“Thermal Design and Analysis”
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“Chasing Die Temp—What Impacts the Actual Die Temp in Burn-in? How About the Socket?”
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“Metal Interface Materials for Burn-in Applications”
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Indium Corporation

“Optimized Air Cooled Test Socket”
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IBM Microelectronics
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Thermal Design and Analysis

2008 Burn-in and Test Socket Workshop
March 9 - 12, 2008

Harlan Faller, P.E.
Johnstech International

Agenda

• Introduction
• Concepts of Heat & Heat Transfer
• Thermal Characteristics of Selected Materials
• Critical Factors of Thermal Paths
• Thermal Analysis of DUT/Test Socket/LB
• Case Study With Data
• Conclusions
• Glossary of Terms
• Appendix
Introduction

• Objective of this Presentation:
  – To demonstrate how Thermal Concepts and Laws are applied to Test Socket Analysis.

• Goal:
  – To provide a Set of Guidelines to users of the methodology presented herein.

• Future Work:
  – Expand on the Guidelines and formalize them into a spreadsheet.

Concepts of Heat & Heat Transfer

• Thermodynamics
  – Deals with Systems in Equilibrium
  – Will predict State Change in Equilibrium
  – Won’t predict Rate of Change of a System not in Equilibrium

• Heat Transfer
  – Will predict Energy Transfer between Material Bodies resulting from Thermal difference
  – Will predict Rate of Heat Exchange
  – Obeys the Laws of Thermodynamics
Laws of Thermodynamics

• Zeroth Law
  – If two Thermodynamic Systems are in Thermal Equilibrium with a third, they are in Thermal Equilibrium with each other.

• First Law
  – In any process, the Total Energy of the Universe remains constant.
  – Energy cannot be created or destroyed.

Laws of Thermodynamics

• Second Law
  – Energy Systems have a tendency to increase their Entropy (Heat Transfer Content) rather than decrease it.

• Third Law
  – As the Temperature approaches absolute zero, the Entropy of a System approaches a constant.
Mechanisms of Heat Transfer

- **Conduction:** \[ Q = -kA(\Delta T)/L \]
- **Convection:** \[ Q = h_cA(T_s-T_m) \]
- **Radiation:** \[ Q = \varepsilon\sigma F_{1,2}A(T_1^4-T_2^4) \]

- **Q** = Quantity of Heat Transferred (Watts)
- **k** = Thermal Conductivity of Material (W/m-K)
- **A** = Cross-Sectional Area (m²)
- **\Delta T** = Temperature Difference (°C)
- **L** = Length of Heat Transfer Path (m)
- **h_c** = Coefficient of Convective Heat Transfer (W/m-K)
- **T_s, T_m** = Temperature of Surface and Media (°C)
- **\varepsilon** = Emissivity of radiating Surface (dimensionless)
- **\sigma** = Stefan-Boltzmann Constant (5.67x10⁻⁸ W/m²-K⁴)
- **F_{1,2}** = Shape Factor between Surface Area of Body 1 & 2 (≤1.0)
- **T_{1,2}** = Surface Temperature of Bodies (Kelvin)

### Thermal Characteristics of Materials

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>CONDUCTIVITY</th>
<th>SPECIFIED HEAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ag</td>
<td>429.0 W/m-K</td>
<td>235 J/Kg-K</td>
</tr>
<tr>
<td>Cu</td>
<td>401.0</td>
<td>384</td>
</tr>
<tr>
<td>Au</td>
<td>319.0</td>
<td>129</td>
</tr>
<tr>
<td>Al</td>
<td>237.0</td>
<td>903</td>
</tr>
<tr>
<td>W</td>
<td>173.0</td>
<td>125</td>
</tr>
<tr>
<td>Ni</td>
<td>90.4</td>
<td>444</td>
</tr>
<tr>
<td>Be-Cu</td>
<td>90.0</td>
<td>420</td>
</tr>
<tr>
<td>Fe</td>
<td>80.4</td>
<td>450</td>
</tr>
<tr>
<td>Pt</td>
<td>71.6</td>
<td>133</td>
</tr>
<tr>
<td>Sn</td>
<td>66.8</td>
<td>227</td>
</tr>
<tr>
<td>Pb</td>
<td>35.3</td>
<td>128</td>
</tr>
</tbody>
</table>

Reasons for Cooling DUT’s in Test

• Heat causes Noise in Electronic Circuits.
• Non-Dissipated Heat increases Junction Temperature of the Die.
  – +150°C max. for GaAs
  – +175°C max. for Silicon
• Cooling can increase Semiconductor Performance, Life and Reliability.
• Every 10°C increase in Junction Temperature reduces Life by 50%.

