IC/Package Co-Design of Heterogeneous Integrated Systems

Multi-Physics and Multi-Scale Modeling

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Wafer, Package, Board and System Levels

Electronic Packaging

Board and System

Wafer Fabrication & Backend Process
Design of a package must consider the interactions among wafer, package, and board (e.g. CPI – chip-package-interaction).
Typical Failures under Various Stresses

- Fatigue crack
- Thin film delamination
- Pad cratering
- Solder brittle failure
- Interface delamination
- Film rupture

Mechanical load

Temperature load

Moisture load

Electrical current
Need for Multiphysics Modeling

Multiphysics Modeling

- Thermal
- Mechanical
- Electrical
- Optical
- Moisture
- Transport
- Frequency

An example – electromigration modeling

\[ J_v = -D_v \nabla C_v - D_v C_v \frac{Z^* e \rho_f}{k_B T} - D_v C_v \frac{\Omega}{k_B T} \nabla \sigma - D_v C_v \frac{Q^*}{k_B T} \nabla T \]

- electron wind
- temperature gradient
- chemical-potential
- stress gradient
Need for Nano-Scale Modeling

Today’s 14-nanometer-node processors contain more than 10 km in the same area.

Today’s solution is to deposit copper interconnects within trenches lined with 2-nanometer-thick walls of tantalum nitride.

At 0.3 nm, graphene might be an option.

CK Hu, Impact of impurities, liner, Co cap and short length on electromigration in Cu damascene lines, 2014 Stress Workshop, Austin.

SJ Yoon, Improved electromigration-resistance of Cu interconnects by graphene-based capping layer. 2015 VLSI Technology (VLSI Technology)
Multi-Scale Modeling

Copper

SiO₂

Cu-OO bonded  Cu-O bonded  Cu-Si bonded

First principles simulation  Molecular dynamics simulation  Finite element simulation

State of the Art: Multilevel Submodeling Technique

- Multilevel models are chained to obtain the driving force for delamination.
- Thousands of lines in ANSYS APDL codes have been written for the model.
- Typical model has one million DOF and takes a few hours to solve.
Summary

• **The state of the art**
  – Multiphysics modeling software available.
  – Open source code for materials modeling at each scale available.

• **Key challenges that need to be overcome to enable**
  – Fundamental theory on constitutive relationship.
  – Characterization of material properties at different scales.
  – Bridging among different scales.

• **What needs to happen to overcome these challenges?**
  – Develop fundamental constitutive theory for material behavior.
  – Develop theory and implementation for multiscale modeling.
  – Develop micro-/nano-scale material characterization techniques.