SIZE EFFECT IN CLEAVAGE CRACKING IN POLYCRYSTALLINE THIN FILMS

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The reliability of polycrystalline thin films is essential to assuring safe performance of micro/nano-electromechanical systems. Usually, they are of through-thickness grain structures and are brittle at working temperatures, and therefore their fracture properties are dominated by the resistances offered by grain boundaries to cleavage cracking [1].

As a cleavage crack front propagates across a wide high-angle grain boundary, it would first penetrate across a number of break-through points, and the persistent grain boundary areas would then be separated through shear fracture or ligament bending. It is, therefore, envisioned that as the film thickness is smaller than the characteristic distance between the break-through points, which is often in the range of 0.5-5 microns, the crack front transmission can be significantly confined by the film surfaces, leading to an either beneficial or detrimental size effect. That is, the fracture toughness of the polycrystalline thin film is not a material constant; rather, it highly depends on the film thickness.

In order to analyze this relatively un-investigated problem, we carried out both experimental and numerical studies. The upper limit and the lower limit of the grain boundary toughness are calculated via crack trapping and *R*-curve analyses, respectively [2,3], both indicating that there exists a transition zone of film thickness. As the film thickness is outside this zone, the fracture resistance of the thin film is size independent; otherwise, it would increase as the film thickness rises. At the upper shelf of the transition zone, the saturation effect is dominant; at the lower shelf, the smooth crack front transmission governs the crack-boundary interaction.

The testing samples of various thicknesses have been successfully prepared, for which lab techniques of combined polycrystal characterization and thermal modification as well as bicrystal harvesting and thinning have been developed. Preliminary fracture experiment is being carried out. The results are quite encouraging. It has been shown that the fracture surface shifts form the cleavage plane of grain “A” to that of grain “B” across the grain boundary. Different from the phenomena observed in iron-silicon bicrystals, the front transmission in a silicon sample does not demand shear deformation or fracture of the grain boundary itself; rather, separation of a secondary cleavage plane in grain “A” takes place, by which the crack can “channel” through the boundary affected zone. Detailed fractography study is in progress to understand the details of this phenomenon.

References

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