Erosion Measurements on the Inner Wall of the Stellarator W7-AS

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1. Introduction

The new stellarator W7-X presently under construction will be equipped with many optical lenses and mirrors for diagnostic purposes. Due to the interaction with the plasma and depending on the specific location with respect to the magnetic configuration erosion and deposition phenomena will occur at the surface of these components. Even at larger distances from the plasma these in-vessel components will be subjected to the same kind of radiations as the first wall if they are positioned in view of the plasma. It is the aim of this experiment to measure surface modifications of wall elements caused by the plasma exposure and in particular impurity deposition and erosion by charge exchange neutrals on the stellarator W7-AS.

Similar to the magnetic configuration of W7-X the stellarator W7-AS exhibits magnetic islands at the plasma boundary which are the basis of the concept of the presently investigated boundary-island divertor [1]. In preparation for this phase, preliminary studies of the relevant plasma configurations and edge parameters have been carried out in W7-AS with inboard limiters. During that time a number of long term samples were mounted at the inner wall of W7-AS protected from direct impact of plasma ions by the inboard limiters. Earlier investigations with collector samples at the outer wall and with top and bottom limiters have shown that deposition of plasma impurities and wall erosion by ion sputtering in discharges with magnetic islands is concentrated in regions intersected by plasma fans emerging from the X-point of the helical edge [2,3] .

2. Experimental Details

W7-AS consists of five modules, each of which had an upper and lower inboard limiter, toroidally separated [4]. The long term samples (LTS) were mounted in the shadow of these limiters in the equatorial plane at different toroidal locations of the inner wall in module 3. The sample surface was 2 cm in front of the wall and about 7 cm behind the limiter edge. A special sample holder with a ferromagnetic shutter also used in the tokamak ASDEX-Upgrade

[5] allowed an exposure of the sample surface only when a magnetic field is applied in order to avoid surface contamination during boronization or glow discharge cleaning procedures. The samples were made of polished fine-grain graphite and silicon. They were covered with an amorphous hydrogenated ^{13}C-layer of 360 nm thickness giving the possibility of simultaneous measurements of ^{12}C-deposition and ^{13}C-erosion. After 9 months of operation (from November 1998 until August 1999) with about 4000 discharges (total plasma exposure time of ~ 2000 s) and 5 wall boronization procedures the surfaces of the samples and the shutters were investigated using Secondary Ion Mass Spectrometry, Rutherford backscattering and Elastic Recoil Detection (ERD). The dominant plasma impurity observed by spectroscopy was carbon mainly released from the inboard limiters.

3. Results

Figure 1 shows the depth distribution of the carbon isotopes ^{12}C and ^{13}C and deuterium measured on a graphite collector sample by Secondary Ion Mass Spectrometry just before the plasma exposure. The depth profiles were obtained by ion sputtering with 10 keV O_2-ions. To avoid crater edge effects in depth profiling only ions from the 16% central part of the eroded area have been analysed. The depth scale was calibrated by measuring the final crater depth by laser profilometry. As shown in fig.1 the original ^{13}C-layer had a thickness of 360 nm. It contains the carbon isotope ^{12}C with a concentration of 10 % due to the gas composition during layer manufacturing. The signal of mass 13 in the graphite substrate originates from ^{12}CH-molecules. Rutherford Backscattering and ERD yielded for this virgin ^{13}C-surface layer total amounts of $1.64*10^{22}$ ^{13}Catoms /m^2, $1.6*10^{21}$ ^{12}C-atoms /m^2 and $0.7*10^{22}$ H-atoms /m^2, respectively. This indicates an atomic density of the ^{13}C-layer of $0.5*10^{23}$ C-atoms /m^2. The observed deuterium signal in fig.1 has to be considered as background.

Figure 2 shows as an example the depth distribution of ^{12}C, ^{13}C and D on a graphite sample after the plasma exposure in W7-AS. It indicates a reduced thickness of the ^{13}C-layer of 240 nm which corresponds well to $1.05*10^{22}$ ^{13}C-atoms / m^2 found by Rutherford Backscattering. At the surface the implanted deuterium is found with an exponential decay up to a depth of about 160 nm in fig.2. It has to be noted that the measured depth profiles of ^{13}C and D were found not to depend on the used substrate material (polished graphite and silicon) indicating a negligible influence of the surface roughness of the used graphite material on the measured profiles. The total amount of the remained hydrogen and the trapped deuterium was determined by Nuclear Reaction Analysis to be 0.,$3*10^{22}$ H-atoms /m^2 and $0.05*10^{22}$ D-atoms

/m^2, respectively. Significant deposition of plasma impurities like ^{12}C, boron or metals were not detected on the ^{13}C-layer. In contrast the movable shields of the sample holders are covered with a thick insulating layer consisting mainly of boron. This contamination is the result of wall boronization procedures.

