DISTRIBUTION OF EROSION AND DEPOSITION ON THE JET BELT LIMITERS

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1. Introduction

The distribution of erosion and deposition of limiter material is of importance both for extrapolating to the next generation of fusion machines and for understanding impurity transport in the boundary layers of present day tokamaks. Erosion patterns have previously been reported for the JET discrete graphite limiters used up to 1986 [1]. We have now made measurements on the belt limiters used in 1987-88. These measurements show that although the pattern of net erosion is qualitatively similar to the earlier results the new maximum erosion (∿40μm) is reduced by about a factor 5, consistent with the larger limiter surface area.

2. Experimental Observations: Belt Limiters

The two toroidal belt limiters were installed in JET in 1987 on the low field side of the vacuum vessel, above and below the midplane [2]. These limiters consist of a large number of graphite tiles on water cooled inconel mounting plates. The physical dimension of a number of tiles were carefully measured before installation. Two tiles were removed in August 1987 after about two months operation, ∿ 470 discharges. A further 8 tiles were removed in May 1988 after ∿ 4000 discharges. They were then remeasured. The difference between two sets of measurements is plotted in fig 1 as a function of the distances along the centre-line of the tile. The erosion is 20-50μm, which compares with the much larger erosion of 150μm at the discrete limiter tiles exposed to 2800 discharges in 1986. The lower erosion rate is expected because the belt limiter area is about ten times larger than the discrete limiters, and the total particle outflux is similar. The tiles are mounted in adjacent pairs and generally reproducible results are obtained for each pair. The pair exposed for only 2 months have erosion/deposition values less than 10µm. The tiles from the bottom limiter and from 2 toroidal positions on the top limiter have quantitatively similar results with erosion/deposition changes ∿ 20-40 µm. This indicates reasonable toroidal uniformity, consistent with Langmuir probe results [3]. A cross-check on the absolute deposition was carried out by sectioning the tiles. Typical results are also shown in fig 1. Where deposition is indicated by the physical measurements it is clearly observed in the sectioning; where erosion is indicated by the measurements no deposition can be seen. The results obtained for deposition show the erosion/deposition transition in good agreement with the mechanical measurements.

A series of depth profile measurements were then carried out using SIMS. Samples from different positions on the tile were measured to obtain the nickel, chromium, hydrogen and deuterium depth distribution. Some of the results are shown in fig 2. Nickel was the dominant metal with concentrations up to 10^{21} atoms cm^{-3} (1% of graphite density). Chromium and iron were present at levels ≤ 15% of the nickel. In the samples from the deposition region (fig 2, position A) the metal and hydrogen distributions extends into > 10µm. In the region E where net erosion was measured, the depth of the metals is < 2µm with a peak at 0.3µm. At positions M & P the depth of the metals is 3-4µm. The hydrogen and deuterium depth profiles show similar behaviour to the metals. One surprising result is that the amount of hydrogen in the surface is typically 10-20 times higher than the deuterium, despite the fact that plasma operation and glow discharge cleaning over most of the exposure period was in either deuterium or helium. Sample E, where there is net erosion is an exception. The hydrogen may be due to adsorption of water vapour by the deposited film on exposure to atmosphere.

3. Discussion

The experimental results were first compared with a simple analytical model which neglects ionization in the SOL [1]. The theoretical change in limiter dimension (Δh) has been plotted in fig 2 as a function of position on the tile. We have taken typical experimental values of the ion flux density ($2A/cm^2$) and electron temperature (50eV) at the LCFS and have assumed an exposure time of 5 x 10^4 seconds, corresponding roughly to the integrated duration of the plasma discharges. We have also taken the e-folding distances for the fuel and impurity particle fluxes to be equal (λ_Γ) and the electron temperature e-folding distance, $\lambda_T = 2\lambda_\Gamma$. It has been found that the distributions of net erosion/redeposition are insensitive to the value of λ_T, when $\lambda_T > \lambda_\Gamma$, which is always observed. Similarly, the predicted distributions are insensitive to the assumed temperature in the range 30 eV < T_e (a) < 100 eV, which encompasses most operating conditions in JET.

