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Journal of Nuclear Materials 313–316 (2003) 259–262

journal of nuclear materials

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Boundary plasma behavior under different wall conditions on HT-7 tokamak

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Abstract

The boundary plasma behaviors under different wall conditions on the HT-7 tokamak were investigated using a reciprocating Langmuir probe system. The ion cyclotron radio frequency (ICRF) boronization has become a routine wall conditioning technique on HT-7. After ICRF boronization, the turbulence de-correlation and radial electric field shear in the plasma edge region accompanied the strong reduction of impurity radiation, which resulted in the enhancement of edge transport barrier. The central chord average density scanning experiment had been carried out on HT-7. Accompanying the increase of density an evident increase of radial electric field shear could be found in the plasma edge region, which could be responsible for the turbulence de-correlation and improved particle confinement. The results presented here suggest a link between wall conditions and boundary plasma physics; especially interplay between atomic processes and turbulence through the formation of radial electric field shear in the plasma edge region.

PACS: 52.40.H
Keywords: Boundary plasmas; Langmuir probe; ICRF boronization; Density scanning; Turbulence; Radial electric field shear

1. Introduction

The boundary plasma behavior, especially turbulent transport, is closely related to the impurity influx, impurity radiation and the atomic physical processes, which are strongly affected by the first wall conditions. It is generally accepted that anomalous transport in magnetized hot plasmas is due to plasma turbulence. However the dominant driving mechanisms of turbulence have not yet been fully identified [1]. It is recognized that more than one single mechanism would be needed to explain all the experimental observations of turbulence in the plasma boundary region. Atomic processes such as ionization and impurity radiation can be drivers of turbulence, which might cause anomalous transport in the plasma edge. There have been several measurements that show the importance of atomic processes to the level of edge fluctuations and the value of self-generated radial electric field [2,3]. In the HT-7 tokamak, the boundary plasma behavior under different wall conditions was investigated using a reciprocating Langmuir probe system. The results presented in this paper suggest a link between wall conditions and boundary parameters, in particular a correlation between atomic processes and turbulence through the formation of radial electric field in the plasma edge region, although these results do not fully support the importance of ionization and radiation driven turbulence [4].

2. Description of the experiments

HT-7 is a superconducting tokamak with circular poloidal limiter. The main parameters of HT-7 device are: major radius $R = 1.22$ m, minor radius $a = 27$ cm, toroidal magnetic field $B_\phi = 1$–2.5 T, plasma current $I_p = 100$–250 kA, central line averaged density $n_e = 0.8$–6×10^{19} m^{-3}, central electron temperature $T_{eo} = 0.6$–2 keV, central ion temperature $T_{io} = 0.3$–1 keV,

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PII: S0022-3115(02)01338-7

discharge duration $\tau_d = 0.5$–20 s, deuterium working gas. The liner is made of stainless steel with a radius of 33 cm. Wall conditioning is carried out using an ion cyclotron radio frequency (ICRF) power system with an ion Bernstein wave antenna or a fast wave antenna [5]. A square array (side 2 mm) of four single Langmuir probes (each tip 2 mm in length and 0.5 mm in diameter) was used as a triple probe which was mounted on the top of the tokamak along the central line. It can be rapidly reciprocated over 8 cm in 80 ms. The data are digitized at 1 MHz with 12-bit resolution using a multi-channel digitizer.

3. Ion cyclotron radio frequency boronization experiments

The ICRF boronization [5] has become a routine wall conditioning technique on HT-7 tokamak, which can significantly improve the confinement of plasma. Observable suppression of oxygen, carbon and metal impurities and therefore radiation power and Z_{eff} were achieved. The improved confinement both for particle and energy was observed in entire operation parameters.

