Improve PCB and Package reliability with ANSYS

Rajiv Lochan Rath
Korea 2016 UGM
Overview

- PCB and Packages are used in almost all electronic products across industries.

- Automotive
  - Controller System
  - Audio System
  - Engine Control Module
  - LCD display module

- Aerospace and Defense
  - Attendant Controller Panel
  - Engine control module

- Consumer Electronics
  - Attendant Controller Panel
  - Engine control module

- Healthcare

- Oil and Gas
  - Drill hole tool

© 2015 ANSYS, Inc.  October 14, 2016
Major Causes of Electronics Failures

- Temperature: 55%
- Vibration: 20%
- Humidity: 19%
- Dust: 6%

Material Properties
- Conductivity
- Moisture Permeability

Operation Environment
- Cyclic Vibration
- Shock

Manufacturing Process
- Void/Groove

Manufacturing Process (Assemblies)
- Layering; Lamination (Delamination)
- Bonding
- SJR

Design
- Nonuniformity
- Thickness ($\Delta T$)
- Thermal Via

Operation Environment
- Cyclic Temperature
- High Temperature Gradient (Thermal Shock)

Material Properties
- Coefficient of Thermal Expansion (CTE)
- Coefficient of Moisture Expansion (CME)
Role of ANSYS in PCB and Package Design

• New Design
• Process Design
• Optimization
• Troubleshooting
• Validation
• Reliability
## Reliability

<table>
<thead>
<tr>
<th>DC-IR + Thermal Reliability</th>
<th>Thermo-Mechanical Reliability</th>
<th>Hygro-Mechanical Reliability</th>
<th>Mechanical Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="PCB with Hot Spot" /></td>
<td><img src="image2" alt="Solder Ball Interface" /></td>
<td><img src="image3" alt=" UB M Failure" /></td>
<td><img src="image4" alt="Large Deformation" /></td>
</tr>
<tr>
<td>Hot spot on PCB due to trace heating</td>
<td>Cracks formation at interface between solder ball and PCB due to thermal cyclic loading, CTE mismatch</td>
<td>UBM failure induced by Hygroswelling stress due to CME mismatch, moisture sensitivity</td>
<td>Large deformation when PCB subjected to random vibration</td>
</tr>
</tbody>
</table>

(C) Alcatel Lucent, Intel, Sanmina)

(© expertfea.com)
• DC-IR + Thermal Reliability
• Thermo-Mechanical Reliability
• Hygro-Mechanical Reliability
• Mechanical Reliability
Background: Joule Heating \[ Q = I^2 R \]

- Joule heating effects on copper traces \( \rightarrow \) Temperatures increase \( \rightarrow \) Reliability issues \( \rightarrow \) PCB delamination and failure

- Thermal reliability analysis on printed circuit / wiring boards?
  - High current PCB’s are densely populated with components
    - Reduction of trace and via dimensions
    - Current densities increase
PCB Thermal Reliability

<table>
<thead>
<tr>
<th>Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Predict accurate temperature of PCB</td>
</tr>
<tr>
<td>Understanding both Thermal and Electrical physics and applications</td>
</tr>
<tr>
<td>Transfer data between different physics for accurate analysis</td>
</tr>
</tbody>
</table>

**ANSYS Solution**

- **Slwave** transfers local Joule heating losses into **Icepak**
- Accurate loss calculation with inclusion of thermal effects
- Automatic looping until DC losses & Thermal map are constant
- **Icepak** returns temperatures back to **Slwave**
• **Spatial Power Loss** information from the DC-IR analysis (*SIwave*) is transferred to Icepak as a spatial Joule Heating map.

• **Spatial Temperature** information from the Thermal analysis (*Icepak*) is transferred to SIwave and interpreted as spatial thermal modifiers for electrical conductivity.
WorkFlow Wizard, making the Simulation setup more convenient and user-friendly.
SIwave DC Solutions

Quickly Identify:
- High Currents in Vias
- Current Crowding in Copper
- High Power Loss Regions
- Automated report generation with user defined pass/fail criteria.
SIwave – Icepak Coupling : Accurate PCB Thermal Analysis

Coupled DC-IR Simulation Wizard

- Imports Power map to Icepak and Export Temperature modifiers back to SIwave
- Minimal inputs from Electrical engineer
- Automated coupling till convergence
Icepak Results: Temperature Comparison

