

## **Observation of Impurity Accumulation during Density Peaking in HL-2A**

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Density profile peaking is favourable for plasma performance, such as being benefit to plasma confinement, increasing the bootstrap current fraction and the fusion power in burning plasma. However, the peaked density profile usually causes impurity accumulation in plasma core and the degradation of the performance appears as an enhanced radiative power loss and a dilution of ions. The existence of peaked density profiles has been usually observed in tokamaks even when the fuelling is located at plasma edge. On the other hand, anomalous particle transport together with the classical and neoclassical transport are numerously discussed for understanding the particle distribution phenomena.<sup>[1, 2]</sup> More recently, a natural and quasi-steady state particle transport barrier has been observed in the ohmic plasma in HL-2A as a new observation on density profile. In this paper the observations of impurity accumulation related to the density profile peaking in HL-2A Ohmic plasma are presented with respect to three kinds of fueling methods which have different fueling particle deposited locations.

The main diagnostics involved in these studies were 8 channels of the HCN laser interferometer for measuring electron density profile, five arrays of soft-X ray cameras with 20 channels in each array, three bolometric arrays with 16 channels in each array, as well as VUV spectrometer and visible bremsstrahlung measurement. A tangential H<sub>α</sub> emission detection array (46 channels) were used for the determination of the fueling particles deposited location. Three kinds of fueling methods, which were normal gas puffing from the plasma main chamber (GP-p) and from the high field side divertor chamber (GP-d), and supersonic molecular jet (SMJ) from the low field side of plasma chamber, were used in this study in the HL-2A tokamak ( $R = 1.65$  m,  $a = 0.4$  m,  $I_p = 480$  kA,  $B_t = 2.8$  T) with limiter or downside single null closed divertor configurations. In general, the deeper penetration can be achieved by SMJ and the location of the fueling source can reach at  $\sim 0.7 a - 0.8 a$ ,<sup>[3]</sup> while the others are just near the separatrix.

Dramatic increase of plasma radiation in center plasma was often observed in the high density ohmic discharges both in limiter and divertor configurations by any fueling method mentioned above in HL-2A. A typical discharge with a modulated gas puffing from main chamber is shown in figure 1, where the time evolution of main plasma parameters (Fig. 1a) and bolometric signals in different line of sight (Fig. 1b) are plotted. The character of these discharges was the plasma radiation sharply increased only in the core ( $r < 15$  cm) and kept constant in the outer region of plasma. Meanwhile, the central electron density nearly kept constant and the one at  $r = 0.6a$  gradually decreased with the increase of peak factor  $n_e(0.1a) / n_e(0.6a)$  up to 1.8 in this shot. That means the dramatic increase of the central radiation must be a consequence of impurity accumulation rather than the increase of the central electron density. The soft X-ray emission increased also only at the core region. The neutral gas pressure in plasma main chamber  $P_p$  and divertor chamber  $P_d$ , as well the Da intensity, were not obviously changed after the gas puffing stopped. The volume integrated radiation had a slight increase but it still kept a relative low fraction to the input power by a factor of  $P_{rad} / P_{in} \sim 0.5$ . This experimental result showed that the impurity accumulation were related to the change of density profile in the core plasma, and also suggest an existence of the particle pinch.

