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Reduction of the divertor heat load with impurity seeding in LHD
大型ヘリカル装置における不純物ガスパフを用いたダイバータ熱負荷軽減

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Impurity seeding for the reduction of the divertor heat load was conducted in LHD. Neon, argon and nitrogen were seeded, respectively, and enhanced radiation loss and reduction of the divertor heat load were observed for all cases without drastic change of global plasma parameters such as stored energy and line averaged density. The ratio of the radiation power to the plasma heating power was limited by the radiative collapse of plasma, and that was almost same for the three impurities.

1. Introduction

Reduction of heat and particle loads to divertor is a crucial issue to realize fusion reactor. Divertor detachment is a favorable operation for the purpose. To achieve divertor detachment, reduction of electron temperature (T_e) in scrape-off-layer (SOL) is necessary. One of the effective methods to reduce T_e is radiation enhancement in the SOL plasma. In present medium/large fusion devices, plasma facing material has been carbon, and carbon works as dominant radiator for reduction of T_e. However, carbon will not be utilized in fusion reactor to reduce tritium retention in vacuum vessel and to avoid large erosion of plasma facing components, and metallic material such as tungsten will be plasma facing material. Therefore, it is considered that impurity such as neon seeding is necessary to enhance radiation loss in SOL. In tokamaks, impurity seeding experiment has been conducted, and reduction of T_e in SOL has been observed [1]. Against this background, impurity seeding experiment was conducted in LHD which has unique edge magnetic field line structure such as existence of stochastic layer in SOL. In LHD, neon (Ne), argon (Ar) and nitrogen (N_2) were seeded, respectively. In this presentation, the results of the impurity seeding experiment will be shown.

2. Neon seeding experiment

Figure 1 shows waveforms of plasma parameters during discharges with and without Ne seeding. Ne gas was puffed for 120 ms from t = 4s with the flux of ~ 1.6 Pa·m^3/s. This flux was about 10 % of the hydrogen fueling flux. With Ne seeding, the total

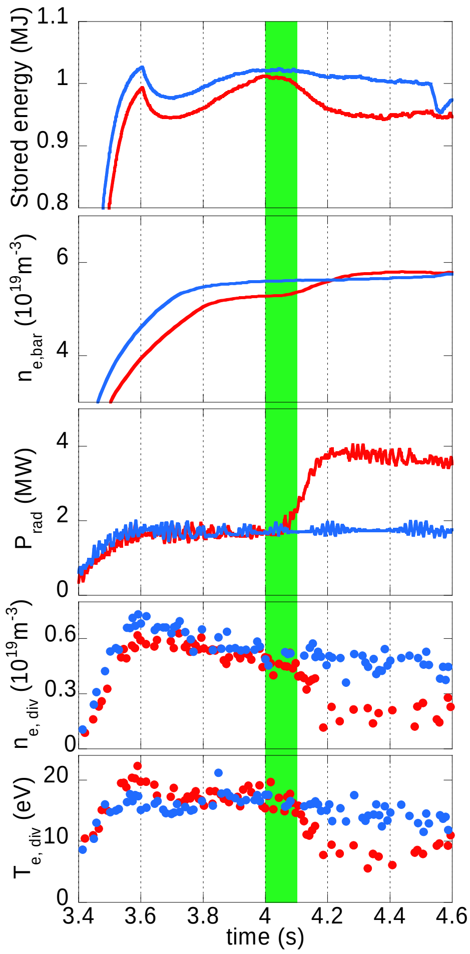

Fig. 1 Typical waveforms of plasma parameters during discharges with (red) and without (blue) Ne seeding. Ne gas was puffed for 120 ms from t = 4s. Plasma heating power with NBI was about 13 MW.

radiation power (P_{rad}) was almost doubled, the plasma stored energy and the central line-averaged density ($n_{e,bar}$) slightly decreased and increased,

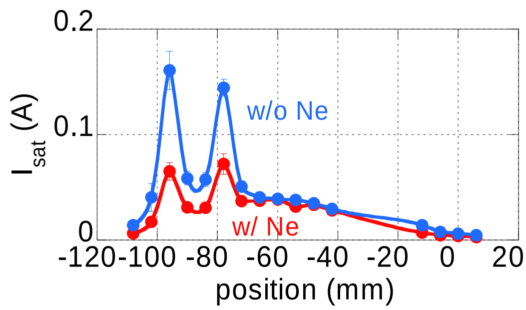

Fig. 2 Ion saturation current profile on a divertor plate at t = 4.2s in the discharges shown in Fig. 1.

respectively, and both the density ($n_{e,div}$) and temperature ($T_{e,div}$) on a divertor plate decreased. Figure 2 shows ion saturation current (I_{sat}) profiles on a divertor plate at t = 4.2s in the discharges with and without Ne seeding shown in Fig. 1. The drastic reduction of I_{sat} was observed at large I_{sat} positions such as position of -96mm and 78 mm. The magnetic field lines structure was considered to relate with this change of I_{sat} profile. The effect of the seeding such as reduction of temperature was limited at the peripheral and the scrape-off layer. The maximum P_{rad} was obtained after the termination of the seeding, and P_{rad} decreased with a long time constant of ~ 4.7s. It suggested that recycling of Ne was large. To increase P_{rad}, seeding amount of Ne was increased. However, plasma collapsed radiatively in the region P_{rad} > ~ 0.3 times plasma heating NBI power (P_{NBI}) in the discharge condition shown in Fig. 1.

Ne seeding in lower density discharge ($n_{e,bar}$ ~ 2×10^{19}m^{-3}) than that in the discharge shown in Fig. 1 was also conducted, and reduction of divertor loads was also observed. In this case, P_{rad}/P_{NBI} reached 0.5, though the effect of the seeding reached deeper inside the last closed flux surface than that in higher density discharge case, and n_e and T_e in peripheral region largely increased and decreased, respectively.

Ne seeding was also applied to Super Dense Core (SDC) discharges with pellet fueling [2], and reduction of the divertor loads was confirmed.

In LHD, other methods to reduce the divertor loads such as divertor detachment with magnetic island formation [3] and SERPENS mode [4] have been conducted. But they cannot be applied to inward shifted magnetic axis configurations up to now, and they need high density plasma. It should be noted that Ne seeding can be applied to inward shifted configurations and relatively low density plasma ($n_{e,bar}$ ~ 2×10^{19}m^{-3}).

3. Other impurity seeding

N_2 and Ar were also examined as radiators to understand the effect of the difference of their atomic and molecule processes in plasma on the radiation enhancement.

In both seeding cases, radiation enhancement was observed as in the case of Ne seeding. The plasma response to Ar seeding was roughly same as that in Ne seeding discharge.

For the case of N_2 seeding, P_{rad} increased only during the N_2 gas-puffing. After the termination of the puffing, P_{rad} decreased immediately. It suggested that N_2 recycling coefficient was much smaller than that of Ne and Ar.

For all these three impurities, the P_{rad}/P_{NBI} limit for the radiative collapse was almost same.

4. Summary

Impurity seeding for the enhancement of radiation and reduction of the divertor heat load was conducted in LHD using Ne, Ar and N_2 gas-puffing, respectively. For all cases, enhanced radiation state was observed. In the state, the effect of the seeding on the plasma performance was small. However, once the radiation power exceeded the limit, plasma collapsed radiatively. The limit was ~ 0.3 times plasma heating power except low density discharge case. Recycling coefficient of N_2 was observed to be much smaller than that of Ne and Ar.

Modeling including atomic and molecule processes and transport is necessary to understand the experimental results and to develop plasma operation scenarios with impurity seeding in future fusion reactor.

References

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