EXPERIMENTAL STUDY ON THE MIGRATION PROCESS OF ADATOM IN THE GROWTH DYNAMIC OF FUZZ

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ABSTRACTS

Tungsten (W) is considered the most promising candidate material for divertors in fusion devices due to its exceptional physical and chemical properties, including a high melting point, low sputtering coefficient, and good thermal conductivity. Over the past two decades, the fusion community has observed a concerning phenomenon on the W surface, known as "fuzz" [1], induced by helium (He), a by-product of nuclear fusion reactions between deuterium and tritium.

It is widely accepted that fuzz formation is linked to the presence of He bubbles, which result from a combination of processes in the initial stages, such as He atom penetration into the material, atomic diffusion, trapping at thermal vacancies, and subsequent bubble formation and aggregation [2]. However, there is ongoing debate regarding whether tungsten migration is the rate-limiting step during late-stage fuzz growth and the specific mechanisms by which tungsten migration occurs [3].

In this study, we experimentally investigate the adatom migration process during fuzz growth. Low-energy (< 100 eV) and high-flux (~ 10^{22} $m^{-2}s^{-1}$) He plasma irradiation experiments were conducted in our linear plasma device, CLIPS (Compact LInear Plasma-Surface interaction device), with sample temperatures ranging from 1000 to 1200 K, incident ion energies from 30 to 90 eV, and helium fluences from 5×10^{24} m^{-2} to 1×10^{26} m^{-2}. Different samples were used, including magnetron sputtering-deposited W films on Si and Mo substrates with varying thicknesses.

Surface morphologies and features were observed and analyzed using scanning electron microscope (SEM) and transmission electron microscope (TEM). The results show that the surface and substrate materials intermingle during fuzz formation, suggesting that bubble growth, rupture, and loop punching contribute to the creation of adatoms, which transport material from the bulk to the surface.

For samples with different W coating thicknesses, the surface nanostructures vary, as shown in Fig. 1. When the coating thickness is 1 nm, a nano-cone structure forms on the surface of the Si substrate, but no fuzz is observed. At coating thicknesses of 5 or 10 nm, a nanocolumn structure develops on the Si substrate, with fuzz growing on top of the nanocolumns. For a coating thickness of 100 nm, the surface exhibits a wavy morphology covered by a fuzz layer. In the case of Mo as substrate, the growth of fuzz was observed under different coatings.

An intriguing phenomenon was observed for samples with 100 nm tungsten coatings on Si substrates. Compared to pure tungsten, the fuzz growth rate is faster under the same irradiation dose. This suggests that the substrate atoms play a role as adsorbents in the complex migration process involved in fuzz growth.

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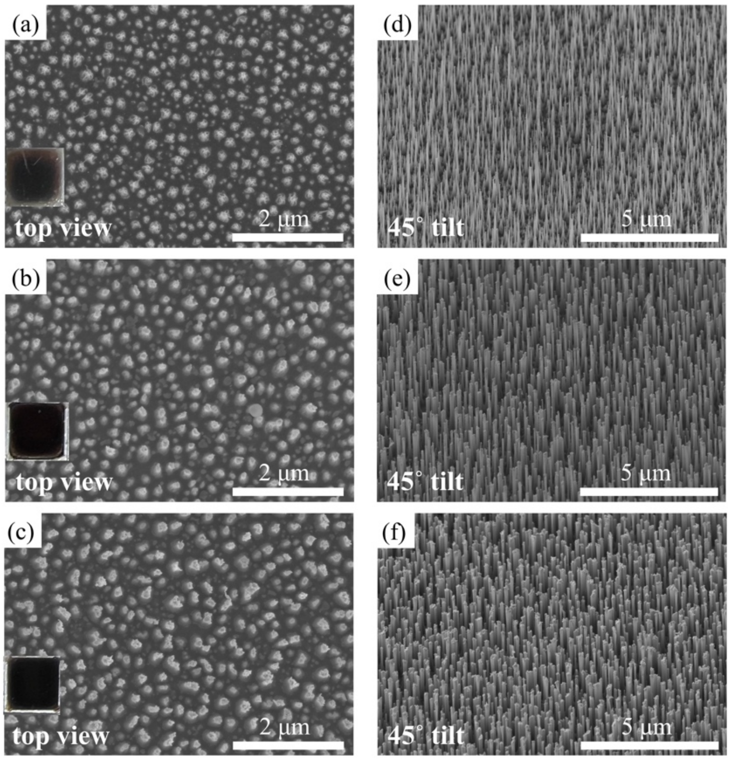

Fig. 1 The top-view FE-SEM images of W film with 1 nm, 5nm, and 10 nm thickness on Si substrate irradiated by He plasma.

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