Sputtered V/Al_2O_3 multilayer x-ray mirrors for the water window

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Multilayers with periods in the atomic range of 1-2 nm are currently of great interest. This is related to their widespread use as normal incidence reflectors for x-ray microscopy in the water window, polarizers for synchrotron radiation and in other fields. Moreover, the interest in multilayers containing 3d-transition elements (Sc, Ti, V, Cr) is called forth by the high reflection in the range of the anomalous dispersion at their 2p-absorption edge. On the other hand, our previous investigations indicate that the Al_2O_3 layers show very low absorption and smooth growth characteristics with a root-mean-square roughness of about 0.2 nm. Therefore, V/Al_2O_3 multilayer structure might be a very promising systems for these application in this energy range.

We have presented an investigation of ulrathin sputter-deposited V/Al_2O_3 multilayers using hard x-rays (CuK_α radiation) and tunable synchrotron radiation in the soft x-ray range. The period spacing was between 2.15 and 2.5 nm, which determines the working range to be in the soft x-ray range with the special emphasis on the water window.

V/Al_2O_3 multilayers were deposited by rf sputtering (13.56 MHz) in a high-vacuum environment with a base pressure of $1 \cdot 10^{-7}$ mbar after liquid-nitrogen cooling. Sputtering was carried at room temperature out in an atmosphere of $5 \cdot 10^{-3}$ mbar 99.999% pure Ar with an electrical power input of 50 and 150 W for V and Al_2O_3, respectively. The resulting sputtering rates were 0.03 nm/s for V and 0.012 nm/s for Al_2O_3. Single-crystalline [11-20]-oriented sapphire with a size 10 by 10 mm^2, with miscut angle below 1° and mosaicities around 0.004° was used as substrates.

We employed a medium resolution diffractometer at a 18 kW rotating anode source with CuK_α radiation for the structural characterization in the hard x-ray range. We also performed synchrotron radiation measurements using a UHV-reflectometer chamber at the BESSY beamline PM4. An excellent performance was measured close to the 2p-absorption edge of V, where the reflectance and energy resolution is resonantly enhanced. For that, a 3-dimensional scan option was implemented into the computer control, which enables to scan simultaneously the incoming photon energy while scanning the multilayer around the Bragg peak ($h\nu$ -θ-2θ scan). In addition, the reflectance at normal incidence (θ=86°) was measured for all multilayer structures.

V/Al_2O_3 multilayer mirrors exhibit a reflectivity of R=18% for a 28° glancing angle at a photon energy of 512 eV (λ=2.42 nm) and a reflectivity of 0.14% for a normal incidence (θ=86°) at a photon energy of 240 eV (λ=5.17 nm).
The hard x-ray reflectance data correlated with the soft x-ray reflectivity measurements and all samples exhibit well pronounced Kiessing fringes near the Bragg peaks (both in the hard and in the soft x-ray regime) indicating the homogeneity of the individual layers.