Diffuse Scattering Sheets in Q-Space Corresponding to Kiessig Fringes for X-ray Multilayers

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Introduction

Multilayer (ML) optics have a variety of uses on synchrotron beamlines. They can be used as monochromators with bandpasses typically 1000 times larger than crystal monochromators,[1] and they can be used as analyzers for x-ray fluorescence.[2,3] Not only flat, but also focusing optics are coming into use. Sagittal focusing has recently been implemented using a ML grown on curved substrate.[4] Optical designs can also be used to take advantage of the fact that layer thickness can be graded.[2,5,6] A critical issue for performance of multilayers is the propagation of roughness from interface to interface. This topic has been addressed theoretically by several authors.[7,8] In this short report we describe x-ray diffuse scattering data corresponding to Kiessig fringes,[9] and we report results of fitting using a full roughness propagation model.

Sample Details

Tungsten–carbon multilayers having 20 periods and 28-Å d-spacing were prepared by magnetron sputtering.[10,11] The multilayer consisted of 20 periods of tungsten/carbon bilayers. The tungsten layers were 10 Å thick, and the C layers were 17 Å thick. A specular scan is shown in Fig. 1. The first order occurred at 1.65 deg and the reflectivity was measured to be 24.6%.

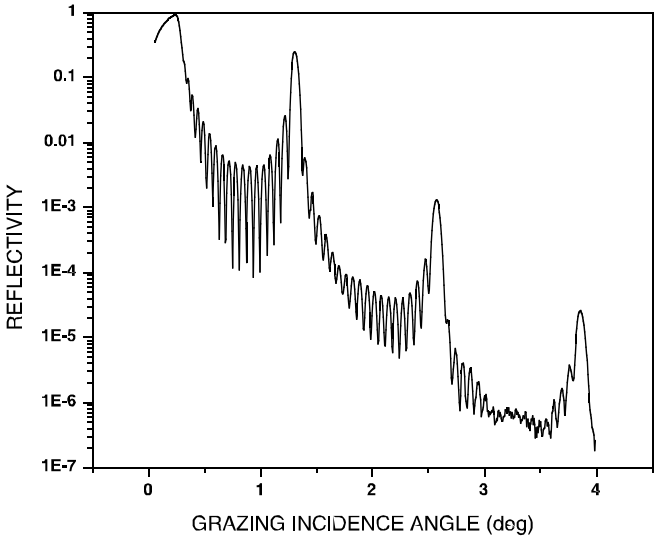

FIG. 1. Specular (theta-two theta) scan of the multilayer. Three diffraction orders are visible, as well as many Kiessig fringes.

Diffuse Scattering Data

A contour map corresponding of the intensity in reciprocal space is shown in Fig. 2. These data were obtained at beamline 2-BM of the Advanced Photon Source using a conventional Eulerian cradle geometry. An out-of-plane component of the momentum transfer (Q_y) was implemented by tilting the sample normal out of the vertical diffraction plane using a chi-rotation.[12] This means of implementing a lateral momentum transfer component permits Q_y values out to ~0.2 Å^{-1}, whereas the more conventional ω-rocking method (sample normal remains in the diffraction plane) is limited to ~0.06 Å^{-1} [13] by the fact that the incident angle must lie above total external reflection or the scattered beam must exit the surface.[14] A sheet of intensity at the first order at Q_z = 0.236 Å^{-1} is visible. As is well known, this sheet has a lateral extent, i.e., along Q_y, that corresponds to the spatial power spectrum of the roughness that is conformal between successively grown interfaces.[13,15] That there are sheets corresponding to the Kiessig fringes, however, is less well known. These also clearly visible in Fig. 2. These fringes correspond to roughness that is correlated between the substrate and the top of the entire layer stack. They provide another point of comparison for modeling of the roughness propagation and the physics of layer growth under sputtering deposition.

