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Surface Layer Deposition in ASDEX Upgrade with a Tungsten Wall as Measured by SIMS, AES and PIXE

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Introduction

Using carbon as plasma-facing material, strong erosion and intense carbon deposition will occur in a future fusion device. Especially, the formation of thick tritium-containing hydrocarbon layers is considered a serious problem in a fusion reactor. In order to test the potential of tungsten as a plasma-facing material in the main chamber, about 85 % of the graphite tiles of the central column of ASDEX Upgrade were replaced by tungsten coated tiles ($d_W \approx 1000$ nm).

After plasma exposure in 2002 some tungsten-coated tiles from the inner heat shield, as well as tiles from the inner and outer divertor strike point modules were investigated by surface analysis techniques.

Experimental

The arrangement of inner and outer divertor tiles in ASDEX Upgrade is shown in Fig. 1.

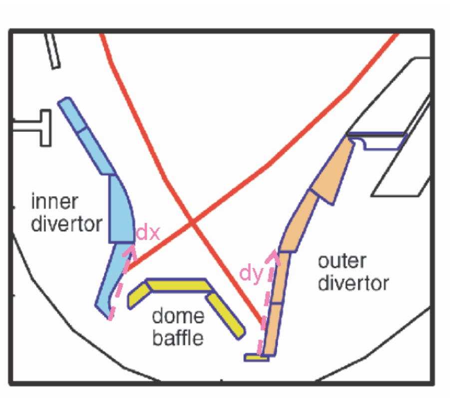

Figure 1: Arrangement of the inner and outer divertor tiles in ASDEX Upgrade.

The inner divertor strike point tiles were made from carbon-fibre composite (CFC). They were exposed from June 1997 to August 2002 for about 15200 seconds discharge time in divertor configuration during ohmic and H-mode discharges with heating powers up to 15 MW. During this time 19 boronizations and 5 siliconizations were performed. The outer divertor tiles were made from fine grain graphite and exposed from May 2001 to August 2002 for about 4500 seconds total discharge time in divertor configuration. In the last period 6 boronizations were performed. The plasma densities near the last closed flux surface varied in the range between $5 \cdot 10^{18}$ and $7 \cdot 10^{19}$ m^{-3} [1] and the electron temperature in the range between 20 and 200 eV depending on the discharge conditions. After plasma exposure the tiles were investigated by Secondary Ion Mass Spectroscopy (SIMS), Auger Electron Spectrometry (AES), and Proton Induced X-ray Emission (PIXE).

Results

At the central column the plasma impact caused a modification of the original tungsten surface by erosion and deposition phenomena. The toroidal distribution of erosion and deposition dominated areas on individual tiles indicates that the erosion of the tungsten layer is mainly caused by plasma ions [2,3]. Up to $2 \cdot 10^{18}$ W-atoms cm^{-2} were eroded in erosion dominated regions of the inner heat shield tiles with 1 μm W-coating.

The migration of eroded tungsten can be divided into several parts. The main fraction is redeposited at the inner heat shield itself. Another part is transported through the SOL-plasma of which a small fraction is penetrating the confined plasma. Most of the tungsten is eroded during limiter phases. Due to the magnetic configuration only tungsten eroded during divertor operation can be deposited on the strike-point regions of the inner and outer divertor. The tungsten deposition due to the last mentioned process was studied by measuring the composition and depth distributions of the deposition layers on the inner and outer divertor. Figures 2 and 3 show the element depth distributions of the deposition layers in the regions with maximum deposition. The sample positions refer to the distances from the bottom of the limiter tiles.

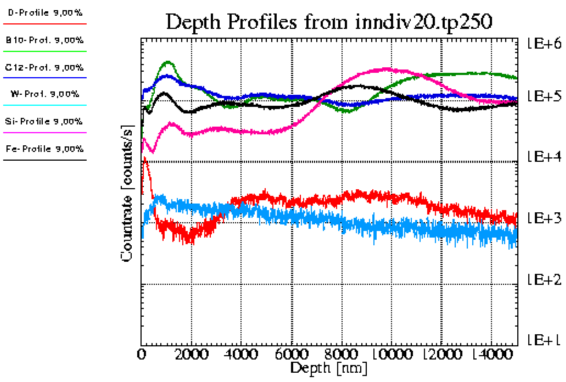

Figure 2: SIMS depth profiles from the inner divertor at the sample position dx = 20 mm

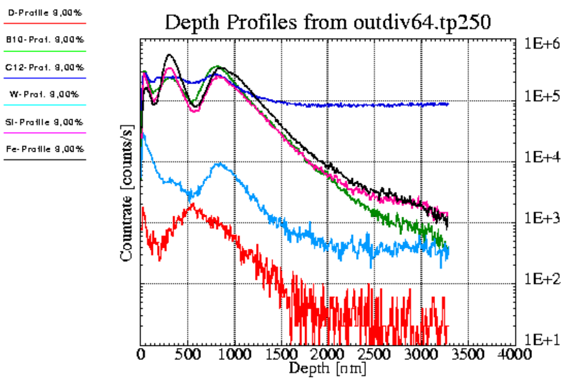

Figure 3: SIMS depth profiles from the outer divertor at the sample position dy = 64 mm

The figures show clearly the netto growth of the deposition layer characterized by boron maxima due to the boronizations during the operating period. The poloidal dependence of the thickness of deposits can be seen in Figs. 4 and 5. The maximum netto deposition rates correspond to 1 nm/s for the inner divertor and 0.2 ... 0.3 nm/s for the outer divertor.

