INVESTIGATING THE FORMATION AND GROWTH OF FUZZY NANO-STRUCTURES DUE TO THE INTERACTION OF HELIUM PLASMA WITH TUNGSTEN UTILIZING A DC GLOW DISCHARGE PLASMA DEVICE

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As fusion research advances toward long-pulse and steady-state tokamak operations, the degradation of plasma-facing materials remains a critical challenge. Actually, Plasma-material interactions play a critical role in determining the performance and longevity of plasma-facing components in fusion devices. Among various plasma species, helium has a unique effect on materials, particularly tungsten, which is widely used in tokamak divertors due to its high melting point, low sputtering yield, and excellent thermal conductivity. However, prolonged helium plasma exposure can lead to significant surface modifications, including the formation of helium bubbles, nanostructures, and fibre-like "fuzzy" growths, which can alter the material's properties. Understanding these effects is crucial for predicting material behaviour in future fusion reactors and optimizing plasma-facing components for long-term operation.
Helium glow discharge plasma is extensively used for preconditioning vacuum vessel walls, reducing impurity accumulation, and improving plasma confinement. The ability of helium to efficiently remove contaminants while minimizing fuel retention makes it an ideal choice for discharge cleaning in fusion devices. However, recent studies show that although the helium glow discharge cleaning method can help clean and condition the tokamak wall, it can also cause the production of fuzzy nano-structures[1].
This study presents experimental observations on the formation and growth of fuzzy nanostructures on tungsten surfaces due to helium plasma exposure using a DC glow discharge plasma device (a PECVD device). In fact, plasma devices may provide a reliable platform for investigating the impact of plasma ions on surfaces, simulating conditions relevant to tokamak environments. Additionally, Plasma-Enhanced Chemical Vapor Deposition (PECVD) techniques offer precise control over plasma exposure, allowing researchers to analyze the evolution of surface features at different plasma conditions such as glow discharge cleaning environments. By employing these methods, it is possible to gain deeper insights into the mechanisms responsible for tungsten surface modification in helium-rich plasmas.
As Figure 1 shows, the fibre-like nano-structures are formed on the surface of tungsten specimens. The fuzzy nanostructures didn't cover the surface completely and were grown as the isolated islands. Reports published to date suggest that isolated fuzzy nanostructures develop under two key conditions: the influence of ion energy modulation[2,3] and the presence of impurities[4-6]. Since a dc plasma was used in these experiments, the formation of these nanostructures cannot be due to ion energy modulation and is probably due to the presence of impurities. It should be noted that since the vacuum vessel of the PECVD device must be opened for specimen mounting, and the base pressure in the experiments is approximately 2×10^{-2} Torr, it is normal for small amounts of residual air to mix with the helium plasma. Furthermore, in ITER and DEMO, impurity gas seeding is considered a key method for heat-load mitigation to protect divertor plates during standard operation campaigns[7,8]. Therefore, it is crucial to investigate the potential effects of impurity ion irradiation on the morphological changes of the tungsten surface.

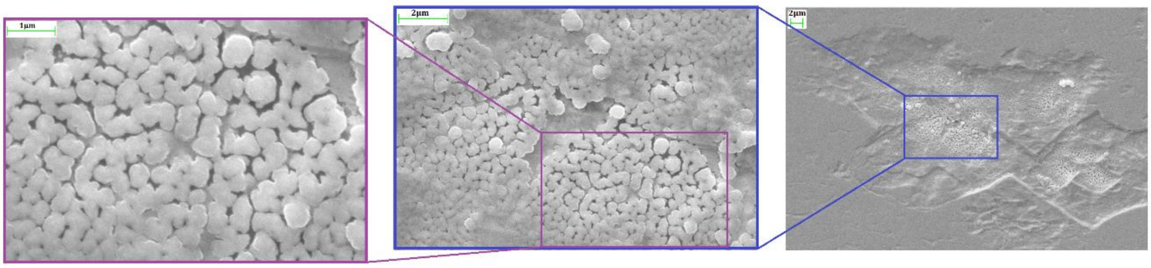

Figure1. *SEM image of tungsten surface exposed by helium glow discharge plasma in different magnifications*

