

Improved structural quality of multilayers and superlattices by ion-assisted magnetron sputter deposition

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Abstract

Magnetron sputter deposition is one of the most widely used physical vapour deposition methods in industrial production as well as lab-scale experiments thanks to a combination of desirable features such as flexibility, stability, scalability, environmental friendliness, etc. Although too often neglected, the ionized species in the deposition chamber can be taken advantage of by attracting them to the growing film surface which may have profound effects on the growth and properties of the layer such as significantly reduced temperatures for epitaxial growth and formation of compound thin films as well as circumventing decomposition in synthesis of thermodynamically unstable compounds.

We show how we utilize concurrent high fluxes (>1 ion per deposited atom) of low energy ions (<30 eV) during magnetron sputter deposition to yield close to atomically flat and abrupt interfaces in metallic multilayers and ceramic superlattices intended as normal incidence Bragg-mirrors for soft X-rays with wavelengths in the range [1.5-3.4 nm].

In order to achieve high reflectivity for a particular X-ray wavelength, the multilayers are typically grown as 300-600 consecutive layer pairs of amorphous transition metals e.g., Cr/Sc, Ti/Cr, and Ni/V, where one of the metals has an absorption edge in the vicinity of the x-ray wavelength. The requirement of near-normal incidence means that the multilayers typically are grown with bilayer repeat periodicities (Λ) in the order of 0.8-1.7 nm. With individual layer thicknesses of only a fraction of a nanometer, interface widths of only 0.3 nm are often enough to kill the reflectivity. Interface imperfections such as roughness, interdiffusion, and intermixing on the atomic scale must thus be avoided. We utilize ion-assisted magnetron sputter deposition dynamically to achieve both abrupt and flat interfaces by the following scheme: The deposition of the first couple of monolayers of *each* layer occur without ion-assistance in order to form an as abrupt interface as possible to the previous layer, then for the remaining part of each layer, a high-flux low-energy ion-assistance is applied in order to densify and flatten the layers before commencing the deposition of the next material. Such interface engineered multilayer mirrors always exhibit much improved interfaces with significantly improved soft X-ray optical properties. For Cr/Sc, normal incidence reflectivity $R=20\%$ ($\lambda=3.374$ nm) was achieved for multilayers with 600 periods (an improvement in reflectance by $>30\%$ as compared to continuous ion-assistance) and Ni/V multilayers, which previously had not been successfully implemented at all, reached $R=2.7\%$. Mirrors designed as polarizers exhibit extinction ratios R_s/R_p exceeding 5400 and 4100 for Cr/Sc and Ni/V, respectively. We have implemented an analytical model, based on the binary collision approximation, to aid in the prediction of the required ion energies and ion fluxes when implementing the interface engineering by modulated ion assistance during growth.

We also show additional effect of ion assisted magnetron sputter deposition of ultrathin multilayers and superlattices. For example, ion assistance was found to be necessary for epitaxial growth of single crystal CrN/ScN (001) superlattices. The resulting CrN/ScN superlattice X-ray mirrors exhibit atomically abrupt interfaces with high soft X-ray reflectance but with a 4 times higher mechanical hardness than pure Cr/Sc and being thermally stable up to 850 °C (<100 °C for pure Cr/Sc).