In ohmic discharges, since loop voltage dropped evidently, ohmic heating power was less than that in metal wall case. Although radiation power fraction was quite low with boronized wall, the boundary electron temperature did not increase as shown in Fig. 1. However, the electron temperature profile in the plasma edge region was steepened. The measurement were carried out in two ohmic heated discharges with the same discharge conditions: $I_p = 140$ kA, $n_e = 1.5 \times 10^{19}$ m^{-3}, $B_\phi = 2$ T. Fig. 1 also shows that the electron density profile was also sharply steepened in the edge of plasma, while there was no obvious change in scraped-off layer (SOL). The formation of edge density pedestal accompanied the broad density profile observed after boronization. The increase in the pressure gradient is mainly due to the rise in edge density. Fig. 2 (left, (a)) plots the boundary

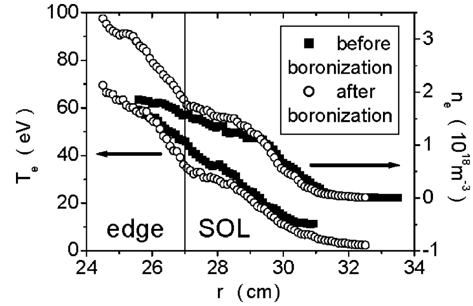

Fig. 1. Profiles of boundary electron temperature T_e and electron density n_e before boronization (■) and after boronization (○). The comparison is between two ohmic dishrags with the same discharge conditions.

floating potential profiles. Intensive shear can be found in the plasma edge with boronized wall. As a result, the relative fluctuation level of ion saturation current was suppressed in the same radial region as shown in Fig. 2(left, (b)). Similar suppression effect can also be observed in Fig. 2(left, (c)) which displays the absolute fluctuation level of floating potential.

As shown in Fig. 2(right, (a)) the coherence between electron density fluctuations and poloidal electric field fluctuations was reduced by about 40% in the edge shear layer, while there was no observable change in SOL. This is a clear evidence of shear de-correlation effect. The phase difference between electron density fluctuations and poloidal electric field fluctuations was also influenced by the existence of edge shear layer as shown in Fig. 2(right, (b)). The phase difference increased obviously with boronized wall. Because the fluctuation levels, the coherence and the phase difference are three critical quantities influencing the particle transport, the turbulent particle flux dropped more than a half in the edge shear layer region, which can be seen in Fig. 2(right, (c)), although the absolute fluctuation level of electron density did not decrease apparently. Therefore it can be seen that the improved control of impurity and recycling by wall conditioning plays an important role in the generation of edge transport barrier.

4. Density scanning experiments

The central chord averaged density scanning experiments had been carried out on HT-7 tokamak to research the impact of neutral influx on boundary plasma behavior. Fig. 3(left, (a)) shows the boundary electron density profiles in several central line averaged density situations. With the increase of edge density, a steeper density profile could be observed in the plasma edge region. As shown in Fig. 3(left, (b)), the edge electron temperature decreased considerably. This decrease of edge electron temperature was a result of the enhancement of radiation. Accompanying the increase of density, electron temperature profile became steeper in the plasma edge, while it was flattened in SOL. Accordingly the pressure gradient rose rapidly with density in the plasma edge region, which indicated better confinement. In Fig. 3(right, (a)), the boundary plasma potential profiles showed an evident increase in the radial electric field shear close to the radial location of last closed flux surface (LCFS), when the density was raised. Although the boundary electron density and temperature changed markedly, there were no obvious variation on the relative fluctuation levels of ion saturation current and floating potential as displayed in Fig. 3(right, (b)).

Fig. 4 shows the profiles of poloidal correlation length L_{c_θ} of fluctuations obtained via the standard two-point correlation technique [6] using two floating

