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1. INTRODUCTION

On the JET tokamak the divertor outer target plate made by carbon-fibre composite is monitored by an InfraRed (IR) camera [1], of which both time and spatial resolutions allow for an accurate study of the deposited heat flux patterns. This paper reports on a survey carried out over 7686 JET discharges, the majority being high powered H-Mode plasmas with NBI injected power of 10 to 23MW. The appearance and the temporal development of features, which are attributed to changes of the surface heat conduction [2] due to plasma surface interaction, i.e. deposition of carbon layers on the target plate, are shown and their effect is characterized. The link connection between these modifications of the surface thermal properties and the position of the Outer Strike Point (OSP) on the target is also established.

2. HEAT FLUX PROFILES ON THE OUTER TARGET

The temperature measurements along the outer target plate provided by the IR system have a spatial accuracy of 1.7mm and a time resolution down to 80μs. This allows an accurate ELM-resolved analysis of the deposited heat flux patterns on the divertor tiles. Figure 1a shows a typical ELM-averaged and an inter-ELM heat profile; the average is performed over all type-I ELMs occurring in the discharge. The OSP is located at R = 2.65m and the Scrape-Off Layer (SOL) extends toward the right; the maximum heat deposition for both cases is found to be at the OSP. The analysis of such profiles along the different campaigns with various OSP variations on the outer plate has preveiled the development of features in the ELM-averaged profile, as depicted on Fig.2a. They cannot be attributed to ELM physics as they appear at the same position over several days of operations regardless of plasma parameters and magnetic configurations. These persistent features usually evolve over a few tens of discharges. Also striations reported in [2] appear at different target locations from one ELM to another. On Fig.2b one can see a visible image taken at a time close to the pulse shown on Fig.2a. The comparison of Fig.2a and 2b show that these patterns can be linked to a local alteration of the surface, i.e. a deposited a-C:H layer.

3. TARGET SURFACE ALTERATION AT THE OSP POSITION

The origin of these modifications, referred as “surface layers” in this paper, can be understood from Fig.3a and 4.a, where heat profiles are given for two JET discharges. Figure 3a shows an distinguished peak at R = 2.74m when Fig.4a exhibits two peaks, at R = 2.74m and at R = 2.69m, leading to the conclusion that a new layer has developed at the latter position within 376 discharges. The confidence in the interpretation of these peaks as layers comes from two observations. First is that on clean targets the maximum heat flux is always associated with the OSP position and the heat profile along the target monotonically decays with R. The second evidence is that important negative heat fluxes are observed at the layer locations in the profiles in the time steps following each ELMs, indicating that the surface heat conduction coefficient used in our model is not valid [3]. In order to understand why a layer has grown, we looked at the configurations used between these two pulses, focusing on the OSP position computed from IR data. The result is plotted on fig.4b. This plot clearly indicates that the surface properties are modified where the OSP has been located for many discharges between Pulse No's: 77191 and 77567. As a check, we show on fig.3b the same plot for discharges before Pulse No: 77191: the configuration involved in the second peak on Pulse No: 77567 has almost not been in use before Pulse No: 77191 explaining the absence of that peak in the heat profile. The appearance is thus related to the deposition of carbon in the SOL and the formation of a fresh a-CH layers as observed before by spectroscopy for a strike-point sweeping in the inner divertor leg [4]

4. ^{13}C EXPERIMENT AND LAYER

The last day of operations at JET before the removal of the vessel protection tiles was dedicated to a carbon migration experiment with ^{13}C labelled methane as a marker. During this experiment, a same magnetic configuration has been used for 30 identical plasma discharges (172sec of plasma), $^{13}CH_4$ has been injected in deuterium plasmas so that its implantation in the tiles can be assessed by post-mortem analysis. Figure 5a shows the heat flux profiles for 6 different discharges. The data suggest that the maximum heat flux observed on the outer target increases by a factor 1.7 between the first and the last pulse of the experiment, though the same input power was used. As discharges were identical, this net increase is attributed to the growth of a layer in the immediate vicinity of the OSP, less than 3cm away in the SOL, and thus a modification of the heat conductivity at this place. On Fig.5b, the amount of ^{13}C detected on the target by two different techniques [5] is plotted together with an ELM averaged heat profile. The maximum concentration is found to increase at the OSP position and the maximum matches the layer observed in the IR profiles, confirming that carbon layers grow in the SOL, in the vicinity of the strike point. Carbon spectroscopy [4] confirms the in-situ grow by additional appearance of CH A-X emission during the experiment as shown in 5c. CH is resulting from chemically erosion of the local deposited layer. Please note that the local area is usually a net erosion zone, but that the additonal C source, $^{13}CH_4$, leads to a transition to a local deposition zone, thus, in this case the net effect leads to the growth of the layer.