Critical Factors of Thermal Paths

• Pressure at the Interface
• Hardness of the Contact Surfaces
• Size of the Contact Surface Asperities
• Geometry of Contacting Surfaces
• Average Gap Thickness of Void Spaces
• Thermal Conductivity of Fluid in Void Spaces
• Thermal Conductivity of Contact Materials
**Interface Geometry for DUT/TS/LB**

- Applied Force (Newtons)
  - Device Under Test
    - Interface #1
    - Contact Pin
    - Interface #2
    - Load Board
    - T-amb

**Block Diagram of Interface Geometry**

---

**Interface Geometry for DUT/TS/LB**

- Die Junction
  - Tj
  - Tcase
  - Rth j-c
  - Rth Hsg
  - Rth IF+Pins
  - Rth LB-amb
  - Tamb

**Schematic Diagram of Interface Geometry**

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Paper #1
Interface Geometry for DUT/TS/LB

• Per Schematic Diagram on previous slide:
  \[ R_{th_{j-c}} = \theta_{j-c} \quad = \text{Thermal Resistance, Die Junction to Case} \]
  \[ R_{th_{if-pins}} = \theta_{if-pins} \quad = \text{Thermal Resistance, Interfaces + Contacts} \]
  \[ R_{th_{hsg}} = \theta_{hsg} \quad = \text{Thermal Resistance of Socket Housing} \]
  \[ R_{th_{LB-amb}} = \theta_{LB-amb} \quad = \text{Thermal Resistance, Load Board to Ambient Air} \]
  \[ \theta_{Total} = \theta_{j-c} + [\theta_{if-cp \parallel \theta_{hsg}}] + \theta_{LB-amb} \]

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Interface Geometry for DUT/TS/LB

• For Semiconductors, \( \theta_{j-c} \) is an internal function of Design and Manufacturing Techniques.

• Plastic Semiconductor Cases are often used for low-power Devices. In some cases, \( \theta_{j-c} \) could be >50°C/W.

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Thermal Resistance

- Heat Transfer can be defined in terms of Thermal Resistance, θ:
  \[ θ = \frac{ΔT}{Q} \text{ °C/W} \]
  - \( Q \) = Quantity of Heat Transferred (Watts)
  - \( ΔT \) = Temperature Difference between two Surfaces (°C)
- \( θ \) characterizes the Transmission of Heat through the Heat Transfer Path

Mounting Interface

- Mounting Interface is a critical area of Heat Transfer.
- Heat is conducted when Surfaces touch.
  - Usually only 1% - 5% of Total Surface Area

Source: Electronics Cooling Magazine, May 1997
Heat Transfer through 2mm “S” Contacts to Ambient Air for DUT / TS / LB

- DUT: 7x7mm, 48 TQFN, 2.95 Watt Device
  - $\theta_{ja} = 2^\circ$C/W
- Heat Load: ~2.9 Watts
- Contacts: 2mm, 0.508mm wide “S” type
- 10 Contacts in Torlon™ Housing from DUT Pad to Load Board
- Typical Thermal Resistance:
  - $\theta_{Torlon} = 120^\circ$C/W
  - $\theta_{LB-Air} = 12^\circ$C/W
  - $\theta_{Amb-Air} = +27^\circ$C

Case Study:

Simplified Methodology for Case Study

- Determine or calculate the following:
  - Cross-Sectional Area of Contact
  - Thermal Resistance of the Contact
  - Thermal Resistance of Pad-Contact Interface
  - Thermal Resistance of Contact-Load Board Interface
  - Total Thermal Resistance of the Heat Path
- Plug in the numbers and crank
Calculation of Contact's Thermal Resistance

- Determine these Contact characteristics:
  - Volume
  - Mass (dependent on Volume and Density of Material)
  - Cross-Sectional Area of Contact to Heat/Current Flow
- Thermal Resistance is defined as:
  \[ \theta = \frac{L}{kA} \]
  
  - \( L \) = Length of the Contact (m)
  - \( k \) = Thermal Conductivity of Contact material (W/m-K)
  - \( A \) = Cross-Sectional Area of the Contact (m²)

Interface Thermal Resistance of DUT-Contact & Contact-Load Board

- Determine the following factors:
  - Apparent and Real Area of Contact of Interface Surfaces (m²): \( A_{\text{real}} = 0.3 \times A_{\text{apparent}} \)
  - Force of Contact (Newtons)
  - Contact Material and Finish (microns)
  - Pressure on Contact at IF (N/m²)
  - Average Surface Roughness of Materials at Interface (microns)
    - \( \sigma_{\text{avg}} = (\sigma_1^2 + \sigma_2^2)^{1/2} \)
    - \( \sigma_1 \) = Surface Finish of Material 1 (microns)
    - \( \sigma_2 \) = Surface Finish of Material 2 (microns)
Interface Thermal Resistance of DUT-Contact & Contact-Load Board

