Influence of the initial D concentration on damage stabilization during self-damaging of tungsten

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In most experiments on hydrogen isotope retention in displacement-damaged tungsten (W) the samples are first W irradiated and only then protium, deuterium or tritium are used to fill the initially created defects. In contrast to this, in a future fusion environment neutron irradiation will create displacement damage while hydrogen isotopes are present. Recently, experiments using multiple sequential W irradiations and deuterium (D) plasma exposures showed that the presence of D during displacement damage being created increases the density of defects [1]. Macroscopic rate equation modelling could successfully describe the observations and ascribed the increase in defect density to the fact that D can occupy defects and hence can stabilize them against recombining with e.g. self-interstitials [2].

The present study pursues this approach of multiple sequential W irradiations and D exposure cycles focusing on the influence of the initial D concentration on the final defect density. Recrystallized, mirror-polished tungsten samples were irradiated with 20 MeV tungsten at room temperature to create displacement damage within the first 2.3 µm. Different initial D concentrations were achieved by varying the first W irradiation fluence between 3×10^{15} W/m^2 and 8×10^{17} W/m^2 to create displacement damage between 0.001 and 0.2 dpa. Exposure of the samples to a low-energy D plasma at 370 K resulted in trapped-D concentrations between 0.07 and 1.8 at.%. For all samples, the subsequent second W irradiation fluence was chosen identical (8×10^{17} W/m^2 equal to 0.23 dpa). Also, the following second plasma exposure was identical for all samples and was chosen such that all defects within the W-irradiation depth were decorated. ^{3}He nuclear reaction analysis (NRA) was used to quantify the local D concentration and the total amount of retained D within the first 7.2 µm from the surface after the first and the second plasma loading. Finally, thermal desorption spectroscopy (TDS) was applied to determine the D desorption kinetics.

All samples showed D retention above the value known for W self-irradiation of hydrogen-free tungsten $c_{0,max}$ (1.8 at.% for 370 K plasma loading) in accordance with previous work [1,2]. In addition, the final D concentration and, hence, the defect density clearly increased with the initial amount of trapped D, even for the samples with only 0.07 at.% D. Quantitative analysis revealed that for initial D concentrations c_{init} up to 0.76 at.% the final D concentration after the second W irradiation and D plasma loading is equal to $c_{init} + c_{0,max}$, meaning the effect is additive. The same holds true also for the total D amount derived from NRA and TDS. Only for the highest initial D concentration of 1.8 at.% the final concentration is not additive but $c_{init} + 0.8\times c_{0,max}$ in accordance with [1] indicating a saturation beahvior at larger D concentrations.

[1] T. Schwarz-Selinger et al., Nucl. Mater. Energy 17, 228–34 (2018).
[2] M. Pecovnik et. al., submitted to Nucl. Mater. Energy (2020)