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

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Tungsten and dense nano-structured tungsten (W) coatings are used as plasma-facing materials in current tokamaks and suggested to be used for future fusion devices. In this regard, a study of accumulation of deuterium (D) and helium (He) in advanced W materials and corresponding material modifications under normal operation conditions and 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 (polycrystalline W, nano-structured W coating and W-10%Cr-0.5%Y alloy) 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 and compared with stationary plasma loads. 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 D_2. 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. In the normal operation regime using either pure D or D/He plasmas as well as photonic radiation, an additional increase in the D retention was found in all W-based samples after ELMs-like events due to D trapping in defects created by high thermal load. Effect of alloying elements and nano-structure of W is discussed. 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. The results obtained give possibility to assess the particle retention in divertor areas subjected to high thermal loads at different operation regimes and to compare advanced W-based materials with respect to the D and He retention and material modifications.