- Determine the following factors:
  - Average Thermal Conductivity (W/m-K)
    \[ k_{\text{avg}} = \frac{2k_1k_2}{k_1 + k_2} \]
    \( k_1 \) = Thermal Conductivity of Material 1 (W/m-K)
    \( k_2 \) = Thermal Conductivity of Material 2 (W/m-K)
  - Average Asperity Angle, \( \tan \Phi \)
    \[ \tan \Phi_{\text{avg}} = \left( \tan^2 \Phi_1 + \tan^2 \Phi_2 \right)^{1/2} \]
    \( \tan \Phi_1 \) = Asperity Angle of Material 1 (dimensionless)
    \( \tan \Phi_2 \) = Asperity Angle of Material 2 (dimensionless)

Heat Transfer through an Interface

- \( h_i = 1.45k_{\text{avg}}(P/H)^{0.985}\tan \Phi_{\text{avg}}/\sigma_{\text{avg}} \)
  \( h_i \) = Heat Transfer Coefficient (W/m²-K)
  \( P \) = Pressure at Interface (N/m²)
  \( H \) = Hardness of Softer Material at Interface (N/m²)
- \( h_{\text{ga}} = k/y = k/[(y/\sigma) \times \sigma_{\text{avg}}] \) W/m²-K
  \( k \) = Thermal Conductivity of Gap Media
    (air = 0.0252 W/m-K)
  \( y/\sigma \) = Constant (use “8” as an average for machined surfaces)
- \( h_{\text{a}} = h_i + h_{\text{ga}} \) (W/m²-K)
- \( \theta_a = (h_a \times A_{\text{app}})^{-1} \) °C/W
Case Study Data:

- **Parameters**
  - Surface Finish (microns): 1.6x10^{-6} 1.6x10^{-6} 1.6x10^{-6}
  - Tan\(\Phi_n\): 0.15 0.15 0.15
  - Thermal Cond. (W/m-K): 66.8 90.0 319.0
  - Mat'l. Hardness (N/m^2): 0.5x10^8 5x10^8 5x10^8

- **Pressure @ Interface 1**: 4.597x10^7 N/m^2
- **Pressure @ Interface 2**: 3.798x10^7 N/m^2
- **Other pertinent data on Slides 17 & 29**

Summation of Thermal Resistances for Heat Path:

- **Thermal Resistance of Interface 1 & Interface 2:**
  \[ \theta_{IF1} = (h_{a1} \times A_{real(IF1)})^{-1} \, ^{\circ}C/W \]
  \[ \theta_{IF2} = (h_{a2} \times A_{real(IF2)})^{-1} \, ^{\circ}C/W \]

- **Total Thermal Resistance of Interfaces plus Contact:**
  \[ \theta_{IFs+pin} = \theta_{IF1} + \theta_{pin} + \theta_{IF2} \, ^{\circ}C/W \]

- **Sum Total of Thermal Resistance for DUT/TS/LB:**
  \[ \theta_{j-amb} = \theta_{j-c} + [\theta_{IF-cp || hsg} + \theta_{LB-amb}] \, ^{\circ}C/W \]

- **At Tamb the Die Temperature is defined as:**
  \[ T_{die} = T_{amb} + (\theta_{j-amb} \times P_{diss}) \, ^{\circ}C \]
  \[ P_{diss} = \text{Heat Conducted away from Device Die} \]
Case Study Result Calculations:

Reference: Slide 17, 2.9 Watt, 48 TQFN Device with 2mm, 0.508mm wide “S” Contacts

- $\theta_{\text{pin}} = 98.8^\circ\text{C/W}$
- $\theta_{\text{IF1}} = 2.6^\circ\text{C/W}$
- $\theta_{\text{IF2}} = 15.1^\circ\text{C/W}$
- $\theta_{\text{f-a-pin}} = 116.5^\circ\text{C/W}$
- $\theta_{\text{c-LB}}$ = 10 pins @116.5°C/W || 120°C/W = 10.6°C/W
- $\theta_{\text{j-amb}} = \theta_{\text{j-c}} + \theta_{\text{c-LB}} + \theta_{\text{LB-amb}} = 2 + 10.6 + 12 = 24.6^\circ\text{C/W}$
- $T_{\text{die@+27^C}} = + 27 + (24.6 \times 2.9) = 98.3^\circ\text{C}$
- Measured Test Results gave a Die Temperature of 96°C.
- The difference between Calculated and Measured Values is 2.3°C.

