DEUTERIUM AND IMPURITY CONTAMINATION OF DIVERTOR TILES AND COLLECTOR PROBES OF ASDEX-UPGRADE

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1. Introduction

The uptake and release of hydrogen isotopes at the plasma-facing components in magnetic confinement fusion devices affects the working gas recycling, the plasma behaviour and the tritium inventory [1]. This attracts considerable interest in the investigation of hydrogen trapping during plasma exposure. The most intensive plasma material interaction occurs on limiters and divertor plates.

Post-mortem analysis of such components gives information on the total amount of hydrogen isotopes retained in the material after plasma exposure. Recent investigations of divertor tiles of ASDEX-UPGRADE have shown that the dominant trapped deuterium amount is contained in the deposited material at the surface [2]. This surface contamination consists mainly of carbon, boron and the hydrogenic isotopes. Movable collector probes have been applied to investigate the hydrogen trapping and impurity deposition under specific plasma conditions.

In the present paper results on the impurity and deuterium contamination at the surface of collector samples are presented and compared with corresponding results from the divertor tiles. The collector samples were exposed to the scrape-off plasma of the main chamber (SOL-probe) and to the divertor plasma (DIV-probe).

2. Experimental Details

The collector samples were made from the target tile material and covered with a 150 nm thick C^{13}-layer in order to detect deuterium trapping, carbon deposition and erosion simultaneously. They were exposed to the scrape-off plasma in ohmic and NI-heated discharges using the midplane or the divertor manipulator.

The front side of the SOL-collector probe head was located 3 mm behind the ICRH-limiter and the samples were rotated behind a slit shield during the discharges to obtain a time resolution of about 0.6 s. The plasma particle density and electron temperature were determined at that location by using a Langmuir probe head in similar discharges. Samples of the divertor probe replaced a part of a target tile of the outer divertor [3] where the most intensive plasma target interaction is expected. Data from target-integrated electrical probes are used for an estimate of the particle fluence [4]. The surface of the divertor samples were exposed during single discharges without time resolution [5].

3. Results

Fig. 1 shows depth distributions of the carbon isotopes C^{12} and C^{13}, boron and deuterium measured on a SOL collector sample by Secondary Ion Mass Spectrometry (SIMS) after plasma exposure. The C^{13}-layer deposited before the plasma exposure is clearly identified. The thickness of this layer was not reduced after the plasma exposure indicating that erosion effects were negligible at this location. However, the plasma exposure caused a contamination consisting of carbon (C^{12}), boron, deuterium and hydrogen (not shown here) with varying amount. Note, the strong correlation of the depth distributions of all deposited species in the contamination at the surface already observed with the graphite and tungsten target tiles.

Fig. 2 shows the temporal evolution of the trapped deuterium amount and the impurity deposition on the SOL collector probe in discharges with ohmic and neutral beam heating.

The carbon and boron values were determined from the thickness of the contamination layer and calibration of the boron signal by Auger Electron Spectroscopy (AES). The deuterium amounts were derived from Nuclear Reaction Analysis (NRA). In a Round-Robin Experiment it was demonstrated that amounts of deuterium contained in thin contamination layers on uneroded graphite surfaces (EK98) derived from NRA-measurements agree well with results from other methods [6].

The radial distribution of the deposited carbon amount on the surface of the SOL-collector probe is shown in Fig. 3 for discharges with ohmic and neutral beam heating. The radial decay length for both impurities, carbon and boron, is found to be about 20 mm during ohmic and NBI-heated phases and is quite similar to that of the plasma fluxes. Fig. 4 shows for comparison the radial dependence of the incident deuterium fluence and the electron temperature derived from Langmuir probe measurements and using an exposure time of 1.2 s.

SIMS- and AES-analysis on samples from the divertor probe exhibit similar impurity and deuterium depth profiles as found for the SOL-probe.

