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Tungsten redistribution patterns in ASDEX Upgrade

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Abstract

In ASDEX Upgrade tungsten is used as a high-Z plasma facing material. Its erosion, migration and subsequent deposition have been studied by analysis of a set of customised marker tiles, which was installed in the divertor and at the central column for one experimental campaign. Erosion rates were determined at the central column, which was the main tungsten source in that campaign. Deposition rates were determined at the central column and in the divertor region. The W-deposition in the divertor is strongly correlated to the local strike point exposure time. In contrast to low-Z wall materials, where deposition occurs mainly in the inner divertor, tungsten is found in similar quantities also in the outer divertor. The total amount of tungsten deposited outside the central column is about 40% of the gross W-source at the central column. One possible explanation for the 60% undetected tungsten might be the prompt local redeposition of eroded W atoms.

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1. Introduction

In ASDEX Upgrade tungsten is used as plasma facing material, replacing increasing fractions of the original carbon based wall components. The tungsten surface is to some extent eroded by impact of plasma ions. The eroded atoms will be ionised and will migrate through the plasma boundary and, in a smaller fraction, through the confined plasma, until they are finally redeposited at other locations in contact with the plasma. To assess aspects like lifetime of plasma facing materials, plasma impurity content and material mixing processes, it is necessary to study these processes in detail, particularly with respect to the extrapolation and model validation requirements for future fusion devices.

Erosion fluxes of wall material can be quantified by exposure of thin layers whose change in thickness can be determined very accurately by ion beam analysis methods. Ion beam analysis of retrieved material collection samples is also the only suitable method to quantify the deposition flux of an element. Retrieved tiles had been analysed already after previous campaigns [1] but the interpretation of the results was hampered by the fact that there was no consistent set of samples exposed in the same experimental campaign.

Therefore, in experimental campaign 2002–2003, a customised set of tiles with erosion markers was installed

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both in the lower divertor of the machine as well as at the central column.

2. Experimental set-up

The tungsten plasma facing surfaces in the campaign 2002–2003 consisted of the entire inner column (denoted W_1), the inner divertor baffle (W_2) and, at the low field side, the tiles covering the upper passive stabilisation coil (PSL, W_3) as shown schematically in Fig. 1. The tungsten components were manufactured by applying a 1 μm PVD coating on graphite tiles [2]. The total area (14.6 m^2) of the W-coated tiles was 40% of the total surface of plasma facing components, with 8.1 m^2 of W-coated tiles at the central column, 1.5 m^2 at the inner divertor baffle and 5.0 m^2 PSL tiles.

The tiles equipped with dedicated markers are shown in Fig. 1 with filled outlines. Of such tiles two different sets were installed at the central column and the divertor respectively. For the central column, metallic marker stripes were prepared along the toroidal coordinate on uncoated polished graphite tiles. At three poloidal positions at the upper and lower edge of the central column

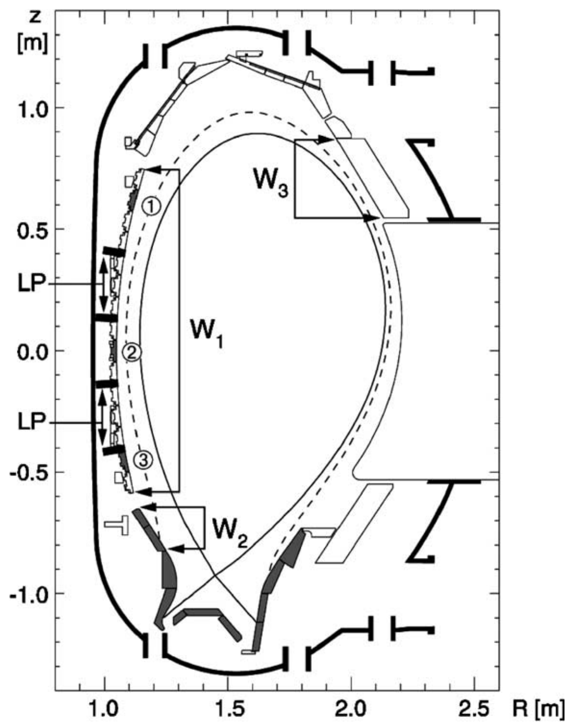

Fig. 1. Cross-section of the ASDEX Upgrade vacuum vessel with tungsten plasma facing components in experimental campaign 2002/2003. Installed diagnostic tile sets are shown in grey shade. The four central column Langmuir probes are denoted by LS.

and at the midplane position, one tile was installed with marker stripes of molybdenum and tungsten and another tile at the adjacent toroidal segment with markers made of nickel. For each element, two markers were prepared at the upper and lower half of the tiles. In the divertor, a carbon layer was prepared on a complete cross-section of tiles by magnetron sputtering. To allow separation of the carbon layer from the carbon substrate by ion beam analysis, a rhenium interlayer was used as a depth marker [3].

Before installation in ASDEX Upgrade the markers were characterised by Rutherford backscattering (RBS) using protons in the energy range from 1.6 to 2.5 MeV. The area density of the marker material was derived from the RBS results by fitting a given layer structure to the measured spectra using the SIMNRA program [4]. In cases where a detailed depth profile was required, the program NDF [5] was used, which solves the inverse problem of extracting the depth distribution of elements from a Rutherford backscattering spectrum by a simulated annealing algorithm.

During the experimental campaign the tiles were exposed to 1205 plasma discharges with a total discharge time (determined as time where $I_p > 300$ kA) of 5973 s. For the calculation of average erosion rates, the integral erosion of the marker samples is divided by this time. To obtain average deposition rates in the divertor, only the plasma operation time with divertor plasma exposure (4934 s) is taken into account.

After the experimental campaign the retrieved tiles were again analysed by proton RBS to determine the thickness change of the markers and by PIXE to quantify the amount of deposited tungsten.

3. Tungsten erosion measurements

3.1. Campaign integrated erosion of tungsten markers

The measured W-layer erosion at the three marker tile positions is shown in Fig. 2. The pronounced toroidal asymmetry at the midplane position and at the lower edge of the central column is a result of the field line intersection geometry with the surface of the tiles. Depending on the inclination angle of the B field against the tile surface, the incident ion flux will be either shadowed or elevated. A similar behaviour was already observed at marker tiles installed during the experimental campaign 2001. In this case, the erosion was, however, measured only at one half of a toroidal segment with the tile surface oriented in a way that the maximum observed erosion was found at the upper half of the central column [1].

For the marker tile at the top of the central column, the erosion is below the detection limit because of the limited contact with the plasma. Average erosion rates