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In situ measurement of hydrogen retention in JET carbon tiles

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Abstract

The retention of hydrogen isotopes, particularly tritium, in the plasma-facing walls of fusion devices presents a serious difficulty for the exploitation of future machines. Investigation of techniques to reduce this effect is hampered by the difficulty in making measurements. Current methods rely on analysis of samples removed from machines after venting to atmosphere (J.P. Coad, et al., J. Nucl. Mater. 226 (1995) 156). Conclusions have, therefore, been drawn on a global basis, since it is not possible to assess the effects of individual plasma configurations. Detailed studies require a more prompt means of measuring the hydrogen content of samples, ideally on a shot-by-shot basis and without the necessity of breaking the machine vacuum (A. Huber, et al., this Conference). A new technique is described that meets these criteria and has been demonstrated at JET. © 2001 Published by Elsevier Science B.V.

Keywords: Carbon; Hydrogen; Retention; Plasma-facing components; JET

1. Experiment arrangement

Electron density and temperature data from the JET edge plasma region are obtained using a LIDAR Thomson scattering system [1]. This employs a series of brief (~300 ps) laser pulses (energy typically 2 J, but varying 1–3 J in a series) directed onto a small area (~1 cm dia) of an inner wall divertor tile, where most deposition is observed [2]. This new technique makes use of the LIDAR laser and, therefore, uses laser pulses which are not specifically for the purpose. The laser alignment is normally fixed but for these investigations it was adjusted onto a fresh spot, corresponding to the position of one of the fixed Langmuir probes. Prior to the realignment, laser pulses were triggered without plasma, to confirm that signals in these circumstances were negligible. Small amounts of the surface are ablated during a discharge by the laser pulses, mainly carbon and hydrogen, some of which enters the plasma where it is excited and ionised. The resulting Hα and CIII emission are sampled at 250 kHz and provide a measure of the hydrogen content in the surface layers of the carbon tile.

Studies were made during discharges with fixed values of plasma current and toroidal field, in which a divertor phase was followed by a limiter phase. The laser was triggered four times at a rate of 1 Hz during this limiter period so that the material deposited during the immediately preceding divertor phase could be investigated. Fig. 1 shows a drawing of the camera view inside the vessel and Fig. 2 shows a camera image taken when a laser pulse occurs during a plasma. At this stage the plasma has a limiter configuration, with background light originating almost exclusively from the inner and outer limiters. The small bright spot in the figure is due to the laser beam striking the tile at the inner divertor, and above it is the cloud of ablated material that has been excited in the plasma edge region. Some emission, presumably from higher charge states, can be seen extending toroidally.

Fig. 3 shows the limiter plasma equilibrium for one of the discharges studied, expanded to show the divertor region. The laser path is shown as an arrowed line, the light-shaded region is the observation volume and the dark-shaded area represents the plasma edge where excitation takes place. The positions of the fixed Langmuir

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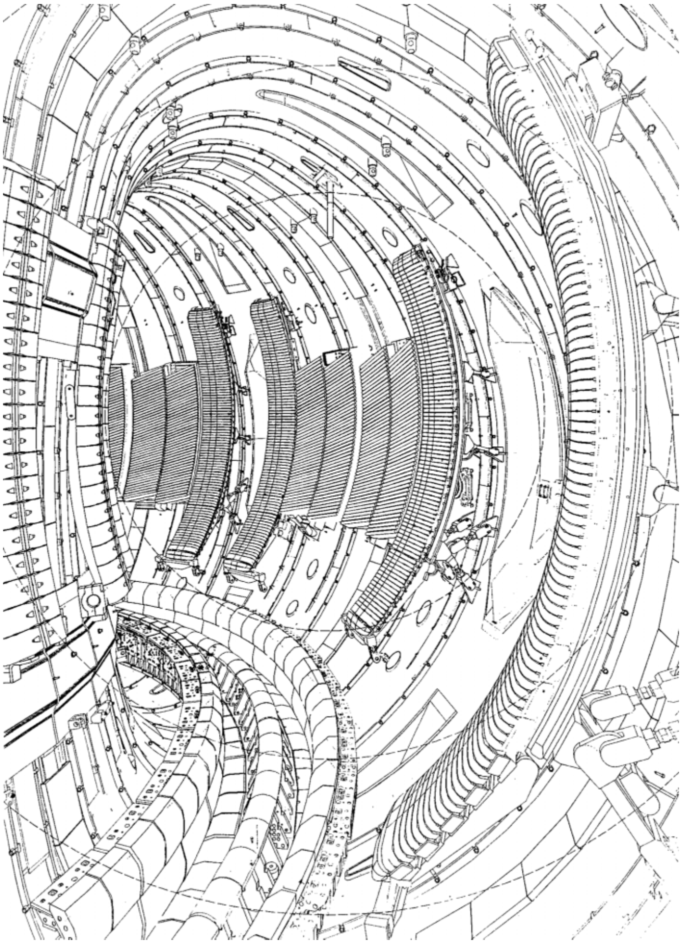