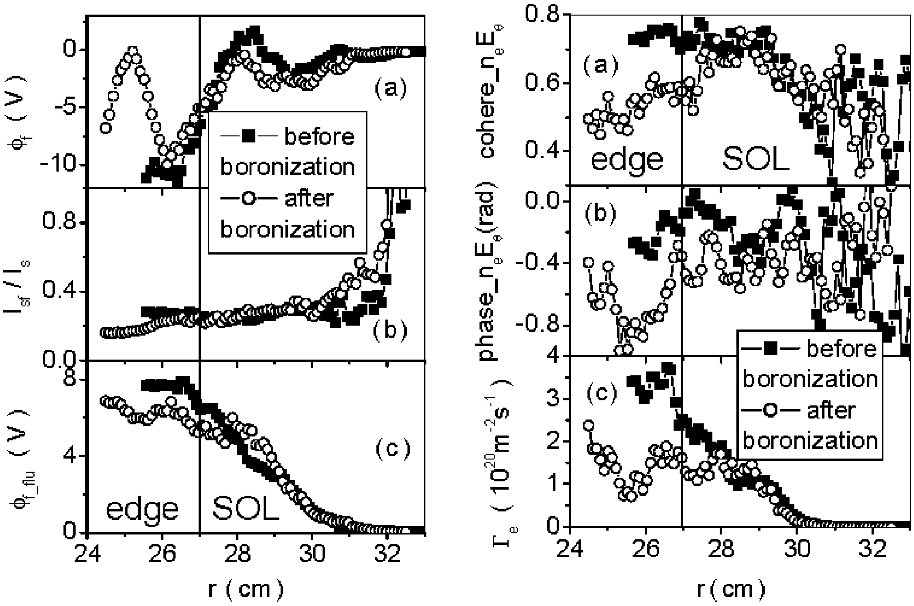

Fig. 2. Left: Profiles of boundary (a) floating potential ϕ_f, (b) relative fluctuation level of ion saturation current I_{sf}/I_s, (c) absolute fluctuation level of floating potential ϕ_{f_flu} before boronization (■) and after boronization (○). Right: Profiles of boundary (a) coherence between electron density fluctuations and poloidal electric field fluctuations, (b) phase difference between electron density fluctuations and poloidal electric field fluctuations, (c) turbulent particle flux Γ_e before boronization (■) and after boronization (○). These data were from the same discharges as used in Fig. 1.

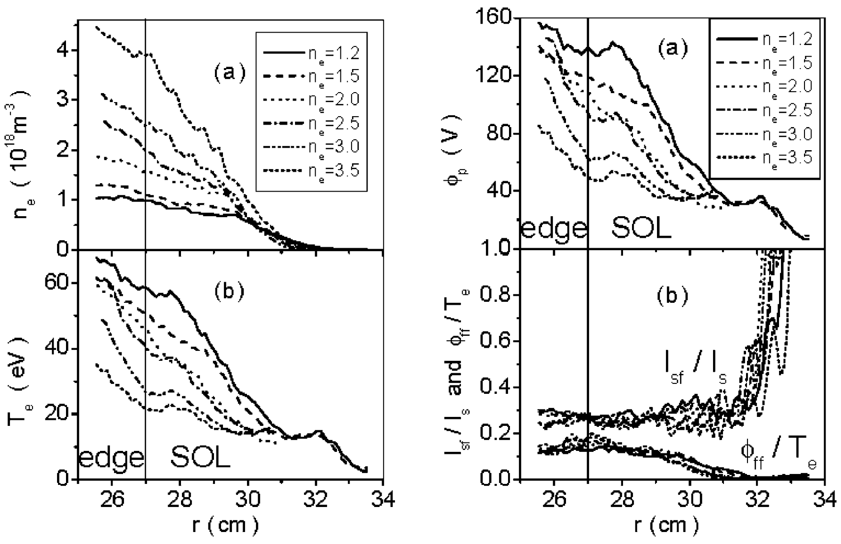

Fig. 3. Left: Profiles of boundary (a) electron density n_e, (b) electron temperature T_e in six central line averaged density situations. Right: Profiles of boundary (a) plasma potential ϕ_p, (b) relative fluctuation levels of ion saturation current I_{sf}/I_s and floating potential ϕ_{ff}/T_e in six central line averaged density situations.

