DIVERTOR CHARACTERSITICS AND CONTROL ON THE W-SHAPED DIVERTOR WITH PUMP OF JT-60U

N. HOSOGANE, H. KUBO, S. HIGASHIJIMA, K. ITAMI, K. SHIMIZU,
H. TAKENAGA, H. TAMAI, S. KONOSHIMA, N. ASAKURA, S. SAKURAI,
A. SAKASAI, T. ISHIJIMA*, M. SHIMADA AND THE JT-60 TEAM
Japan Atomic Energy Research Institute,
Naka Fusion Research Establishment,
Naka-machi, Naka-gun, Ibaraki-ken, 311-0193, Japan

Abstract

Roles of the inner leg pumping and the private dome, which are special features of the W-shaped divertor of JT-60U, have been investigated. The following observations were made: The inner leg pumping functions well in attached states or partially detached states with weak X-point MARFE where the inner particle recycling is enhanced. A combination of main gas puff and inner leg pump is effective in reduction of intrinsic carbon impurity. Geometrical effects of the private dome on transport of hydrocarbons in the private flux region was confirmed by spectroscopic measurements of CD-band intensity profile and impurity transport simulation code using experimental data.

1. INTRODUCTION

In JT-60U, the previous open divertor was modified to a semi-closed W-shaped divertor with pump (Fig. 1) in 1997 [1]. Special features of the W-shaped divertor are a dome in the private flux region (private dome) and a pumping scheme from the inner divertor channel in the private flux region (inner leg pumping). The inner leg pumping takes advantage of the enhancement of particle recycling at the inner divertor channel [2]. The dome separates the inner and outer divertor channels with respect to the behavior of neutral particles, which realizes the inner leg pumping scheme. However, particle recycling distribution in the divertor changes with divertor states, i.e., attached, partially detached and strongly detached states. Therefore, it is important to study the operational regime where the inner leg pumping is effective, for example, for generating SOL flow by “puff and pump” [3,4]. On the other hand, the private dome is expected to prevent the upstream transport of hydrocarbons generated by chemical sputtering [5], and to reduce a resultant carbon influx to the main plasma. Therefore, understanding the effects of the inner leg pumping and the private dome is very important for both improving divertor performance and designing a new divertor like ITER.

2. INNER PUMPING CHARACTERISTICS

The inner leg pumping characteristics has been investigated in ELMy H-mode discharges with I_p = 1.2 MA, B_T = 2.5 T and P_{NBI} = 18 MW. Figure 2 shows degree of in-out asymmetry of particle recycling in the divertor defined by $I_{D\alpha}^{in}/(I_{D\alpha}^{in} + I_{D\alpha}^{out})$ and neutral pressure under the outer baffle (baffle pressure) as a function of inner D_α intensity (Fig. 1). From this figure, it is found that as the particle recycling increases, the degree of in-out asymmetry of particle recycling increases up to around 0.8 in the “no X-point MARFE” state (attached at the outer divertor), but begins to decrease after a weak X-point MARFE (partially detached at the outer divertor) appears and finally drops to around 0.5 as a strong X-point MARFE is established. In the attached state, the baffle pressures for δ_g = 2 cm and δ_g = 6 cm are proportional to the inner D_α intensity, respectively, showing the inner leg pumping works well. Here, δ_g is a gap between the inner separatrix and the inner wing of the dome (Fig. 1). The difference in baffle pressure for the same inner D_α intensity indicates that the pumping speed can be controlled by adjusting the position of

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* University of Tsukuba, 1-1-1, Tnnoudai, Tsukuba-shi, Ibaraki-ken, 305-0006, Japan

the inner separatrix to the pumping slot. From the baffle pressure and the pumping port conductance, the throughput for δ_g = 2 cm in the attached state is estimated to be about 3% of the particle recycling flux in the divertor. On the other hand, in the partially detached states with a weak or strong X-point MARFE, the inner D_α intensity becomes saturated as the electron density is increased by gas puff. The estimated throughput reaches near the applied gas puff rate (70 – 90% for the discharge with δ_g = 2 cm). This is probably because the ionization process of neutral particles in the inner divertor channel changes as the degree of detachment proceeds.

