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Deuterium and helium retention and corresponding modifications of W-based materials under transients

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Tungsten and dense nano-structured tungsten (W) coatings are used as plasma-facing materials (PFMs) in current tokamaks and suggested to be used for future fusion devices. The high particle and heat loads occur during transients that lead to major damage in PFMs. In this regard, a study of accumulation of deuterium (D) and helium (He) in advanced W materials and corresponding material modifications under transient events appears necessary for assessment of safety of fusion reactor due to the radioactivity of tritium and material performance and for the plasma fuel balance. Therefore, sequential and simultaneous (with 10% of He seeding) D/He plasma exposure of W-based samples in quasi-stationary high-current plasma gun QSPA-T below and above the melting threshold with a pulse duration of 1 ms and number of pulses from one to thirty was performed. Material modification was investigated using an electron microscope equipped with a focused ion beam for in-situ cross sectioning and an x-ray diffractometer. The D and He retention in irradiated samples was measured by a method of thermal desorption spectroscopy using high resolution quadrupole mass-spectrometer to separate signals of He and D2. The D retention already after 10 pulses of the D plasma gun exposure was higher than that after stationary plasma exposure even at sample temperature of 600 K indicating the dominate influence of ELM's-like events on the D retention compared to normal operation regime. This effect occurs for both pure D and mixed D/He plasma exposure. As modelling results show, the increased D diffusion into the bulk due to high temperature gradient during the ELMs is one of the reasons of the enhanced D retention after ELMs. A formation of a layer of a thickness of ~10–30 μm with columnar crystal structure oriented perpendicular to the irradiated surface was observed for all W grades after the exposure of samples to both pure D and mixed D/He plasmas with the heat flux exceeded the melting threshold. After irradiation with D/He plasma in QSPA-T above the W melting threshold, spherical cavities in a layer of columnar crystals, containing a lot of D, were observed. It is shown that the synergetic effect of D, He and high heat flux leads to completely different particle retention and material modification compared to separate/sequential irradiation.

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