**Without Trace heating**

**1st Iteration**

**2nd Iteration**

**3rd Iteration**

**With Trace heating**

<table>
<thead>
<tr>
<th>Simulation Type</th>
<th>Maximum Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without Joule Heating</td>
<td>40.0 °C</td>
</tr>
<tr>
<td>Slwave-Icepak Coupling (First Iteration)</td>
<td>69.0 °C</td>
</tr>
<tr>
<td>Slwave-Icepak Coupling (Last/Third Iteration)</td>
<td>76.6 °C</td>
</tr>
</tbody>
</table>
Case Study: Power Supply Board

- Difference between Icepak / SIwave + Icepak coupling
  
  Hotspot off by **10.3 C** vs experiments

  Icepak (no Trace heating)  
  
  SIwave + Icepak  

  Hotspot off by **2.3 C** vs experiments

- Difference between Icepak + Mechanical / SIwave + Icepak + Mechanical coupling

  Shift of max stress quantity and location

  Icepak + Mechanical  
  
  SIwave + Icepak + Mechanical

Courtesy: Toshiba Corporation, ANSYS Advantage
• Thermal Reliability

• Thermo-Mechanical Reliability

• Hygro-Mechanical Reliability

• Mechanical Reliability

(© Alcatel Lucent, Intel, Sanmina)
PCB and Package Warpage

**Challenges**

- Predict local warpage accurately during reflow
- Understanding effect of belt speed, geometry of package
- Accurately calculating the local material properties

**ANSYS Solution**

- Reflow Profile applied for Warpage
- R17 feature in Mechanical and SpaceClaim for Copper and FR4 distribution
- Trace in Mechanical
- Warpage calculation in Mechanical
Comparison of Warpage with and w/o Trace in PCB

Comparison of Equivalent Stress

<table>
<thead>
<tr>
<th>Probe</th>
<th>Detailed PCB</th>
<th>Trace PCB</th>
<th>Lumped PCB</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>202.75 MPa</td>
<td>199.67 MPa</td>
<td>237.63 MPa</td>
</tr>
<tr>
<td>B</td>
<td>197.72 MPa</td>
<td>198.55 MPa</td>
<td>234.86 MPa</td>
</tr>
<tr>
<td>C</td>
<td>213.68 MPa</td>
<td>232.71 MPa</td>
<td>211.96 MPa</td>
</tr>
<tr>
<td>D</td>
<td>332.99 MPa</td>
<td>356.42 MPa</td>
<td>247.07 MPa</td>
</tr>
</tbody>
</table>

Comparison of Deformation

<table>
<thead>
<tr>
<th>Probe</th>
<th>Detailed PCB</th>
<th>Trace PCB</th>
<th>Lumped PCB</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3.545 E-3 mm</td>
<td>3.037 E-3 mm</td>
<td>1.263 E-2 mm</td>
</tr>
<tr>
<td>B</td>
<td>1.323 E-2 mm</td>
<td>1.457 E-2 mm</td>
<td>1.226 E-2 mm</td>
</tr>
<tr>
<td>C</td>
<td>1.205 E-1 mm</td>
<td>1.218 E-1 mm</td>
<td>1.421 E-1 mm</td>
</tr>
<tr>
<td>D</td>
<td>9.068 E-2 mm</td>
<td>9.169 E-2 mm</td>
<td>1.113 E-1 mm</td>
</tr>
</tbody>
</table>

Probe locations for comparing stress and deformation
Flip-chip package Warpage

Why important is to consider the warpage
- critical to the subsequent package process after post mold cure process (reflow failure, solder-joint reliability failure)

Standard : JESD22-B112A from JEDEC

Step I: Silicon, solder bump and substrate bond at reflow temperature (>180 C)

Step II: Cool down from 180 C to room temperature

Step III: Underfilling, cure at 150 C, Cool to room temperature

Step IV: Lid attach/encapsulation at ~120C, cool down to room temp

Step V: Ball attach & reflow at > 180C
Solder Joint Life Cycle Estimation

**Challenges**

- Predict time to failure
- Understanding simulation procedure for life cycle estimation

**ANSYS Solution**

- Life cycle estimation
- Prediction using Darveaux method
- ACT Extension to Automate Simulation Process
Darveaux Method – Cycles to Failure
Fatigue Post-processing

