Analyzing & Testing

Thermal Resistance and Effective Thermal Conductivity Measurements of Thermal Grease Using the Flash Diffusivity Method

IMAPS New England Symposium 2018
Introduction

• Reliable performance measurements of thermal grease and other thermal interface materials used in electronics packaging are important for material selection and design validation.

• With thin layers typically 10’s of microns, measurements can be difficult with various steady-state thermal conductivity methods.

• Utilizing multilayer analysis and special sample holders, the flash diffusivity method is well-suited to measurements of interfacial resistance and effective thermal conductivity of thin interfaces.

• Materials including grease, phase-change, filled epoxy, filled elastomeric pads can be tested in a “sandwich” configuration.
Flash Diffusivity Method:
Measurement Principle Introduced by Parker et al. 1961

Thermal diffusivity is a measure of how quickly a material can change its temperature.

The front surface of a plane-parallel sample is heated by a single short light or laser pulse.

The temperature rise on the rear surface is measured versus time using an IR detector.
Thermal conductivity can be derived by combining measurements of thermal diffusivity, specific heat and density

\[
\lambda(T) = \alpha(T) \cdot c_p(T) \cdot \rho(T)
\]

for adiabatic case (Parker formula):
Flash Diffusivity – 2 and 3 Layer Models

2 layer: film on substrate

2 layer: contact resistance

3 layer: film – substrate sandwich

Sample holder for application of clamping pressure
Thermal Interface Materials – Sandwich Method

\[ R_{\text{th}} = \frac{\Delta T \times A}{Q} \]

\[ R_{\text{tot}} = R_{\text{intr}} + 2(R_{\text{con}}) = \frac{\Delta x}{\lambda} + 2(R_{\text{con}}) \]

\[ R_{\text{con}} = \frac{\Delta T_{\text{int}} \times A}{Q} \]

- \( R_{\text{th}} \): thermal resistance (mm²-K/W)
- \( \Delta T \): temperature difference (K)
- \( Q \): heat flow (W)
- \( A \): area (mm²)
- \( R_{\text{con}} \): contact thermal resistance (mm²-K/W)
- \( \Delta T_{\text{int}} \): interface temperature difference (K)
- \( R_{\text{tot}} \): total gap thermal resistance (mm²-K/W)
- \( \lambda_{\text{eff}} \): effective thermal conductivity (W/m-K)

\[ \lambda_{\text{eff}} = \frac{\Delta x}{R_{\text{tot}}} = \frac{\Delta x}{\frac{\Delta x}{\lambda} + 2(R_{\text{con}})} \]

> measure and plot \( R_{\text{tot}} \) vs \( \Delta x \) to determine \( 2(R_{\text{con}}) \) and bulk \( \lambda \)
## Experimental – 3 layer sandwich thermal diffusivity measurements

### Properties at 25°C

<table>
<thead>
<tr>
<th>Material</th>
<th>Description</th>
<th>$\rho$ (g/cm$^3$)</th>
<th>$C_p$ (J/g-K)</th>
<th>$\lambda$ (W/m-K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dow Corning® 340</td>
<td>silicone based, ZnO filler</td>
<td>2.10</td>
<td>0.80</td>
<td>0.67 (datasheet)</td>
</tr>
<tr>
<td>Arctic Silver® 5</td>
<td>non-silicone, Ag, Al$_2$O$_3$ and BN fillers</td>
<td>4.05</td>
<td>0.60</td>
<td>n.a.</td>
</tr>
<tr>
<td>Al alloy substrates</td>
<td>12.7 mm x 2 mm</td>
<td>2.70</td>
<td>0.90</td>
<td>139</td>
</tr>
</tbody>
</table>

### Instrument

Netzsch LFA 467 (xenon flash source, InSb IR detector, 400 µs pulse width)
Experimental – 3 layer sandwich diffusivity measurements

DC 340 – 0.075 mm thickness, 2 mm Al alloy substrates
Experimental – 3 layer sandwich diffusivity measurements

Dow Corning® 340
Properties at 25°C

\[ y = 1369.6961x + 17.4614 \]
\[ R^2 = 0.9971 \]
### Dow Corning® 340 Properties at 25°C

<table>
<thead>
<tr>
<th>Gap Δx (mm)</th>
<th>( \lambda_{\text{eff}} ) (W/m-K)</th>
<th>( R_{\text{tot}} ) (mm²-K/W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.136</td>
<td>0.682</td>
<td>199</td>
</tr>
<tr>
<td>0.104</td>
<td>0.650</td>
<td>160</td>
</tr>
<tr>
<td>0.076</td>
<td>0.59</td>
<td>128</td>
</tr>
<tr>
<td>0.049</td>
<td>0.56</td>
<td>88</td>
</tr>
<tr>
<td>0.035</td>
<td>0.54</td>
<td>65</td>
</tr>
<tr>
<td>0.023</td>
<td>0.49</td>
<td>47</td>
</tr>
<tr>
<td>0.013</td>
<td>0.39</td>
<td>34</td>
</tr>
<tr>
<td>0.005</td>
<td>0.22</td>
<td>23</td>
</tr>
</tbody>
</table>

- \( \lambda \) (1/slope): 0.73 W/m-K
- \( 2(R_{\text{con}}) \) (y-intercept): 17.5 mm²-K/W
Experimental – 3 layer sandwich diffusivity measurements

Arctic Silver® 5 – 0.099 mm thickness, 2 mm Al alloy substrates
Experimental – 3 layer sandwich diffusivity measurements

Arctic Silver® 5
Properties at 25°C

\[ y = 780.0467x + 7.6365 \]

\[ R^2 = 0.9991 \]
Experimental – 3 layer sandwich diffusivity measurements

Arctic Silver® 5
Properties at 25°C

<table>
<thead>
<tr>
<th>Gap $\Delta x$ (mm)</th>
<th>$\lambda_{\text{eff}}$ (W/m-K)</th>
<th>$R_{\text{tot}}$ (mm²-K/W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.141</td>
<td>1.21</td>
<td>116</td>
</tr>
<tr>
<td>0.099</td>
<td>1.15</td>
<td>86</td>
</tr>
<tr>
<td>0.057</td>
<td>1.08</td>
<td>53</td>
</tr>
<tr>
<td>0.032</td>
<td>0.98</td>
<td>33</td>
</tr>
<tr>
<td>0.018</td>
<td>0.81</td>
<td>22</td>
</tr>
<tr>
<td>0.011</td>
<td>0.64</td>
<td>17</td>
</tr>
<tr>
<td>0.007</td>
<td>0.56</td>
<td>13</td>
</tr>
<tr>
<td>0.004</td>
<td>0.45</td>
<td>9.0</td>
</tr>
</tbody>
</table>

bulk $\lambda$ (1/slope): 1.28 W/m-K
$2R_{\text{con}}$ (y-intercept): 7.6 mm²-K/W
Conclusions

- The flash diffusivity method is well-suited to measurements of thermal resistance and effective thermal conductivity for thin interfacial layers.
- With three-layer “sandwich” measurements over a range of gap thickness, contact thermal resistance and bulk thermal conductivity can be estimated.
- Measurements of two commercially available thermal greases showed significant differences in bulk thermal conductivity and contact resistance.
Thank you for your attention!

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