or three times as large as that of the L-mode plasmas [1,2], while in the heliotron/torsatron devices the improvement is at most by ~40 % [3]. Therefore, it is important to investigate relation between density gradient and heat transport in the heliotron/torsatron devices. In this paper we present the transport analysis for the HIT mode plasma on CHS.

2. High Ion Temperature Mode on CHS

The HIT mode plasmas in CHS were produced by neutral beam injection (NBI) into the target plasma that was produced by electron cyclotron heating (ECH). The time evolutions of the electron temperature and the density profiles were measured with multipoint YAG Thomson scattering system [6] (24 spatial channels, 10 ms time resolution). The time evolutions of the ion temperature profiles were measured with multichord charge exchange spectroscopy [7] (30 spatial channels, 20 ms time resolution). The kinetic stored energy which is calculated from the above measurement has good agreement with a diamagnetic stored energy. The differences are within about 10 %.

The characteristics of the HIT plasmas in CHS are shown in Fig. 1. The target plasma is produced by the ECH (53 GHz) from $t=15$ ms. After the ECH is switched off, the neutral beam is injected from $t=50$ ms (co-injection, 800 kW) to 150 ms. In the case of the HIT mode, the plasma is produced by neutral beam fueling without gas puffing in low recycling condition.

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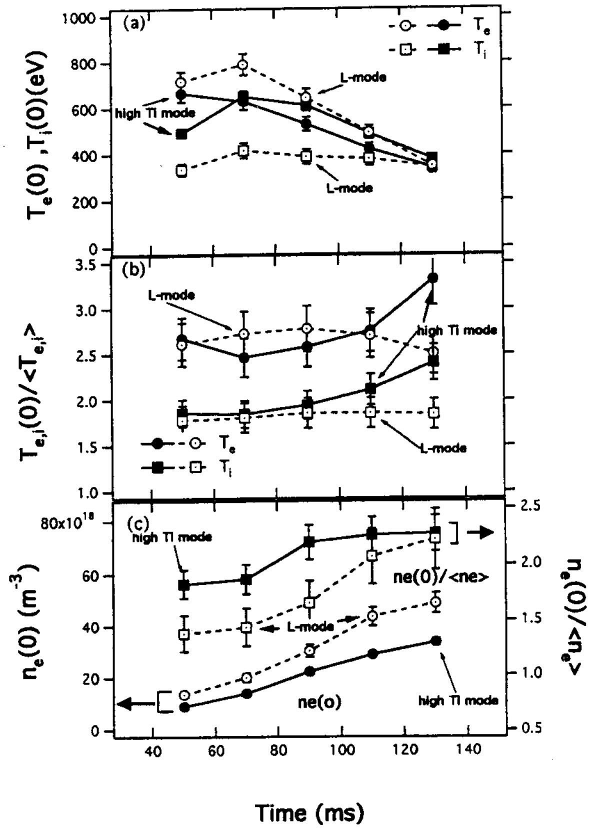

Fig. 1 (a) Temporal evolution of central temperature for ion and electron, (b) temporal evolution of peaking parameter of temperature profiles, (c) temporal evolution of central electron density and peaking parameter of density profiles. $< T_{e,i} >$ denotes the volume-averaged temperature. $< n_e >$ denotes the volume-averaged electron density. The data are plotted every 20 ms.

On the contrary, the L-mode plasma is produced by the same heating procedure with the gas puffing, so that the density is slightly larger than that in the HIT mode discharge as shown in Fig. 1(c). In the HIT mode discharge, the central ion temperature $T_i(0)$ is almost the same as or slightly higher than the central electron temperature $T_e(0)$, while in the L-mode discharge $T_i(0)$ is much lower than $T_e(0)$ as shown in Fig. 1(a). The density profile in the HIT discharge is more peaked than that in the L-mode discharge as shown in Fig. 1(c). The shapes of the ion and electron temperature profiles are little changed except the later phase of the discharge as shown in Fig. 1(b). In the L-mode discharge,when $T_i(0)$ becomes to be equal to $T_e(0)$ as the electron density increases, the peaking parameters of the density profiles become to be almost equal to that of the HIT mode discharge.

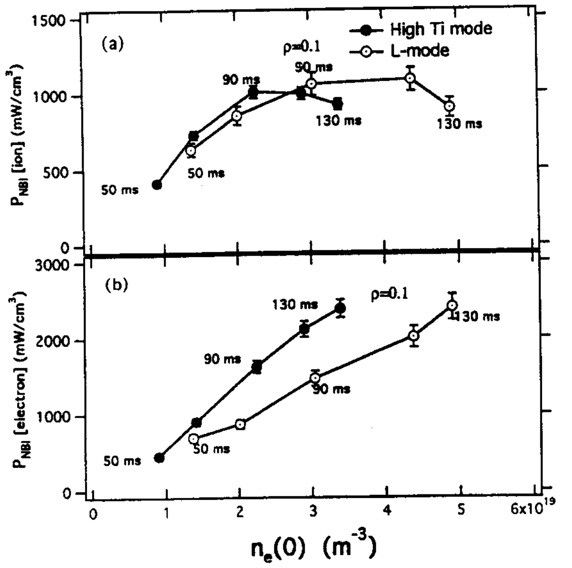

Fig. 2 (a) Power deposition of the neutral beam to ions as a function of the central electron density, (b) power deposition to electrons as a function of the central electron density. The position of the plotted data is $\rho = 0.1$. The data are plotted every 20 ms.

