

Plasma induced surface modification in the divertor strike point region of ASDEX Upgrade



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Experimental

The investigation concerned 13 samples from outer divertor Tile 1 of the tokamak ASDEX Upgrade from different position in respect to the strike point (designated as I-1 to III-5). This tile was installed in the machine for one campaign in 2009, during which three boronizations took place. The samples differed in received flux, which can be specified based on their position. The tile was coated with a 10 µm W layer deposited on fine grain graphite with a 2-3 µm Mo interlayer.

The aim of post-mortem analyses (HRSEM, EDS, HRSTEM, FIB, EELS, XPS, AES, roughness measurements) was the evaluation of materials mixing and evidence of plasma-induced damage.









SEM overview image of the coating surface in the initial state (a) and after the campaign (b-d) together with a scheme of the divertor cross-section in ASDEX Upgrade. Arrows indicate directional erosion. Ovals indicate local re-deposition locations.

The erosion of the samples has clear directional character, which agrees with the direction of the particles flux/magnetic field lines.

- Two processes were observed: (a) changes brought about by erosion and (b) (re-) deposition.
- \checkmark The deposit distribution is inhomogeneous. It forms mainly in the shadowed areas,

Photoelectron spectra of W 4f region of samples: a) I-2 and b) II-3, before (red) and after 180 s sputtering (green); charging shift -2.64 and -2.4 eV respectively

Results of XPS measurements

Sample	[at. %]	C 1s	W 4f	O 1s	N 1s	B 1s	Fe 2p3
I-2	initial	36.0	19.3	39.0	5.0	-	5.0
	sputtered	14.4	41.8	39.3	3.7	I	3.7
II-3	initial	36.1	24.7	34.8	4.1	I	0.2
	sputtered	18.3	57.4	14.6	-	9.4	0.4

The examined deposits are composed of the same main elements, that are: tungsten (40-60at.%), oxygen (15-40 at.%) and carbon (15-20 at.%). Residues of iron were also found. Boron was detected at the level of several atomic percent only in II-3 sample.

often at the slopes of the irregularities of the surface.

Results - STEM





STEM Z-contrast images representing cross-sections of eroded and deposited layers



EDX line scan through one of the sublayers present in the grown deposit on sample III-3

Results – roughness measurements



Results	of	roughness	measurements
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Sample	Ra* (at mag. 2.9x)			
I-1	1.03 µm			
III-3	890 nm			
I-3	819 nm			
* roughness average				

The largest roughness was measured for sample I-1, which still showed the original tungsten/ substrate structure. The intermediate value was obtained for sample III-3 and the smallest one for sample I-3, which was also subjected to the highest flux. The results are in agreement with the microscopic observations.

Summary

✓ It has been generally observed that the surface morphology of the tungsten coating after the exposure shows a directional character of erosion and deposition. The deposits form mostly in the shadowed areas. Their thickness, according to FIB/STEM examinations varies from 200 nm to 1.5 µm, depending on the sample location and amount of received flux. The investigations revealed mostly W and W/O deposits. The structure of the re-deposited tungsten contains many small inclusions of light elements mixed with tungsten.
✓ The XPS examinations confirmed that the main constituents of the deposits are tungsten, oxygen and carbon. Residues of iron were also observed. The amount and morphology of the boron deposition varied strongly with the position of the sample.
✓ The roughness measurements confirmed surface smoothening caused by erosion.

EELS spectra of sub-layer present in the grown deposit on sample III-3

- ✓ The thickness of re-deposited material varies from the 300 nm for sample I-1 to 1-1.5 μ m in the case of samples III-3 and I-3 (the lamellas were cut from the shadowed areas).
- \checkmark Re-deposited tungsten contains inclusions of light materials mixed with tungsten, with the diameter of inclusions from 3-4 to tens of nm. The embedding matrix is tungsten.
- ✓ Boronizations performed during the campaign resulted in the presence of about 80 nm sub-layers being a mixture of B, C and O (*).

The tungsten coating was not fully eroded at ant place.

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