Fig. 1. Diagram showing the view from the in-vessel camera.

probes are shown as large dots, although these are at another toroidal location. Light from a section of the ablation cloud was collected at the top of the machine using a telescope connected via an optical fibre to Hα and CIII interference filters and detectors. The filters had 1 nm bandwidth and, therefore, it was not possible to discriminate between hydrogen species. The plasma equilibrium during the divertor phase is depicted in Fig. 4. The neutral beam heating power and the vertical position of the strike points were altered for successive discharges, providing a variation in the particle flux onto the tile near the laser spot.

2. Results

In Fig. 5 are shown typical raw data for the Hα and CIII line intensities from a laser pulse. Particle fluxes were calculated from integrated raw data, using photon efficiencies obtained from ADAS [3] and plasma edge data obtained from a reciprocating probe [4]. These are plotted in Figs. 6 and 7 against the total fluence at the surface obtained by integrating the data from fixed probe #2. Typically from the first laser pulse in a sequence $\sim 10^{15}$ C atoms and $\sim 3 \times 10^{16}$ D atoms were observed.

Prior to this experiment the telescope was connected to a spectrometer for one discharge.Three consecutive 200 ms exposures from it are shown in Fig. 8, only one of which included light from a laser pulse. In the lower trace the differences between the three exposures are shown. Hence the solid line is the spectrum due to ablated material. The strong diatomic line intensities indicate that the ablated carbon includes some material in the form of clusters of atoms [5].

3. Discussion

In this investigation, the optical arrangement allowed only a small fraction of the cloud of excited material to

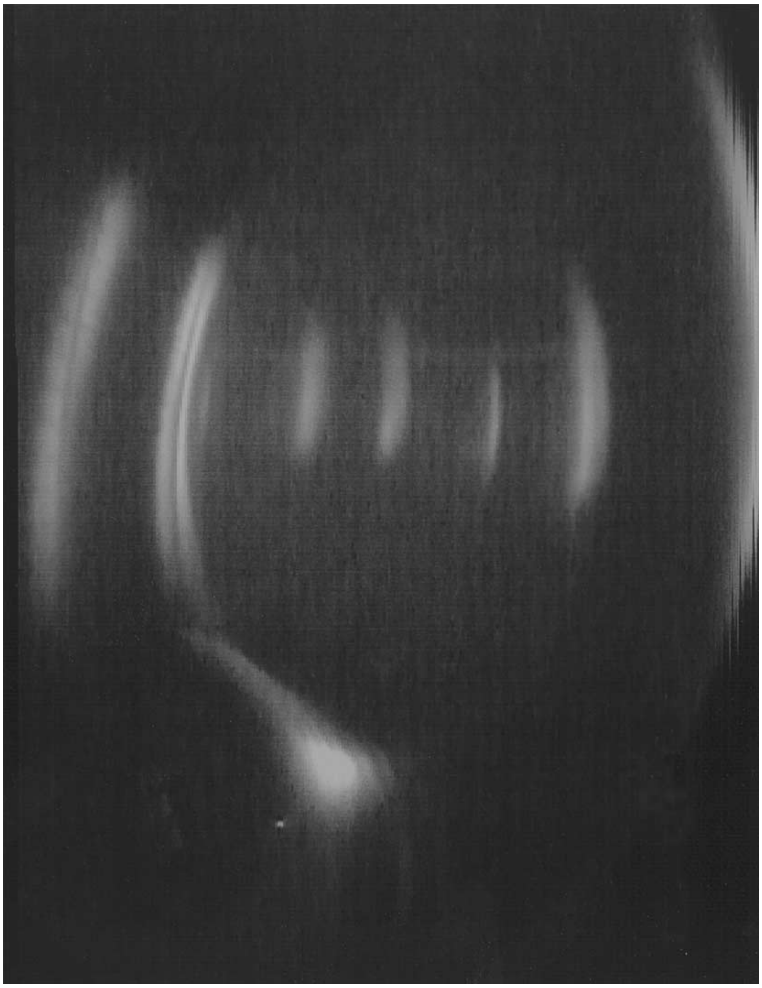

Fig. 2. TV camera image showing the effect of a laser pulse during a limiter plasma.

be sampled. The emission extended toroidally (see Fig. 1) and the ablation spot was distant from the plasma edge (Fig. 2). Both these effects extended the cloud beyond the observed region. Despite this, a clear dependence was found between the deduced levels of ablated particles and the particle fluence onto the tile. Such relationships are consistent with the laser ablation depth being adequate to remove the deposited carbon layer without greatly affecting the tile itself, and suggest that the carbon content of the edge plasma does not vary significantly. However, there are indications consistent with a much greater ablation depth.