5. FRONT THERMAL HEAT TRANSMISSION MODIFICATION

The layer effect on heat flux measurement can lead to significant overestimations of Q_{max} the maximum heat flux, up to a factor 2 for the discharges presented on Fig.3a and 4a. The method adopted at JET to correct layer effect first fits the heat profiles with an exponential decay (as observed for clean targets) and Gaussian functions for the layer. Then, the front thermal heat transmission coefficient, which gives the relation between the heat fluxes deposited and the temperature increase measured on the tile, is lowered at the layer location in order to damp the peak(s) and to match the exponential profile. Such a correction has been carefully performed for more than 40 pulses (covering nearly 2 years of operations) exhibiting peak(s) and the result of the correction on Q_{max}, average heat flux and power deposition is presented in Fig.6. The layers do not significantly affect the measured power deposition and the average heat fluxes as their values usually vary by 5-20%. The conclusion strongly differs for Q_{max} as the typical error is about 30-40% so that any analysis based on this quantity has to take into account layer corrections.

CONCLUSION

A long term survey of the heat flux patterns on the JET outer divertor tiles has shown that layers grow there and strongly affect IR measurement. An analysis combining IR data, visible investigations of the tiles, in-situ spectroscopy and post-mortem analysis has demonstrated that these layers develop in an area starting at the OSP position and that extent a few centimeters in the SOL direction. The relative error induced by these layers in the heat flux calculation is usually around 5-10 percent for the power deposition but is reaches 40% for the maximum heat flux so that a correction method has to be applied before any data analysis.

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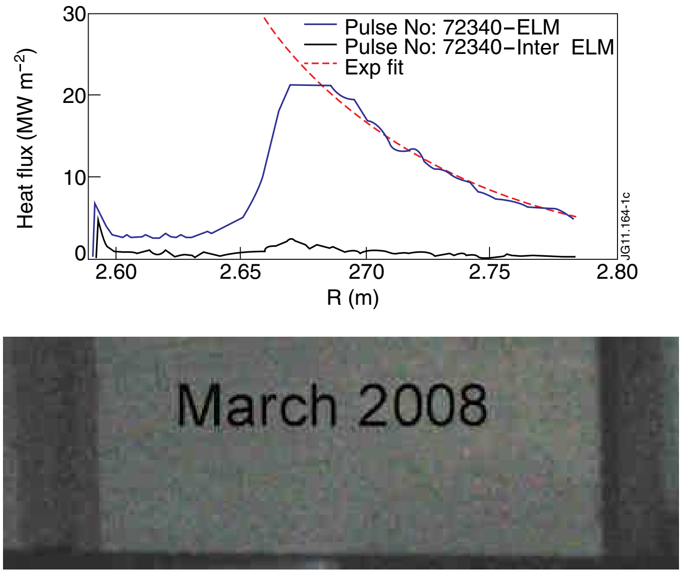

Figure 1: (a) ELM and inter-ELM heat flux profile on outer target. (b) Visible picture of the same – clean - target.

