interface is formed, which introduces an electromigration (EM) problem due to the highly different resistances against EM. To fully understand the EM degradation of this structure these interfaces have to be particularly addressed.

In this work, we present studies about the EM reliability of open TSVs by means of finite element method based simulation. The calculation of the material flux and the stress build up in the TSV is based on the three-dimensional EM model of Sarychev, a drift-diffusion model where the flux is driven by the concentration gradient, the stress gradient, and the electrical field representing the EM force. Furthermore, the Rosenberg-Ohring term to model the annihilation/generation of vacancies due to stress in the structure is employed. These equations are coupled to the Navier-Cauchy equations for solid mechanics through the inelastic strain due to vacancy flux and their generation/annihilation. When the condition for a void nucleation is fulfilled, a void is placed at the most probable position and its evolution is described by a phase field model.

The EM failure calculations are based on a two-step approach. In the first step the stress development of a void free structure is analyzed using only the Sarychev model. This analysis indicates the locations, where voids due to stress are most probably nucleated. It was found that these locations are close to the tungsten/aluminum interfaces as well as to the silicon-oxide/aluminum interfaces. This is due to the shrinking of the aluminum caused by EM, which does not occur in the tungsten or in the silicon-oxide. In the second step voids are placed in the high stress regions of the aluminum and their evolution is traced. The result of this simulation shows the development of the TSV's resistance in time. After a void is placed and allowed to grow with time, it is found that the resistance rises more than linearly because the growing void reduces the conducting cross section. Finally, an abrupt resistance jump is observed leading to an open circuit failure. Our findings are in good agreement with results of accelerated EM tests and give hints, where the most problematic regions for EM are.

Stress Analysis in Open TSVs after Nanoindentation

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Three-dimensional technology is considered necessary to maintain integrated circuit performance on the path described by Moore's law. Several layers of different materials compose an open Through Silicon Via (TSV) structure. For the sake of the TSV's mechanical stability, it is important to understand and to predict the behaviour of each material subjected to an external force.
A possible mechanical characterization to study the physics of the stress development, cracking, and plasticity is the nanoindentation. This technique enables to study the stress development in each layer of a TSV and to assess the risk of cracking and delamination. It is one of the most common experimental tools to test the mechanical properties of materials. Nanoindentation is based on an interaction between the tip and the material. The tips can have different shapes and can be made of different materials.
In this work we have investigated nanoindentation in TSV structures by means of simulation. For our calculations we have considered a spherical diamond tip. During the nanoindentation, the tip penetrates into the TSV and applies a force onto the material, causing a deformation of the material. The comparison between the loading force and penetration depth allows obtaining information about the mechanical properties of the device.
We have investigated two different settings. First, the materials are considered only within the elastic limit and then, the simulations are extended beyond the limit of the plastic deformation.

From the comparison between simulations and the experimental data we can deduce how and where the plastic deformation starts in the materials due to an external force. Our simulations are useful to understand how the plasticity and the stress develop inside of the device, in particular in different layers of the TSV. The results show the areas with a high concentration of stress. We define these areas as the critical zones, where delamination or cracking can be expected.
The equations of the mechanical model are solved using the finite element method. The obtained results enabled to understand the stress development and the plasticity in the different layers composing the TSV. The stress fields and the plasticity are found to be particularly sensitive to the thickness of the layers. Thereby our investigations have improved the understanding how an external force influences the device structure and the location, where the conditions for cracking, delamination, or fracture are met.

In situ TEM Nano-Compression and Mechanical Analysis of Ceramics Nanoparticles

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