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Failure Modes and Fracture Mechanics in Co-Fired Engineering Ceramics

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Co-fired engineering ceramics can provide integration of multiple functions in one package, and lead to device miniaturization. Co-fired metals have thermal and elastic mismatches with the ceramic, producing local residual stresses which severely impact the fracture behavior and reliability. Observations and fracture analysis of a commercial low temp co-fired ceramic with gold vias show that while strength is reduced by as much as 60%, the susceptibility to sub-critical crack growth (SCG) is not lowered. A circumferential cracking mode around the vias has been observed in this system. Fracture mechanics solutions are derived to describe this failure mode, and correlated with fracture observations of crack kinking. In *in vivo* simulations of a commercial high temperature co-fired alumina ceramic-platinum via system, circumferential cracking is observed, but only at the slowest stressing rates. Processing changes made to these materials, which ultimately led to strength and SCG characteristics that were undistinguishable from the base materials, are described.

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Abstract: Miniaturization and integration of multiple functions into one component is desired for device downsizing. Both low-temperature and high temperature co-fired ceramics alumina, with its high strength and bio-compatibility, provides an option for integration and higher reliability medical devices. A 92% alumina-platinum via HTCC material was characterized for failure modes and sub-critical crack growth, and modifications to processing were implemented to obtain a material with strength and SCG characteristics similar to bulk alumina. In phase I development, this material had strength equivalent to bulk alumina, except at low stressing rates in saline, body fluid-like environments, where a novel failure mode (circumferential cracking) was encountered. Processing changes implemented for Phase II materials led to failures emanating as radial cracks from the vias with slight loss of strength. Changes made to Phase III materials led to strength and SCG characteristics that were undistinguishable from the base materials. Fractographic evidence indicates that cracking originates tangentially to the via in Phase III material

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The use of Low Temperature Co-Fired Ceramics (LTCC) is a very attractive material option for advanced packaging. For applications, a variety of features are printed in the base material: thermal and electrical vias, resistors, solder pads to name a few. Most of these features have materials that are thermally and elastically mismatched from the LTCC, producing a localized residual stress. These stresses impact the strength and reliability of the LTCC package. Here we present results and analysis for the strength and reliability assessment of an LTCC (Dupont^{TM} 951) with and without Au vias. The reliability of the ceramic material is assessed from the perspective of its susceptibility to sub-critical crack growth (SCG). Metallic vias can significantly lower the strength of the LTCC, however, their presence does not change the measured susceptibility of the material to SCG. Using our experimental data, and empirical descriptions of SCG laws, safe design life for LTCC packages under a particular stress state is estimated.

The strength and fracture behavior of a low-temperature co-fired (LTCC)-gold via microelectronic packaging system is analyzed. The biaxial fracture strength of the LTCC-gold via combination was ~ 60% lower than that of the base LTCC material indicating that the residual stress state around the via significantly impacts the strength. Planar and fracture surface examination of the samples revealed that circumferential (arc) cracking at the gold-LTCC interface was a prelude to fracture of the samples. Final fracture occurs due to the kinking of the arc crack into the LTCC matrix. Two dimensional stress intensity factor solutions for interfacial arc cracks around circular inclusions are used to derive the driving force for the arc crack as a function of the crack angle. Under the combination of the radial (residual) tensile stress and biaxial (applied) loading, and for the material pair under consideration, the crack driving force exhibits a maximum at an arc crack angle of ~50°. Crack kinking into the matrix was experimentally determined to occur for crack angles ranging from 58°-88°, i.e., on the decreasing part of the strain energy release rate curves. Based on experimental observations and physical arguments, a curve for the interfacial toughness as a function of arc crack angle is proposed. The crack extension behavior is described, and used to explain the lowered strength, and improved strength variability of the LTCC material with gold vias.

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