§30. Temperature Impact on Tungsten Surface Exposed to He Plasma in LHD and its Consequences for the Material Properties

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Helium plasma exposure experiments have been carried out in LHD and linear plasma device PSI-2, in order to expose tungsten to the wide range of helium flux.

Tungsten is a primal candidate for plasma facing materials such as divertor and first-wall in fusion reactor. The first-wall is exposed to boundary plasma and charge exchange particles. The incident flux is estimate to 10^{21} – 10^{22} /m^2/s and, it contain several % helium which produced by fusion reactions in the burning plasma. Helium irradiation is known to drastically affect tungsten surfaces, even at energies below the threshold energy of the sputtering yield. The fist-wall temperature, i.e. the blanket surface, is kept at allowable maximum temperature of structure materials of the blanket, for high-efficiency power generation. The maximum temperature is $\sim$ 550 °C in the case of the Reduced-Activation Ferritic/Martensitic Steels and $\sim$ 700 °C in the case of the vanadium alloy. The operational temperature of the the first-wall is, therefore, significantly below 900 °C which is the lower threshold temperature of the fuzz nanostructure formation. Although large number of studies have been made on the fuzz nanostructure, little attention has been given to such a low temperature ranges below the threshold temperature.

We have made a start on the helium plasma exposure experiments using the Large Helical device (LHD) at the same temperature with a first-wall of fusion reactor. The experiment shows that a heavily damaged layer is formed at the very surface layer, and bubbles are observed much deeper than the range of helium implantation rising concerns about the consequences for the material properties conservation. Nano-indentation measurements showed that the hardness of exposed tungsten indeed increases as the dislocation loops are tangled up and large bubbles appear in the material. In these experiments, however, the flux and fluence are rather low to foresee the material damages at the first-wall in fusion reactor. In order to explore the helium effects on tungsten under the higher flux and fluence conditions, helium plasma exposure experiments have been carried out in a linear plasma device PSI-2.

Surface morphology of the helium exposed tungsten is shown in Fig. 1. Under the low fluence condition at 3.0×10^{23} /m^2, there are almost no difference in damage structure between low flux and high flux exposure conditions. In both flux, slight surface roughness is seen at 473 K, and holes 3 - 15 nm in diameter are formed at 1073 K. Under the heavy exposure conditions at fluence of 1.0×10^{26} /m^2, significant surface morphology is observed. An undulating surface structures are formed under low temperature conditions below 1073 K, and the fuzz structure is formed at 1573 K. The surface modifications are matter of concern in the first-wall in fusion reactor by enhancing surface erosion which determines a lifetime of the first-wall.

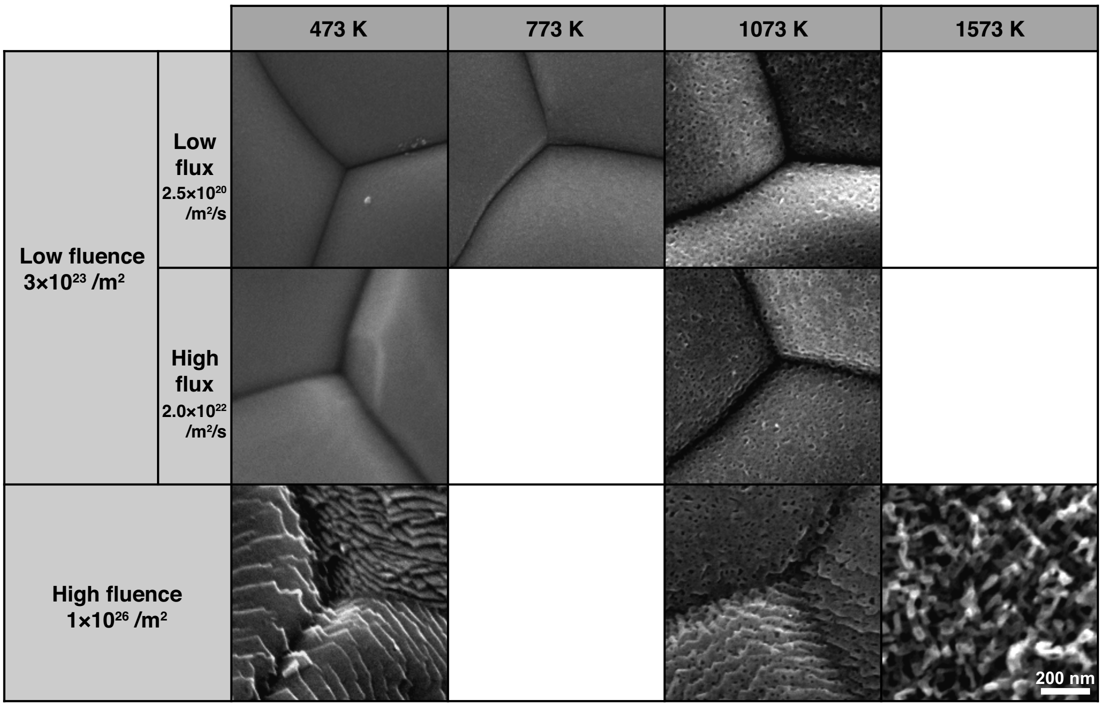

Fig. 1: Surface morphology of helium plasma exposed tungsten.