Deuterium Retention in Beryllium Exposed to a 60kV Deuterium Beam – Consequences for Next Step Devices

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1. INTRODUCTION

The trapping of tritium is an important parameter for the selection of a suitable first wall material. In the JET Neutral Beam Test Bed we can study *actively cooled* first wall samples with a power flux relevant for a fusion plant. The particle energy of 20 - 60 keV is considerably higher than the ion energy expected in a divertor (but comparable to charge exchange particles) and the particle flux is consequently lower.

2. TEST SECTIONS AND EXPERIMENTAL PROCEDURE

Table 1: Composition of the deuterium fraction (ions and neutrals) during charging

component	full energy	half energy	third energy	impurities
composition (% of power)	43.4	10.5	34	12
composition (% of flux)	22	10	50	18
energy per atom [keV]	60	30	20	3.2

Actively cooled Beryllium test sections (Brush Wellman grade S65C) were exposed to a composite Deuterium beam at near normal incidence. The composition of the charging flux is detailed in table 1. After exposure the test sections were removed from the vacuum and exposed to air for approximately 1 week before the concentration was measured with Nuclear Reaction Analysis (NRA). The test sections were mounted in aspecial large vacuum chamber with Be-handling facilities attached to the University of Sussex 3 MeV accelerator. For D analysis a 2.5 MeV ^{3}He beam was used, and protons produced by the reaction D(^{3}He, p)^{4}He. The exact energy of the proton peak from the reaction with D depends on the depth within the surface from which the proton was emitted, so that the peak shape gives a picture of the distribution of D within the surface: The maximum depth from which information can be derived with a 2.5 MeV beam is 8 μm.

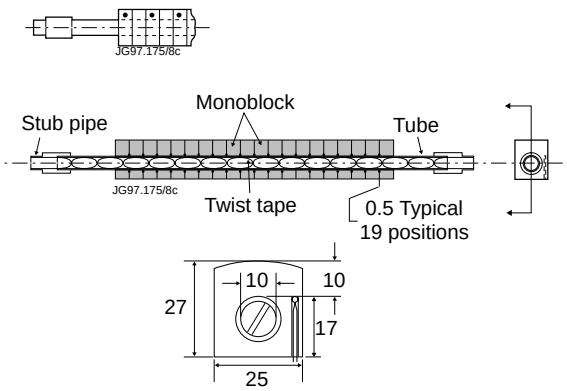

Fig.1: Schematic of the test section: Be monoblocks are brazed to a copper cooling pipe.

The test sections consists either of 20 Beryllium monoblocks brazed onto a 12 mm id cooling pipe (Fig. 1) or of 2 mm thick beryllium tiles brazed to a Hypervapotron as heat sink (see [1, 2] for details). In the case of the monoblock the experiment was done in two steps:

1. The test section was exposed to a power density of 4 - 5 MW/m^2 with a fluence of 2 10^{19} deuterium atoms/cm^2.
2. The test section was exposed to high power densities of 20 MW/m^2 which brought the surface into melting.

3. IMPLANTATION OF DEUTERIUM IN BERYLLIUM MONOBLOCKS.

Table 2 shows the measured concentration for tiles 1, 3, 5, 7, 9, and 11, measured in the centre of the tiles, and the typical bulk temperature rise of the respective tile, measured with a thermocouple 10 mm below the exposed surface. The tile numbering is from top to bottom. The measured concentrations after the charging run at 5 MW/m^2 are almost uniform.

The deuterium to hydrogen ratio in the charging beam flux increased from 2/3 to 3 during the charging scan (recirculating gas, see [3] for details). As even at the end of the charging scan only 75% of the beam were deuterium atoms we estimate that the concentration in a pure deuterium beam would have been 1.33 times the measured concentration, say 2.2 10^{18} $atoms/cm^2$. Using an implanted range of 0.2 - 0.6 micron as derived from the stopping power [4] for 80% of the flux (impurities neglected) we get an implanted density of 4 10^{22} $atoms/cm^3$ (30 at%). The fluence in the charging scan was 1 10^{19} deuterium $atoms/cm^2$.

