Nanoprobing Fracture Length Scales

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ABSTRACT

Ever since fracture mechanics resolved the lift-off, payload optimization for space exploration in the 60s, applications to structural reliability have multiplied. With relatively few exceptions these have remained scale invariant taking into account plane stress/plane strain transitions. With the advent of nanoscale structures in microelectronic, magnetic memory, and MEMS devices, a whole new set of length scale problems have emerged. This involves flow and fracture stresses and potentially the modulus of elasticity at the smallest of scales. Three major tools have come to the forefront in probing these length scales – transmission electron microscopy (TEM), Scanning Probe Microscopy (SPM) and acoustic emission (AE).

- TEM – In the 1970s, *in situ* observations led to toughening mechanisms based upon crack-tip shielding by both tip and external dislocation sources. These can also be used for length scale effects in thin film fracture.

- SPM – In the 1980s, scanning tunneling and atomic force microscopes were developed. These were rapidly followed in the 90s by both interfacial force microscopy and nanoindentation for probing length scales associated with plastic deformation. Most notable are indentation size effects. More recently is the probing of scale effects in delamination of thin films. Not too surprising are the similarities of length scales found with indentation-induced or crack-tip induced plastic zones in thin films.

- AE – Most recently in the 2000s we have seen nanoindenters emerge with tip-incorporated acoustic sensors having the ability to detect both plastic and fracture instability. For example channel cracking in nanometer scale thin diamond films gives a large signal to noise ratio. Previously, yield instabilities associated with cooperative dislocation motion have also been easily detected.

The present paper gives both an overview of how these techniques can be utilized with computational approaches to investigate various length scale problems involving deformation, fracture, friction and wear. Specific materials involved include Au thin films and nanoboxes, Si nanospheres and towers, thin diamond films and nanolaminate structures.