potential signals. From this figure, one can see that the poloidal correlation length decreased dramatically with the increase of density in the plasma edge region. This is a direct evidence of de-correlation effect of turbulence, which agrees with the enhanced radial electric field shear in the same radial region. Consequently, the turbulent particle flux derived from Langmuir probe signals did not increase observably in the vicinity of LCFS. Since the density rose, while the particle flux only changed a little, the calculated particle confinement time increased

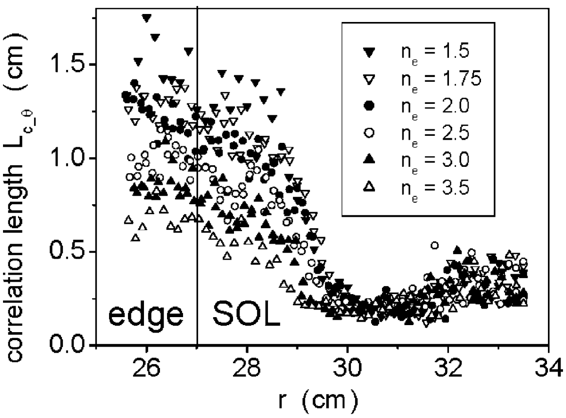

Fig. 4. Profiles of poloidal correlation length L_c of fluctuations in six central line averaged density situations.

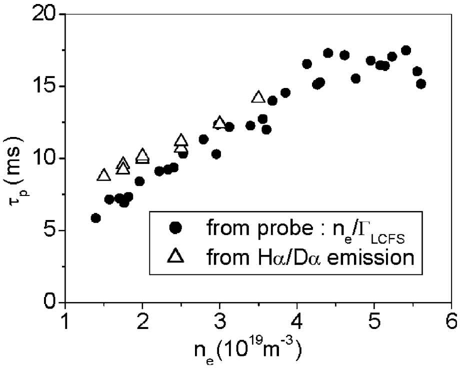

Fig. 5. Particle confinement time vs. central line averaged density. The comparison is between the particle confinement times calculated with Hα emission signals (●) and Langmuir probes signals (△).

with density as shown in Fig. 5. This relationship was consistent with the result estimated from $H\alpha$ emission signals, which is also plotted in Fig. 5. From this figure, one can see that the particle confinement time increased with density and saturated at density $n_e = 4 \times 10^{19}$ m^{-3}. Similar relation had been reported on TEXT tokamak [7], which had the comparable size of HT-7 tokamak.

In high-density case, the low sheath potential near the surface of limiter benefited from low boundary electron temperature, which would substantially suppress the impurity sputtering. Hence the Z_{eff} decreased rapidly with the increase of density. The reduced impurity content and impurity radiation in the plasma edge region might have an active influence on the particle confinement. Accompanying the increase of density, Hα emission intensity and turbulent particle flux did not increase accordingly, which suggests the neutral influx and the turbulent particle outflux was not sensitive to the density condition. The improved particle confinement with high density coupled with the increase of radial electric field shear in the plasma edge. These results indicate that the recycling process is an important ingredient not only in confinement but also in turbulent transport, even in the formation of radial electric field shear.

5. Conclusion

In conclusion, the boundary plasma behaviors under different wall conditions on the HT-7 tokamak were investigated using a reciprocating Langmuir probe system. The ICRF boronization has become a routine wall conditioning technique on HT-7. After ICRF boronization, the turbulence de-correlation and radial electric field shear in the plasma edge region accompanied the strong reduction of impurity radiation, which resulted in the enhancement of edge transport barrier. The central chord average density scanning experiment had been carried out on HT-7. Accompanying the increase of density an evident increase of radial electric field shear could be found in the plasma edge region, which could be responsible for the turbulence de-correlation and improved particle confinement. The results presented here suggest a link between wall conditions and boundary plasma physics; especially interplay between atomic processes and turbulence through the formation of radial electric field shear in the plasma edge region.

Acknowledgements

This work was supported by the National Natural Science Foundation of China under grant no. 10175069 and the Chinese Academy of Sciences under grant no. 01062525.

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