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Experimental Study of Deuterium Retention and Thermo-mechanical Properties in Ion-beam Displacement-damaged Tungsten

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We present plasma-implanted D retention and thermo-mechanical properties in ion-beam displacement damaged tungsten targets. Cu ion beams with energies ranging from 0.5-5 MeV induce displacement damage of up to 1 displacement per atom (dpa) in the first micron of the surface in W samples held at a controlled temperature. Damaged samples are then exposed to D plasmas at 300-400 K to decorate damage sites with trapped D. Nuclear reaction analysis (NRA) and thermal desorption spectroscopy (TDS) are then used to characterize the effect of damage on D retention. Nano-indentation and nano-scale thermal diffusivity studies provide thermo-mechanical data localized to the near-surface damaged region in ion-beam damaged samples. In samples damaged at 300-400 K, NRA and TDS analyses show the trapped D inventory increases in proportion to dpaˆ0.65 for damage levels up to 0.1 dpa and begins to saturate as 1 dpa is approached. For W samples exposed to a D plasma ion fluence of 10ˆ24/cm2 with 0.2 dpa displacement damage at 300 K, the retained D retention inventory is 6x10ˆ20 D/cm2, about 4 times higher than in undamaged samples. The retained inventory drops to 2x10ˆ20 D/cm2 for samples damaged to 0.2 dpa at 1000 K, consistent with onset of vacancy annealing during the ion irradiation; at 1200 K damage temperature the D retention is reduced to 1x10ˆ20 D/cm2 and nearly equal to values seen in undamaged materials, suggesting that retention in high temperature radiation-damaged tungsten may not be affected as severely as might be expected at low temperatures. A 1D diffusion model with distributed trap sites reproduces the measured D spatial profiles in samples damaged at 300-400 K; work is underway to model to capture the reduced retention observed at higher damaging temperatures. The thermal conductivity of Cu ion-beam damaged surfaces drops from the un-irradiated value of 182 W/m-K to 53±8 W/m·K in W with 0.2 dpa damage at 770 K; slight further decreases occur at higher damage levels. The hardness increases from 5.3 GPa in undamaged W to 7.3 GPa for W damaged to 0.5 dpa with He ion beams, while no change in elastic modulus is found within the experimental uncertainties. We discuss the implications for the performance of W-based plasma-facing components, divertor heat flux management, tritium inventory management and fuel self-sufficiency in fusion energy systems.

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