SURFACE MODIFICATIONS OF W-BASED MATERIALS UNDER HELIUM AND DEUTERIUM ION IMPLANTATION

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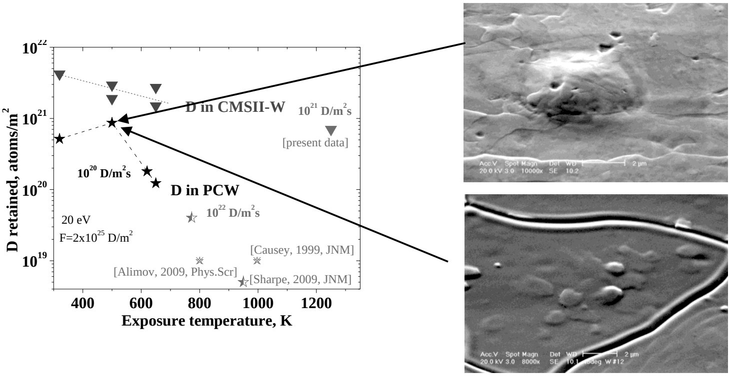
In a thermonuclear reactor, materials will be irradiated with hydrogen isotopes and helium (He), neutrons, and heat fluxes. Tungsten (W) and dense nano-structured tungsten (CMSII) coatings are used as plasma-facing materials in current tokamaks and suggested to be used for future fusion devices. In this regard, the study of the accumulation of He and deuterium (D) in W-based materials and corresponding surface 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, in this work, irradiation of W-based materials with D and He ions in stationary regime and in quasi-stationary high-current plasma gun QSPA-T below and above the melting threshold has been performed. In QSPA-T, a pulse duration was 1 ms and number of pulses was varied from one to thirty. In stationary plasma loads, ion energy was varied from 20 to 3 keV, temperature 300-1200 K and flux/fluence 10^{17}-10^{21} at/m2s/10^{20}-10^{25} at/m2.

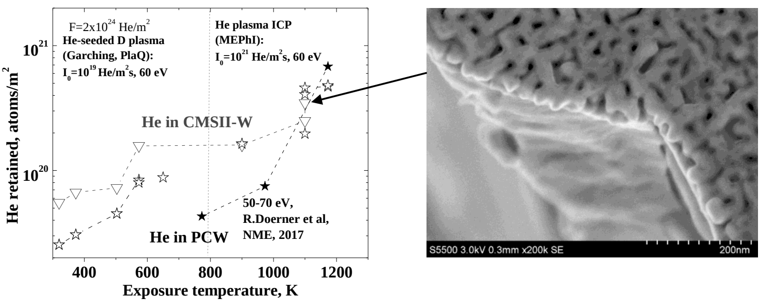
Material modification was investigated using an electron microscope equipped with a focused ion beam for in-situ cross sectioning and an x-ray diffractometer. The D and He retention in irradiated samples was measured by a method of thermal desorption spectroscopy using high resolution quadrupole mass-spectrometer to separate signals of He and D_2. The D retention in polycrystalline W (PCW) decreases with increasing the temperature at low fluence to 10^{22} D/m2 and always decreases with increasing the temperature in the case of CMSII-W coating (Fig. 1a). The D retention in PCW initially increases and then decreases with increasing the temperature at high fluence (Fig. 1a). In low-temperature range, blisters in W occurs (Fig. 1b). However, He retention in W does not significantly depend on temperature at ion energy above 400 eV and low fluences up to 10^{22} He/m2, while increases with increasing the temperature at ion energy below 80 eV and high fluences (Fig. 2a). The most destructive surface modifications caused by D (blistering, Fig. 1b) and He (nano-tendrils, or 'fuzz', Fig. 2b) occurs at low and high temperatures, respectively.



a) **b)**

Fig. 1. a) The D retention in W coating (CMSII) and polycrystalline W (PCW) as a function of the temperature. b) SEM images of blisters. The arrows indicate the conditions of blister formation.

Large-scale surface modifications occur at low temperature under D irradiation



a) **b)**

Fig. 2. a) The He retention in W coating (CMSII) and polycrystalline W (PCW) as a function of the temperature. The vertical line indicates experiments made at IPP, Garching and at MEPhI, Moscow. b) The high resolution SEM image of He-induced W 'fuzz'. The arrow indicates the conditions of fuzz formation.

Critical He retention for 'fuzz' grow in W-base materials is $>2x10^{20}$ He/m^2 and temperature above 900 K. After exposure to the plasma gun, the W fibers in fuzz is enlarged and an open porosity is formed by interconnecting bubbles in 'fuzz' with an increase in the number of pulses **(**Fig. 3). He retention decreases only by a factor of three.

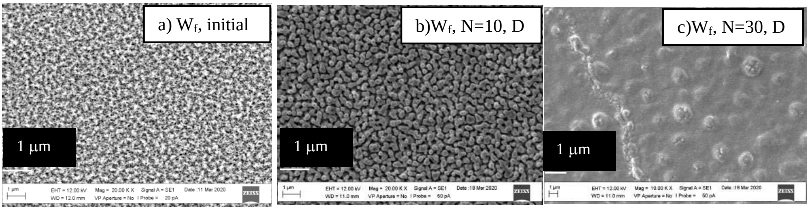


Fig. 3. *SEM image of the surface of W_f before (a) and after D plasma gun exposure at $T<T_m$ with ten (b) and thirty (c) pulses. W_f means W with He-induced 'fuzz'.*

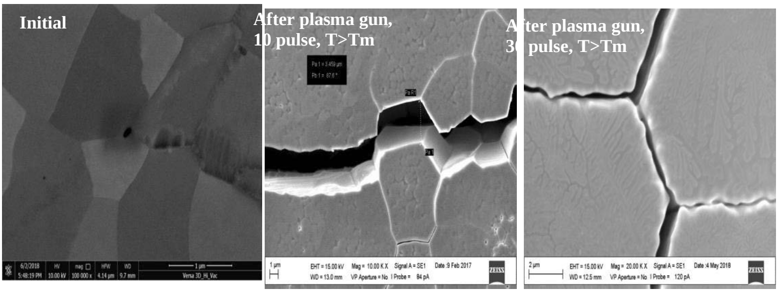


Fig. 4. *SEM images of the surface of PCW before (a) and after D plasma gun exposure at ten (b) and thirty (c) pulses at $T>T_m$.*

Fig. 4 shows some example of SEM images of the surface of PCW before and after D plasma gun exposure at ten and thirty pulses at temperature above the W melting temperature. Higher D retention was observed in this case compared to stationary plasma loads.

The combination of heat flux and D ions leads to various surface modifications, which are discussed in this paper. The correlation between the retention of D and He and the modification of the surface under different experimental conditions is discussed. The results obtained give possibility to assess the particle retention in divertor areas subjected to high thermal loads at different operation regimes and give recommendations for the development of tungsten-based materials with improved properties in relation to hydrogen embrittlement and helium swelling.