The effect of He-induced surface fuzz on deuterium permeation through W

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Tungsten (W) is the primary candidate for plasma-facing materials (PFMs) in fusion devices due to its high melting point, high thermal conductivity, low sputtering yield, low swelling, low tritium retention, etc. [1, 2]. In the Tokamak device like ITER, W will be exposed to deuterium (D) and tritium (T) plasma with an operation temperature of 473-1473 K [3]. The design of a fusion reactor requires an understanding of hydrogen retention and recycling behaviors in nuclear materials, as the permeation and retention of hydrogen isotopes in nuclear materials are critical to issues like hydrogen embrittlement, tritium self-sufficiency, and radioactive safety in fusion reactors. The W materials will also undergo high-flux helium (He) plasma irradiation in fusion devices that may alter hydrogen isotope behaviours. However, few works focused on the effects of He plasma-induced surface modification on hydrogen permeation.

In this study, we combine plasma exposure and gas-driven permeation techniques to investigate the effect of He-induced surface fuzz structure on deuterium permeation through W. The experimental results indicate that the surface fuzz shows a significant deuterium permeation enhancement effect. The enhancement becomes stronger with the increase of fuzz thickness and temperature. After removing the He-induced fuzz, the deuterium permeabilities return to the unirradiated W, proving that the He-induced fuzz dominates the deuterium permeation enhancement. The large increasing surface area with fuzz nanotendrils may enhance deuterium adsorption, contributing to deuterium permeation enhancement. At low temperatures, the permeation enhancement becomes weaker, offset by the sluggish diffusion effect driven by He bubbles.

This work is the first to discuss the effect of the structural characteristics of He-induced fuzz on deuterium permeation behavior. This work reveals that the He plasma-induced surface modification can greatly impact the deuterium permeation behaviors through W, which should be taken into consideration in the application of W-PFMs in future fusion reactors. Further work will focus on investigating the effects of He-W co-deposition layers on deuterium permeation behavior, aiming to extend our understanding of plasma-induced surface modifications under more realistic fusion reactor conditions.

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