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Reduced deuterium trapping by plasma-implanted He nanobubbles in radiation damaged tungsten

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The presence of a plasma-implanted helium nanobubble layer significantly reduces deuterium (D) retention in undamaged commercial ITER grade tungsten (W). In this paper, we show evidence that this phenomenon can survive displacement damage. A He plasma exposure (sample temperature: 643 K, ion flux: 10²² m⁻² s⁻¹ at 100 eV, fluence: 10²⁵ m⁻²) pre-treatment was performed to create a thin He nanobubble layer in the first ~15 nm of ITER grade tungsten samples. Samples were then irradiated by 5 MeV Cu ions at room temperature to create 0.001 to 0.1 dpa with peak damage rates occurring about 860 nm below the sample surface. Samples without He plasma exposure pre-treatment were also irradiated by 5 MeV Cu ions to provide a controlled baseline. All samples were subsequently exposed to D plasma at 373 K to a fluence of 10²⁴ m⁻². NRA results show that across a range of peak dpa ranging from 0.001 to 0.1 dpa, D retention inventory in the samples with He plasma exposure pre-treatment is reduced by a factor of 2 compared to samples without He plasma exposure pre-treatment (Fig. 1). Transmission electron microscopy (TEM) directly showed a surviving nanobubble layer after 0.1 dpa damage. However, the thickness of the bubble layer appears to have been reduced (Fig. 2 and Fig. 3). The results suggest that the plasma-implanted He nanobubble layer can survive radiation damage and still function to reduce D diffusion and retention in tungsten-based plasma facing components.

These new results have significant implications for early operation of a W-walled DT device such as DEMO or CFETR. With the wall in such a device held at 500-600 K and exposed to a cross-field SOL He ion flux in the range of 10²⁰-10²¹ m⁻²s⁻¹ (typical values expected in such devices), a He bubble layer would form in a few hours when exposed to pure He or mixed D/He plasma operation. When such a previously prepared wall is then subsequently exposed to a DT plasma while the wall is held at 500 K or higher temperature, previous work shows that fuel retention will be reduced by nearly an order of magnitude over the retention that would otherwise occur in a wall without He nanobubbles. The crucial new result shown here for the first time indicates that this bubble layer can survive displacement damage levels of up to 0.1 dpa. For the expected annual neutron-induced displacement dose of ~5 dpa/year in such a device, 0.1 dpa within the PFM would correspond to a full week of DT operation. Thus these experiment imply that such He nanobubble layer formation can have significant impacts on DT fuel inventory control and tritium self-sufficiency in future W-walled long pulse DT devices.

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