Defect evolution in self-damaged tungsten due to transient heating

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The evolution of defects in self-damaged tungsten is investigated using laser heating to simulate the effect of thermal cycling on hydrogen retention in neutron-irradiated tungsten. Pulsed laser heating (1100 nm wavelength) of tungsten previously damaged by W^{6+} ions to 0.23 dpa causes defects to annihilate, which is determined by decorating remaining defects with deuterium (80 eV) at 373 K up to a fluence of $4x10^{24}$ Dm^{-2}. Deuterium trapping and depth profiles are measured using ^3He nuclear reaction analysis (NRA), secondary ion mass spectrometry (SIMS), and thermal desorption spectrometry (TDS). Control samples with no laser heating have three distinct TDS release peaks at 450 K, 600 K, and 850 K, and the largest D concentration is observed in the 850 K peak corresponding to release from vacancy clusters. A strong annealing effect is seen after 200 laser pulses of 1 s duration with 10 MWm^{-2} power density and 950 K peak surface temperature during each pulse, resulting in a factor of 5 reduction of total deuterium retention.

Damage recovery occurs due to a reduction of both monovacancies and vacancy clusters, with the reduction of clusters being most pronounced. However, when samples are heated with only 10 laser pulses there is minimal change of deuterium retention compared to the no-laser case. Thus, varying the total heating time by varying the pulse number allows determination of the defect mobility timescale with high accuracy. With a lower laser power density of 5 MWm^{-2} (peak surface temperature of ~650 K), the strongest reduction of retention is seen in the low temperature TDS peak associated with monovacancies, providing further insight into how defects evolve as a function of both heating time and peak surface temperature. In addition, recent work indicates a synergistic effect between damage creation and the presence of hydrogen in tungsten [1,2]. Synergistic effects between defect evolution and hydrogen are further explored in the present work by laser heating both with and without simultaneous deuterium exposure.

Laser induced desorption spectroscopy (LIDS) with 1 s pulses has been previously shown to completely desorb deuterium from W-D codeposits [3], and here it is demonstrated that the same laser can anneal defects using multiple or longer pulses (required due to the lower mobility of defects compared with deuterium solute mobility in tungsten). This opens the possibility to use a rastering laser as a tool in future fusion devices to not only detritiate plasma facing components, but also to partially anneal neutron-induced defects.

[1] E.A. Hodille, et al., Nucl. Fus. 59 (2019) 016011
[2] S. Markelj, et al., Nucl. Mat. and Energy 12 (2017) 169
[3] J.H. Yu, et al., Rev. Sci. Instr. 90 (2019) 073502