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Strike-point- and ELM-dependent carbon migration in the JET inner divertor

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1. Introduction

Carbon-fibre composites are currently foreseen as material for the high heat load areas of the ITER divertor target plates. Erosion will largely determine both the lifetime of these components and the long term retention of fuel via the formation of hydrogen-rich carbon layers on the targets themselves and on remote areas. At JET the horizontal target plate (HT) in front of the pumping duct of the inner MKII-HD divertor leg was previously identified as the location with strongest carbon deposition on a plasma-facing area [1]. Post mortem-analysis of MKII divertor tiles after the DT campaign discovered the thickest carbon layers with high fuel content in the louvre area of the inner divertor [2]. The migration of carbon in the inner divertor was assumed to be stepwise, however, the key parameters and the exact mechanism remained unclear.

The new experiments presented here focus on the study of deposited material on the HT as function of the magnetic field configuration, the ELM strength, and the so-called “history effect” - the influence of previously performed discharges in different magnetic configuration. The local carbon erosion, transport and deposition are determined by the interplay of these parameters, in particular the history effect can largely influence the interpretation of experimental findings. In the following we will act with a) “hard layers” which represent the "bulk" material, b) “historic layers”: the topmost -mostly soft- layers which can be deliberately removed in “cleaning discharges”, and c) “freshly deposited (soft) layers” which are caused by erosion and subsequent deposition in one magnetic configuration. A discharge scheme, described in **2**, was developed to ensure (soft) layer-free starting conditions at the HT for the experiments presented in **3** and **4**. The role of each contributor to the transport will be discussed in **5**.

2. The history effect

The first touch of the inner strike-point (ISP) on a plasma-facing side in a new magnetic configuration can lead to an artificially high carbon release coming from re-erosion of the layer at the target surface. The detection of such a historic layer is done with the aid of slow ISP sweeps (fig. 1a) in L-mode discharges ($B_t = 2.4T, I_p = 2.4MA, P_{NBI} = 1.5MW$) and spatially resolved hydrocarbon spectroscopy. L-mode sweeps provide usually not

deposition on tile 4 using strike points on a) the HT (#68135-7) and b) on the lower vertical target plate (VT) (#68141-43). The QMB deposition rates (fig. 2b) are highly reproducible in comparable discharges and about a factor 2 larger in HT configuration. CLDs applied after each series and combined with hydrocarbon spectroscopy can be used as an effective measure for the accumulated carbon deposited on tile 4 - the freshly growing soft layer. About 30% more deposition is found after discharges with the ISP on the HT itself, right from the deposition zone, compared with discharges in VT configuration. The layer location on tile 4 after discharges in VT configuration is slightly shifted away from the pumping duct in comparison to the location of the layer built up after discharges in HT configuration. The deposition on tile 4 is in both configurations determined by the impinging ion flux distribution; the deposition in VT configuration on tile 4 is mainly caused by particle reflection at tile 3. Note, that in HT configuration also particles can be reflected and deposited on tile 3 (see discharges discussed in **4**). The corresponding spectroscopic carbon fluxes (CIII, CD and C_2), taken from an integral line-of-sight (wide chord, fig. 2a) and normalised to deuterium fluxes (D_β), show little difference in both series indicating that the gross erosion is comparable in HT and VT configuration.

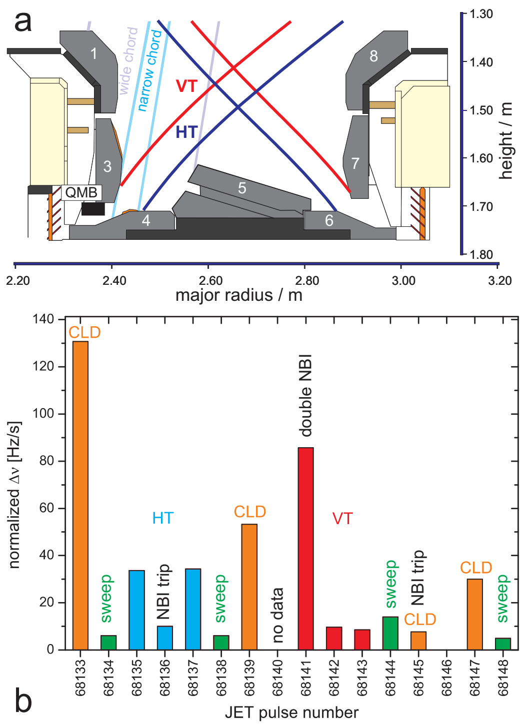

Figure 2: *a) The applied symmetric VT and HT magnetic configuration and spectroscopic lines-of-sight. b) Deposition on the QMB in discharges with different magnetic configuration and in CLDs.*

