Influence of tungsten microstructure and ion flux on deuterium plasma-induced surface modifications and deuterium retention

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Tungsten is to be used as plasma-facing material for the ITER divertor due to its favourable thermal properties, low erosion and fuel retention. Bombardment of tungsten by low energy ions of hydrogen isotopes, fluxes of which will vary by several orders of magnitude at various locations along the divertor, can lead to surface modifications and influence the fuel accumulation in the material. In addition to the particle flux, these changes are strongly affected by the surface temperature during the exposure.

In our previous work, a comparative study of the influence of the particle flux on plasma-induced surface modifications of tungsten and fuel retention was performed by exposing tungsten samples (~40 µm grain size) at temperatures of 530 K, 630 K and 870 K to two different ranges of deuterium ion fluxes (~$5\cdot10^{23}$ $m^{-2}s^{-1}$ and $9\cdot10^{21}$ $m^{-2}s^{-1}$), using the Magnum-PSI and PSI-2 linear plasma devices, respectively [presented at ICRFM-16]. The total ion fluence (10^{26} m^{-2}) and the average ion energy (~38 eV) were similar in both experiments. At low temperatures, the total deuterium retention was higher after the low flux exposure. This effect was attributed to a deeper diffusion of deuterium in tungsten as a consequence of the longer exposure time required to reach the given fluence. Nevertheless, at 870 K deuterium retention was higher at the high particle flux due to the formation of additional defects in the material during irradiation. Small blisters of 40 – 50 nm in diameter were formed at the high particle flux, whereas after the low particle flux exposure no surface modifications were observed.

This contribution continues the previous work and investigates the impact of material microstructure on the correlation between the particle flux, surface modifications and deuterium retention in tungsten. A second set of experiments was performed by exposing polished tungsten samples with smaller grain size (~20 µm) to deuterium plasma in Pilot-PSI and PSI-2 devices at a surface temperature of 510 K, 670 K and 870 K, ion energy of ~40 eV and ion fluence of 10^{26} m^{-2}. The high and low ion flux ranges were ~$2 – 5\cdot10^{24}$ $m^{-2}s^{-1}$ (Pilot-PSI) and ~$9\cdot10^{21}$ $m^{-2}s^{-1}$ – $1.5\cdot10^{22}$ $m^{-2}s^{-1}$ (PSI-2).

Surface roughening and formation of blisters up to few micrometers in diameter were detected after the exposure at high particle flux while no blisters were found after the exposure at high temperature (870 K) at low flux. Small blisters of 40 – 50 nm persisted after exposure at high flux and high temperature, confirming the previous results. Depth profiling of deuterium in all the samples was done by secondary ion mass spectroscopy (SIMS) technique. A clear diffusion profile of D in tungsten was obtained for the sample exposed at high flux and temperature (up to ~200 nm depth) whereas at low flux the D content was relatively negligible. At low temperature (510 K), a peaked D profile indicating implantation at the near-surface region (10 – 20 nm) was observed in both cases. Further investigations on the deuterium retention will be presented based also on NRA and TDS measurements. Modelling of the D desorption spectra with the coupled reaction diffusion system model (the CRDS code [1]) will be also presented.

[1] R. Piechoszek, et al. Journal of Nuclear Materials, 438 (2013) S1072 – S1075