3. EFFECTS OF GAS PUFF AND PUMP ON IMPURITY REDUCTION

Effects of "puff and pump" on reduction of intrinsic carbon impurities have been investigated in ELMy H-mode discharges described in Section 2. Figure 3 shows Z_{eff} obtained in these discharges as a function of electron density. Here, main gas puff is supplied at the top of plasma and divertor gas puff is supplied to the inner separatrix leg through the pumping slot. It is found that at the same electron density, Z_{eff} is low in the discharges with main gas puff, use of pump and narrow gap, for the cases of no X-point MARFE and weak X-point MARFE. A combination of divertor gas puff and pump is not effective. As described above, the throughput of the inner leg pumping is large for the narrow gap, and is comparable with the gas puff rate in the divertor state with weak X-point MARFE. Thus, the reduction in Z_{eff} is attributed to the effect of the inner leg pumping. Core plasma performance is not considered to be a cause for this difference, because these discharges have almost the same confinement properties; H-factor = 1 - 1.3 at $n_e^{main} \approx (3 - 4) \times 10^{19}$ m^{-3} and type I ELM with frequencies of 130 - 140 Hz and 220 - 230 Hz before and after the onset of X-point MARFE.

After the divertor modification, carbon is the dominant impurity in JT-60U. To understand the effect of "puff and pump" on reduction of Z_{eff}, a relationship between gas puff rate (or throughput) and Z_{eff} should be investigated under the same condition of carbon generation in the divertor. For this investigation, three discharges with main gas puff are compared; (A) with pump and δ_g = 2 cm, (B) with pump and δ_g = 6 cm and (C) without pump and δ_g = 6 cm. Figure 4 shows electron density, ratio of the estimated throughput to the divertor recycling flux $\Phi_{D\alpha}^{div}$, CII intensity in the divertor and Z_{eff} of these discharges as a function of gas puff. The data set of (A_1, B_1) and (A_2, B_2, C_2) are from the attached states of the discharges (A) and (B) and the partially detached states with weak X-point MARFE of the discharges (A), (B) and (C), and are sampled at the timings when CII intensity profiles, i.e., indexes of carbon generation, as well as D_α intensities are almost the same in the respective states. In this figure, Z_{eff} is found to decrease for the both divertor states as the gas puff rate increases. The gas puff rate of 73 Pam^3/s for A_2 corresponds to 15% of the divertor recycling flux. The estimated throughput increases up to about 14% of the divertor recycling due to intermediate flow effect. Thus, it is possible to consider that a combination of large main gas puff and inner leg pumping generates SOL flow and reduces carbon impurities.

4. DOME EFFECT ON CARBON IMPURITY REDUCTION

In order to investigate the dome effect on carbon impurity transport, profiles of CD band were compared intensity in the W-shaped shaped divertor and in the previous open divertor under the same L-mode discharge condition; I_p = 1.2 MA, B_T = 3.5 T and P_{NBI} = 4 MW. The divertor pump was not used for comparison. Figure 5 shows CD-band intensity profiles measured with the 60-channel fiber array (Fig. 1); (a) low density case, $n_e = 1.3 \times 10^{19}$ m^{-3} and (b) medium density case, $n_e = 1.8 \times 10^{19}$ m^{-3}. It is noted that when the electron density increases, the increasing rate of CD band intensity in the private flux region is smaller by about 40% in the W-shaped divertor than the open divertor, and the intensity profile between separatrix strike points keeps a deep valley in the W-shaped divertor compared with the open divertor. Assuming that hydrocarbons are mainly generated by bombardment of charge exchange neutrals to the tiles in the private flux region [5], the ratio of CD-band intensity to D_α intensity can be used as a measure for reduction. Here, averaged intensities between the inner and the outer strike points are used. With these parameters, it was found that the averaged D_α intensities in the W-shaped divertor $D_{\alpha\text{-av}}^W$ were larger than those in the open divertor $D_{\alpha\text{-av}}^{O}$; $D_{\alpha\text{-av}}^{W} / D_{\alpha\text{-av}}^{O} \approx 2$ at $n_e = 1.3 \times 10^{19}$ m^{-3} and $D_{\alpha\text{-av}}^{W} / D_{\alpha\text{-av}}^{O} \approx 1.4$ at $n_e = 1.8 \times 10^{19}$ m^{-3}. This increase is due to the closeness of the W-shaped divertor. On the other hand, CD-band intensity ratios were $CD_{av}^{W} / CD_{av}^{O} \approx 1.1$ at $n_e = 1.3 \times 10^{19}$ m^{-3} and $CD_{av}^{W} / CD_{av}^{O} \approx 0.7$ at $n_e = 1.8 \times 10^{19}$ m^{-3}. Consequently, the ratio of CD-band intensity to D_α intensity is reduced to about 0.5 in the W-shaped divertor. This means that in the W-shaped divertor, a large fraction of hydrocarbons is lost in the dissociation process though the number of hydrocarbons generated by chemical sputtering is considered to increase. This is attributed to the geometrical effect of the dome, which prevents the free motion of neutral hydrocarbons in the private flux region. To confirm this effect, a two-dimensional impurity code based on Monte Carlo technique (IMPMC-code) [6] has been developed. The following processes are incorporated into the IMPMC-code; chemical sputtering process by neutral deuterium atoms as well as deuterium ions, dissociation process of methane and electron excitation rate coefficient for calculating CD-band intensity. Figure 6 compares the measured and calculated profiles of CD-band intensity at $n_e = 1.9 \times 10^{19}$ m^{-3}. The calculated profile agrees well with the measured one within a factor of 2. In this calculation, the neutral particle source at the baffles, which has been observed in the W-shaped divertor [7], is taken into account so as to reproduce the measured D_α intensity profile between separatrix strike points. The resultant calculated CII intensity between separatrix strike points is smaller than the measured one, but is within a factor of 2. This result is considered to indicate that the modeling of dissociation process of methane is valid and the geometrical effect of the dome predicted by the impurity simulation code exists. However, the observed carbon impurity concentration in the main plasma was not reduced compared with the previous open divertor, suggesting the existence of other mechanism for carbon impurity contamination.

