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Determination of the Scaling Parameter of the Interface Morphology in Metallic Multilayers	28-01-140

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Report:

Controlled ballistic deposition leads to a self-affine surface morphology whose scaling behaviour corresponds to the Kardar-Parisi-Zhang (KPZ) equation [1], which is a modification of the well known Edwards-Wilkinson (EW) model which describes the evolution of the interface using a linear Langevin equation [2]. Such a self-affine surface can be modelled assuming a fractal description which incorporates a cut-off associated with the in-plane correlations. The height-height correlation function in such a system is given by $C(R) \propto \exp\left[-\left(R/x\right)^{2h}\right]$ where x is the in-plane correlation length and h is the scaling or fractal parameter [3]. The pioneering work of Salditt *et al* [4,5] showed how the scaling parameter h can be obtained by conducting scans in which the diffuse scatter is probed as a function of the in-plane momentum transfer thereby measuring the intensity out of the scattering plane. In such an experimental geometry, there is no cut-off associated with the critical angle at low $q_{//}$ and the intensity as a function of $q_{//}$ is shown for a UHV deposited Fe/Cr multilayer in figure 1, and an MBE deposited Au layer on MgO/Fe.

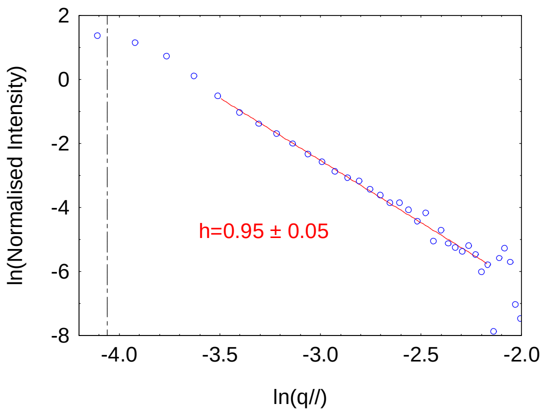


Figure 1: The scaling of the diffuse scatter as a function of in-plane momentum transfer for a Fe/Cr multilayer – h=1 and $\xi_{//}$=380Å

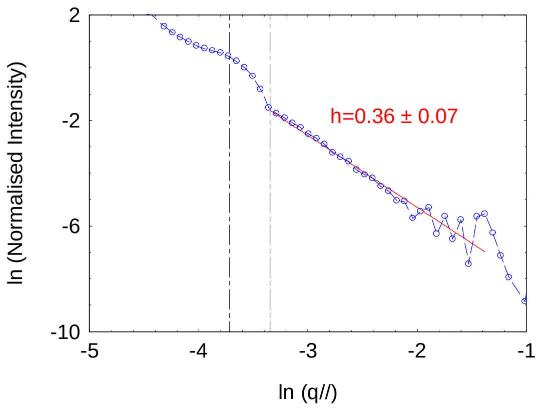
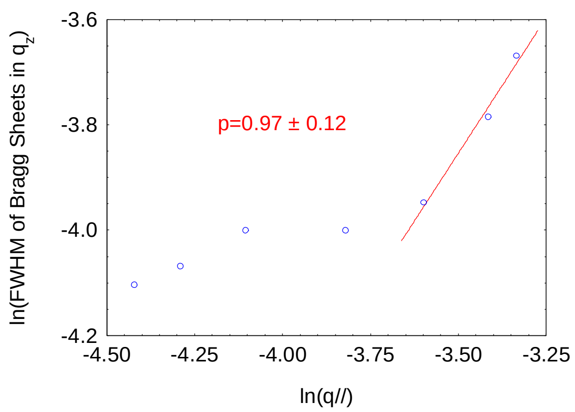


Figure 2: The scaling of the diffuse scatter as a function of in-plane momentum transfer for a MBE MgO/Fe/Au system multilayer – h=0.4 and $\xi_{//}$=180 and 210Å

We observed clear scaling behaviour in all samples studied, with the fractal model describing most samples well. The value of the scaling parameter was close to those predicted theoretically for the differing growth modes – MBE systems having a low value of *h* close to 0.3, and sputtered samples resulting in high values of *h*, in the range 0.6 to 1 [6]. However, we observed different behaviour of the diffuse scatter as a function of the vertical scattering angle. The fractal parameter deduced was always the same, but at low vertical scattering angles there was often evidence of two, or more, in-plane length scales. We have attributed this to the correlated and uncorrelated roughness components having different in-plane correlation lengths. The diffuse scatter associated with the conformal roughness only resulted in a single in-plane correlation length which was in the range of 150-350Å for all the samples studied.

In deposition where the kinetic energy of the incident atoms is reduced through thermal collisions, the growth mode changes and although the interface can still be described using a self affine model, a columnar structure can develop. We have observed behaviour in the Fe/Cr system that can be explained through the growth model proposed by Tang, Alexander and Bruinsma (TAB) [7]. In this model, both the in and out-of-plane correlation lengths ($x_{//,z}$) follow the scaling law $x_{x,z} \propto q^{p}$ with *p* having a characteristic value which depends on the statistical nature of the surface [4]. Figure 3 shows the scaling behaviour for the Fe/Cr sample, and figure 4 shows the same data recorded for a Co/Pd sample with a measured fractal parameter of *h*=0.8±0.1.



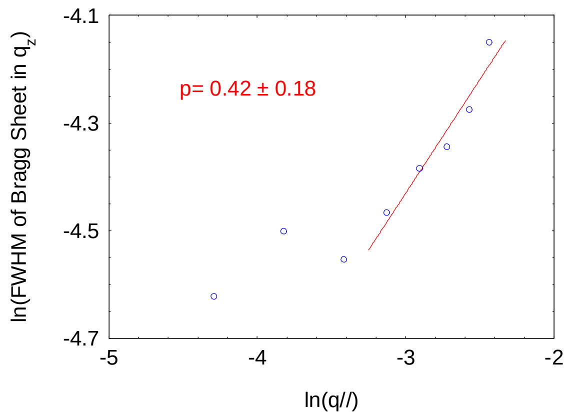


Figure 3: Ln-ln plot to show the scaling behaviour of the FWHM of the 1st Bragg peak of the Fe/Cr multilayer in q_z as a function of $q_{//}$.

Figure 4: Ln-ln plot to show the scaling behaviour of the FWHM of the 1st Bragg peak of a Co/Pd multilayer in q_z as a function of $q_{//}$.

Within the TAB model, it is argued that the relation, $p = (2-h)^{-1}$ should hold for a *self similar surface* and in figure 4 we see that this is the case (in figure 1 we measured a value of *h*=0.95). The same is not true for the Co/Pd sample. The value of *p* deduced is closer to that predicted for an uncorrelated Gaussian surface which does not agree with the self-similar scaling used to model the diffuse data. The data we have recorded shows that there current scaling models can be used for certain systems, but that the models are overly simplistic in that they do not take into account the frequency dependence of the roughness propagation in multilayers. The width of Bragg sheet in q_z can only be used to determine the inter-relation between *p* and *h* when the roughness is *totally conformal* and *all frequencies* of roughness propagate. Current scaling laws have been developed for single films which evolve as a function of time, or thickness and their applicability to multilayer interface morphology evolution has yet to be tested fully. In particular, the mechanism of roughness propagation from the substrate to the surface must be incorporated into scaling models. Our studies have indicated that the scattering geometry employed is suitable for the measurement of the scaling parameter directly, and that both the in-plane and out-of-plane correlation lengths can be measured.

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