After the second charging scan, in which the surface temperature on most tiles was well above liquidus, the deuterium was released on all measured tiles apart from the uppermost three tiles, which stayed below liquidus. The actual surface temperature of the three unmelted tiles at the top could not be measured with the IR imaging system (restricted viewing angle). If we assume that tile 3 was just below liquidus - say 1200 ^oC - and that the surface temperature is proportional to the thermocouple temperature we estimate a temperature of 800^oC for tile 1 and 1000^oC for tile 2.

Table 2: Thermocouple temperature and Deuterium concentration

	run without surface melting		run with surface melting	
block	concentration $10^{18}/cm^2$	temperature [° C][1]	concentration $10^{18}cm^{-2}$	temperature [° C][2]
1	1.7	51 (383)	0.36	169 (1070)
2			0.13	(1270)
3	1.74	69 (421)	0.009	244 (1470)
5	1.63	86 (458)	0	320
7	1.51	109 (508)	00	400
9	1.66	120 (531)	0	449
11	1.67	121 (533)	0	443

[1] This is the peak TC temperature measured 10 mm below the exposed surface. In brackets the estimated surface temperature is given in ^oK. Direct IR measurements are unreliable due to strong changes in emissivity near the liquidus temperature.

[2] In brackets given is a rough estimate of the surface temperature as explained in the text.

3.1 Distribution of the implanted Deuterium

Figure 2 shows a comparison of the NRA spectrum from the center of the Monoblock (a) with a spectrum from a point on one of the Mk I Be divertor tiles after use in JET during 1995 (b) [5]. The spectrum (c) is recorded from a graphite sample implanted with $6x10^{17}$ atoms cm^{-2} of D at 5keV, which TRIM calculations suggest should give a film 0.15μm thick saturated with D (i.e. to a D:C ratio of 0.4:1).

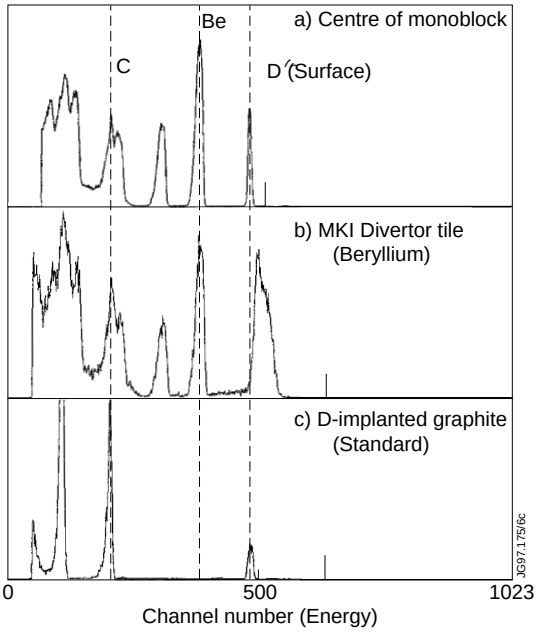

Fig.2: Comparison of NRA spectra. Sample c) has a 0.15 μm saturated film (TRIM calculations).

The D peaks in (a) and (c) are at the same channel number (which is proportional to energy) and of the same width. Furthermore spectrum (b) shows that for a film with D present throughout the analysable depth the peak would be much wider, to higher channel numbers (Reactions occurring at greater depth lead to protons of greater energy due to the kinematics of the reaction). The peak from the implanted standard has a half-width perhaps a factor of ten less than from the thick (8μm or more) film, but the D is actually within 0.15 μm, so this peak width represents the resolution of the detector. The. peak from the monoblock is the same width, so we can conclude that the D is certainly all within the first micron, but we cannot say how much thinner than that the layer is

4. IMPLANTATION IN FLAT TILES WITH HIGH PREVIOUS EXPOSURE

Finally a third scan was performed with surface temperatures of approximately 500 ^{0}C on a different test section with actively cooled Beryllium tiles. Before the test the tiles were exposed to a fluence of 4 $10^{20}/cm^2$ in a thermal test with hydrogen beams. During the charging scan parts of the surface were shielded by a movable scraper thus allowing to measure the deuterium build-up as a function of fluence.