5. SUMMARY

Effects of the inner leg pumping and the private dome on divertor performance have been investigated. In attached states, the throughput of the inner leg pumping was confirmed to increase with the enhancement of inner particle recycling and to be controlled by adjusting the position of the inner separatirx. Even in partially detached state with weak X-point MARFE where the in-out asymmetry becomes weak, the inner leg pumping is still effective. This may lead to the reduction in Z_{eff} by a combination of main gas puff and inner leg pump. The effect of pumping location will be clearer by comparing the inner leg pumping and both leg pumping. The both leg pumping experiment is planned in 1999. Geometrical effects of the private dome on transport of hydrocarbons has nearly been confirmed to exist by spectroscopic measurements and calculations with IMPMC-code. The private dome may be considered as a fundamental component in the divertor system.

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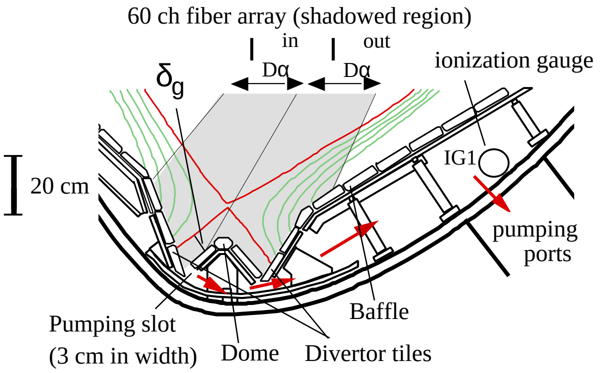


Fig. 1 Cross-sectional view of W-shaped divertor and diagnostic arrangement

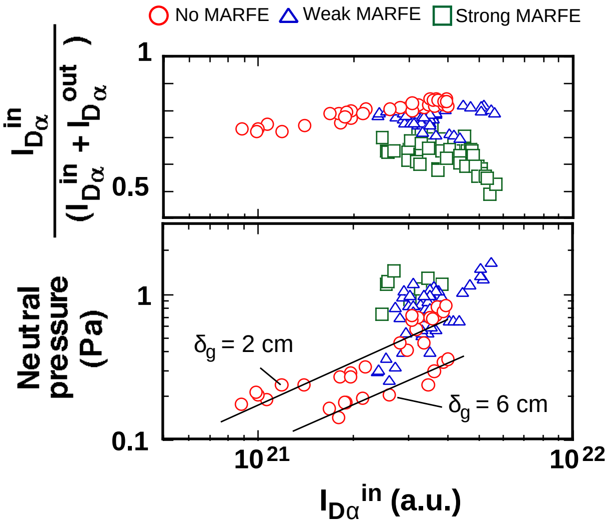
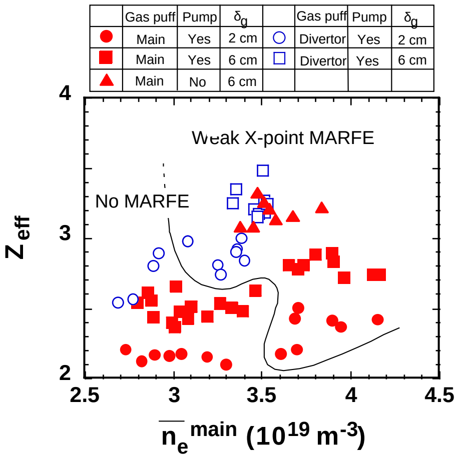