To better understand the formation of these nanostructures, SEM images were also captured at a 75-degree tilt angle. As illustrated in Figure 2, there are fiber-like nanostructures within the islands, each covering an area of tens of square micrometers. The width of nanorods inside the island varies from 200 nm to 700 nm. Energy

Dispersive X-Ray Analysis (EDX) was used to determine the elemental composition of these nanostructures. It indicated that these nanostructures consist of tungsten. Notably, EDX analysis reveals that their atomic composition is similar to that of the reference sample and to regions where these nanostructures have not formed. This implies that their formation is likely driven by an intrinsic effect rather than an extrinsic one.

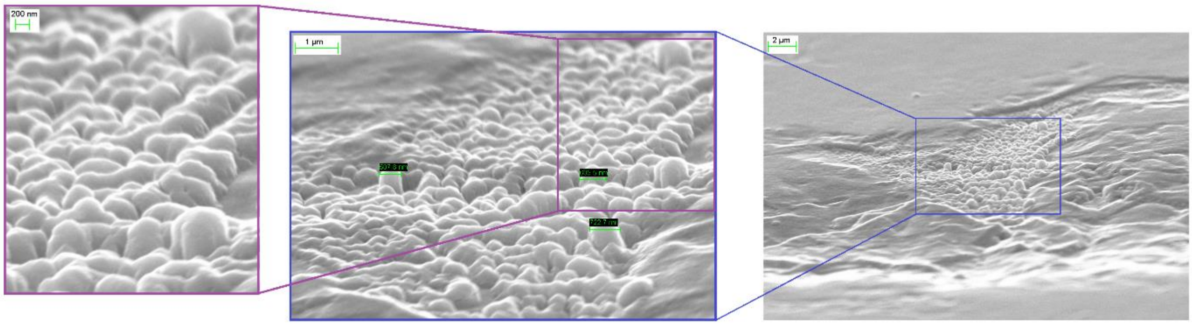

Figure2. Tilted-view SEM image of tungsten surface exposed by helium glow discharge plasma in different magnifications.

Using EDS analysis line scan, some important information was revealed. As illustrated in Figure 3, oxygen atoms accumulate more in the regions where the fuzzy nanostructures exist. Based on the previous reports, oxygen atoms are capable of trapping helium atoms in tungsten [9-11]. Oxygen exhibits a much larger binding energy with helium compared to other interstitial solutes. This means that helium atoms are more strongly attracted to and retained around oxygen atoms. Because of this strong attraction, oxygen impurities can act as helium trapping centers, leading to a local increase in helium concentration around oxygen atoms. Since helium accumulation is a key factor in fuzz formation, controlling the oxygen content in tungsten is important to regulate helium behavior and potentially influence fuzz growth. In conclusion, oxygen atoms significantly enhance helium trapping in tungsten, making their concentration a crucial factor in managing helium retention and its effects on material properties.

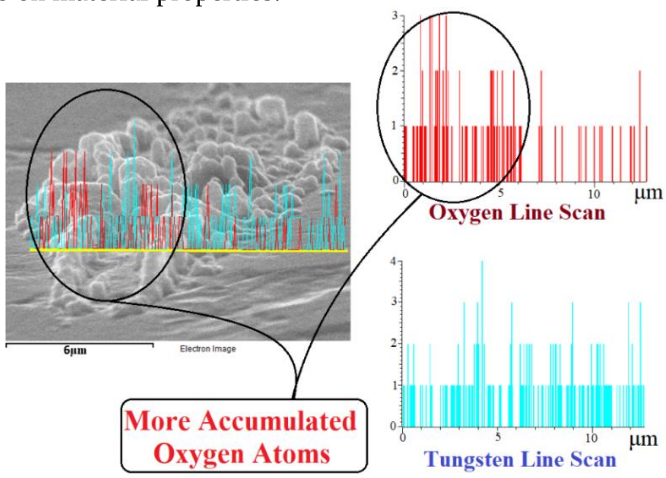

Figure3. SEM micrograph and EDS analysis line scan results for oxygen and tungsten elements; oxygen atoms accumulate more in the regions where the fuzzy nanostructures exist

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