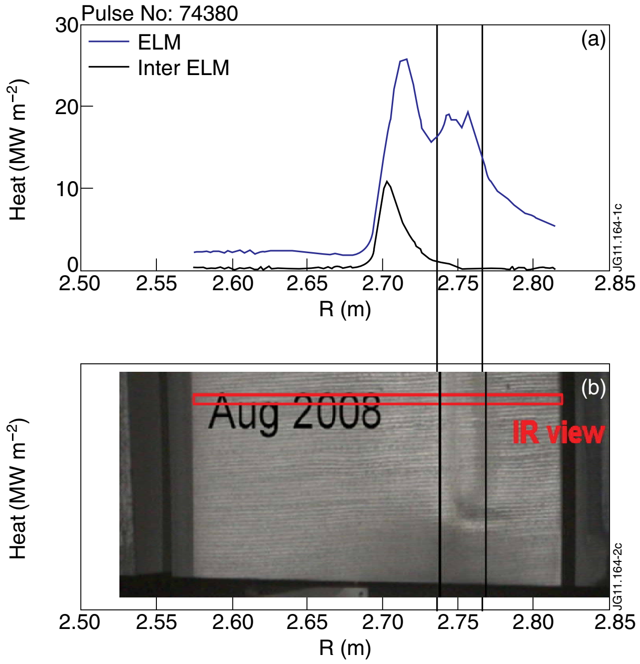

Figure 2: (a) ELM heat flux profile exhibits a peak at 2.75m that can be associated with an alteration of the tile's surface seen on the visible image (b).

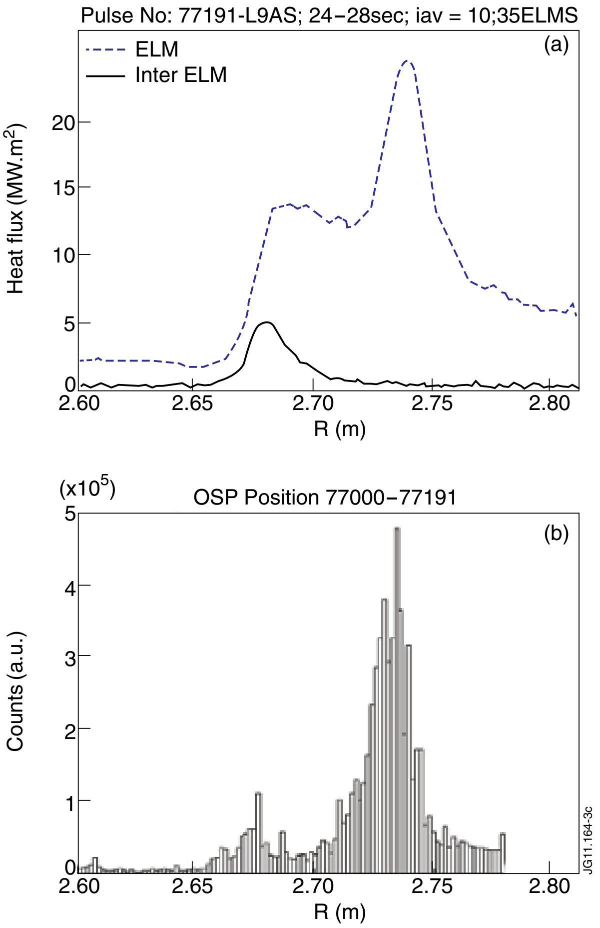

Figure 3: (a) ELM and inter ELM heat profiles on outer taget. A peak two times higher than the OSP is observed at 2.74m. (b) Location of the OSP on the outer target for pulses from JET Pulse No's: 77000 to 77191.

