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Study of the Density Pedestal Width in ASDEX Upgrade using Reflectometry

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1. Introduction

The characteristic of ELMy H-modes is the formation of an edge transport barrier (ETB) with steep pressure profiles. The pedestal of the ETB is directly related to the tokamak performance and thus it is very important to be able to predict its characteristics for next step devices. In order to do this prediction, an understanding of the mechanisms that determine the formation of the edge transport barrier is necessary. In this paper we present results of the density pedestal width and gradient (for low-field side) for ASDEX Upgrade ELMy H-modes. The density profiles are obtained by using an ultra fast broadband reflectometer with high temporal (35μs) and spatial (< 1cm) resolution [1]. These results are then compared with the the neutral penetration model [2] that tries to explain the formation of the density pedestal width.

2. Experiments

To study the influence of plasma parameters on the formation of the ETB, a series of experiments were performed. The scanned parameters are the plasma current ($I_p = 0.6; 0.8$ 1.2 MA), triangularity ($\delta = 0.27; 0.32; 0.44$), input power ($P_{IN} = 2.4$; 5.2; 8.3 MW) and plasma density by fuelling, which leads to an overall variation of the pedestal density of $n_{e,ped}$ = 3-7 $\times 10^{19}$ m^{-3}. For the density scans, each discharge has

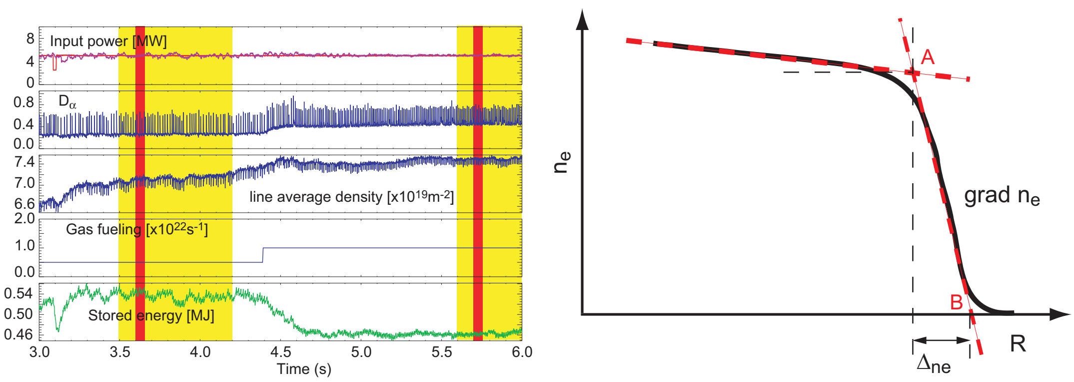

Figure 1: *(a) Typical ELMy H-mode discharge for ASDEX Upgrade with two levels of gas fuelling. The acquisition time window of the reflectometer measurements are shown in red. (b) Schematic density profile showing the definitions, used for this study, of the density pedestal width and gradient using a linear fit.*

two levels of gas fuelling as shown in figure 1(a). All the discharges have $B_T = 2$ T. The density pedestal width ($\triangle_{ne}$) and gradient ($\bigtriangledown n_e$) were determined by using a linear fit to the density profile as shown in figure 1(b), where the density pedestal width is defined as the distance between points A and B. Δ_{ne} and $\bigtriangledown n_e$ were determined for each individual ELM where the density profile was taken a few micro-seconds prior to the onset of the ELM.

3. Density pedestal width and gradient

The result of the analysis of the density pedestal width for all the performed scans (n_e, P_{IN}, δ and I_p) is shown in figure 2. These results show that the density pedestal width stays approximately constant independently of the plasma parameters varied in these experiments. However, a broadening of Δ_{ne} is observed for the discharges at the highest input power ($P_{IN} = 8.3$ MW) as shown in figure 2(b) by the green points. It should be noted that the discharges with 8.3 MW are obtained by combining NBI and ICRH while the lower power discharges are only with NBI heating. The same results have been reported from JET [3] showing an increase of Δ_{ne} for increasing input power, but also in this case, the highest input power is obtained by combined NBI and ICRH. The possible effect of the heating method on the determination of the width of the pedestal density is currently being assessed.