4. The role of ELMs on layer re-erosion

A second experiment in VT configuration (fig. 3a) was used to investigate the dependence of layer erosion on the ELM energy. H-mode discharges ($B_t = 2.4T, I_p = 2.4MA$) with $P_{NBI} = 7.6MW$ (#68333-38) and $P_{NBI} = 4.7MW$ (#68329-31) yielding in energy loss per ELM of $\delta W \simeq 260kJ$ (type-I ELMs) and $\delta W \leq 15kJ$ (grassy ELMs) were compared. The erosion induced by large ELMs lead to a factor 4 higher deposition on the QMB during the discharge in comparison with grassy ELMs. The deposition rate is in both cases about one order higher than in L-mode in VT configuration. The integral ELM energy to the target is only slightly larger in the case of clear type-I ELMs; the erosion seems to increase nonlinear with the ELM energy. Identification of the underlying processes as well as the erosion induced by a single ELM is topic of ongoing research [5].

The initial discharge series in VT configuration (#68323-4) is clearly affected by a historic layer on the lower vertical target. The most probable reason is a redistribution of a deposit from tile 4 to tile 3 in the first CLD. However, the erosion is very reproducible in the previously discussed two subseries after initial cleaning of the vertical target.

5. Discussion and conclusion

(i) The magnetic configuration is the principal factor determining the location and thickness of the deposited layer. Both VT and HT configuration lead to a significant deposition on tile 4, but the deposition in HT configuration is closer to the pump-duct entrance and about 1/3 larger than in VT for comparable conditions.

(ii) The local transport and, in particular to the QMB positioned in the pumping duct of the inner divertor, is mainly in line-of-sight and determined by the impinging ion flux distribution (fig. 3b). Positioning of the ISP on the HT leads to a two times stronger deposition on the QMB than the ISP fixed on the VT for comparable plasma conditions.

(iii) A change of the magnetic configuration after a discharge series can lead to an artificially high re-erosion/disintegration of soft layers at the ISP (history effect). The deposition rate on the QMB which detects a portion of the eroded material can be more than order larger than in the case of a pre-cleaned target.

(iv) ELMs enhance significantly the erosion of layers in the inner divertor. A few large ELMs lead to a stronger erosion and subsequent deposition on the HT and QMB than a multitude of small ELMs though their accumulated energy to the target in the discharge is larger.

(v) Soft layers have been detected by spectroscopy in low power L-mode sweeps. Disintegration of thick "historic" layers is done with large ELMs in CLDs with the ISP fixed on the layer location. The disintegration process, which is associated with both release of clusters and hydrocarbon molecules, is a topic of ongoing research.

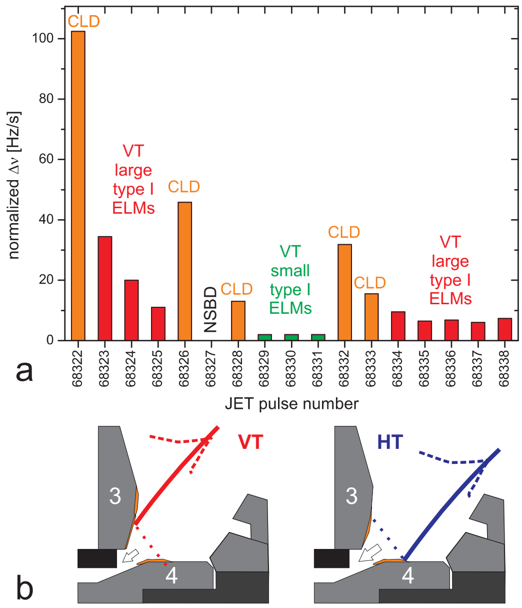

Figure 3: *a) Material deposition on the QMB in two series of discharges with different ELM energy. b) Local carbon migration in the inner divertor.*

These experiments clearly show that a large portion of the deposited material is primarily swept around in the inner divertor with each ISP variation and then, with time, material is transported to inaccessible remote areas. Cleaning discharges, which were e.g. applied at JET after the DT campaign to clean up the targets and release T for re-processing, are the most probable cause for the strong deposition found on the inner horizontal target and the louvre area. Note that although spectroscopy shows that a single CLD re-erodes mainly the top soft layer, repeated CLDs, or other discharges with large type-I ELMs, can lead to re-erosion of the underlying hard layers.

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