

A novel H-unique damaging mechanism experimentally verified for W exposed to hydrogen isotopes plasma at sub-threshold ion energy

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One favorable property of tungsten (W) that qualifies it as plasma-facing material for the ITER divertor and for the first-wall of DEMO is the rather high energy threshold for damaging and sputtering. The commonly accepted damage threshold for W is 40-70 eV [1], corresponding to deuterium (D) with minimum incident energy of ~930 eV or to hydrogen (H) of ~1840 eV. Irradiation damage is typically not expected in W materials exposed to D plasma with ion energy below this damage threshold. However, in our previous work [2], we unravelled a strong surface damage of W samples due to impact of D ions with kinetic energies significantly below the reported energy thresholds [1] for production of stable lattice damage such as Frenkel pairs. This strong damage leads to unexpectedly high concentration of retained D up to 10 at. %.

The present work is intended to uncover the underlying physical mechanism for the observed sub-threshold damaging. We first propose a physical model for hydrogen isotope (HI) plasma to damage crystalline materials even with ion energies far below the threshold for stable Frenkel pair production. Then, we experimentally verify the model by reproducing the previous D-supersaturated surface layer (D-SSL) via H irradiation with twice the ion energy as for D. The such produced H-supersaturated surface layer (H-SSL) was characterized by ¹⁵N NRA with ultrahigh depth resolution. The acquired H depth profile reproduced the previous D profile and agreed well with that predicted by SDTrimSP simulations [3]. Scanning electron microscopy also confirmed the reproduction of the morphology of an H-SSL similar to that previously found for D irradiation. Electron-transparent W samples were exposed and then further characterized using transmission electron microscopy (TEM) to determine the defect microstructures within the HI-supersaturated surface layer. The sub-threshold damaging involves the synergy between temporary Frenkel pair creation by incident energetic HI species and vacancy stabilization by trapping of solute HI atoms. Present results demonstrate the important role of stabilisation of created point defects by solute H, which leads to a significant reduction of the threshold energy for damage creation by energetic projectiles. Synergistic defect generation processes are generally expected upon injection of energetic projectiles (ions, charge-exchange neutrals, neutrons) into HI-containing materials and likely contribute to enhanced material degradation. To this end, a significantly higher HI retention can be expected for W exposed simultaneously to HI plasma and neutrons in future fusion devices.

References:

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