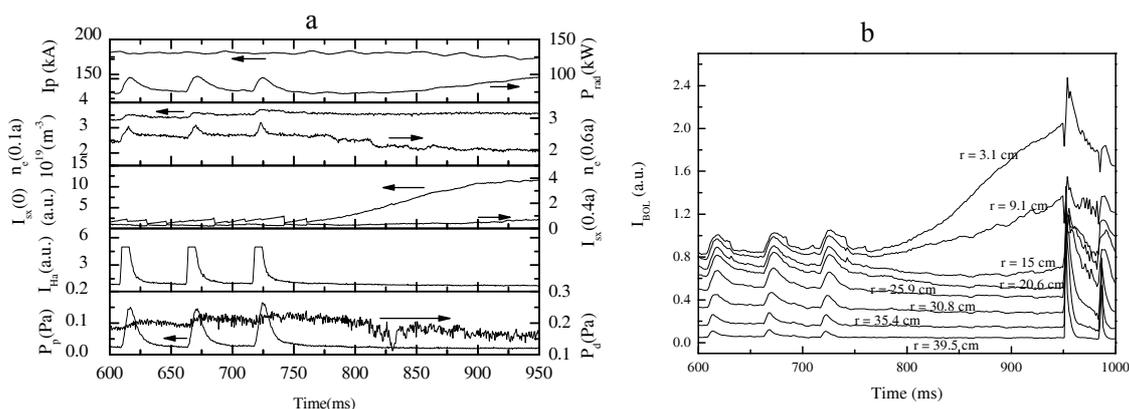


Fig. 1, Time evolution of plasma parameters (a), and bolometer (b) with different chords

Copper and iron were the dominant metallic impurities in present HL-2A plasma. The intensity of their line emissions measured by VUV spectrometer was pronounced increased in the most cases when the central radiation increased, which is shown in figure 2a. The intensity of low Z impurities, such as carbon and oxygen, generally did not change so much.

A data set of about 160 Ohmic observations, covering the usual parameter range ( $150 < I_p$

$< 190$  kA,  $1.3 < B_t < 1.5$  T,  $0.2 < n_e / n_G < 1.2$ ,  $P_{\text{heat}} < 0.5$  MW), was assembled to investigate the relationship between electron density profile and impurity distribution with different gas puffing methods in the whole experimentally accessible density region in 2007 experimental campaign. Figure 2b shows electron density peaking factor  $f_{ne} = n_e(0.1a) / n_e(0.6a)$  as a function of  $n_e / n_G$ , where  $n_e$  is the line-averaged electron density and  $n_G$  is Greenwald density limit. Symbols of MD and ND denote the discharges with disruption and without disruption, respectively. Note that for the discharges without disruption density peaking factor increases with increase of  $n_e / n_G$  in the range  $n_e < 0.6 n_G$  and shows a saturated tendency at  $n_e > 0.6 n_G$ . Most disruptive discharges usually have higher  $f_{ne}$  ( $> 1.5$ ) and greater  $n_e$  ( $> 0.6 n_G$ ). The discharges with high density and no disruption ( $n_e > n_G$ ) have modest density peaking (1.6), and can be achieved by SMJ or GP-d just after siliconization. The achieved peaking factors both by SMJ and GP-p are similar. That means the density profile peaking has not directly relationship with the fueling particle deposited location. However, the discharges fueled by GP-d seems have less density peaking factor and fewer disruption than those of SMJ and GP-p.

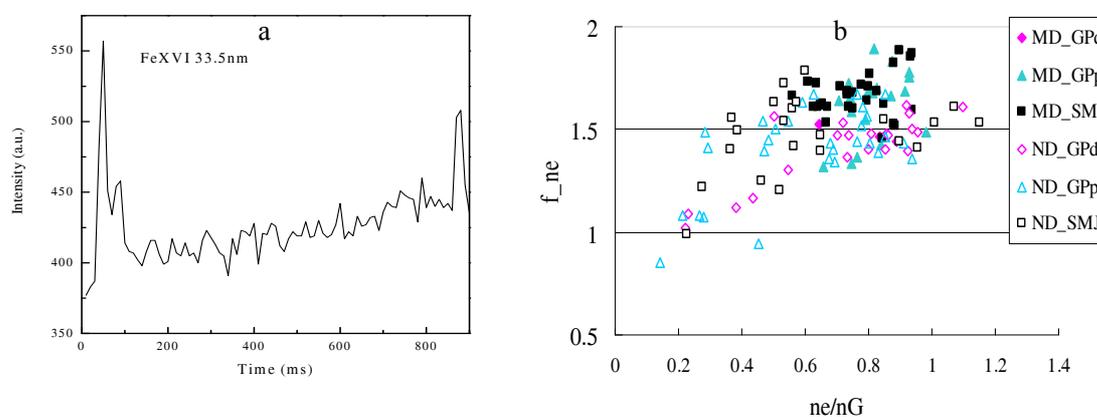


Fig. 2, Time revolution of iron emission from VUV spectrometer (a), Density peaking factor as a function of Greenwald fraction (b): solid with disruption, open without disruption, diamonds fueled by GP-d, triangles by GP-p and squares by SMJ, respectively.

