Characterization of Deuterium Trapping in Neutron-Irradiated Tungsten Using the Compact Divertor Plasma Simulator (CDPS)

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Tungsten (W) is one of the leading candidates for plasma-facing materials in future fusion reactors, owing to its high melting point and low sputtering yield. However, its interaction with hydrogen isotopes, particularly under neutron irradiation, remains a key issue due to the potential accumulation of tritium, which affects both safety and fuel cycle management. Neutron-induced defects such as vacancies and vacancy clusters serve as trapping sites for hydrogen isotopes and significantly alter their diffusion and retention behavior [1, 2]. A deeper understanding of the coupled effects of neutron damage and plasma exposure is essential for reliable prediction of fuel retention in reactor conditions.

In this study, W samples irradiated to 0.06 dpa in the BR2 reactor were exposed to deuterium (D) plasma using the Compact Divertor Plasma Simulator (CDPS) [3], a linear plasma device operated in a radiation-controlled environment at the International Research Center for Nuclear Materials Science, Tohoku University. Plasma exposures were conducted at 563 K and 773 K for durations of 1500 s, 6000 s, and 24000 s, with ion flux of 5.4×10^{21} $m^{-2}s^{-1}$ and ion energy of 110 eV. Surface oxide layers were removed by electro-polishing prior to exposure. D retention was quantified via thermal desorption spectroscopy (TDS), and vacancy-type defects were characterized using positron annihilation lifetime spectroscopy.

The results demonstrated that D retention in neutron-irradiated W increased with the square root of plasma exposure time [4], consistent with diffusion-trap models [2]. Furthermore, TDS spectra exhibited broadening toward higher temperatures with increasing exposure, indicating deeper D penetration. Positron lifetime measurements revealed that significant growth of vacancy clusters occurred only in samples exposed at 773 K, while little change was observed in those exposed at 563 K or in samples that were only annealed (i.e., without hydrogen isotope plasma exposure). These findings indicate that the defect evolution in neutron-irradiated W is strongly dependent on plasma exposure temperature and the presence of hydrogen isotopes.

These results contribute to a better understanding of plasma–material interactions in neutron-irradiated tungsten and provide important insights for the design and safety evaluation of plasma-facing components in future fusion reactors.

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