In fig.3 the measured depth distribution of the implanted deuterium of fig.2 is compared with implantation profiles calculated by the TRIM programm [6]. The calculations have been done for implantation of deuterium in amorphous carbon for a Maxwellian energy distribution and an isotropic angular distribution of the incident particles. Parameter is the particle temperature. The comparison is based on an atomic density of $5*10^{28}$ Catoms/m^3 (upper scale). As can be seen the simulated results show good agreement for a particle temperature of about 50 eV which seems to be a plausible value for the temperature of the edge plasma which is the main source of the charge exchange neutrals [7].

In fig.4 the thickness of the ^{13}C-layer on the carbon samples before and after the plasma exposure is presented in dependence on the toroidal location with respect to the inboard limiters. The plasma exposure during high power discharges caused erosion of the ^{13}C-layer ranging from 120 and 240 nm. This corresponds to a mean erosion rate of ^{13}C between 0.06 and 0.12 nm / s or $3 – 6 * 10^{18}$ C-atoms /m^2 s. The lower value is similar to that found for the outer wall of ASDEX-Upgrade [5]. The higher erosion for the sample located between the limiters in fig.4 can be explained by the fact that the limiters are a strong neutral gas source causing higher CX-fluxes locally [7].

4. Conclusion

Large parts of the inner vessel wall of W7-AS are erosion dominated in high power discharges. No significant material deposition is expected on lenses and mirrors provided that shutters are used during wall conditioning procedures as boronization. Erosion and related surface roughening due to the impact of CX-neutrals remain as serious problem.

References

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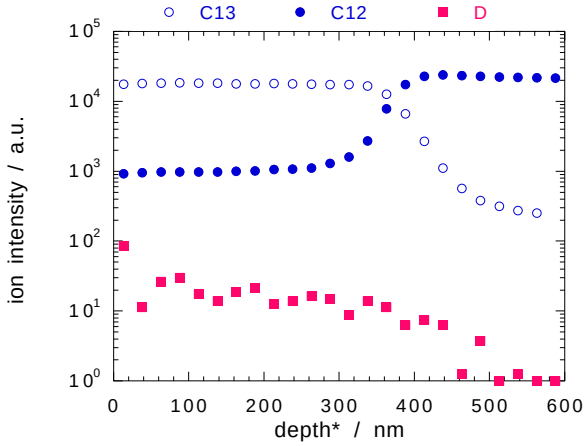

Fig.1: Depth profiles of different isotopes taken at the surface before plasma exposure

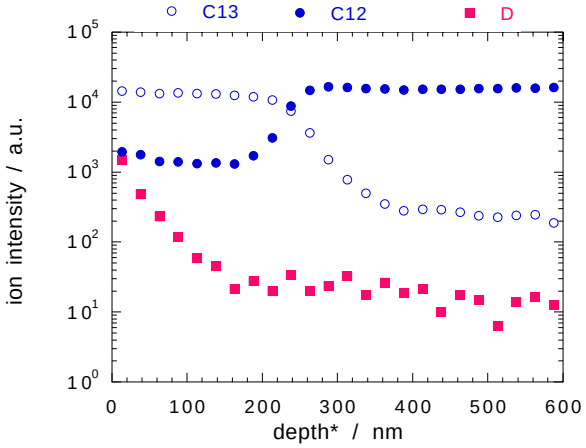

Fig.2: Depth profiles of different isotopes taken at the surface after plasma exposure indicating the implanted deuterium, the erosion of the ^{13}C-layer and negligible ^{12}C deposition

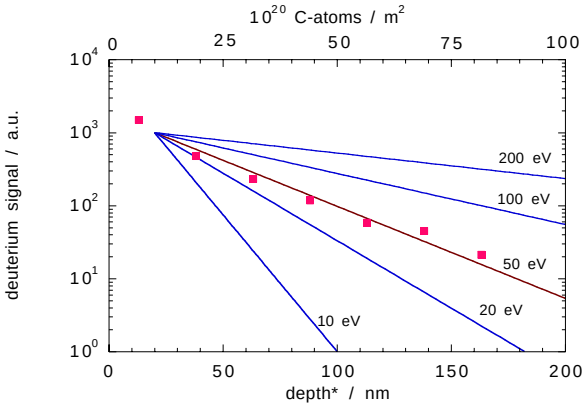

Fig.3: Comparison of measured depth profile of deuterium and calculated implantation profiles using the TRIM-code [6]

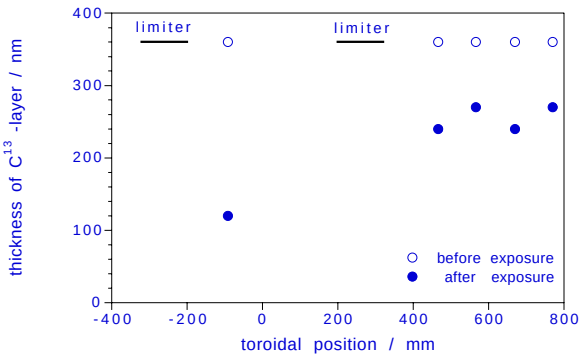

Fig.4: Toroidal dependence of the measured ^{13}C erosion in respect to the limiter position