J-integral Evaluation for Through Silicon Vias

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Abstract

Through Silicon Via (TSV) is one of the key technologies for 3D integration. It is a vertical electrical connection that passes through a silicon wafer and establishes the signal transmission between the front and the backside of the device.
In the so-called "TSV last" integration scheme, holes are etched into the silicon wafer from the backside until the first CMOS metal layer is reached. The remaining CMOS backend stack (metal and intermetal dielectric layers) thus form a membrane at the TSV bottom. After insulating the TSV sidewalls using a dielectric material such as silicon dioxide, metal is deposited for the electrical connection. The most common used materials for metallization are tungsten and copper.
The different coefficients of thermal expansion between materials silicon, silicon oxide and metal can lead to high mechanical stresses. These stresses could lead to delamination especially for copper metallization where the CTE mismatch to the surrounding layers is highest.
Experimental observations of thermal cycling (TC) tests on TSVs with copper metallization and varying geometries showed the delamination of the whole interface between the electrochemical-deposited (ECD) metal and the seed layer.
In order to determine the critical TSV metal thickness for delamination occurrence, simplified FEM simulations of a crack along the interface between the membrane and the TSV metal have been performed. The J-integral along three different paths for a single TC step on TSVs with varying copper thicknesses was calculated (Figure 1). For this purpose, the derivation of the J-integral for an axial-symmetric structure of the TSV is introduced and implemented in COMSOL Multiphysics® using the Solid Mechanics interface.
Results show that the J-integral increases significantly by one order of magnitude in the range between 2-5µm. The figure shows also that the result of calculating the J-integral along three different paths is the same confirming the path-independency of the J-integral.
A comparison between the simulation and the experimental conducted TC tests showed that the calculated thickness, at which the J-integral increases drastically, corresponds to the used TSV metal thicknesses, where the delamination was observed.

Reference
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Figures used in the abstract

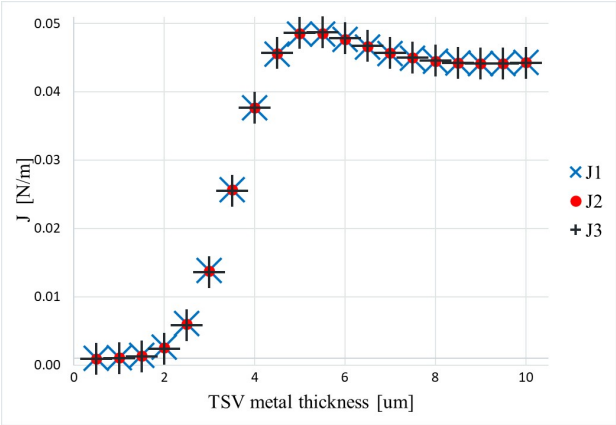

Figure 1: J-integral value for three different paths over the TSV metal layer thickness.