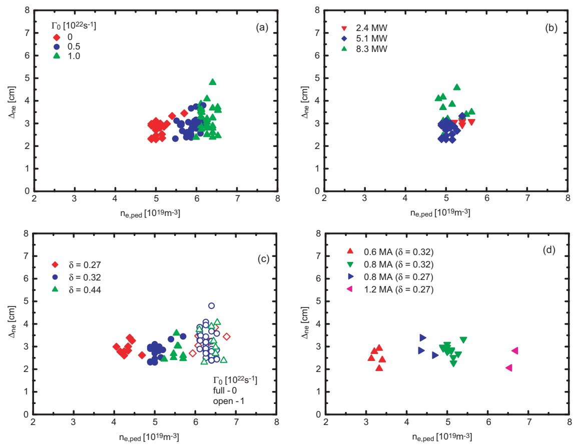

Figure 2: *Density pedestal width for a (a) density scan, (b) power scan, (c) triangularity scan and (d) plasma current scan.*

Figure 3 shows the density gradient for the same discharges above. In this case, the density gradient changes dramatically with plasma triangularity and current (q). In the case of the triangularity scan, fuelled and unfuelled discharges are shown. However, the increase of Δ_{ne} with triangularity, is due to δ and not to the increase of $n_{e,ped}$, as seen from figure 3(a), where $n_{e,ped}$ is increased for constant triangularity and the density gradient increases slightly. A significant change of $\bigtriangledown n_e$ with plasma current is also observed. In figure 3(d), for the same triangularity there is an increase

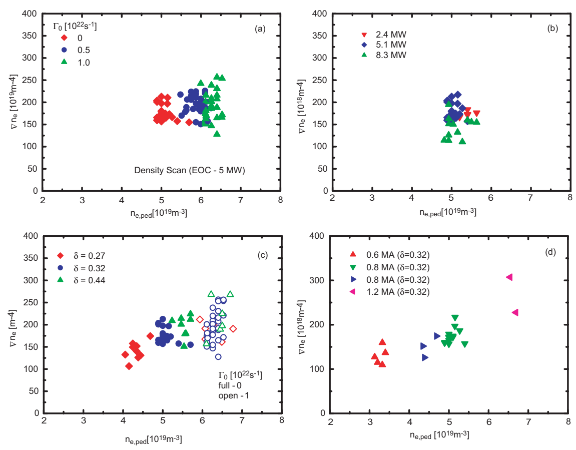

Figure 3: *Edge density gradient for a (a) density scan, (b) power scan, (c) triangularity scan and (d) plasma current scan.*

of $\bigtriangledown n_e$ proportional to I_p^2.
The density pedestal width and gradient is also determined for Ohmic and L-mode discharges and compared with Δ_{ne} for the H-mode discharges described above, including all the scanned parameters (n_e, P_{IN}, δ and I_p). Although L-mode and Ohmic regimes do not have an ETB, a " density pedestal" can be defined, as the point where the density gradient changes abruptly as shown in figure 4. For ELMy H-mode discharges Δ_{ne} does not change significantly with the plasma parameters (used in this study) and its value lies around 2-3.5 cm except the high power discharges, where Δ_{ne} goes up to approximately 4.5 cm. Contrary to the H-mode, in L-mode, Δ_{ne} increases with density as shown in figure 5(a). Although $\bigtriangledown n_e$ increases for all types of confinement a stronger increase is observed for the H-mode discharges. A comparison between an L- and H-mode discharges with similar pedestal density shows that Δ_{ne} for L-mode is about a factor 3 higher than that of the H-mode and $\bigtriangledown n_e$ is about 3 times smaller.