Fig. 2 Degree of in-out asymmetry of particle recycling defined by $I_{D\alpha}^{in}/(I_{D\alpha}^{in}+I_{D\alpha}^{out})$ *and neutral pressure under the outer baffle as a function of inner Da intensity in ELMy H-mode discharges. Divertor radiation losses of "no MARFE", "weak MARFE", and "Strong MARFE" are 10 - 40%, 30 - 50% and 50 - 80%.*



	Gas puff	Pump	δ_g		Gas puff	Pump	δ_g
●	Main	Yes	2 cm	○	Divertor	Yes	2 cm
■	Main	Yes	6 cm	□	Divertor	Yes	6 cm
▲	Main	No	6 cm				

Fig. 3 Z_{eff} *of ELMy H-mode discharges with vairous combinations of gas puff location, use of pump and gap* δ_q*.*

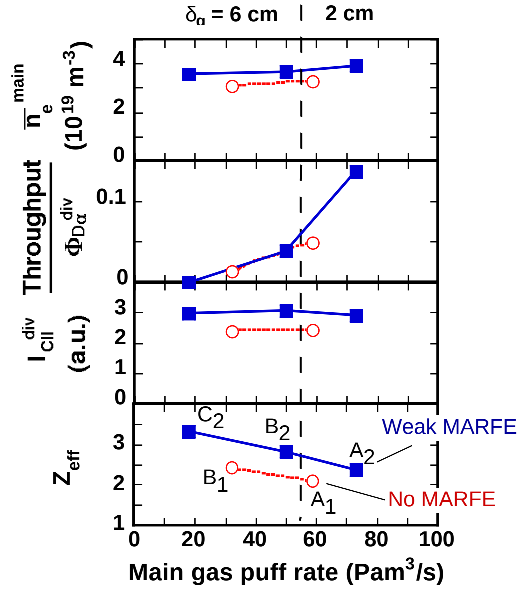


Fig. 4 Electron density, pumping rate defined by throughput/$\Phi_{D\alpha}^{div}$*(divertor recycling flux) and* Z_{eff} *as a function of main gas puff rate under the same carbon generation (*I_{CII}^{div}*) condition in the divertor.*

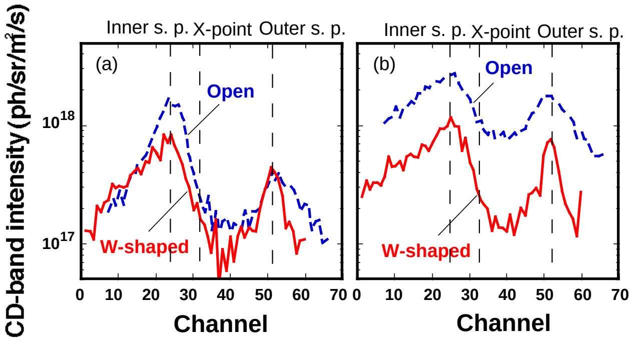


Fig. 5 Comparison of measured CD-band intensity profiles between the W-shaped divertor and the previous open divertor. (a) $n_e = 1.3 \times 10^{19}$ m^{-3}*, (b)* $n_e = 1.8 \times 10^{19}$ m^{-3}

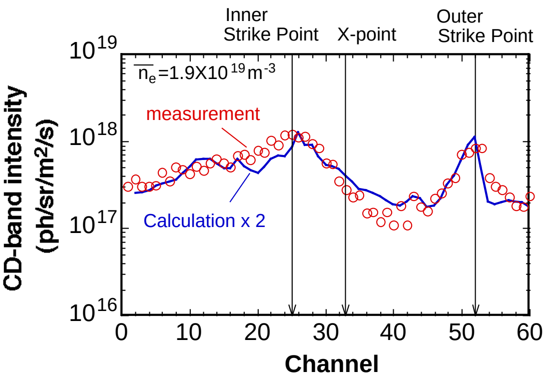


Fig. 6 Comparison of the measured CD-band and the calculated one with IMPMC code for the medium density case.