J-integral Evaluation for Cracks in Through Silicon Vias

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INTRODUCTION: The possibility of delamination along the bottom edge of an open through silicon via (TSV) [1] is investigated by simulating the cooling step (20 to -65 °C) of the thermal cycling test.

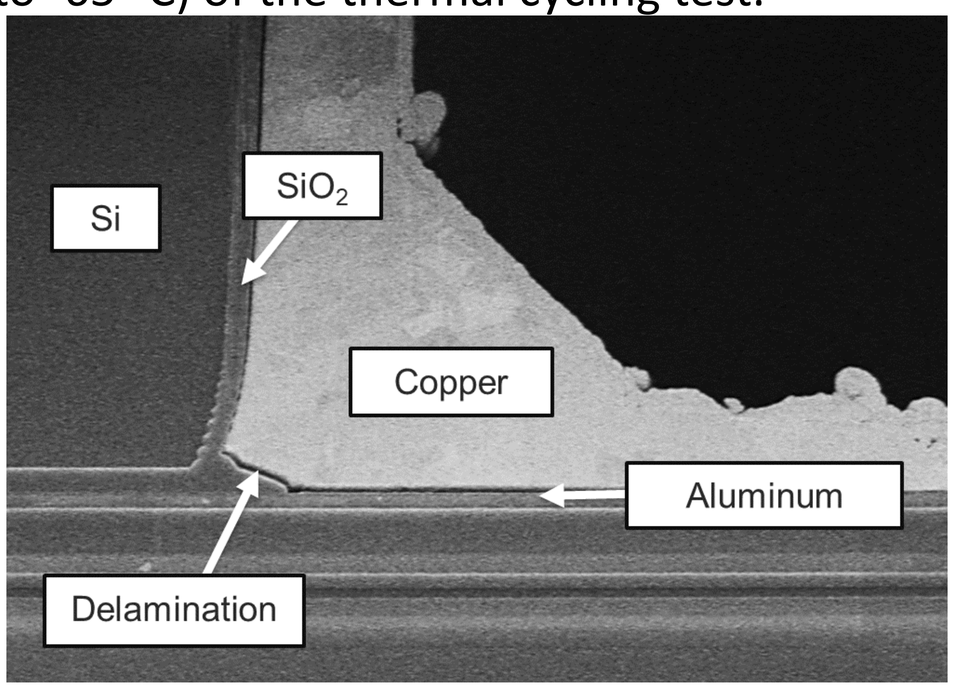

Figure 1. Cross section of a TSV after 500 cycles of TCT at a temperature range of -65 °C to 175 °C.

COMPUTATIONAL METHODS: The first task was the determination of the point along Cu-Al interface (see Figures 1 and 2) with the highest probability of crack nucleation by stress calculation (see Figure 3) using an axial symmetric model of the TSV.

Subsequently, the J-integral of a crack along the Cu-Al interface in the TSV axial symmetric model was calculated for different Cu thicknesses using Carpenter formula [2] :

$$J = \oint_S \left[W n_1 - \frac{du_i}{dx_1} \sigma_{ij} n_j \right] ds \underbrace{- \int_A \frac{d}{dx_3} \left(\sigma_{i3} \frac{du_i}{dx_1} \right) dA}$$

for a crack with axial symmetric geometry = 0

Then, the J-integral of the same crack in a 3D model was calculated using Rice [3] formula in order to prove the previous simplification.

RESULTS: The simulation showed that the crack origin is at the TSV edge (see Figure 3) and both Carpenter and Rice formulas of J-integral are the same (see Figure 4). With both formulas, the J-integral increases by one order of magnitude when the copper thickness is above 2 µm for the considered TSV structure.