3. Transport Analyses for High Ion Temperature Mode

Transport analysis for the HIT mode discharges was carried out with the profile analysis code PROCTR-MOD [8].

There is a problem whether the increase in the ion temperature is due to the increase in the deposition power of the neutral beam or due to the improvement of the ion transport. To make sure of this, we calculate the power deposition. Figure 2 shows calculated deposition power as a function of the central density. In this experiments, the NBI power mainly deposited in the central region of plasma. The behavior of the deposited power at $\rho = 0.1$ represents the behavior of the total deposited power. As shown in Fig. 2(a), the deposition power to the ions in HIT mode is almost the same as that in L-mode in central region of plasma. The difference of the power deposition near the edge plasma is negligible. In the case of this experiment, the beam power is mainly transferred to the electrons. The deposition power to the electrons in the HIT mode is larger than that in the L-mode and increases with the density increasing, as shown in Fig. 2(b), since the electron temperature in the HIT mode is lower than that in the L-mode. However, because the differences of the temperature between the ion and the electron are small in the HIT mode, the energy that is transferred from

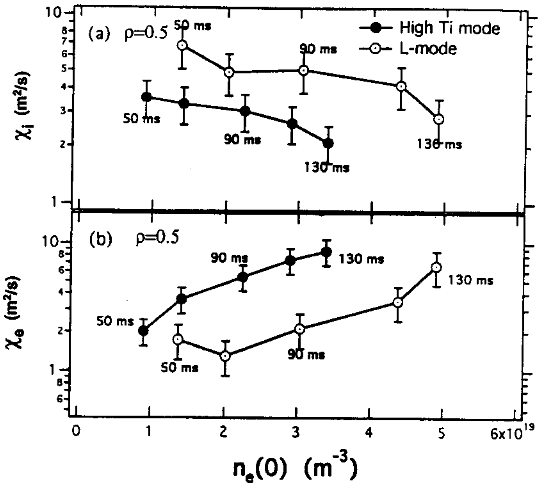

Fig. 3 (a) Ion thermal diffusivity as a function of the central electron density, (b) electron thermal diffusivity as a function of the central electron density. The data are plotted every 20 ms. The position of the plotted data is $\rho = 0.5$.

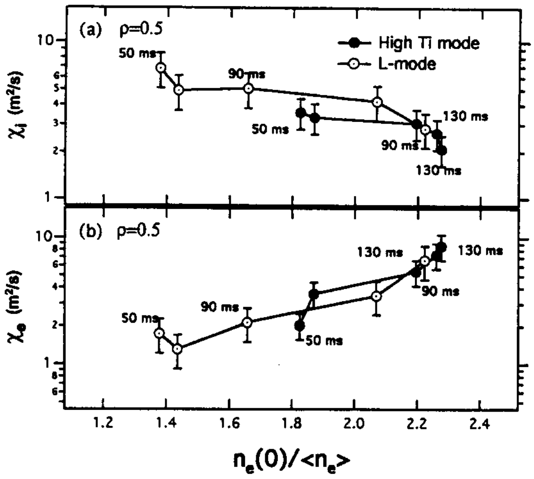

Fig. 4 (a) Ion thermal diffusivity as a function of the peaking parameter of the electron density profiles, (b) electron thermal diffusivity as a function of the peaking parameter of the electron density profiles. The data are plotted every 20 ms. The position of the plotted data is $\rho = 0.5$. $< n_e >$ denotes the volume-averaged electron density.

the electrons to the ions is small in comparison with the deposition power. Therefore, it is difficult to explain the increase in the ion temperature of the HIT mode by the increase in the deposition power. Figure 3(a) shows comparison of the calculated ion thermal diffusivity of the L-mode and the HIT mode at $\rho = 0.5$ as a function of the central density. The density dependence of the thermal diffusivity is similar on almost whole place in the plasma. The diffusivity of the HIT mode is reduced in comparison with the L-mode. The increase in the ion temperature in the HIT mode is mainly due to the improvement of the ion transport.

On the other hand, although the deposition power to the electrons increases, the electron temperature in the HIT mode is lower than that in the L-mode. The calculated electron thermal diffusivity of the HIT mode is increased in comparison with the L-mode as shown in Fig. 3(b). Therefore, the improvement of the energy confinement by the reduced ion thermal diffusivity was cancelled by the degradation of the electron confinement.

The results of the transport analyses also show there is a significant correlation between the heat transport and the electron density gradient as shown in Fig. 4. Although there is a large difference of the thermal diffusivity as a function of the central density between the HIT mode and the L-mode, the thermal diffusivity of both modes as a function of the density peaking parameter $n_e(0)/< n_e >$ exists in the same line. This fact shows that the thermal diffusivity correlates to the density gradient.

The code of the NBI deposition in the PROCTR-MOD is developed for the large density ($> 2\times10^{19}$ m^{-3}). There may be a little error of the calculation in the low density case (especially $< 1\times10^{19}$ m^{-3}). It is necessary to give careful consideration to the discussion about the density dependence. We have to further improve the accuracy of the calculation for the low density.

4. Conclusion

The reason for the increase in the ion temperature in the HIT mode of the NBI heated plasma on CHS is the smaller ion thermal diffusivity than that in the L-mode. On the contrary, the electron diffusivity in the HIT mode is larger than that in the L-mode. There is an important correlation between the thermal diffusivity and the density gradient.

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