Conclusions

- Heat Transfer obeys the Laws of Thermodynamics.
- It is crucial to remove Heat from DUTs.
- It is possible to calculate the Heat Flow from DUTs through the Test Socket to the Environment.
- Equations were presented to use in Heat Calculations.
- Results of the Case Study were in good agreement with Measured Results.
THANK YOU for your time and attention!

Any Questions?

Glossary of Terms

• Terms and units used in Heat Transfer
  – Heat Flux \( \text{J/m}^2\text{-s} \)
  – Heat Transfer Rate \( \text{dQ} = qA(W/m}^2\)\)
  – Mass Density, \( \rho \) \( \text{Kg/m}^3 \)
  – Specific Heat, \( c_p \) \( \text{J/Kg-k} \)
  – Thermal Conductivity, \( k \) \( \text{W/m-k} \)
  – Thermal Energy \( Q(\text{Joules}) \)
  – Thermal Resistance, \( \theta \) \( ^\circ\text{C/W} \)
  – Thermal Time Constant, \( \gamma \) \( \text{seconds} \)
## Physical Properties of C110 Copper & C172 BeCu

<table>
<thead>
<tr>
<th>Property</th>
<th>C110 Copper</th>
<th>C172 BeCu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>8,940 Kg/m³</td>
<td>8,321.4 Kg/m³</td>
</tr>
<tr>
<td>Elect. Resistivity</td>
<td>1.71x10⁻⁸Ω-m</td>
<td>7.68x10⁻⁸Ω-m</td>
</tr>
<tr>
<td>Hardness</td>
<td>4-9x10² N/mm²</td>
<td>5-10x10² N/mm²</td>
</tr>
<tr>
<td>Melting Point</td>
<td>1082.8°C</td>
<td>982.2°C</td>
</tr>
<tr>
<td>Specific Heat</td>
<td>384 J/Kg-K</td>
<td>420 J/Kg-K</td>
</tr>
<tr>
<td>Tensile Strength</td>
<td>44 Ksi</td>
<td>90-112 Ksi</td>
</tr>
<tr>
<td>Thermal Cond.</td>
<td>401.0 W/m-K</td>
<td>90.0 W/m-K</td>
</tr>
</tbody>
</table>
Chasing Die Temp – What impacts the actual die temp in burn-in? How about the socket?

Michael Noel
Doug Grover
Doug Laing
Dan Wilcox

Freescale Semiconductor

Introduction

• Burn-in
  – Definition:
    • The process of exercising an integrated circuit at elevated voltage and temperature
  – Challenges
    • Knowing temperature of the die
    • Minimize understress
      – Do we miss some we should have caught?
    • Minimize overstress
      – Do we damage some with too much stress?
BI Factors

- Example
  - Burn-in model targets 145 °C die temp (Tj)
  - Assume 5 °C error in temperature

- A sample device Variation
  - Duration of BI at 140 °C = 124 Hrs
  - Duration of BI at 145 °C = 103 Hrs
  - Duration of BI at 150 °C = 87 Hrs

Significant Difference…

Low power devices

- Burn-in for low power devices was simpler

- Minimal power, minimal heat rise from internal stress
- Most devices very close to same temp

But….
Thermal Issues - A Better Understanding

March 2008 Chasing Die Temp

**Thermal Factors**

- Device technology changes
  - Smaller gates, more leakage
  - More leakage, more heat
  - More heat, more thermal issues

- As die generates heat, issue is now cooling
- Simple airflow is not enough

- Not all devices are created equal
  - Variation in power consumed by each DUT
    - Controlling chamber is not enough
  - We need to *Control Each Device*
  - We install some type of active thermal control

- Heater to compensate lower power DUTs
- Case temp monitor

March 2008 Chasing Die Temp
Case temp

- Can we use case temp?
  - Power variation of 3 Watts
  - Package with 6 °C/W / TjC
  - Control all devices to a case temp

  - Temperature of junction could be 18 °C different
  - Depends on knowing TjC
    - Could be a separate topic alone
  - We could have much more variation in device power

Diode or Resistor

- We can monitor die temp using a diode or resistor
  - Are they available?
  - They require calibration
    - How do we calibrate?
  - How reliable are they?
  - What impacts the readings?

- More importantly….
  - Monitoring is not enough... we still need to control the temp
Basic Model

- Basic TjC model
  - Set/Monitor case temp
    - Calculate die temp based on power and TjC

Two Questions:
- Is this accurate enough?
- What is missing.....