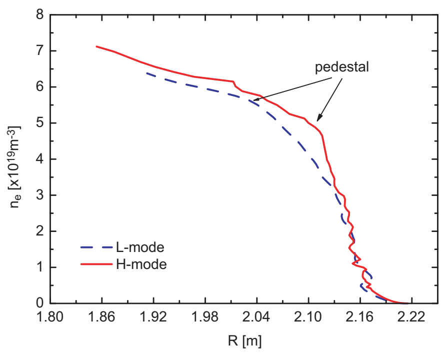

Figure 4: *Definition of pedestal for an L-mode density profile.*

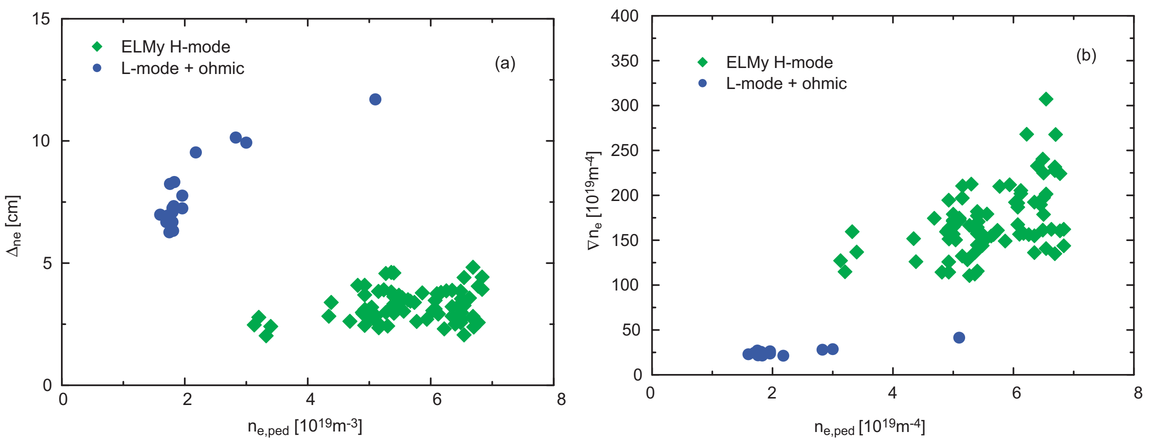

Figure 5: *(a) Density pedestal width for ELMy H-mode, L-mode and Ohmic discharges and (b) the corresponding density gradients.*

4. Comparison with neutral penetration model

The neutral penetration model [2] is, so far, the only model put forward to explain the formation of the density pedestal width. In this model Δ_{ne} and $\bigtriangledown n_e$ are determined by the ionization mean-free path where, $\Delta_{ne} \propto 1/n_{e,ped}$ and $\bigtriangledown n_e \propto n_{e,ped}^2$ independently of the confinement regime, L- or H-mode [4]. This model has been compared with the experimental results from ASDEX Upgrade for L- and H-mode discharges. The estimated values for the ionization mean-free path are given by equation 1, where S_{cx} and S_i are the charge exchange and the ionization rate coefficient respectively and λ_{cx}

is the charge exchange mean-free path defined by $\lambda_{cx} = V_{th}/(n_e S_{cx})$ where V_{th} is the thermal velocity.

$$\lambda_{mfp} = \left(\frac{S_{cx}}{3S_i}\right)^{1/2} \lambda_{cx} \tag{1}$$

In the calculations, the electron temperature is obtained from Thomson Scattering measurements at the pedestal top, and $T_e = T_i$ is assumed.

Figure 6 shows the comparison between the λ_{mfp} for L- and H-mode discharges and the experimental values. The estimated values are within a factor of 2 for H-mode discharges, however more than a factor of 4 between L-mode discharges. Therefore, although for H-mode discharges, in the range of densities shown here, the neutral penetration model may give an approximate estimation of the density pedestal width, for the Ohmic and L-mode discharges this model is in complete disagreement with the experimental results. This indicates that neutral penetration may not be the determining factor for the formation of the transport barrier.

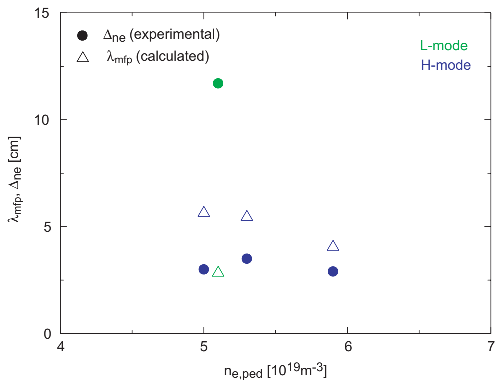

Figure 6: *Comparison of the experimental density pedestal width and calculated ionization mean-free path for L- and H-mode discharges.*

5. Summary

The experimental results show that, in ASDEX Upgrade ELMy H-mode discharges, the density pedestal width is independent of plasma parameters (n_e, P_{IN}, δ and I_p). It is found to be approximately constant in a range of 2 to 3.5 cm (up to 4.5 cm including the high power discharges). The density gradient is seen to vary strongly with triangularity and plasma current, in line with the increase of the ballooning limit allowing steeper edge gradients and therefore higher tokamak performance. Ohmic and L-mode Δ_{ne} are much broader than the H-mode. This difference between L- and H-mode density gradient region widths is not reproduced by the neutral penetration model.

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