Thesis topic: Influence of the particle flux on surface modifications of tungsten

Background: Four sets of experiments have been performed to investigate the impact of material microstructure on the correlation between the particle flux, exposure temperature, surface modifications and deuterium retention in tungsten. "As received" polycrystalline tungsten samples with a grain size of ~20 µm (SGW) and ~40 µm (LGW), recrystallized tungsten at 2273 K with a grain size of ~50 µm (RecW) and single crystal tungsten samples [110] were exposed to deuterium plasma at Pilot-PSI and PSI-2 at temperatures 530 K – 1170 K to two different ranges of deuterium ion fluxes (~$5\cdot10^{23}$ $m^{-2}s^{-1}$ and $9\cdot10^{21}$ $m^{-2}s^{-1}$). All the exposures were performed at the same incident ion energy (40 eV) and particle fluence (10^{26} m^{-2}). From the TDS and SEM analysis of the two first sets of samples, after exposure to high particle flux density and high temperature, small blisters of several tens of nanometres were detected. In addition, an increase of the total deuterium retention compared to the lower flux density exposure was observed. In the case of low exposure temperature, the total deuterium retention is higher after exposure to the low flux density compared to the high flux density [1,2]. In order to better understand the diffusion process of deuterium and the trapping-detrapping processes in the bulk tungsten and at the grain boundaries, recrystallized tungsten with a low dislocation density and single crystal tungsten samples were used in the experiments.

PISCES experiments: In addition to the material microstructure, it is important to study the role of particle flux on deuterium retention and surface modifications when helium impurities are present in the plasma. "As-received" ITER-grade and recrystallized tungsten samples at 2273 K were exposed to various He/D plasma mixtures to similar conditions as the previous experiments. "As received" samples were exposed to He/D mixture plasma and sequential exposure to He and then D in order to verify the molecular dynamics predictions on the deuterium trapping in He bubbles. The results of these experiments will substantially contribute in determining the role of He impurities in the observed deuterium retention variation with temperature and will compare with the pure D and He exposures already done at Pilot-PSI at higher particle fluxes.

The advantage of using PISCES linear plasma device consisted on a well-characterized spectroscopic diagnostic system which determines the ion ratio in the plasma based on the measurements of He I line intensity [3]. The quantitative data are needed as an input for the modelling of the TDS profiles with the coupled reaction diffusion system of equations.

Sample preparation: Recrystallized samples were heated up to 2273 K for 30 min. After the heat treatment, the grain size increased up to ~50 µm and dislocation density was $<10^{11}$ m^{-2}. "As received" ITER-grade were initially annealed at 1273 K for 1 hour. The two sets of samples were mechanically polished to a mirror finish and ultrasonically cleaned in alcohol and acetone.

Exposure conditions:

Sample name	gas composition	Ion flux	Ion fluence	Temperature (K)	Ion energy	Exposure time (s)
RecPA1	5%He/D2	8.01E+21	1.00E+26	523	40	12480
RecPA2	5%He/D2	1.24E+22	1.00E+26	723	40	8040
RecPA3	5%He/D2	1.75E+22	1.00E+26	893	40	5700
RecPA4	5%He/D2	2.06E+22	1.00E+26	1093	40	4860
RecPA5	D2	8.62E+21	1.00E+26	523	40	11600
PAA1	5%He/D2	1.08E+22	1.00E+26	523	40	9300
PAA2	10%He/D2	7.79E+21	1.00E+26	523	40	12840
PAA3	He	2.00E+22	1.00E+25	573	40	500
	D2	4.10E+21	1.00E+26	553	40	23820
PAA4	He	3.00E+22	1.00E+25	773	40	334
	D2	1.20E+22	1.00E+26	773	40	8340

Results: Post-mortem analysis on the exposed samples will include the surface analysis with a scanning electron microscope and transmission electron microscope to investigate the surface modifications and thickness of the He nano-bubble layer. Deuterium and He depth distribution will be studied with the Nuclear Reaction Analysis method and as a final step, D and He will be thermally desorbed to analyse the total trapped amount in the material. Weight measurements didn't reveal any significant loss of the material after exposure.

[1] L. Buzi *et al.* Journal of Nuclear Materials 455 (2014) 316–319

[2] L. Buzi *et al. Proceedings of PSI-21 submitted to* Journal of Nuclear Materials 2014

[3] D. Nishijima *et al.* Physics of Plasmas 14, 103509 (2007)