§1. Progress of Superdense Plasma Research

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The high density operation is favorable for the fusion reactors since the fusion reaction rate is proportional to the density squared. The energy confinement is also expected to improve with density. Since the helical devices are free from the density limit related to the plasma current, high density operation research has intensively been conducted in LHD. The superdense core (SDC) plasma with the formation of the internal diffusion barrier (IDB) was first obtained in 2005. In order to develop the IDB-SDC mode to the reactor plasma, it is essential to sustain it in the steady-state operation. So far the IDB-SDC plasmas have been obtained transiently, therefore the most important and urgent issue is to verify if the continuous pellet fuelling is valid or not for the sustainment of SDC in the long pulse discharge. In the last experimental campaign the IDB-SDC plasma with central electron density of ~ 2 x 10^{20} m^{-3} could successfully be sustained for more than 3 seconds. The IDB was robustly maintained against the strong perturbation of fuelling pellets. No serious increase in radiation power or impurity accumulation was seen during the discharge.

For the demonstration of the quasi-steady-state sustainment of the IDB-SDC plasma, a newly developed repetitive pellet injector which can launch a series of 20 barrels was utilized in the 13th experimental campaign. Figure 1 shows the time evolution of principal parameters of the discharge. In the initial phase of the discharge from 3.70 s to 3.85 s, four pellets are injected to the plasma every 50 ms to rapidly increase the core density. After stopping the initial injection, the core density $n_e(0)$ begins to decrease, while central electron temperature $T_e(0)$ starts to rise. Then the stored energy W_p comes to its peak value due to the "reheat" effect, and the IDB-SDC plasma is established at this moment. The SDC will decay with the time constant of particle confinement time if no active control is applied. In this discharge, the fifth and following pellets are injected to sustain the SDC, which is controlled by the feedback signal of the line integrated density n_el. It can be seen that $n_e(0)$ and $T_e(0)$ are well controlled, and oscillation of W_p is kept within 20 %. This quasi-steady-state phase lasts for more than 3 s. From the n_e profiles it was also demonstrated that highly peaked profile with IDB is sustained during the discharge, except for a little increase in the edge n_e outside the IDB. This is considered to be an increase in the edge recycling, due to the insufficient pumping capability compared to the supplied particles with pellets, which finally degrades the SDC performance. To avoid such a situation, the closed divertor configuration with efficient pumping system is necessary.

During the IDB-SDC discharge, the large Shafranov shift takes place which strongly modifies the edge magnetic topology stochastic, where heat and particle transports are predicted to have different properties from those in the closed flux surface region. In order to further modify the edge magnetic topology, active experiments with resonant magnetic perturbation (RMP, m/n = 1/1) were performed. Figure 2 shows the radial profiles of n_e with and without RMP. It can be seen that the steep gradient is formed at IDB in both cases, while outside of the IDB (mantle), gradients are relatively gentle. It is interesting, in the case with RMP, that n_e in the mantle region is reduced. This phenomenon is similar to the density pump-out observed in the tokamak RMP experiments. From the transport analyses, it was demonstrated that the diffusion coefficient in the mantle region is increased by RMP. This result suggests that modification of magnetic topology in the mantle region enhances the particle transport, which results in the density pump-out effect.

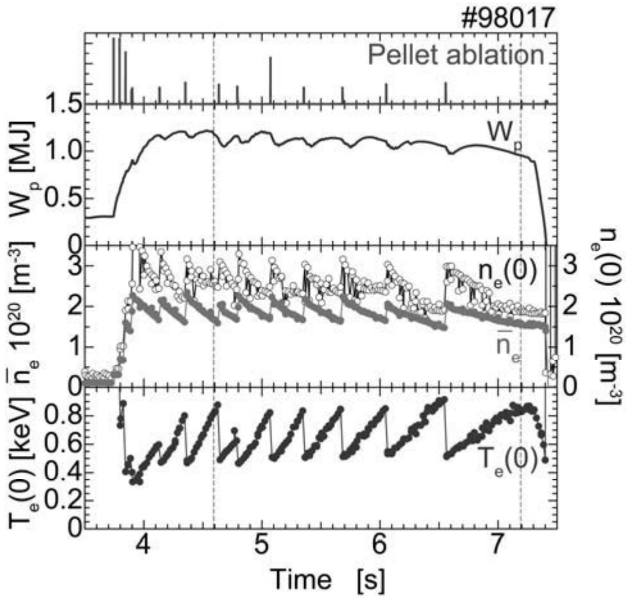

Fig. 1. Time evolution of plasma stored energy W_p, line averaged electron density n_e, central electron density $n_e(0)$ and temperature $T_e(0)$, together with injection signal of pellet (top).

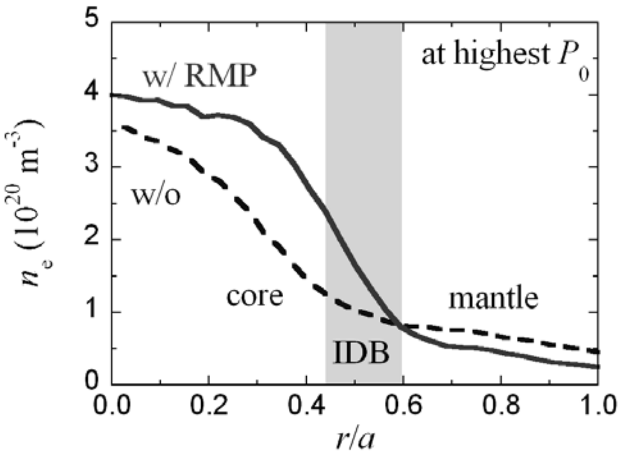

Fig. 2. Radial profiles of n_e with and without RMP.