Quarter Symmetric Package Model

Results Table

Equivalent Plastic Strain

No of cycles to failure

Tabular Data

<table>
<thead>
<tr>
<th>Cycles</th>
<th>Plastic Work Difference</th>
<th>Cycles to Crack Initiation</th>
<th>Rate of Crack Propagation</th>
<th>No. of Propagation cycles to Failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.027554</td>
<td>5262199.92595</td>
<td>1.717152818E+08</td>
<td>22094323.6150</td>
</tr>
<tr>
<td>2</td>
<td>0.017735</td>
<td>1005047.44278</td>
<td>1.115917663E+08</td>
<td>35872803.8193</td>
</tr>
<tr>
<td>3</td>
<td>0.012764</td>
<td>169418.4756</td>
<td>8.0778315999e-09</td>
<td>40518210.0556</td>
</tr>
</tbody>
</table>
• Thermal Reliability

• Thermo-Mechanical Reliability

• Hygro-Mechanical Reliability

• Mechanical Reliability
Moisture-induced Failure

• Requires the Following

1. Absorption under Moisture Sensitivity Level
2. Desorption during bake out or Reflow
3. Heat transfer during Reflow
   – May not be needed since reflow profile temperature is known
4. Moisture Swelling
5. Thermal Warpage during Reflow
6. Combination of 4. & 5. Above
7. Vapor pressure in the volume
8. Vapor Pressure & Interface delamination prediction
Moisture-induced Failure

- The moisture-induced failure
  - Popcorn
  - Delamination
  - common phenomena during solder reflow
  - due to sudden vaporization of moisture absorbed by package at high temperature condition (local moisture concentration at the critical interface)

- Standard
  : J-STD-020C Moisture/Reflow Sensitivity Testing
  JESD22-A113 Reflow Preconditioning

Temperature distribution during reflow

Transient vapor pressure/moisture distribution during moisture preconditioning & reflow
• Thermal Reliability

• Thermo-Mechanical Reliability

• Hygro-Mechanical Reliability

• Mechanical Reliability
Mechanical Reliability

- **Drop test simulation**
  - critical to portable telecommunication devices such as mobile phone, PDA, home appliances
  - Explicit ANSYS Solver (Autodyn, LSDyna)

- **Shock test simulation**
  - critical to vehicle application devices (JESD22-B104)
  - critical to defence system application devices (MIL-STD-883)
  - critical to aerospace application devices (MIL-STD-883)
  - Implicit/Explicit ANSYS Solver

- **Vibration test simulation**
  - critical to vehicle application devices (JESD22-B103)
  - critical to defence system application devices (MIL-STD-883)
  - critical to aerospace application devices (MIL-STD-883)
  - ANSYS Mechanical/APDL

- **Fatigue Test Simulation**
  - critical to improve the reliability of the product in market (QA unit/Self Std)
  - ANSYS Mechanical Fatigue & nCODE for EN/SN Fatigue Simulation
Vibration Reliability

**Challenges**

- Predict the response under Random Vibration Loadings
- Predicting fatigue life due to Random Vibration Loadings

**ANSYS Solution**

- **Time History**
- **Response PSD**
- **Frequencies & Mode Shapes**
- **PSD**
- **Sigma Values**
## Summary

### Value to Customer

- Ease of coupling multiple physics
- Accurate prediction of Temperature
- Accurate prediction of local material properties
- Accurate Deformation, Stress and Life prediction
- Accurate prediction of behavior of an electronic component under vibration
- Quick turnaround time
- Reduced time to market

### Customer using ANSYS Solution

![World map showing customers using ANSYS solution](image-url)
Reliability Analysis of Smart Phone

https://youtu.be/8OsJSnutuVk
**ANSYS Consulting Services** Your partner in Reliability Simulations

• We bring:
  • The largest team of CAE experts
  • The broadest portfolio of simulation software
  • Unmatched industry experience

• With the goal of:
  • Understanding your process
  • Smartly integrating simulation
  • Measuring impact on your business

• To give you:
  • Improved workflow
  • Customized tools
  • Measurable ROI
<table>
<thead>
<tr>
<th>DC-IR + Thermal Reliability</th>
<th>Thermo-Mechanical Reliability</th>
<th>Hygro-Mechanical Reliability</th>
<th>Mechanical Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot spot on PCB due to trace heating</td>
<td>Cracks formation at interface between solder ball and PCB due to thermal cyclic loading, CTE mismatch</td>
<td>UBM failure induced by Hygroswelling stress due to CME mismatch, moisture sensitivity</td>
<td>Large deformation when PCB subjected to random vibration</td>
</tr>
</tbody>
</table>