Real world example

- Is this accurate enough?
  - Example device shows a die temp difference of up to 25 °C
Additional considerations

- Lots of variables are missing
  - Heater in thermal path
  - Device generates heat
  - Heat path through socket
  - Ambient temperature

Improved model

- A different model – one way to look at it

- Include additional variables
  - Heater power
  - Ambient temp
  - $R_{\text{heat sink}}$
  - $R_{\text{socket}}$

- How do these factors impact die temp?
Build a way to explain it

- Convert thermal activity to Ohms law equivalents

\[ V = I \times R \]

Becomes

\[ T_2 - T_1 = P \times R \]

Now we can better predict behavior….

Real world example

- Including additional variables increases accuracy of our predictions
- Lets look at the pieces....
Impact of having a heater

- Heater power can have significant impact
- We now have two heat sources, one trying to add heat, the other trying to dissipate heat

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value 1</th>
<th>Value 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>T\textsubscript{a}</td>
<td>75 °C</td>
<td>75 °C</td>
</tr>
<tr>
<td>R\textsubscript{sink}</td>
<td>1 °C/w</td>
<td>1 °C/w</td>
</tr>
<tr>
<td>TIM</td>
<td>0.5 °C/w</td>
<td>0.5 °C/w</td>
</tr>
<tr>
<td>T\textsubscript{jC}</td>
<td>6 °C/w</td>
<td>6 °C/w</td>
</tr>
<tr>
<td>HTR</td>
<td>40 w</td>
<td>5 w</td>
</tr>
<tr>
<td>R\textsubscript{socket}</td>
<td>20 °C/w</td>
<td>20 °C/w</td>
</tr>
</tbody>
</table>

Die power
- Through lid 40 % 70 %
- Through socket 60 % 30 %

For a 5w package, Tj Error = 8 °C
Can we see impact of heater?

- Try an experiment:
  - Load chamber
  - Set ambient
  - Device power is off
  - Increase heater power to achieve target temp
  - Monitor diode temp
  - Repeat over several temperature ranges

Testing Impact of Heater

<table>
<thead>
<tr>
<th>Temperature Setting</th>
<th>Observed Diode Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>X</td>
</tr>
<tr>
<td>50</td>
<td>O</td>
</tr>
<tr>
<td>55</td>
<td>X</td>
</tr>
<tr>
<td>60</td>
<td>O</td>
</tr>
<tr>
<td>65</td>
<td>+</td>
</tr>
<tr>
<td>70</td>
<td>+</td>
</tr>
<tr>
<td>75</td>
<td>O</td>
</tr>
<tr>
<td>80</td>
<td>X</td>
</tr>
<tr>
<td>85</td>
<td>O</td>
</tr>
<tr>
<td>90</td>
<td>X</td>
</tr>
</tbody>
</table>

Heater Power
- X – Approx 12 Watts
- O – Approx 18 Watts
- + – Approx 24 Watts

Ambient changed
Heater Duty Cycle is changing
What does the model predict?

- Calculated Tj is similar to observed, if heater duty cycle and oven ambient are included
- TJ Error Increases with heater power

Diode with no heater

- Same device, same temps ambient only
- Die temp is much more consistent across various temps
Impact of ambient temp

As ambient increases, so does die temp with equal case temps

Impacts thermal distribution between case and socket paths

Impact of $T_{ambient}$

- $T_{ambient}$ 75 °C 25 °C
- $R_{sink}$ 1.5 °C/W 1.5 °C/W
- $T_{jc}$ 6 °C/W 6 °C/W
- $R_{socket}$ 60 °C/W 60 °C/W

5W device, set case temp to 95 °C (for planned $T_j$ of 125 °C) gives:

- $T_j$ Actual with
  - Ambient 75 121 °C Error of 4 °C
  - Ambient 25 116 °C Error of 9 °C

Lower values of oven ambient increase calculated error when not factored in
Can we see the impact of ambient?

- Try an experiment:
  - Load chamber
  - Set case temperature to fixed value
  - DUT power is on
  - Increase ambient temp in oven
  - Monitor diode temp

Observed impact of ambient

- As ambient is raised, die temp increases even if case temp is held constant
- Some impact from chicken/egg (current & temp both increasing influence each other)
What about the socket itself?

Lower $R_{socket}$ values give much greater error when they are not factored in.

Very high $R_{socket}$ values approximate basic model.

Impact of $R_{socket}$

- $T_a$ 75 ºC 75 ºC 75 ºC
- $R_{sink}$ 1.5 ºC/W 1.5 ºC/W 1.5 ºC/W
- $T_{jc}$ 6 ºC/W 6 ºC/W 6 ºC/W
- $HTR$ 40 W 40 W 40 W
- $R_{socket}$ 20 ºC/W 60 ºC/W $\infty$

$T_j$ with $T_{jc}$ of 6 131 ºC 144 ºC 148 ºC
$T_j$ with $T_{jc}$ of 2 124 ºC 129 ºC 132 ºC

$T_{jc}$ of 6 Error: 17 ºC
$T_{jc}$ of 2 Error: 4 ºC

$T_{jc}$ has large effect, lower values minimize impact of $R_{socket}$
Can we see the impact of $R_{\text{socket}}$?

