In-situ spectroscopic ellipsometry for real-time characterization of the effects of high-flux helium plasmas on tungsten surfaces

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In-situ analysis of surfaces during high-flux plasma exposure represents a long-standing challenge in the study of plasma-material interactions. While state-of-the-art materials characterization can provide rich structural and composition detail during post-mortem analyses, in-situ diagnostics offer the possibility of probing dynamic effects. In this study, we demonstrate the use of spectroscopic ellipsometry for real-time characterization of how tungsten surface morphology evolves during exposure to He plasmas ($I_i = 3.5 \times 10^{16}$ He cm$^{-2}$s$^{-1}$, ion energy = 92 eV.) The range of exposure conditions selected here is conducive to the growth of near-surface He bubbles, and at higher fluence, the formation of W nano-tendrils ranging between 50 – 100 nm in diameter. The evolution of these surface features was probed using a fixed-angle ellipsometer (280 – 1000 nm wavelength range) attached to an RF plasma source with direct line-of-sight to the sample. Over the parameter space explored here, changes in the two angles that define the polarization of the reflected light followed a distinct trajectory in ($\psi$, $\delta$) space with increasing plasma fluence. Ex-situ ellipsometry of 15 additional tungsten specimens tested at a wide range of plasma fluences and temperatures mapped onto these in-situ results well. We used helium ion microscopy and focused ion beam profiling to provide a direct calibration of the ellipsometry measurements. Our results indicate that for a reproducible process such as the growth helium-induced surface morphologies, ellipsometry is a practical in-situ diagnostic to study how fusion plasmas modify materials. To study more general effects of plasmas on surfaces, including co-deposition and sputtering, different approaches to modelling the optical properties of the exposed surfaces are also considered.

In addition to the in-situ approach discussed here, we have also been developing complementary in-vacuo techniques to characterize surface disorder in single crystals following He plasma exposure. We probe the surface structure using low and medium energy ion beams and rely on shadowing and blocking patterns from 2 keV He$^+$ ions backscattered from the surface to provide information on the atomic configuration. The surface channeling pattern is then imaged using a large angle microchannel plate detector, thereby providing insight into the crystallinity of the first 2-3 atomic layers of the surface [1]. We present preliminary results that illustrate how this approach can be extended to larger depths (up to 10 nm) using higher energy ion beams.


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