If ablation removed only the freshly deposited layer then, the first laser sequence onto a fresh tile spot would result in the highest signal levels, by removing the deposition accumulated from previous plasma discharges. In fact the opposite occurred (see circled points in Figs. 6 and 7). Recently, it has been shown that on the tiles in this region is a Be-rich deposit of several μm thickness [1], deposited during previous discharges. The H-retention properties of this complex film are unknown, but may result in the low fluxes observed for the first pulse sequence. Since higher signal levels were recorded during subsequent laser sequences the implication is that the laser power was sufficient to remove most of the beryllium-rich layer during the first sequence and therefore, that the ablation depth was greater than the surface deposited layer thickness. Greater ablation depth may also explain the zero offsets apparent in Figs. 6 and 7.

4. Comparison with model

The experiment geometry was included in a DIVIMP [6] code simulation of the CIII observations. Fig. 9

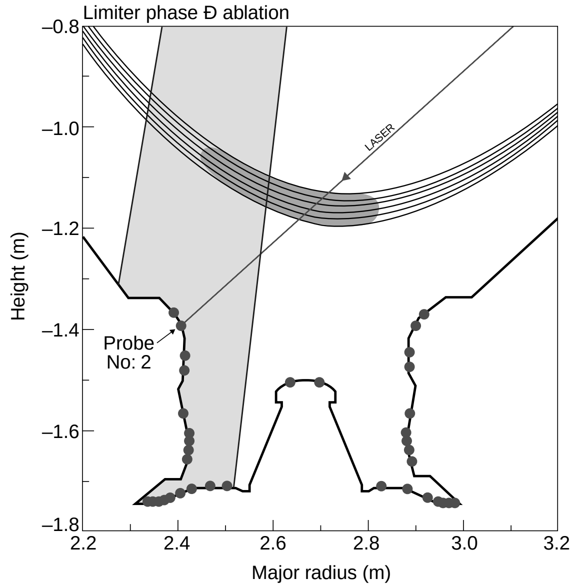

Fig. 3. Plasma equilibrium during limiter (measurement) phase showing probe locations.

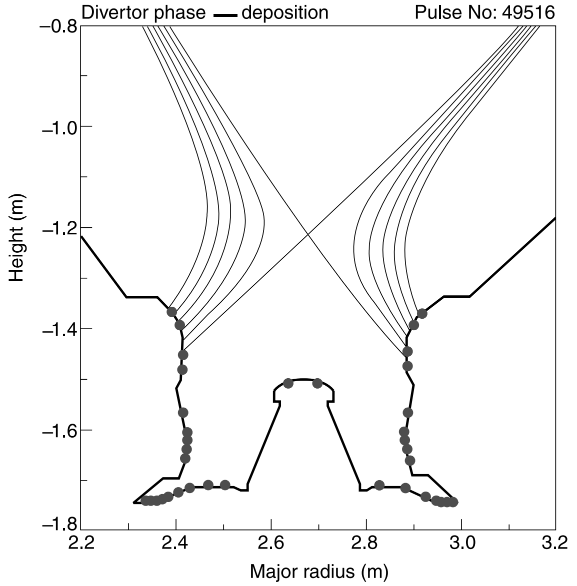

Fig. 4. Plasma equilibrium during divertor (deposition) phase.

compares the normalised CIII data of Fig. 4 with the code results for two values of edge flow velocity (M, Mach number at an assumed average electron temperature of 20 eV) and perpendicular diffusion coefficient (D). Closest agreement was found assuming $M =$ zero and $D = 0.01$. However, the rise time is not well fitted in the simulation and the decay time was greater by a factor ~3. This could be explained by the unknown contribution to the 'CIII' signal from C_2 photons.

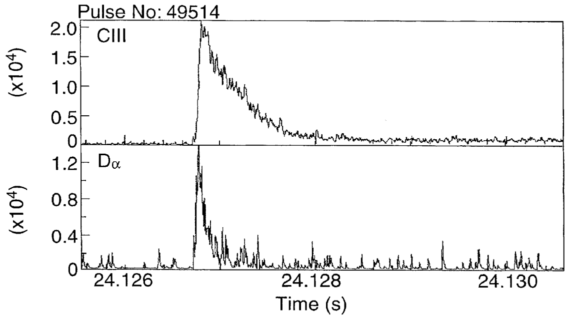

Fig. 5. Typical raw signals.

