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Erosion and Deposition of Tungsten as Plasma Facing Material at the Central Column Heat Shield of ASDEX Upgrade

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1.Introduction

In future fusion devices such as ITER, plasma-material interactions will have a considerably stronger influence on machine performance compared to present experiments, in particular due to the much longer discharge duration. Erosion and deposition are crucial issues because of their impact on plasma contamination, the lifetime of plasma facing components and tritium inventories. Although carbon based materials are used for plasma-facing components in most of today's experiments because of their good properties, tritium codeposition with carbon will lead to a prohibitively high level of radioactive inventory in a fusion reactor.

Tungsten is considered as an alternative material for plasma-facing components in ITER [1], due to its high sputtering threshold energy, low sputtering yield and small tritium retention, and has been successfully employed as plasma Facing Material (PFM) in ASDEX Upgrade. However, tungsten is a high Z material, which can lead to high radiation cooling, because it is not fully ionised at the plasma temperatures of a fusion reactor. A very low concentration ($2x10^{-5}$) will be tolerable in an ITER plasma [2]. Furthermore, it is important to investigate erosion and deposition of tungsten as PFM. Tungsten coated graphite tiles were analysed by means of Rutherfored Backscattering (RBS) and Proton Induced X-ray Emission (PIXE) before and after experimental campaign. The total tungsten erosion flux and the observed lateral variation across single tiles indicate that the dominant erosion process is sputtering by ion impact [3,4]. The strong poloidal variation and the toroidal asymmetries of the tungsten erosion at the central column, and the different tungsten deposition on inner wall and divertor tiles, will be presented in this contribution.

2.Experiment set up

Since the experimental campaign 1999/2000, when W-coated tiles were successfully introduced at the two lowest toroidal rows of the central column in ASDEX Upgrade, a step by step strategy has been executed by increasing the W-coated tile areas for three experimental campaigns. During the present campaign 2002, the W-coated tiles were extended to almost the full central column (see Table.1 and Fig.1)

Tab.1 Summary of three experimental campaigns with tungsten as PMF in ASDEX Upgrade

Experimental campaign	W-coated Area (percent of total)	W-coating thickness	Exposure time (Discharges)	Position at the central column	Divertor Configuration
Nov.1999--- Jun. 2000	1.2 m^2 (13% of total)	0.2-0.5 μm	4600s (919 discharges)	The two lowest Toroidal rows	DivII
Apr. 2001--- Jul.2001	5.5 m^2 (68% of total)	1.0 μm	1780s (374 discharges)	Full inner wall except ramp-down limiter and areas facing NBI	DivIIb
2002	7.1 m^2 (87% of total)	1.0 μm	3690s* (623 discharges)	Full inner wall except areas facing NBI	DivIIb

*Still ongoing

In addition, a complete column of thinner polished W-coated tiles with 60nm thickness was mounted including the limiter regions in experimental campaign 2001 (see Fig.1). The major points of interest were the investigation of the spatial distribution of the tungsten erosion and deposition. During plasma operation with tungsten as PFM, no negative influences on the plasma behaviour were observed, the tungsten concentration in the core plasma remaining below the maximum tolerable limit for fusion reactor relevant discharge scenarios [5,6].

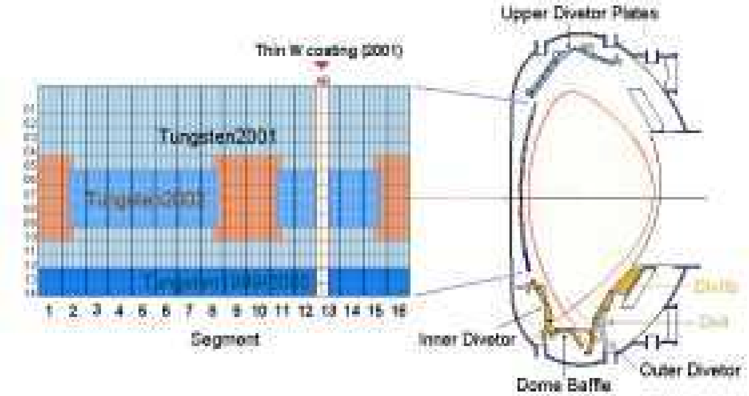


Fig.1 Schematic view of the unrolled central column and the poloidal cross-section of ASDEX Upgrade with the tungsten coated tiles, showing the separatrix and flux surface for typical discharges with DivII and DivIIb.

