Mechanical failure prediction of copper/low-k interconnects in integrated circuits

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Introduction

The miniaturization of integrated circuits (ICs) has led to the use of copper and low-k dielectrics in the interconnect structure. Due to both the use of new materials and the decreased dimensions, the thermo-mechanical reliability of ICs is becoming critical. Simulation tools can assist IC developers to 'design for reliability'.

Objective

Current research focuses on simulating interface delamination in the interconnect structure below bond pads (see figure 1). This failure mode occurs if the structure is not carefully designed. The objective is to develop an interface damage model within a finite element (FE) framework.

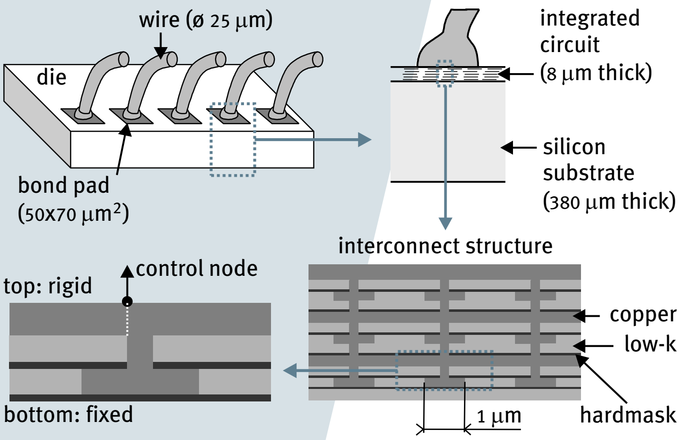

Figure 1 *Schematic representation of IC and 2D plane strain model.*

Theory

The interface damage model, considered here, is based on an exponential cohesive zone model [1]. It describes the nonlinear relation between the separation δ of the two materials at an interface and the traction τ between them (see figure 2). The model is implemented in a 4-node element to be used in a 2D FE model. The solution procedure due to Crisfield [2] is used to simulate the quasi-static response.

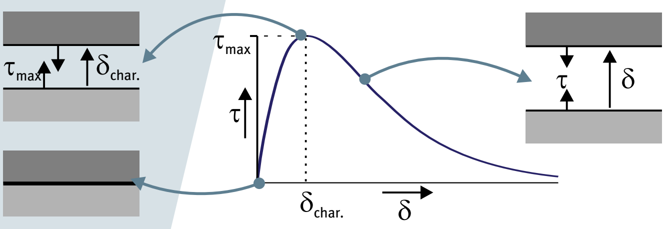

Figure 2 *Cohesive zone model provides nonlinear relation between separation δ and traction τ along a material interface.*

Simulation

Interface delamination of the interconnect structure below bond pads is initiated on the microscopic scale of individual copper lines embedded in low-k dielectrics (see figure 1). A 2D plane strain model is constructed for this small region. Figure 3 shows the complex loading path followed when two interfaces delaminate. Note that crack nucleation follows from the analysis. The simulation illustrates the potential use of the interface damage model.

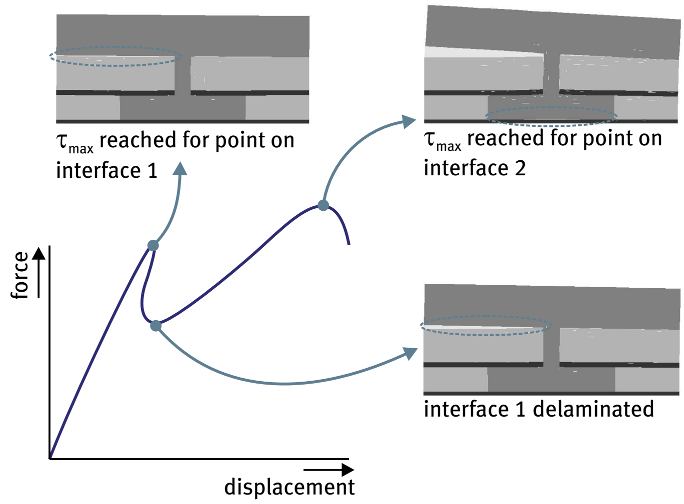

Figure 3 *Force/displacement response in y-direction of control node (see figure 1) with corresponding deformation pattern.*

Remaining question

In reality copper/low-k interface delamination is brittle. Theoretically the cohesive zone model can take this into account in a straightforward manner. However, in simulations Crisfield's solution procedure breaks down in this case. Therefore, the computational treatment of cohesive zones needs to be refined for realistic simulations.

Conclusions

The considered interface damage model is in principle capable of simulating interface delamination and can assist IC developers in the future to design their products for thermo-mechanical reliability. However, further research is necessary in order to cope with brittle fracture.

References:

[1] Ortiz, M., Pandolfi, A.: *Finite-deformation irreversible cohesive elements for three-dimensional crack propagation analysis* (Int. J. Num. Methods Engrg. 44, 1999)

[2] *MSC.Marc A - Theory and User Information* (Manual, 2005)

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