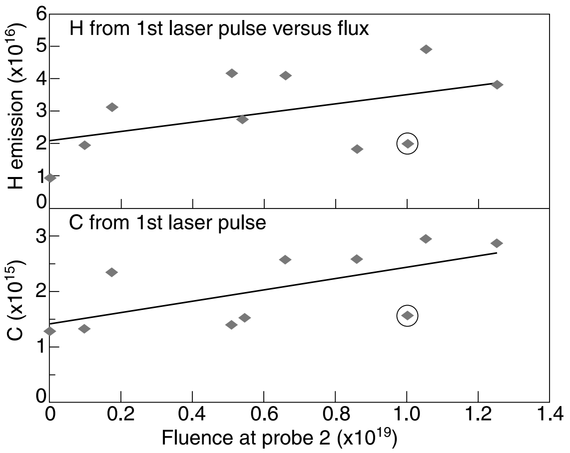

Fig. 6. Deduced influxes from the first laser pulse versus total particle fluence at the ablation spot. Data points from the first discharge circled.

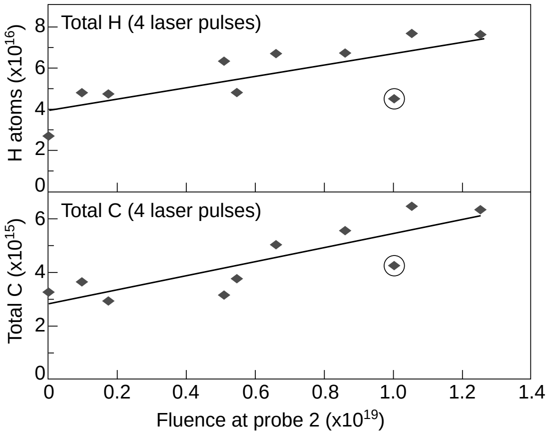

Fig. 7. Deduced influxes from all four laser pulses versus total particle fluence. Data points from first discharge circled.

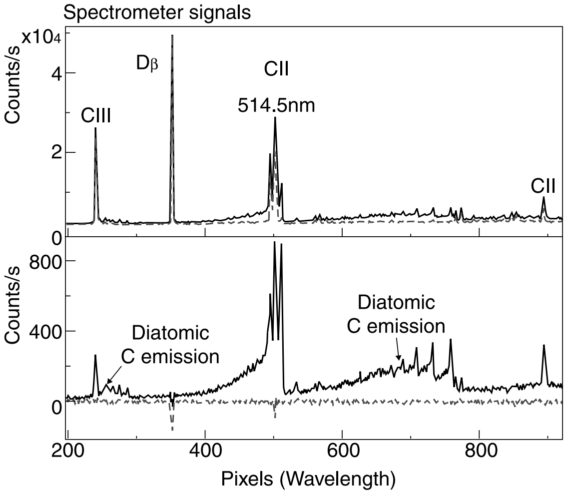

Fig. 8. Spectrometer signals showing contribution from diatomic carbon.

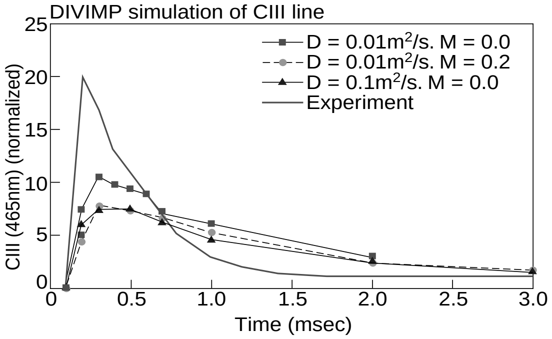

Fig. 9. Comparison of carbon data with DIVIMP simulation.

5. Conclusions

A new technique has been demonstrated that utilises the edge plasma to excite material laser-ablated from a small region of the JET first wall. Study of spectral emission from the resulting cloud of excited material enables its composition to be estimated. In this experiment, neither the laser nor the viewing geometry were optimum for the measurement and the plasma edge was a considerable distance from the ablation region. Despite these limitations optical sampling from the resulting emission cloud has shown a linear relation between the observed prompt hydrogen influx and the particle fluence incident onto this region during the preceding divertor phase of the discharge.

The marked difference observed in the temporal behaviour of the Hα and CIII signals is considered to be partly due to the 1 nm bandwidth of the optical filters used. Thus the Hα signals included contributions from all three hydrogen isotopes and the CIII signals included emission from clusters of carbon atoms. It is presumed that the ablation of such clusters provides an explanation for the lack of agreement between the experimental data and the model predictions, and also contributes to the unrealistic ratio of carbon to hydrogen that may be inferred from the data. Further investigation is required to determine the ablation depth at the wall surface and to study the effect of the beryllium layer on the wall surface.

Significant improvements in sensitivity may be obtained using a more appropriate laser and by optimising the observation geometry. This technique could be used while deposition is taking place and hence, it may be useful in future devices having long duration plasmas and substantial erosion/deposition at the walls.

Acknowledgements

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