

Influence of Surface Roughness on the Deuterium Inventory of ASDEX-UPGRADE Divertor Tiles

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The gas inventory of divertor target tiles used in ASDEX-UPGRADE has been analyzed by Thermodesorption Spectrometry (TDS). Desorbed gaseous molecules have been measured by heating up complete and cut divertor tiles. The largest samples ($80 \times 80 \text{ mm}^2$) could be heated up to temperatures of 1500 K and smaller ones to even higher temperatures.

In addition, surface analysis techniques as Auger Electron Spectroscopy (AES), Secondary Ion Mass Spectrometry (SIMS), Nuclear Reaction Analysis (NRA), electron microscopy and optical surface profiling have been applied for investigating erosion and deposition phenomena. The original plasma facing surfaces of the tiles were graphite (EK98) and plasma sprayed tungsten, respectively. The graphite tiles were used from 1991-1995 for about 1900 discharges and the tungsten tiles in 1996 for about 800 discharges.

Significant differences in gas trapping behaviour and impurity deposition have been observed for inner and outer divertor tiles. The plasma exposure also affected the surface morphology, in particular, for graphite.

On inner divertor tiles a several μm thick deposition layer was found. The mean surface roughness of the graphite tiles was estimated to be about $3 \mu\text{m}$.

Depth profiling and imaging by AES and SIMS showed an uniform contamination at the surface of the tungsten and graphite tiles consisting of carbon, boron, hydrogen and deuterium. The deposited amount on inner divertor tiles was estimated to exceed 10^{24} C-atoms/ m^2 and 3×10^{23} B-atoms/ m^2 . This contamination contained deuterium amounts up to 1.8×10^{23} D-atoms / m^2 (graphite tiles) and 8×10^{22} D-atoms / m^2 (tungsten tiles) as measured by thermodesorption. In order to increase the local resolution in the TDS-measurements some graphite tiles were cut. Then a strong local correlation between the released gas inventory and the amount of the deposited impurity boron became evident. Both, the deuterium inventory and the thickness of the deposition layer minimize in the contact region of the separatrix indicating erosion effects in this restricted region with a width of about 20 mm. The results from cut tiles also demonstrated

that the deuterium amount released from deposits in gaps on sides of the tiles can exceed that from plasma exposed surfaces up to a factor of 4.

Outer divertor tiles showed less contamination and gas inventories in a region near the strike point with a width of about 100 mm. Erosion processes like arcing and sputtering enhanced the surface roughness, in particular, for graphite. Electron microscopy shows microcraters and microcracks on the graphite surface after the plasma exposure. The mean surface roughness on outer divertor tiles exceeded 10 μm .

For complete outer divertor tiles deuterium inventories up to levels of 3×10^{22} D-atoms/ m^2 for graphite and about 1×10^{22} D-atoms/ m^2 for tungsten coatings were found in the contact region of the separatrix. However, these values are much higher than deuterium inventories observed after exposure to a pure deuterium plasma. In fact, exposure of virgin graphite to a deuterium plasma (T_e about 5 eV) representing the divertor plasma without significant hydrogen and impurity contamination caused deuterium retention in the order of 10^{21} D-atoms/ m^2 .

AES- and SIMS- depth profiling and imaging on the target tiles did not show a connected deposition layer at the surface. However, almost identical lateral distributions of deuterium and boron indicate that codeposition of both species occurred on surface depressions of produced microcraters, cracks and microcavities. At these locations the deposits are protected against re-erosion. Boron contamination in surface depressions has been found in excess of several 10^{22} B-atoms/ m^2 .

In order to investigate the depth distribution of the trapped deuterium more quantitatively surface layers of graphite tiles were locally removed by milling. TDS measurements of separated groove areas where layers between 5 μm and 30 μm were milled off showed that the dominant amount of the deuterium is trapped at the surface. In fact, samples where the first ten micrometer with high surface roughness were removed contained deuterium amounts of about 5×10^{21} D-atoms/ m^2 . Only less than 10^{21} D-atoms/ m^2 were found in samples where about 20 μm were milled off. This has to be compared with 1.5×10^{22} D-atoms/ m^2 found at the neighbored unmilled area.

This demonstrates that the dominant amount of deuterium is trapped in the contamination layer, consisting mainly of carbon, boron and the hydrogenic isotopes. In regions with prevailing erosion this contamination is located in plasma produced surface depressions. In this way the surface roughness has a significant influence on gas trapping in regions with prevailing erosion. The contribution of diffusion effects along grain boundaries to the deuterium inventory in graphite is estimated to be smaller than 10 % in eroded regions of the outer divertor and less than 1 % in deposition zones of the inner divertor.