- Try an experiment:
  - Load chamber
  - Set case temperature to fixed value
  - DUT power is on
    - Monitor diodes
  - Remove several socket pins
  - Repeat the experiment
  - Compare the results

Observed with $R_{\text{socket}}$ change

- Increasing $R_{\text{socket}}$ changes the thermal path
- As $R_{\text{socket}}$ increases, die temp error increases compared to traditional model

$T_j = 82.3$  $T_j = 84.7$
**Observed with \( R_{socket} \) change**

- Removing roughly 10% of the socket pins had a visible impact on \( R_{socket} \)
- If \( R_{socket} \) increases enough, error is minimized and \( T_j \) approaches predicted die temp from simple model
- Other factors can impact \( R_{socket} \)
  - Board composition, copper density
  - Airflow across the bottom of the board

**Summary**

- Several factors impact die temp
  - Heaters
    - Heaters in thermal path can increase error
  - Ambient air temperature
    - Changing ambient air temp can impact die temp, even when case temperature is held constant
  - \( R_{socket} \)
    - Lower \( R_{socket} \) values increase error, higher values approach basic model
  - Several other factors can be considered
Summary

• Controlling die temp
  • Using thermal diodes (or resistors) is the most accurate way to monitor junction temperature

  But....

  If using thermal diodes, be careful to calibrate as much as possible using ambient or, if using heater, apply full model to compensate for errors

Summary

It is possible to predict thermal behavior using a mathematical model however, the model needs to include the variables discussed earlier

There are no absolutes, all these variables interact with each other and need to be characterized
Metal Interface Materials for Burn-in Applications

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Metal Interface Materials for Burn-in Applications

- Indium Corporation
- An Introduction to Metal TIMs
- The Needs in Burn-in
- Thermal Resistance vs. Pressure in Metal TIMs
- Discussion and Questions
Applications of Solder & Compressible TIM

- TIMs for the burn-in process
  - Indium
  - Indium silver
  - Indium and aluminum

- Solders for evaporators & heaters in the stack up
  - Engineered melting temps for step soldering
  - High conductivity alloys to help efficiency of design

Types of Metal TIMs for Burn-in

- Compressible Metal
  - Pure indium
  - Indium silver
  - Indium/aluminum clad
Attributes

• Compliant
• High conductivity
• 86W/mK
• Durable, many cycles

<table>
<thead>
<tr>
<th>Material</th>
<th>Thermal Conductivity (W/mK)</th>
<th>Flow Stress (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indium</td>
<td>86</td>
<td>280</td>
</tr>
<tr>
<td>Copper</td>
<td>385</td>
<td>4800</td>
</tr>
<tr>
<td>Lead</td>
<td>35</td>
<td>1800</td>
</tr>
<tr>
<td>LMA</td>
<td>20</td>
<td>-</td>
</tr>
<tr>
<td>Grease</td>
<td>2</td>
<td>-</td>
</tr>
</tbody>
</table>

Burn-in Head with Metal TIM Applied
Features of Metal TIMs for Burn-in

- Tabs for attach
- Custom shapes
- Custom thicknesses based on application
  - Bare die
  - Lid package
- Custom cladding
- Clean
- Faster thru put
- Longer yields

Tabs for Attach
Session 4
Thermal Issues - A Better Understanding

Tabs for Attach

Compliant
Compliant

Resistance: Baseline of Burn-in TIMs

3/11/2008 Metal Interface Materials for Burn-in Applications

Paper #3

March 9 - 12, 2008
Thermal Resistance of Metal TIMs

Increasing Durability for Cycling, Cleanliness

- Alloy indium with silver
- Aluminum clad for no residue
**12 mil 90In/10Ag Cycling Tests**

![Graph showing cycling tests results](image)