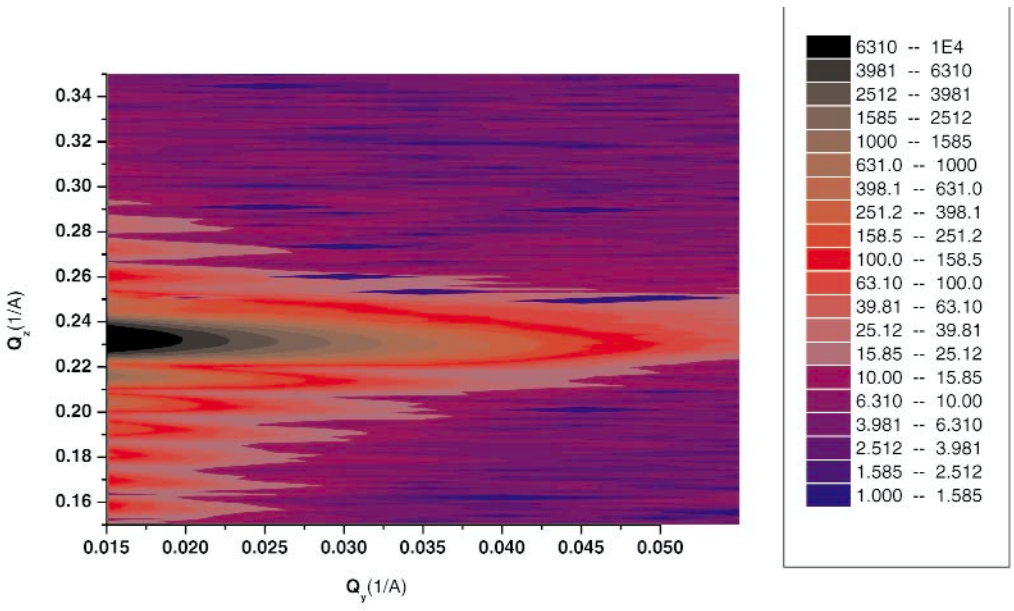

FIG. 2. Contour plot of diffuse scattering intensity showing the off-specular sheets corresponding to the first order and to the Kiessig fringes.

Data for Q_y scans at Q_z values of 0.236 Å^{-1}, corresponding to the first order of diffraction, and at 0.160 Å^{-1}, corresponding to a fringe are shown in Fig. 3. Shown as well are fits to these data obtained by modeling the roughness propagation[16] building on the

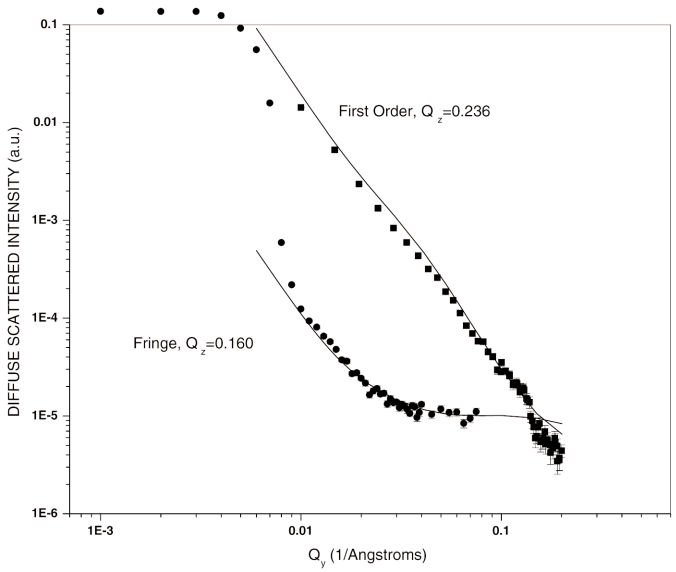

FIG. 3. Lateral Q scans for the first order and for the fringe. The rise in the fringe data at low Q_y shows the edge of the experimental resolution function.

formalism of Sinha et al.[17,18] and of Kaganer et al.[8] and using the modeling of Stearns[7] for the roughness propagation at an interface. A careful check of the "small roughness approximation," wherein the scattering cross section is proportional to the Fourier transform of the height–height correlation function between two interfaces (i.e., power spectral density of the correlated roughness) was made, and at these low Q_z's this approximation was found to result in only very small changes relative to the statistical error bars of the data. The fits reveal that the cut-off (exponential) form of the interface correlation function proposed by Sinha[17] is appropriate for the roughness introduced by the sputtering for the growth of a single layer. The amplitude of this cut-off correlation function needed for the fits was only 2.4 Å and had a range of only 2 Å. This physically corresponds to a sensitivity of atomic dimensions for the sputtered species. This conclusion supports the modeling of Stearns wherein a "growth unit" of 10 Å^3 was invoked.[19] However, unlike the conclusion of Stearns for molybdenum/silicon multilayers,[20] we find that a linear second order Langevin differential equation describes the growth (i.e., the Edwards-Wilkinson Equation) which does not invoke diffusion at the interface.[21]

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