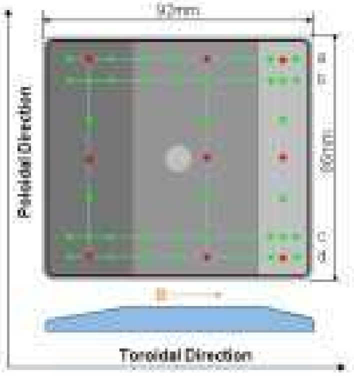


Fig.2 Schematic of the W-coated tile showing the analysis points along poloidal and toroidal directions.

3.Results

3.1 Distribution of tungsten erosion along poloidal and toroidal directions

After the experimental campaign 2001, a complete set of poloidal thin W-coated tiles (Segment13_A, see Fig.1) was removed and analysed by means of RBS using a 2.0MeV ^{4}He ion beam and PIXE using a 1.5MeV proton beam. All analysis points on one tile along poloidal and toroidal directions are shown in Fig.2. Red dots are RBS analyses of the W-coated tiles before plasma exposure, to obtain an average thickness of the original tungsten layer, amounting to 3.5×10^{17}atoms/cm^2. The distribution of the residual tungsten is shown in Fig.3a to Fig.3d. The maximum W-erosion is found at the left side of tiles Seg13_2A to Seg13_6A (see Fig.3b) located in the upper regions at the central column, the eroded tungsten being about 2.0×10^{17}atoms/cm^2. The total tungsten erosion flux and the observed lateral variation across single tiles indicate that the dominant erosion process is sputtering by ion impact, not only due to bombardment by charge-exchange neutrals. The strong poloidal variation and the toroidal asymmetries of the tungsten erosion are correlated with the pattern of the scrape-off layer flux surfaces intersecting the surface of the inner column tiles. Fig.3b shows the schematic view of the tiles at the central column with the local pitch angle of magnetic field lines at the tile surface. The length of the respective yellow line segments corresponds to the fraction $\Gamma_{\parallel}\times\sin(\Phi)$ of the parallel ion flux reaching the surface, where Φ is the field line angle of incidence against the tile surface. Spectroscopic and Langmuir probe measurements point to the fact, that the strong erosion is mainly caused by plasma ramp down at the limiter region. Detailed explanations for this phenomenon can be found in [7]. To confirm the asymmetries of W-erosion, three additional thick W-coated tiles with 1.0µm in segment13_B were also analysed after the experiment (see Fig.3c), direct neighbours of the thinner W-coated tiles (see Fig.3b). The corresponding maximum W-erosion is found at the right side of W-coated tiles locating at lower regions. Dividing the area density of eroded W by the total plasma exposure time one can derive the averaged W erosion flux for every campaign. The maximum campaign averaged tungsten erosion rate is about 1.4×10^{14}atom/cm^2/s for the experiment 2001, which is quite similar to the experiment 1999/2000. Most of the measured W-coated tiles show both regions with net erosion and with local deposition. The amount of the residual W in some deposition regions is close to the original value. Due to W-layer and substrate roughness of the W-coated tiles, and the modification of the W-coating through erosion by impurity ions during plasma exposure, it is difficult to discriminate deposited W-layers from substrate W-layers in the RBS spectrum. The error of the data evaluated for tungsten RBS spectrum using SIMNRA5.0 [8] and WiNDF7.0 [9] with and without roughness is about 10%.