Figure 3a shows a linear increasing tendency in density peaking factor with the growth of the effective collisionality  $\nu_{\text{eff}} = 0.1 R n_e Z_{\text{eff}} / T_e^2$  [4] when  $n_e$  is less than  $0.6 n_G$  and a saturated dependence when  $n_e$  is greater than  $0.6 n_G$ . The result is in good agreement with the result in T-10 Ohmic and ECR heating plasma. [5] The scattering of data was mainly from the electron

temperature measurement. Under the framework of drift instability the density profile peaking could be understood as a result of partial suppression of trapped electron mode (TEM) due to the increasing of collisionality in Ohmic case where the electron temperature  $T_e$  is larger than the ion temperature  $T_i$ .

Figure 3b gives the radiation peaking factor  $f_{\text{rad}}$ , defined by the ratio of bolometric signal at  $r = 0.1a$  to that at  $r = 0.5a$ , as a function of  $f_{n_e}$ . It shows that radiation peaking increases with increase of density peaking and most disruptive discharges usually have high  $f_{n_e}$  (1.5 – 1.9) and high  $f_{\text{rad}}$  ( $> 1.5$ ). For the discharges without disruption it seems that good performances with a relative low  $f_{\text{rad}}$  can be achieved by fueling method of GP-d.

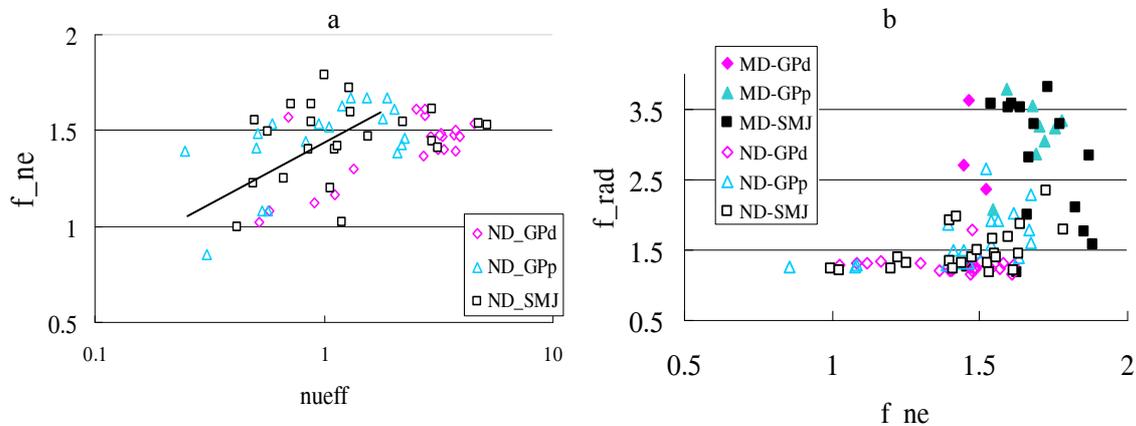


Fig. 3 Density peaking factor vs. effective collisionality (a), and radiation peaking factor vs.  $f_{n_e}$  (b)

In summary, impurity accumulation was often observed when density peaking factor increased up to a value. The radiation enhancement was mainly due to the metallic impurities, while the radiation of low  $Z$  impurities almost kept constant. The density peaking together with the impurity accumulation did not strongly depend on the fueling particle deposited location. However, the performances fueled by GP-d seemed to have less density peaking factor and fewer disruption than those fueled by SMJ and GP-p. The data also showed that the density peaking increased with  $\nu_{\text{eff}}$  when  $n_e$  was low. The results presented in this paper could be understood under the framework of ITG and TEM model. The change of density gradient in the central region might also suggest an increase in the neoclassical pinch effect.

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[3] L Yao, et al. Nucl. Fusion 47 (2007) 1399, [4] C Angioni, et al. Phys. Plasmas 10 (2003) 2335

[5] N A Kirneva, et al. Plasma Phys. Control. Fusion 50 (2008) 065004