The Linear Continuum Model of Thin Film Growth

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We review a stochastic theory for the evolution of roughness in thin film deposition called the linear, continuum growth model[1,2,3]. This model accounts for both the partial replication of the substrate roughness and the intrinsic roughness introduced by the random nature of the growth process. Of particular interest is the application of the model to the structure of the interfacial roughness in multilayer coatings.

The linear continuum model is valid when the deposition flux is fairly collimated and the angle of incidence is near the film normal, that is, conditions where nonlinear and nonlocal (shadowing) effects are not important. The model is defined by a rate equation that describes the evolution of the surface profile h(x,y) with increasing film thickness τ:

$$\frac{\partial h(x,y)}{\partial \tau} = -\tan\beta \hat{m}_P \cdot \nabla h(x,y) - \sum \nu \left| \nabla^n h(x,y) \right| + \frac{\partial \gamma}{\partial \tau} \qquad (1)$$

The first term represents a pure translation of surface features in the direction $\hat{m}_P$ of the incoming flux, where β is the incident angle of the effluent with respect to the film normal. The second term accounts for the relaxation of the surface towards thermal equilibrium during film growth. The value of the exponent n depends on the driving force for the relaxation process and the parameter ν characterizes the kinetic rate of relaxation. The last term in Eq. (1) is the fluctuation of the deposition rate due to the random shot noise of the deposition process. This term is the stochastic part of the model and it necessarily contributes roughness to the growing film.

The deterministic part of the model can be used to simulate the response of film growth to perturbations at the substrate. The propagation of substrate defects through a multilayer film is a subject of particular interest in the fabrication of reticles for EUV lithography. We will show recent studies of defect formation in multilayer films that are in good agreement with the predictions of the theory.

The stochastic part of the model describes the roughening of a growing film due to the random deposition of growth units of volume Ω. The power spectral density (PSD) of the intrinsic roughness of the film (i.e. the roughness of a film deposited on an ideally smooth substrate) is given by,

$$P(\mathbf{f};\tau) = \Omega \frac{1 - \exp[-2\tau \sum \nu |2\pi f|^n]}{2\sum \nu |2\pi f|^n} \qquad (2)$$

This has a characteristic behavior of white noise at low frequency rolling off to a power law at high frequencies. Measurements of the surface topology of films using atomic force microscopy are consistent with Eq. (2), and provide a direct method of determining the growth parameters Ω, ν and n.

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[1] D. G. Stearns, Appl. Phys. Lett. **62**, 1745 (1993).
[2] D. G. Stearns, D. P. Gaines, D. W. Sweeney and E. M. Gullikson, J. Appl. Phys. **84**, 1003 (1998).
[3] E. M. Gullikson and D. G. Stearns, Phys. Rev. B **59**, 273 (1999).