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Fluence Dependent Surface Modification on Tungsten Coatings Using Low Energy Helium Ion Irradiation at Elevated Temperatures

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ABSTRACT

Nuclear fusion is the most promising renewable energy source for the near future. It can provide a large amount of energy using a very small amount of fuel, as compared with that of the coal, oil, or nuclear fission. The chain reaction in nuclear fusion produces the energy and fuel, from hydrogen isotopes available in see water. Tungsten (W) is a leading candidate material for the plasma-facing component (PFC) in nuclear fusion reactors such as ITER (international thermonuclear experimental reactor), because of its high melting point, high yield strength, low erosion and low hydrogen isotope retention. Recent studies showed deeply convoluted fiber-form nanostructures (fuzz) formation on W surface under high-flux low-energy He^+ irradiation relevant to fusion conditions. The fuzz greatly degrades the mechanical, thermal, and optical properties of W. The significant enhanced surface area, and fragility of such fuzz, raise several serious concerns for its usefulness as PFC materials in fusion reactors. The fuzz can also be easily eroded and is a major concern for plasma contamination and short lifetime. In this study, we report on the effect of helium ion irradiation on the surface morphology evolution of W exposed to low energy He^+ ions at constant elevated temperature. Submicron thickness W films were deposited on Silicon (100) at room temperature using RF sputtering deposition technique. Several samples were cut and were exposed to 100 eV He^+ ions having a constant flux of 1.2×10^{21} ions m^{-2} s^{-1} and sample temperature (1173K). The fluence was varied in the range of $4.3 \times 10^{24} – 1.7 \times 10^{25}$ ions m^{-2}. Post ion-irradiation samples (including pristine) were characterized using field emission scanning electron microscopy (FE-SEM), X-ray photoelectric spectroscopy (XPS), and optical reflectivity measurements for monitoring the changes in surface morphology, chemical composition, and surface roughness/optical properties, respectively. We observed a sequential enhancement in the W fuzz density, sharpness, and protrusions from the film surface, with increasing helium ion fluence. Ex-situ XPS study shows the evidence of W_2O_3 phase formation due to natural oxidation of W fuzz in the open atmosphere. The study is also relevant to potential applications in solar power technology and in water splitting for hydrogen production.

KEYWORDS

Nuclear Fusion, Ion Irradiation, Tungsten, Scanning Electron Microscopy (SEM), X-ray Photoelectron Spectroscopy (XPS), Optical Reflectivity.