After calibrating of SIMS measurements by means of neighboured AES depth profile studies

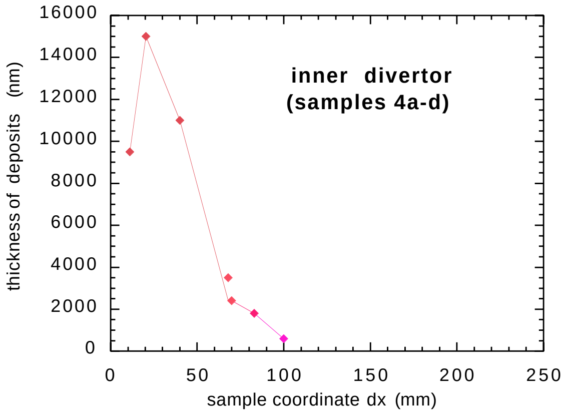

Figure 4: Thickness distribution of deposited B, C, D, Fe and Si on the inner divertor

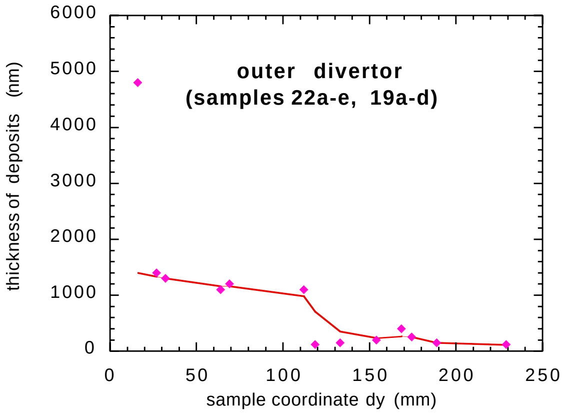

Figure 5: Thickness distribution of deposited B, C, D, Fe and Si on the outer divertor

the tungsten areal densities are shown in Figs. 6 and 7 and compared with results from PIXE ion beam analysis. The tungsten areal densities determined by PIXE (exhibiting a maximum systematic error of 25%) are lower by a factor of about 3, indicating the same behaviour qualitatively with a broad distribution around the strike point regions. So it can be concluded, that the in/out-asymmetry of divertor deposition found for light elements, especially carbon, does not hold for tungsten.

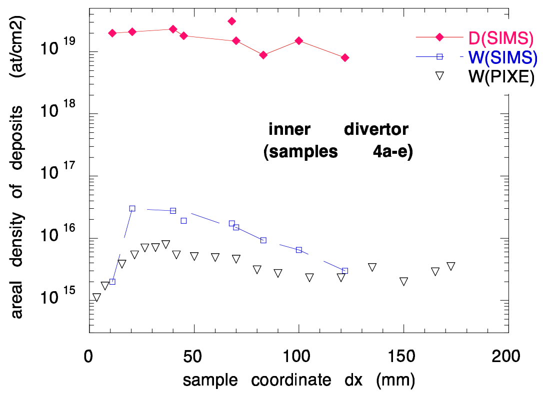

Figure 6: Poloidal dependence of the tungsten and deuterium areal density of the inner divertor measured by SIMS and PIXE

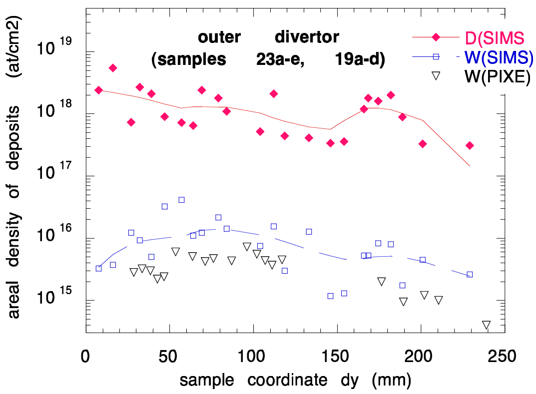

Figure 7: Poloidal dependence of the tungsten and deuterium areal density of the outer divertor measured by SIMS and PIXE

Comparing the total amount of deposited tungsten with the eroded tungsten at the inner heat shield reveals that only about one percent of the eroded tungsten was deposited on the inner and outer divertor tiles. This is a result of the predominant tungsten erosion in limiter configuration, where tungsten cannot reach the divertor.

Summary and Conclusions

The deposition layers have been characterized with respect to their compositions (W, C, D, B, Si and O) and their depth distributions. The thickness of deposition layers on the outer divertor varied between some 100 nm and 1 μm. On the inner divertor a maximum thickness of 15 μm was measured. This explains that deuterium inventories in the layer of the inner divertor were determined to be more than 1 order of magnitude higher compared to the outer divertor. The depth distributions of boron and silicon on the inner divertor reflect the number of boronizations and siliconizations during the operating period. This indicates that these layers exhibit an accumulation effect. On average, $1 \cdot 10^{16}$ W-atoms cm^{-2} were deposited both on the inner and outer divertor.

The measurements reveal the dominance of carbon even at a level of 85% tungsten coverage of the central column. This is consistent with the finding, that there is still carbon influx in the main chamber and divertor and carbon is the dominante impurity during plasma discharges [4].

References

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