**Solder in Burn-in Equipment**

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Melting Point (°C)</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>19</td>
<td>60</td>
<td>51 In, 32.5 Bi, 16.5 Sn</td>
</tr>
<tr>
<td>1E</td>
<td>118</td>
<td>52 In, 48 Sn</td>
</tr>
<tr>
<td>281</td>
<td>138</td>
<td>58 Bi, 42 Sn</td>
</tr>
<tr>
<td>290</td>
<td>143</td>
<td>97 In, 3 Ag</td>
</tr>
<tr>
<td>201</td>
<td>199</td>
<td>91 Sn, 9 Zn</td>
</tr>
<tr>
<td>238</td>
<td>217</td>
<td>90 Sn, 10 Au</td>
</tr>
<tr>
<td>121</td>
<td>221</td>
<td>96.5 Sn, 3.5 Ag</td>
</tr>
<tr>
<td>182</td>
<td>280</td>
<td>80 Au, 20 Sn</td>
</tr>
<tr>
<td>183</td>
<td>356</td>
<td>88 Au, 12 Ge</td>
</tr>
<tr>
<td>184</td>
<td>363</td>
<td>96.8 Au, 3.2 Si</td>
</tr>
<tr>
<td>176</td>
<td>382</td>
<td>95 Zn, 5 Al</td>
</tr>
<tr>
<td>186</td>
<td>424</td>
<td>55 Ge, 45 Al</td>
</tr>
</tbody>
</table>

3/11/2008  Metal Interface Materials for Burn-in Applications  15
Summary

• Burn-In speed can be enhanced by high performance thermal interfaces.

• High performance thermal interfaces can accommodate multiple contacts without making a "mess" on the chips.

• Cladding or altering the alloy can increase durability and usefulness of the Metal TIM.

• The evaporator/heater stack benefits from multiple thermal interfaces made through step solder processes - without this solder, the system would not function efficiently.
Optimized Air Cooled Test Socket

2008 Burn-in and Test Socket Workshop
March 9-12, 2008

Grant Wagner - IBM
David Gardell - IBM

Overview

• Hand plug test sockets
• Historical development
  – Thermal chamber
  – Single jet impingement (UT2)
  – Multiple jet impingement
  – Liquid cooled
• Measured data
  – Thermal test chip
  – Noise
  – Pressure and flow
Handplug Test

- Used for engineering characterization
- Low volume manufacturing where automated handler not justified

3/2008 Optimized Air Cooled Test Socket

Current Test Equipment

- Dry compressed house air
- Meriam Laminar Flow Element (LFE) 50MW20-1 ½ with Smart Flow gage 2110F
  - LFE accurate to +/- 0.72% of reading
  - Accurate to +/- 0.1% FS (+/-0.06 cfm)
- Absolute pressure measured with Meriam gage
- Gage air pressure – Omega DPG1002
  - 0 to 100 psi, accuracy = 0.25% FS
  - Inlet to UT2 body at barb fitting
- SCFM flow rate calculated from measured flow corrected for:
  - Viscosity, absolute pressure, absolute temperature

3/2008 Optimized Air Cooled Test Socket
Bare Die Thermal Test Chip

- 8.8 x 8.8 mm chip
- Flip chip attach
- 42.5 sq x 4.5 mm ceramic substrate
- 9 temperature sensors
- Serpentine heater pattern
- Various chip sizes

Salsa Thermal Test Board
Thermal Chamber

- Part heats up above chamber temperature as power is increased

Chip to air Thermal Resistance, 14 mm bare die chip

- Thermal Resistance = (max chip temp – air temp) / total chip power
Single Jet Development

- Airflow directed to chip center

Single Jet Development UT2

- Small central hole for high velocity air jet
- Optional spring loaded thermocouple
**Resistance vs Nozzle Diameter**

Thermal Performance vs Nozzle Diameter and Noise
14.7 mm thermal chip, nozzle to chip gap=13 mm, 22C air

- 1.8 scfm, 2.5 psi
- 3.9 scfm, 11.5 psi
- 7.2 scfm, 0.3 psi
- 19.5 scfm, 2.5 psi

Thermal Resistance (˚C/W)

Nozzle Diameter (in)

**Pressure & Flow vs Diameter**

Airflow vs Nozzle Diameter at 84 db
14.7 mm thermal chip, nozzle to chip gap=13 mm, 22C air

- R-square = 0.975   # pts = 5
- y = 0.145x^-1.57

Airflow vs Nozzle Diameter (in)

- Airflow (green triangles)
- Pressure (blue squares)
Thermal Issues - A Better Understanding

Session 4

Resistance vs Flow

Thermal Performance vs Airflow
14.7 mm Thermal chip, .1875" nozzle, .1" gap, 22 C air

C/W=3.85 scfm ^ -.413
psi=.0723 scfm ^ 2.03

UT2 – Active Thermal Control

Thermostream UT2 100 C DUT Mode, EFK Spring Loaded Thermocouple
19x 20 mm Spinnaker Test Chip with 12 On-Chip DUT Sensors

- Good performance, ∆T =20 C @ 42 W on 20 mm chip
- Response time limitations
Multiple Jet Development