Reasonable agreement is obtained between the experimental curves and the theoretical results in fig 1, both in the relative shape of the erosion pattern and the absolute level. One striking disagreement occurs in the region of the tangency point, where in the model the erosion/redeposition approaches a null since the field lines are parallel to the surface at this point. In contrast, the experimental results show significant net deposition in this region which may result from ionisation of impurities in the SOL. Net deposition near the LCFS for the belt limiters is also in contrast with those from the discrete limiter case, where there was net erosion at the limiter surface closest to the plasma [1]. To assess the effect of ionisation in the SOL we have used the Monte Carlo code, LIM [4]. Earlier calculations have shown that ionisation in the SOL becomes significant (≥ 25% of total ionisation), when the edge density reaches a value $\approx 3 \times 10^{18}\ m^{-3}$. This leads to redeposition near the LCFS where the ionisation rate is high [5]. The results are shown in fig 1. It is seen that net deposition does occur near the tangency point. The reason for the difference between the belt limiter results and the earlier discrete limiter data is probably the higher operating density associated with high power additional heating.

No direct measurements have yet been made of erosion and deposition on the divertor target plates. However, the spatial distribution of deuterium, hydrogen and metal concentrations on the plates has been studied by Martinelli [6]. Comparison of the results with present measurements indicates that there is net erosion at the ion and electron side separatrix with deposition elsewhere. A similar picture emerges from the recent β back-scattering measurements [7].

Conclusions

An erosion and redeposition pattern has been observed on the JET belt limiters. The effect is toroidally symmetric. The radial distribution is similar to that observed for the earlier discrete limiters, except that there is now some net deposition near the LCFS, where previously there was net erosion. This effect is probably due to the higher operating densities leading to ionisation in the SOL. The effect has been modelled with the Monte Carlo code LIM and moderately good agreement with the spatial distribution has been obtained.

References

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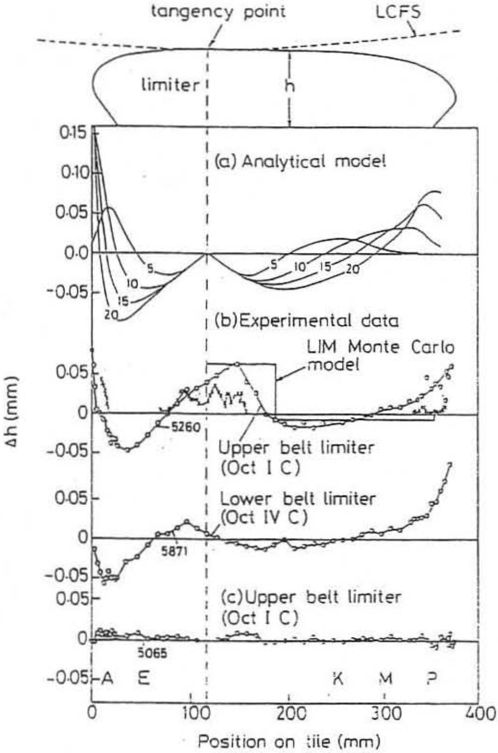
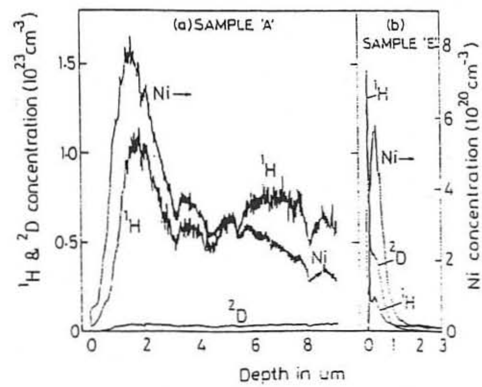


1a Calculated erosion of limiter tile using analytical model [1] which neglects ionisation in the SOL. Ion current density 2A cm^{-2} deuterons, Te(a) = 50 eV, exposure times 5 x 10^4s, for different λ_Γ and $\lambda_T = 2\lambda_\Gamma$.

b. Spatial distribution of erosion and redeposition on the JET belt limiter after exposure to ∿ 4000 discharges in 1987-88. Physical measurements °°°°°, measurements of deposition obtained by sectioning xxxx. Monte Carlo calculation using LIM code for $T_e(a)$ = 50eV λ_Γ = 20mm λ_T = 40mm $D_\perp$ = $1m^2s^{-1}$ $n_e(a) = 3 \times 10^{18}m^{-3}$

c. Distribution on belt limiter after 470 discharges; physical measurements.



2. Depth distribution of nickel, hydrogen and deuterium measured on two samples; 'A' from a region of deposition; 'E' from an erosion region, see fig 1. The distributions were obtained by SIMS using a 15keV O^{2+} beam.