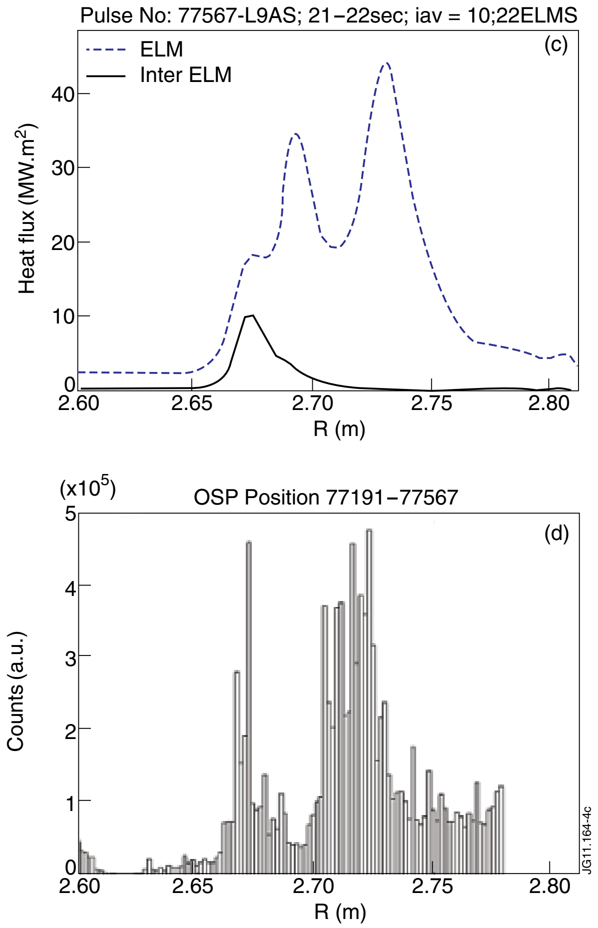

Figure 4: (a) ELM and inter ELM heat profiles on outer taget. Two peaks are observed in the ELM profile at 2.69 and 2.74m. (b). Location of the OSP on the outer target for pulses from JET Pulse No's: 77191 to 77567.

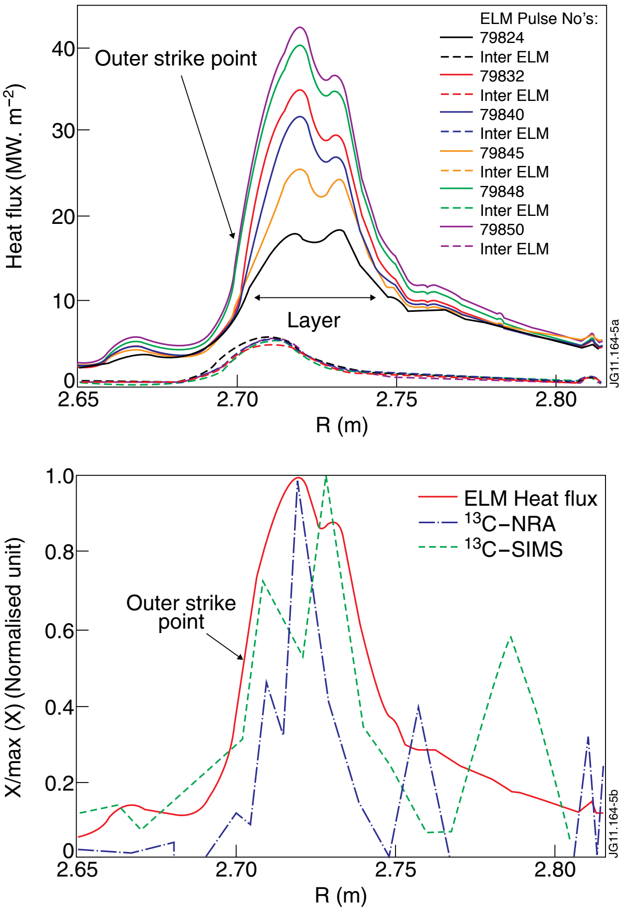

Figure 5: (a). ELM and inter ELM heat profiles for 6 different discharges with $^{13}CH_4$ injection. The heat flux apparent increase is attributed to the growth of a layer revealed by post-mortem analysis (5b).

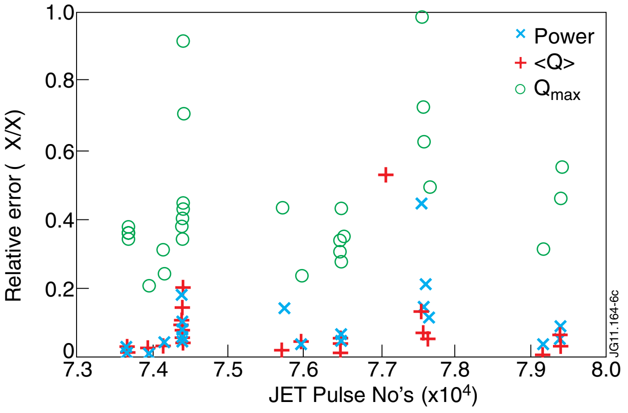

Figure 6: Influence of thermal properties modification on the power, Qmax and <Q>, respectively maximum and average heat flux measured on the target.