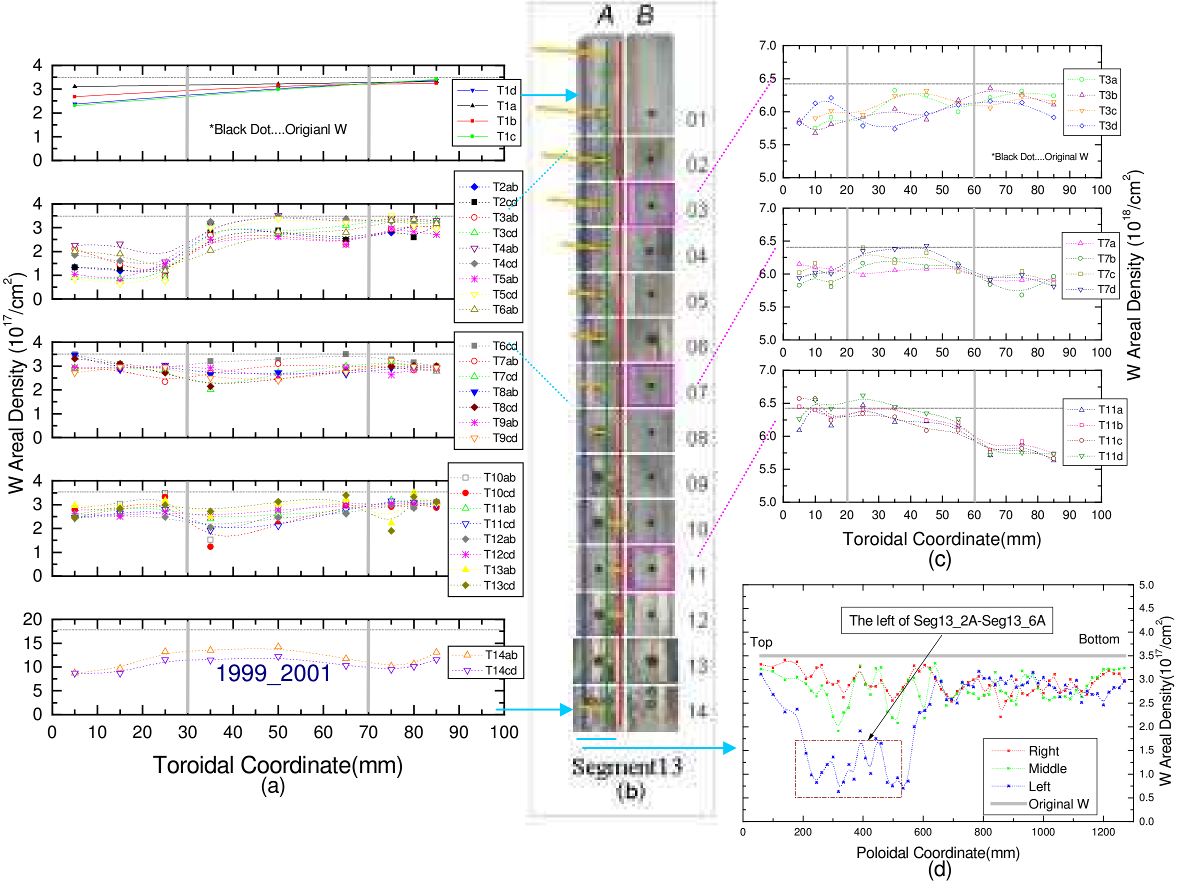
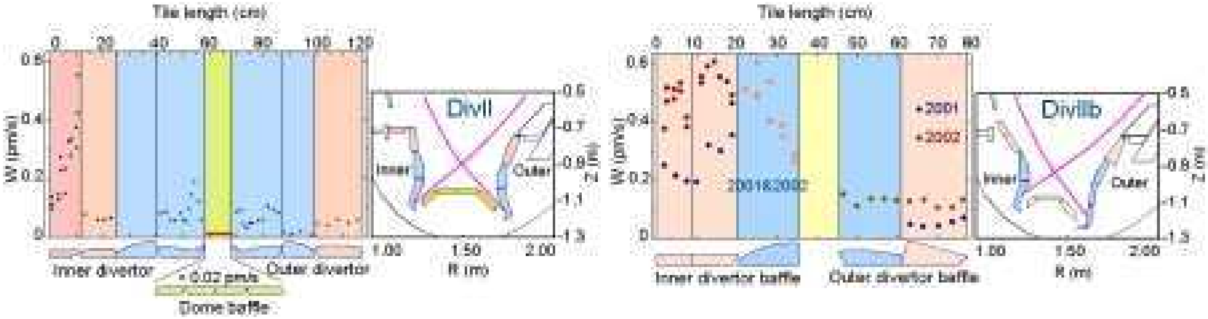


Fig.3 The spatial distribution of the tungsten erosion at the central column. (a) The residual tungsten on the tiles with thin W coating along the toroidal direction. (b) View of two complete vertical columns of 14 W-coated tiles after experiment 2001. (c)The residual tungsten on the tiles with thick W coating. (d) Poloidal distribution of the residual tungsten on the complete set of thinner coated tiles.