The deposited carbon amount (C^{12}) on the surface of the divertor probe after exposure to two NBI-heated discharges (exposure time 4s) has been found to vary between $6x10^{20}$ atoms/m^2 and $1.2x10^{22}$ atoms/m^2 depending on the poloidal position. Highest deposition rates are observed near the strike point during NBI-discharges.

The surface contamination after pure ohmic discharges was measured to be at least lower by an order of magnitude. Boron deposition rates were about a few percent of the carbon deposition rates as in the case of the SOL-probe (see Fig. 2). Moreover, the relative concentration of deuterium compared to carbon was similar to that found for the SOL-probe.

4. Discussion

The comparison of Fig. 2a and Fig. 2b demonstrates that the impurity deposition rates of carbon and boron as well as the trapping rate of deuterium are highest during the neutral beam heated phase (between 2s and 5s in Fig. 2b) and exceed the corresponding rates during the

ohmic phases (Fig. 2a) by a factor of 10. Moreover the strong temporal correlation between impurity deposition and deuterium trapping is evident in Fig. 2b indicating that deuterium inventories higher than 10^{21} D-atoms/m^2 are caused by codeposition with carbon and boron as already found for the target tiles [2]. Merely, during the start-up phase of the ohmic discharge (at 1s in Fig. 2a), where higher electron temperatures (up to 50 eV) and very low impurity deposition occurred deuterium trapping seems to be dominated by implantation. In fact, measured deuterium inventories of several 10^{20} D-atoms/m^2 were found after implantation [2,7].

Comparing Fig. 3 and 4 we get a carbon contamination of the SOL-plasma higher than 10 %.

In order to compare the deposition rates found for the probes in single discharges with the contamination on the target tiles we have to consider only the exposure during NBI-heated phases with a mean duration of about 2 s and can neglect impurity deposition and deuterium trapping during ohmic phases. Using the results from the SOL-probe (Fig. 2) we would expect a contamination layer of $3x10^{25}$ C-atoms/m^2, $2x10^{24}$ D-atoms/m^2 and $3x10^{23}$ B-atoms/m^2 after an estimated exposure time of 1000 s. In fact, on inner divertor tiles, similar boron amounts were found whereas the measured contamination with carbon and deuterium was about one order of magnitude lower. One possible explanation is a preferential re-erosion of carbon and deuterium from the target tiles by chemical effects.

Impurity deposition rates measured by the DIV-probe are lower by an order of magnitude than those measured by the SOL-probe.

The deposition rates in the outer divertor near the strike point were $3x10^{21}$ C-atoms/m^2s, $2x10^{20}$ D-atoms/m^2 and about $5x10^{19}$ B-atoms/m^2sin discharges with NB-heating. Strong erosion effects prevent the built-up of a thick deuterium containing contamination layer at this location. The contamination with carbon, boron and deuterium found in surface depressions of graphite target tiles near the strike point region of the outer divertor amounts to 10^{22} atoms/m^2 [2]. Considering the estimated exposure time of 1000 s this indicates that most of the material deposited near the strike point of the outer divertor is re-eroded.

References

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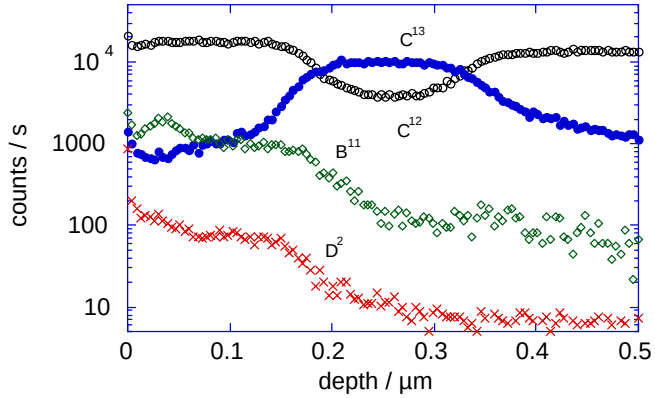

