Controlling Stress Gradients and Fracture Resistance in CVD Diamond and other Materials for MEMS Applications

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Small dimensions in many advanced materials introduce new issues and opportunities associated with controlling residual stresses. Key examples of this are materials for MEMS devices, where Si is widely used, primarily because the necessary fabrication methods are readily available. However, a number of other materials such as diamond and SiC have better mechanical, thermal, and chemical properties. Residual stresses are an important consideration in all MEMS materials. A major problem is stress gradients that produce bending in small components, particularly when the substrate is removed to produce a fully or partially free standing film. An example of the severe bending that can occur in a free-standing CVD diamond film is shown in Fig. 1.

Our current research focuses on stress control in polycrystalline diamond and SiC films. In conventional CVD diamond, our experimental efforts show that tensile stress gradients of several GPa can produce significant bending. A detailed model of this phenomena has been developed, using a finite element scheme to predict the stress distribution in the film [1]. Several of these calculations are shown in Fig. 2, where the stress gradient evolves over a film thickness on the order of the grain size. This is consistent with experiments, where detailed analysis of bending in free-standing films was used to quantify the stress gradients. Thus, our model predicts that stress gradients can be substantially reduced in films with very small gradients. This is consistent with experimental observations for CVD diamond with very small grain sizes.

In most other polycrystalline films, including CVD SiC, compressive intrinsic mechanisms are significant (in contrast to CVD diamond). This creates opportunity to control stress gradients by balancing the tensile and compressive mechanisms. For example, free-standing films with no net bending can be created in this way. A comprehensive model that describes both tensile and compressive intrinsic stress mechanisms will be presented. This will be compared with experimental results for CVD SiC.

Another important property for a variety of applications is the fracture resistance of polycrystalline films, which is related to both the microstructure of the material and its residual stress state. Our ability to control residual stresses without changing the grain structure provides us with an excellent opportunity to decouple the residual stress effects from microstructural contributions. To conduct these studies, we have developed a new indentation-based testing procedure. Results obtained with this method will be presented for both CVD diamond and SiC.

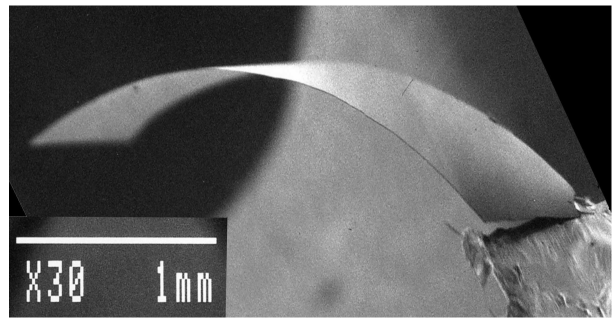

Figure 1. Free-standing diamond film (10 hour growth at 850ºC and 1% CH_4). The top surface shown here was originally attached to the Si substrate (removed by etching). The observed bending is indicative of increasing tensile stress during film growth.

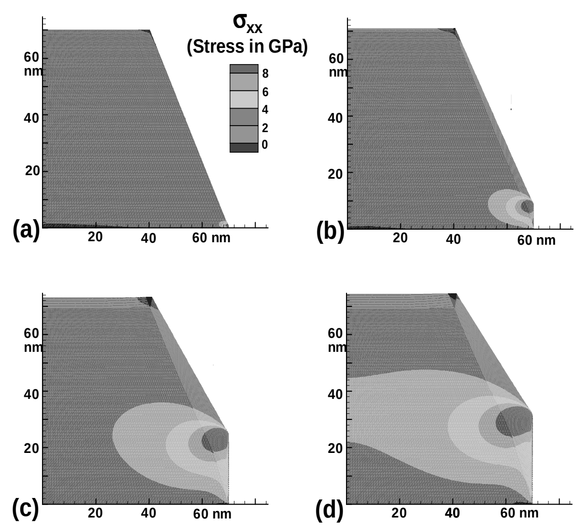

Figure 2. In-plane stresses based on the FE model, with a biaxial modulus of 100 GPa and $\Delta\gamma$ = 0.5 J/m^2 [1]. Results are for average film thicknesses of (a) 55 nm, (b) 58 nm, (c) 63 nm, (d) 66 nm (i.e., increasing times).

[1] A. Rajamani, B.W. Sheldon, E. Chason, and A.F. Bower, "Intrinsic stress and grain boundary formation during Vomer-Weber film growth", *Appl. Phys. Lett*, **81**, 1204 (2002).