3.2 Tungsten deposition in the divertor region

Tungsten deposited on divertor tiles was investigated by post campaign PIXE and RBS analysis. Because of the tungsten deposition at divertor tiles being very small, it is below the detection limit for RBS at the strike point zones. Recently, a newly available was used in PIXE analysis. After the experimental campaign, a poloidal set of graphite divertor tiles was analysed. The maximum deposition was observed at the inner and outer divertor baffles, whereas only small amounts of deposited tungsten were found at the divertor dome baffle (shown in Fig.4). There is a similar spatial distribution of deposited tungsten being observed in both divertor configurations (DivII & DivIIb). During the present experimental campaign 2002, however, the W deposition on the baffle tiles is about two times larger than before, presumably due to the additional source of tungsten from the midplane area, which is generally closest to the separatrix and used as ramp-down limiter. The strong tungsten erosion during plasma ramp-up and ramp-down will not contribute to divertor deposition, although W-coated tiles at midplane were directly hit by the highest plasma particle and heat loads. A comparison of the total W-erosion with the deposition rates in the divertor shows that only 10% of the eroded tungsten is deposited on the divertor. Beside the mentioned erosion in limiter phases, the effects of prompt redeposition and redistribution at the central column can also explain this. Three graphite tiles at various positions were analysed to obtain the tungsten deposition at the central column [7]. The maximum deposition found nearest to the W-coated tiles was 5-7 times higher than at the inner divertor baffle, decreasing with distance from the W-coated tiles. From the spatial distribution of deposited tungsten and the spectroscopically determined low tungsten plasma penetration probability [5], one can infer that most of the eroded tungsten migrates via direct transport channels in the outer scrape-off layer regions without penetrating the confined plasma. This is a good agreement with tungsten transport modelling by the DIVIMP code [10].



(a) (b)

Fig.4 (a) The deposited tungsten on DivII during the experimental campaign 1999/2000.
(b) The deposited tungsten on DivIIb during the experimental campaign 2001 and 2002.

4. Summary

After the tungsten divertor experiment, the central column of ASDEX Upgrade was covered with tungsten coated graphite tiles in a step by step approach. In the present campaign 2002, the W-coated area was extended to 7.1 m^2. Tungsten erosion and deposition were studied by ion beam analysis. Most of the W-coated tiles at the central column show both regions with net erosion and with local deposition. The maximum campaign averaged W-erosion rate was found to about 1.4×10^{14}atom/cm^2/s. The strong poloidal variation and the toroidal asymmetries of the tungsten erosion appears to correlate with the pattern of the scrape-off layer flux surfaces intersecting the surface of the inner column tiles. Spectroscopic and Langmuir probe measurements point to the fact, that the strong erosion is mainly caused by plasma ramp down at the limiter regions. Tungsten deposition on inner wall and divertor tiles was also investigated. The maximum tungsten deposition was observed at the inner and outer divertor baffle modules, only small amounts of deposited tungsten were found at the divertor dome baffle. Comparison of the total W-erosion with the deposition rates in the divertor shows that only 10% of the eroded tungsten is deposited in the divertor region.

References

[1] *G. Janeschitz, ITER JCT and HTs, J. Nucl. Mat. 290-293 (2001) 1-11*

[2] N. Peacock, et al., in: P. Stott, G. Gorini, E. Sindoni (Eds.), *Diagnostics for experiment Thermonuclear Fusion Reactors*, Varenna, (Plenum, New York, 1996) p.291

[3] K. Krieger, et al., ICFRM-10, 2001, accepted for J. Nucl. Mat.

[4] A.Tabasso, H. Maier, K. Krieger, J. Roth, J. Nucl. Mat. 290-293 (2001) 326-330

[5] R. Neu, et al., PPCF, 44 (2002) 811

[6] V. Rohde, et al., *Tungsten as first wall material in main chamber of ASDEX Upgrade*, 28th EPS Conf. on Contr. Fus. and Plasma Phys., P1-042, 2001

[7] K. Krieger, et al., *Erosion and migration of tungsten employed at the main chamber first wall of ASDEX Upgrade,* PSI-15, O-14, 2002, submitted to J. Nucl. Mat.

[8] M.Mayer, *SIMNRA User's Guide*, Max-Planck-Institut für Plasmaphysik Report IPP 9/113 (1997)

[9] N.P. Barradas, C.Jeynes, R.P.Webb, Appl. Phys. Lett. 71(1997) 291

[10] A.Geier, et al*., this conference*