Tungsten growth on silicon oxide and boron carbide and additional role of spacer in the ultrashort period multilayer X-ray mirrors

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Ultrashort period multilayer X-ray mirrors with the layer thickness down to 1 nm or less represent a technological challenge. Here, the layer thickness becomes comparable to the interface roughness inherited from the substrate which along with clustering effects may result in discontinuous layers producing strong diffuse scattering. Hence, the growth of refractory metal layers on various substrates is an important issue. We present here a study of W growth on SiO_2 and B_4C underlayers performed in real time by the in-situ grazing-incidence small-angle X-ray scattering (GISAXS). A microfocus X-ray source IμS equipped with focusing Montel optics (Incoatec) and 2D X-ray detector Pilatus 200K (Dectris) were mounted on a custom-designed dual-ion beam sputtering apparatus (Bestec). A tungsten 5 nm thick monolayer as well as a 15 period W/B_4C multilayer mirror with 1.8 nm period and 0.33 gamma ratio were sputter deposited at the base argon pressure of 2×10^{-8} mbar and working pressure of 4×10^{-4} mbar on a Si wafer covered with a $\approx$2 nm thick native oxide layer. Simultaneously, the GISAXS frames were collected repeatedly with the integration time of 8 s at the incidence angle of 0.25 degree close to the critical value to get a real-time movie of the process in the reciprocal space. The GISAXS measured close to the critical angle profits from a resonant enhancement of scattered intensity (Yoneda effect). The temporal study of the growing multilayer was performed by analysis of the lateral profiles (along the surface) of consecutive GISAXS frames extracted at the critical angle that provide the power spectral density (PSD) function. This follows from the fact that the lateral component of the scattering vector in the non-coplanar GISAXS geometry is not affected by refraction, hence, the kinematical theory of X-ray scattering is applicable. Two types of the PSD function were considered, namely those for the self-affine and mounded surfaces. The former PSD function typical for randomly rough surfaces decreases monotonously above a cut-off frequency while below it comes to saturation as the roughness cannot grow to infinity. The latter PSD is characteristic by a ridge controled by periodicity of "mounds" and is typical for cluster formation. Hence, by linear fitting in a proper interval of the PSD functions derived from GISAXS frames we were able to distinguish between the 2D (negative slope) and 3D (positive slope) growth. In particular, the growth of W/B_4C multilayer starting with W exhibits a gradual transition from the initial cluster formation to the 2D growth mode. The B_4C layers obviously favor the 2D growth and support such a regime also for W which finally prevails over the initial 3D growth of the first W layers. Contrarily, the GISAXS frames of the growing W monolayer show satellite maxima suggesting the mounded surface and cluster nucleation followed by cluster coalescence. These results indicate different growth modes of W on SiO_2 and B_4C underlayers but also demonstrate additional spacer role which is vitally important for ultrashort period multilayer X-ray mirrors, namely to allow formation of thin continuous refractory layers.