On this test section the implanted saturation density is increased by approximately 30% and the implanted deuterium is spread over a depth of approximately 3 μm, showing a distribution with two partially overlapping ranges (Fig. 3). This wider deposition range in samples which had a higher hydrogen fluence before the implantation test could indicate that the front layer has become partially transparent for the incoming flux (bubbles ?). Further tests and evaluations are required to substantiate this assumption which would provide a mechanism for spreading the implanted hydrogen with increasing fluence. The build up of the retained deuterium is well described by the local mixing model. The best fit is obtained assuming that the

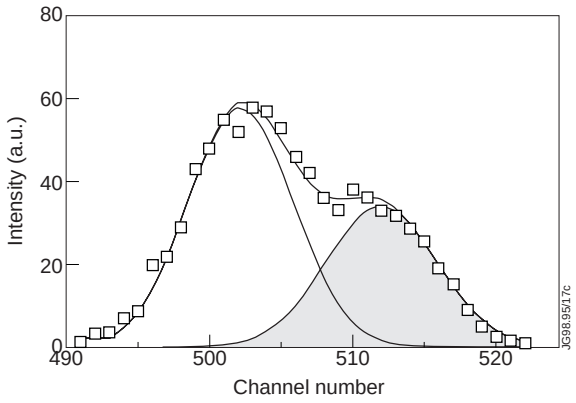

Fig.3: NRA spectrum on the Be tiles. The spectrum appears as superposition of two Gaussian distributions

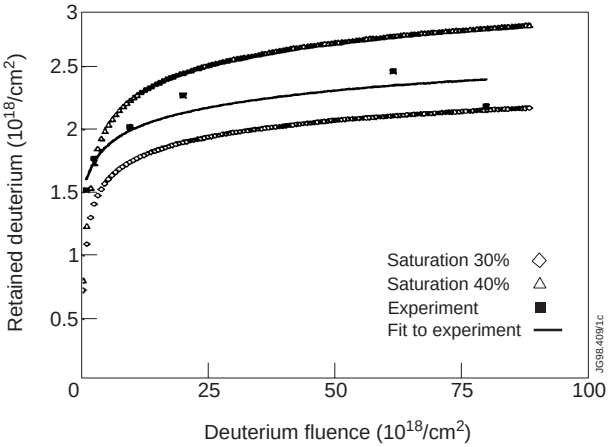

Fig. 4: measured and calculated deuterium buildup

panel is degassed before the charging scan (Fig. 4). A repeat of the NRA analysis 9 months after the previous analysis of the flat Beryllium tiles shows a reduction in the Deuterium concentration by a factor 2.2. In the time between the two measurements the test section was stored in air at ambient temperature. This justifies the assumption that the panel was degassed as the time between the initial exposure to hydrogen and the exposure to deuterium was 4 years.

5. CONCLUSIONS

Exposed to sufficiently high fluxes of energetic hydrogen the implantation in Beryllium is very similar to that observed previously in the copper beam dumps of neutral beam injectors [6] and can be described by the local mixing model developed for the implantation in graphite [7]. The case of Beryllium is different in that the wall degasses, when the surface temperature approaches or exceeds the liquidus temperature. The implanted material is initially trapped within the penetration depth and the deuterium build up saturates very quickly with the total amount of trapped hydrogen of the order of $2\ 10^{18}$ atoms/cm^2 which corresponds to 0.5 gr/m^2 in the case of a 1:1 deuterium:tritium mix. At ambient conditions the time constant for the exponential discharging process is of the order of 1 year. This means that inward diffusion of the implanted hydrogen should be small.

The absolute amount of implanted deuterium agrees well with other measurements [8]. The observed widening of the depth profile is a possible mechanism for deeper penetration with increasing fluence, which could be caused damage of the structural material by the implanted gas (bubbles) which in turn reduces the stopping power for the incoming flux and therefore allows deeper penetration.

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