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A STRAIN GRADIENT CRYSTAL PLASTICITY MODEL FOR THE LENGTH SCALE DEPENDENCE OF FREE-STANDING THIN FILMS

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ABSTRACT

Micro-electromechanical systems (MEMS) have begun extensively being used in a variety of fields within the last decade and fast track developments in modern technology have been bringing the necessity of improvement of MEMS along. This demands a characterization of the micro-scale response of materials and accurate estimates for the reliability and the lifetime of MEMS devices.

In the present case, an RF-MEMS tuneable parallel plate capacitor is considered. It consists of a free-standing Al alloy thin film ($5\,\mu$m), which acts as an upper electrode under electrostatic loading, suspended by springs above a metal film which is the bottom electrode. For such a micro-scale device, it is of utmost importance to preserve the stability of the thin film during service life by avoiding any kind of mechanical degradation, e.g. because of violent dynamic loads or creep. This requires a detailed understanding of the scale dependent material behavior which is originated by the microstructural features of the material and external constraints like hard surface coatings. Classical continuum theories cannot describe this scale dependent behavior since they do not have any material length scales in their constitutive formulations.

Micro-beam bending experiments have been carried out through application of a point load at the tip of cantilever test structures (made out of Al and AlCu with different thicknesses and different lengths, and in case of Al with or without an oxide layer (SiO_2) on the specimen surface) to investigate the influence of material composition (i.e. precipitates), dimensions of test structure (i.e. film thickness), microstructure and presence of an oxide layer on the specimen surface on the mechanical response of free-standing thin films. Orientation imaging microscopy (OIM) has been employed to examine microstructural properties (topography, size and orientation of grains, through thickness grain structures etc.) of test structures since a careful definition of the geometry of test specimens and their microstructure is essential for the generation of a numerical model. These experiments have been simulated with a finite element model to observe size effects on mechanical properties, yield strength and hardening rate. A strain gradient crystal plasticity (SGCP) model based on the formulation of Evers *et al.* [1] has been incorporated in the numerical simulations. The model accounts for the densities of the statistically

stored dislocations (SSDs) and geometrically necessary dislocations (GNDs) to capture the scale dependent material behavior. Different evolution laws are utilized in the formulation in order to make a distinction between the influences of SSDs and GNDs on the material response. The outcome of the numerical simulation has been analyzed in comparison with the experimental results. Special attention is given to the influence of grain boundaries, interfaces and precipitates on the macroscopic behavior.

REFERENCES

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