Fig. 1: Depth profiles of different isotopes taken at the surface of the collector probe after plasma exposure indicating the contamination of the C^{13}-surface with C^{12}, B^{11} and D

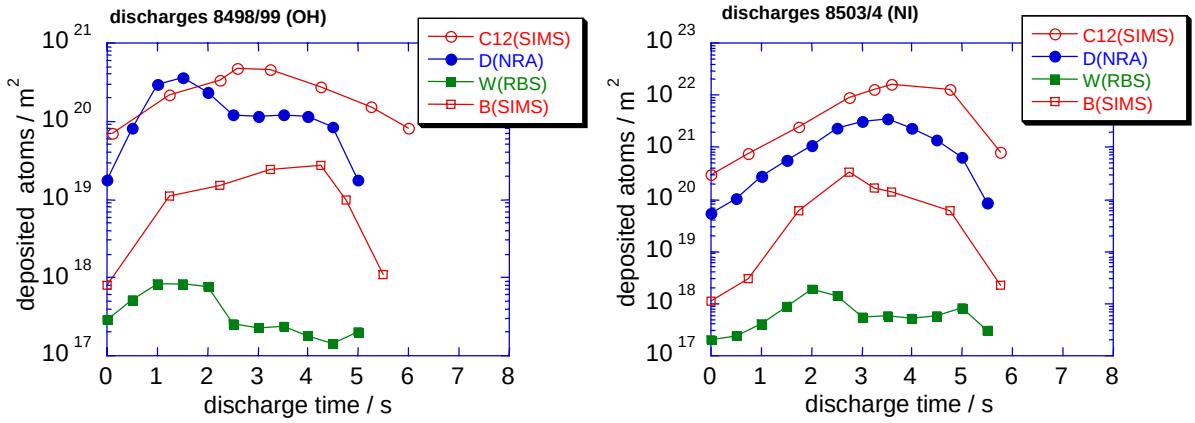

Fig. 2: Temporal evolution of impurity deposition and deuterium trapping in discharges with ohmic (a, left hand side) and NB-heating (b, right hand side)

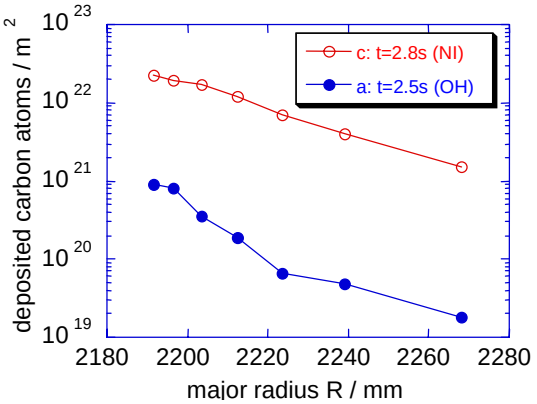

Fig. 3: Radial dependence of the carbon amount deposited on the surface of the SOL-collector probe

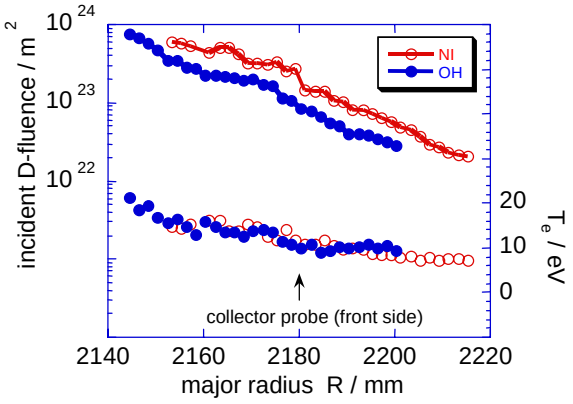

Fig. 4: Radial dependence of the deuterium fluence and electron temperature at the location of the SOL-probe