Modelling & Simulation

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Co-Chairs
Scope

• Key Stakeholders
• Five sections
  • Electrical Analysis
  • Thermal Analysis
  • Materials Modelling
  • Mechanical & Multi-Physics Analysis
  • Reliability and Prognostics
• Chapter details
  • State of the Art
  • Challenges/Requirements
  • Potential solutions
Supporting the Knowledge Base for HI

**Component Design**
- Actives & Passives
- Electronic, Electrical, MEMS, Biological, Optoelectronic, sensors
- IC’s: Digital, Analogue, Mixed Signal, SoC
- Scale nm - um

**Package Design**
- System in Package
- BGA, Flip-Chip, QFN’s
- Wafer Level (Fan-in, Fan-Out)
- Substrates, Interposers & TSV’s
- 3D & 2.5D Packages
- Heterogeneous Integration
- Scale: um - mm

**Market Drivers**
- Internet of Things
- Wearable Devices
- Mobile Devices
- HPC and Data Centres
- Medical & Health
- Consumer Devices
- Automotive
- Aerospace & Defence

**System Design**
- PCB’s: Organic, Ceramic
- Subassemblies & Enclosures
- Heterogeneous Integration
- Products: IPAD, Radar, Pacemakers ...
- Scale: mm - m
HI Design and Simulation Environment

EDA & Simulation
- Cadence
- Synopsis
- Keystone
- Zuken
- Mentor/Siemens
- ANSYS
- etc

System Specs
- Process
- Constraints
- Variability

Architecture
- Floor Plans
- Layouts (I/O), etc

Verification
- PI/SI
- Reliability, etc

Multiple Design Rules
- PDK’s, ADK’s

Foundries
- Chip Design Flow
  - SoC, Logic, MEMS, HBM...
- mm - um

OSATS
- Package Design Flow
  - WLP, 2.5D, 3D...
  - um - mm

Systems
- Board / System Design Flow
  - Cooling Technologies, etc
- (mm – m)

Interactions: Electrical, Thermal, Mechanical and Multi-Physics

Electrical Analysis
- Frequency & time domain
- Spice & lumped Parameter Models

Thermal Analysis
- Compact Models
- CFD Models

Mechanical Analysis
- FEA Models

Multi-Physics/Scale Requirements

IEEE
IEEE photonics Society
SEMI
Electronics Packaging Society
ASME
Electron Devices Society
Moving towards a new Paradigm

Today (Generally)

- Different design flows / Tools
- EDA (Spice Models, PDK’s)
- Packaging (ADK’s); Therma/Mechanical – System level

Future

- Design flow that captures Multi-Physics/Scale Interactions
- Collaborative Design
- System aware design
## Multi-Physics/Scale Domains

<table>
<thead>
<tr>
<th>Scale:</th>
<th>Devices (nm)</th>
<th>Packages (um-mm)</th>
<th>Boards (mm-cm)</th>
<th>Systems (cm-m)</th>
</tr>
</thead>
</table>

### Data:
- Materials
- Manufacturing Characterization
- Mission Profiles
- Industry 4.0, etc

### Model Fidelity:
- Analytical
- Circuit/Network
- Compact/Response Surface
- MOR
- MD/FEA/CFD

### Knowledge Base:
- Design Rules
- PDK’s ADK’s, etc

### Model based Optimization; Big Data Analytics; Physics of Failure Models; Prognostics; etc.

### Design for Performance, Manufacturability, Reliability & Robustness

#### Thermo-Mechanical Interactions
- Joule Heating
- Hot Spots
- Active vs Passive Cooling

#### Electro-Thermal Interactions
- Electrical
  - PI/Sl
  - EMI/Crosstalk
  - Power Maps
  - Mobility shifts

#### Electro-Mechanical Interactions
- Mechanical
  - Delamination
  - Fatigue
  - Warpage
  - Metal Migration
  - Corrosion
Electrical Analysis

• State of the art
  • Solvers: SPICE, IBIS, MoMaxwell Solvers (FDTD), etc.
  • Customised solutions for die, package and system

• Challenges/Requirements
  • Accurate simulations for scale of features (die <-> package <-> System)
  • Standardisation of interface files between tools

• Potential Solutions
  • Compact models for co-analysis
  • Integrated solutions for Power and Signal Integrity / EMC, etc
  • Application of machine learning for generating fast models for use in HI EDA design flows
Thermal Analysis

• State of the art
  • CFD/FEM: Complex set-up

• Challenges/Requirements
  • Self heating - Localised hot-spots
  • Ability to predict temperatures across the length scales
  • Accurate models for active cooling

• Potential Solutions
  • Probabilistic input parameters to CFD
  • Use CFD models for machine learning training for deep autoencoders (DAE)
  • Use DAE in HI EDA design flows
Mechanical & Multi-Physics

- State of the art
  - Finite Element tools
  - Compute intensive tools

- Challenges/Requirements
  - Stress in die due to package constraints
  - Stochastic Models for Materials
  - Multi-physics aware floor-planning/placement

- Potential Solutions
  - Fast accurate ROM models for stress/warpage
  - Combined physics models with machine learning
  - Integrate into HI EDA design flow

Fig. 7 Copper metal line scaling over the past generations of CMOS technology
Reliability & Prognostics

• State of the art
  • Classical reliability
  • Physics of failure (PoF) models

• Challenges/Requirements
  • New failure mechanisms/modes
  • System health management
  • Smart Testing

• Potential Solutions
  • New PoF models
  • Prognostics (Data and model driven)
  • Combined physics models with machine learning for integration into HI EDA design flows

Classical Reliability
- Based on standardized (Q&R) tests
- Experimental failure analysis
- Usage is information is assumed - not fully predictive (can only predict system reliability for failure modes that are known)

Data Analytics
- Looks for correlations of signals to failure (real usage conditions)
- Lots of signals needed due to black box approach ‘big data’
- Improved prediction horizon

Prognostics and health monitoring
- Build physics-based models to understand data (beyond correlation)
- Characterize black box leading to tailored set of signals ‘less data’
- Full prediction of occurring failures using real usage conditions
## Metrics

<table>
<thead>
<tr>
<th>Metric</th>
<th>5 years</th>
<th>10 years</th>
<th>15 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concept to Product</td>
<td>5 years</td>
<td>3 years</td>
<td>18 months</td>
</tr>
<tr>
<td>DfR (Accuracy)</td>
<td>200%</td>
<td>150%</td>
<td>110%</td>
</tr>
<tr>
<td>Product validation in Virtual Environment</td>
<td>50%</td>
<td>70%</td>
<td>100%</td>
</tr>
<tr>
<td>AI/Machine Learning</td>
<td>Use of Machine Learning - single package and physics</td>
<td>Use of Machine Learning - multiple packages and single physics</td>
<td>Use of Machine Learning - for multiple packages and physics</td>
</tr>
<tr>
<td>Multi-Physics</td>
<td>Electro-thermal analysis at single package level (chip-package co-design)</td>
<td>Accurate multi-physics analysis for chip-package co-design</td>
<td>Accurate multi-physics analysis for whole system</td>
</tr>
<tr>
<td>Data Sharing</td>
<td>Interfaces between tools and ADK’s and PDK’s</td>
<td>Data and model sharing through supply chain</td>
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Acknowledgements and Status

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• Status
  • Version 1 complete
  • Editing taken place
  • Some minor additions expected
    • Reliability section
    • Metrics
  • Ready for peer review
  • Version 2
    • Closer alignment with Co-Design Chapter
    • Optical analysis
    • Materials Characterisation for models