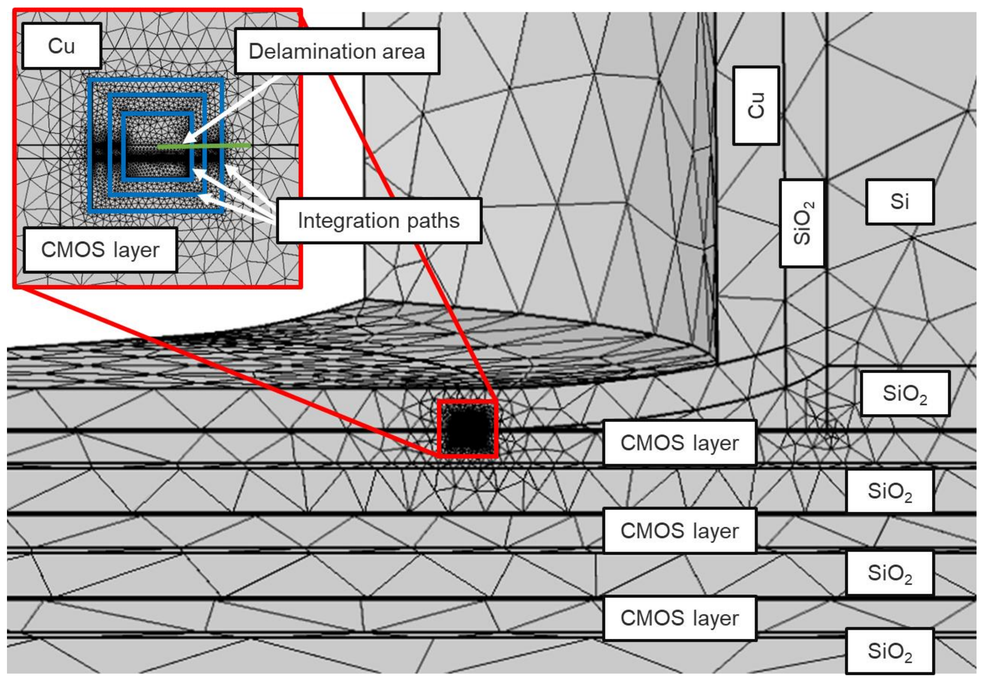

Figure 2. Meshed model geometry at the TSV bottom

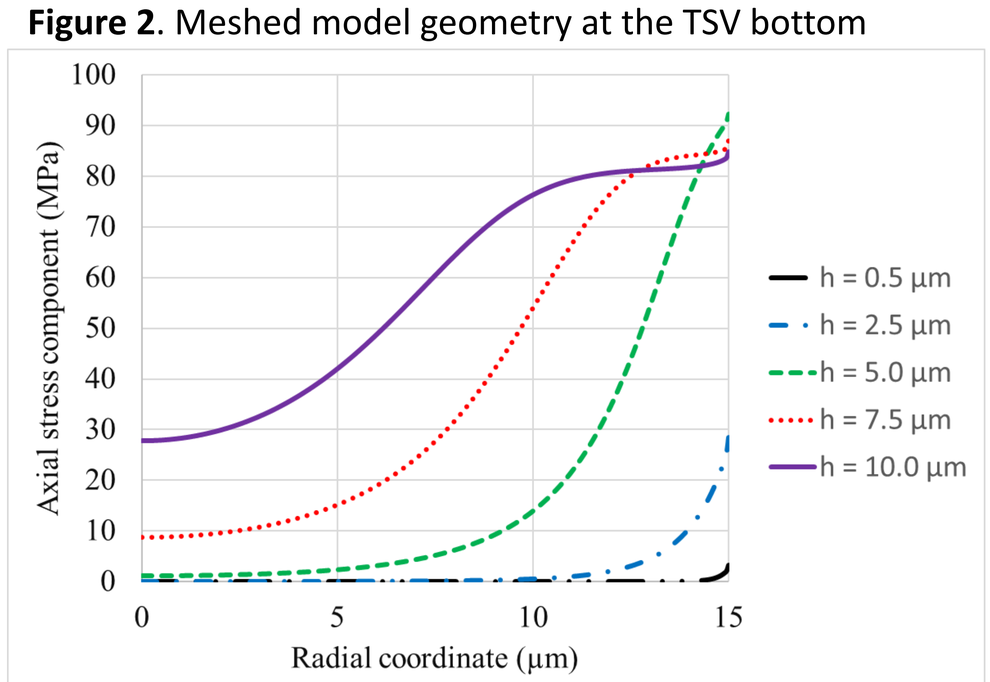

Figure 3. Stress distribution at the Cu-Al interface

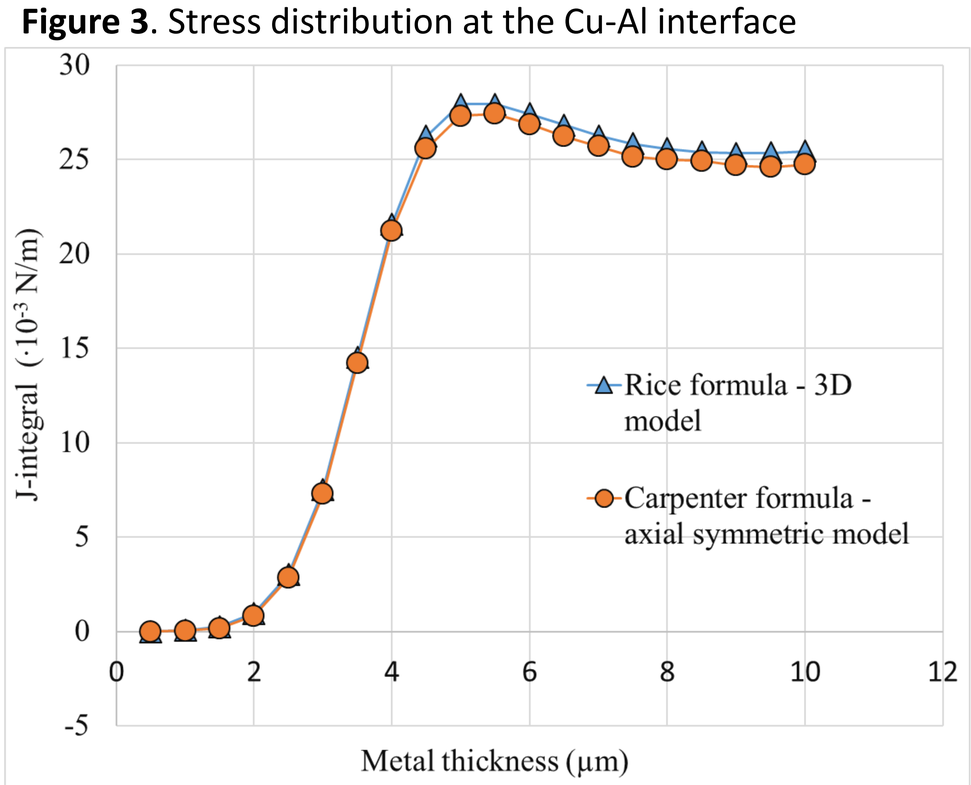

Figure 4. J-integral formulas comparison

CONCLUSIONS:

- Simulation results matched the underlying TCT tests, giving a design rule to improve the mechanical stability of TSVs with copper metallization.
- The J-integral for axial symmetric cracks can be calculated through the Rice formula [2], leading to a simplified analysis of these type of cracks in more complicated 3D models.

REFERENCES:

1. J. Kraft et al. 3D sensor application with open though silicon via technology. IEEE Electronic Components and Technology Conference, 560-566, Lake Buena Vista, FL, USA, 2011.
2. W.C. Carpenter, et al., “Comparison of several path independent integrals including plasticity effects”, International Journal of Fracture 31:303-323 (1986).
3. J. R. Rice, “A Path Independent Integral and the Approximate Analysis of Strain Concentration by Notches and Cracks”, J. Appl. Mech, vol. 35, no. 2, pp. 379–386, Jun. 1968.