§5. Favorable Aftereffect of Methane Discharges Observed in LHD Pellet Shot

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Methane (CH_4) gas-puff discharge experiment has been carried out to test the controllability of an effective charge (Z_{eff}) and the possibility of metal impurity reduction by the real time carbonization (RTC) effect. In the ideal RTC scenario, carbon atoms are effectively coated on the small wetted areas. Therefore, the total amount of CH_4 gas becomes much smaller than that used in the usual glow discharge method. In the experiment, the performance of the pellet shot after four discharges introducing ~20 Pa·m^3 of CH_4 was significantly improved, although the CH_4 discharge itself showed only slight improvement in the confinement property.

Two typical pellet shots before and after CH_4 discharges are compared in Fig. 1. At the time $t = t_0 = 1.1$ s in both discharges, W_p, n_e, P_{NB}, and T_e are almost the same. However, the decay time of n_e in the pellet shot after CH_4 discharges (#23114) is mitigated to about twice of that before CH_4 discharges (#23046). This directly results in the larger plasma stored energy W_p, since the temporal behavior of the electron temperature T_e is almost the same in these discharges. Here we compare the time slice of #23046 at $t = t_1 = 1.25$ s and that of #23114 at $t = t_1' = 1.4$ s, to keep n_e in both slices the same. Then it can be seen that it takes 0.15 s (= $t_1 - t_0$) in #23046 and 0.3 s (= $t_1' - t_0$) in #23114 to obtain the same decrease in n_e. Taking into account that $dW_p/dt \sim 0$ in these time slices, the energy confinement time in #23114 is larger than that in #23046, since P_{NB} and n_e are identical in both slices. Detailed transport analysis gives -60% reduction in the particle transport coefficient D, and -40% reduction in the electron thermal transport coefficient χ_e at the half of the averaged minor radius. Returning to Fig. 1, the total radiation loss P_{rad} and the emission of FeXVI become smaller after CH_4 discharges. This can be understood as the metal impurity reduction, which is expected as the real time carbonization (RTC) effect. The reduction of metal impurity irradiation can be also recognized in the soft X-ray spectrum and the radial profile of the radiation loss.

In the case discussed here, the total amount of CH_4 (or, the number of carbon atoms) introduced into the vacuum vessel is about 20 Pa·m^3 (~5×10^{21}). The number of introduced carbon atoms roughly corresponds to 2 – 100 layers of graphite (the surface density of one monolayer graphite is assumed as ~3×10^{19} atoms/m^2). Here we used the area of the footprint of divertor legs (~1 m^2) and that of the vacuum vessel directly facing the main plasma (~300 m^2) for the minimum- and the maximum-estimations of the wetted area. In conclusion, only a small amount of CH_4 gas is enough to coat the metal plasma-facing components by RTC, as was experimentally observed. The following problem is to find out the scenario, which connects the phenomenological observations of RTC effect and the improvement in both of the particle and the electron thermal transport, which cannot be explained directly by the reduction of metal impurity or the radiation loss. To answer this, more detailed and systematic experiment together with the various measurements on the electro-static fluctuation and magnetic fluctuation is needed.

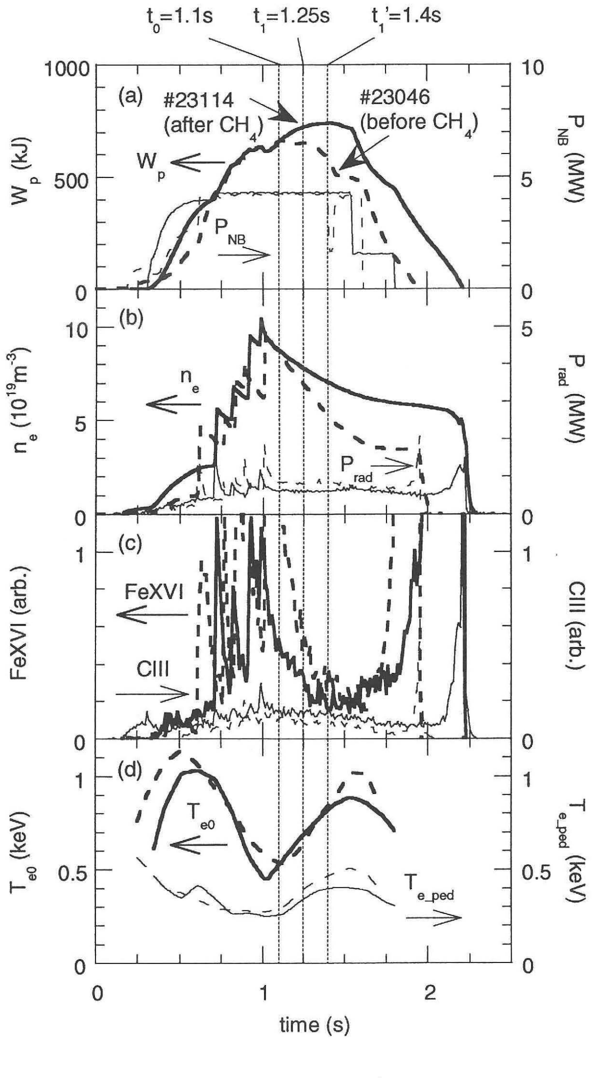

Fig. 1. Waveforms of (a) W_p and P_{NB}, (b) n_e and P_{rad}, (c) the emission intensities of FeXVI and CIII, (d) the electron temperature at the plasma center T_{e0} and the pedestal ($\rho = 0.9$) T_{e_ped}. Broken and solid lines denote #23046 (before CH_4 discharges) and #23114 (after CH_4 discharges).