- A matrix of small holes for jet impingement
  - Interstitial holes for air exhaust
  - Exhaust from one hole does not effect flow from adjacent holes
- 10 mm square array
- Thermal data measured on 8.8 mm chip
- Data compared to UT2
  - Single 0.18” diameter jet

Multiple Jet Development

- Calculate “thermal resistance” based following:
  \[ R = \frac{\text{avg chip temp} - \text{air inlet temp}}{\text{chip power}} \]
- Total chip power is uncorrected for heat loss to fixture
- Air inlet temperature is uncorrected for adiabatic air temperature decrease
- Resistance measured at high power approximates slope of line
  - Indicates performance in manufacturing
Mezzo LIGA Process, Nickel

1. X-ray lithography
2. Electroplating
3. Molding
4. Metallization
5. Polymer removal

3/2008 Optimized Air Cooled Test Socket

2(a) Schematic of the MJCA concept
2(b) Side view of the fabricated MJCA. The conduit connecting top and lower surface are the jet inflow conduits. The holes in the lower surface are the exhaust ports.
2(c) Fabricated 1x1 sq. cm MJCA
2(d) Bottom view of the MJCA with the jet impingement holes (large holes) surrounded by the exhaust ports (small holes)
Mezzo MJCA Measured with FRT Tool

- Supply holes are approximately 345+/-20 microns
- Return holes are approximately 165+/-40 microns

Typical Thermal Test Results

- Measure all temperatures during a 60 second step power
- Temperatures reach steady state, 380 micron gap
- Chip temperature initially below air inlet at high pressure
Temperature vs Power, Several Tests

- Plot steady state temperature vs power
- Chip temperature initially below air inlet at high pressure

Resistance vs Chip-to-Plate Gap

- Thermal performance improves at closer spacing
- Tolerance and pressure concerns at extremely small gaps
Mezzo vs UT2 on 8.8 mm Salsa Chip

- Mezzo has lower resistance, lower noise and lower pressure at same flow as single jet impingement

3 Tests Determine Heat Flow Paths

1. Normal test, no insulation, heat flows into:
   - Chip surface and air flow
   - Chip to substrate surface to airflow
   - Chip to substrate to socket to board to ambient air

2. Insulate only top surface of ceramic substrate, airflow only onto top of chip
   - Difference from test 1 is heat flow from substrate

3. Insulate top surface of chip and substrate
   - All heat is forced into test socket, board, and ambient air
**Thermal Issues - A Better Understanding**

**Mezzo at 8.7 scfm on Salsa**

- Only 58% of heat is lost from chip top surface

**Microchannel Liquid Cooled Heat Sink for Bare Die**

- Nickel plated Cu
- Undersized pedestal
  - Polished surface
- Coaxial bellows
  - Fluid inlet & outlet
  - Compliance & die force

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*Paper #4*

*March 9 - 12, 2008*
Resistance & Pressure vs Flow

Microchannel on salsa (8mm bare die), PG interface

- Point of diminishing return, 45/55 PG/water

Avg. Chip Temp, 8.8 mm Bare Die Chip

Gardell File Mezzo UT2 11 9 05.123

3/2008 Optimized Air Cooled Test Socket
**TV994 – Lidded Thermal Module**

- 14.7 mm square chip
- 42.5 mm ceramic substrate
- Aluminum DLA lid 2 mm thick
- 4 heater elements
- 9 temperature sensors

**DLA Impingement Designs**

- Plastic DLA
- Cu DLA
- Cu Mezzo DLA – 20mm array
**Plastic DLA Transient Response**

POR DLA Plunger 2.7 scfm, 5.8 psi, with snubbers
Lidded TV994 Mod, 20 Watt Power Step, 10 sec to 150 sec

- Thermal resistance is 2.2 C/W at 2 minutes

**Resistance & Air Pressure Vs Flow**

DLA Air Impingement HS's on TV994

- Mezzo flow/pressure is limited by inlet fitting
Liquid Cooled Heat Sink for Lidded Modules

- Nickel plated copper
- Serpentine channel pattern
- Spring loaded thermocouple

Liquid Cooled Heat Sink

Liquid Cooled HS on TV994 (lidded), PG LTI

Wagner file: hndplg TV994 2 5 07.xls
**Conclusions**

- Single jet nozzle diameter and nozzle-to-chip gap were optimized
  - Smaller diameters result in improved thermal performance at the cost of higher pressure

- Multi-jet arrays outperform single jets on small bare die test modules

- On large lidded packages, multi-jet arrays require high airflow for optimum performance
  - Investigate use of high pressure blowers

- Air cooled solutions are still inferior to liquid cooled solutions in terms of thermal performance, but can be a good low cost, non contact alternative for low power applications