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Interface-induced enhanced deuterium plasma-driven permeation in chemical vapor deposition tungsten-copper composite

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With tungsten (W)-copper (Cu) bonding potentially used in the plasma-facing components (PFCs) in fusion devices, hydrogen isotope (HI) transport through the W/Cu interface is a key concern for tritium self-sustainment and operation safety.

To investigate HI permeation through W/Cu interface, a series of low-energy deuterium (D) plasma-driven permeation (PDP) experiments were performed on chemical vapor deposition tungsten (CVD-W)/Cu composite, bare CVD-W, and bare Cu, across a temperature range of ~600 K-800 K. The effective D diffusion coefficient of CVD-W was found to be higher than that of rolled W and forged W, likely due to the grain boundary as a high diffusivity path of D diffusion. Under the identical experimental conditions, an unexpected result is found that the steady state permeation flux in CVD-W/Cu was higher than that in bare Cu, with 3.1E18 m-2 s-1 in CVD-W/Cu and 4.1E17 m-2 s-1 in Cu at 741 K. And the time required in CVD-W/Cu to reach steady state exceeded the sum of time required for CVD-W and Cu individually. Rate equation simulations suggest that a high D concentration segment with a low HI solution energy of 0.65 eV is necessary to replicate the high permeation flux in CVD-W/Cu. The thickness of the segment is in line with the experimental observation of the W-Cu mixture region near the CVD-W/Cu interface. And density functional theory calculation confirms that Cu in W could reduce the HI solution energy in W. Furthermore, an analytical solution for the steady state permeation flux in a generalized three-layer composite is derived from a modified analytical equation for the fast evaluation of permeation flux.

This work provides experimental data evaluating HI transportation in W/Cu composite which have been rarely reported before. The measured permeation flux and the implication of the high HI concentration in W/Cu mixture could provide a better understanding of the tritium transportation through PFC and the bonding strength between W and Cu during tokamak operation.

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