The Crucial Influence of Thermal Interface Material in Power Electronic Design

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Available Thermal Interface Materials (TIMs)

• Thermal interface solutions for the electronics market have been available for decades – aka generic thermal grease

• Advancements in thermal interface materials
  • Explosive growth in consumer electronics, early 1990’s - 2000’s
  • Personal computing and handheld electronics
  • Home entertainment, gaming and the internet

• TIM developments driven by the specific needs of the consumer market
  • Simplicity of application and increased performance
    • Low cost labor for OEMs or home installation – overclockers
    • High performance greases, more elaborate filler types
  • Rapidly changing designs and short term needs
    • Increased acceptance of disposable consumer electronics
  • Numerous grease and phase change materials (vendors) emerged
    • “Flavor of the day” greases
TIM Selection for the Power Electronics Market

- Power electronics designers and assemblers have had to rely on commonly available thermal interface materials

- Material selection based on data sheet values
  - End performance doesn’t always meet expectations
  - Unexpected TIM performance and poor application methods
  - Lifetime predictions fall short due to uncertainties in the stability data

- Improvements in performance and longevity could be achieved by utilizing a TIM solution specific to the needs of the power electronics market

- Focus will be on a robust TIM pre-applied by the module manufacturer
  - Problems from end user application methods eliminated
  - Lifetime predictions ensured through rigorous testing
  - Enhanced thermal performance not available from off the shelf TIMs
The Challenge for the Power Module Manufacturer

- Find the best thermal interface material, suitable for power electronics, while avoiding detrimental features

Solid or Separates
Insufficient thermal range
Suffers from Dry-Out
Electrically Conductive
Silicone based

Ask a TIM manufacturer to fill the gap
What is so special in Power Electronics?
Thermodynamics
Thermal Cycling - Consequences

- Forced air-cooled heat sink, 2 Minute cycle, 50% duty cycle
- Current tuned to achieve $T_{j\text{max}} \sim 150^\circ\text{C}$

- Thermal transfer remains intact only if the material stays in place
- Datasheet values for thermal conductivity are no more than an indicator
- Wetting ability matters
- Creeping ability matters
- Long term stability matters

Chip-Temperature increase of >20K due to pump-out of thermal grease within 630 cycles/32 hours test time
Basic Physics

Heat from Device

A: Path through TIM

$\lambda_{th} < 10 \frac{W}{mK}$

B: Metal-to-Metal Contact

$\lambda_{th} > 100 \frac{W}{mK}$

- Maximize $\lambda_{th}$ for TIM
- Minimize areas with path A
- Maximize areas with path B
- Achieve smallest possible bond lines
Optimizing the Filler Components

Measured results from ASTM High Pressure Testing

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<th>Thermal Resistance [K/W]</th>
<th>Optimizing the Filler Components</th>
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Long-Term Stability

- Throughout the development, High-Temperature-Storing (HTS) was found suitable to achieve reliable results. 125°C, 1000h

- Gradual increase due to aging effects
- Triggered effect after a certain time
- Stable behavior as demanded
- IFX-TIM with improved performance
Convincing 3rd Party Results

Highly Accelerated EoL-Test

1000h Test $\triangleq$ 20 years of lifetime

End of life if 150°C is reached

Chip Temp. [°C]

Test time [h]

General Purpose Grease 1  General Purpose Grease 2  New IFX-TIM
Lifetime Considerations

• Predicted module lifetime relies on thermal performance stability
• Changes in junction temperature can lead to unexpected failures

At end of test, MOD-3 yielded $\Delta T_{vj}$ of 100K with predicted lifetime of $7.4 \times 10^4$ cycles

Improved TIM gave 30K reduction at end of test, for a predicted lifetime of $2.5 \times 10^5$ cycles
In House Thermal Testing

In Thermal Testing on LonGwin LW-9389

Casting a layer of material on a polymer film (release liner)
Dry in 125°C oven for 1 hour

Cutting to the testing size 2.54 cm² and peel of the release liner

Samples are ready for testing (0.195-0.120mm and 0.145-0.155mm)

LonGwin TIM tester
Starting thickness might affect thermal resistant at lower temperature and lower pressure.
It looks like the material reaches to the saturated point at the pressures from 552 to 690 kPa.
Lower starting thickness seems to have consistent thermal reaction; and at 70, 85, and 100°C, material shows same thermal resistant range.
Material shows same trend of melting rate and with corresponding thermal resistant. However, with thinner starting thickness seems transfer heat better.
Comparison of Bondline vs Start thickness

A Quick Look on Thermal Profile at 100°C Operating Temperature

With a starting thickness of 0.15mm, material can reach to the bond-line thickness of ~ 0.02mm at 100°C and 700kPa to have a thermal impedance of ~ 0.24 °C*cm²/W
Affects of bondline on Conductivity

Thermal Conductivity at Different Operating Temperatures

Sample thickness ~ 200µm, tested at different pressures 138, 276, & 552kPa (or 20, 40, and 80psi)

- At higher operating temperature (or high temperature makes material thinner with same operating press) Change in slope observed with higher temperature likely due to tighter packing of filler.
- At 55°C material is around at melting point which is not completely melt and forming a thicker bond-line range contributing to a thermal conductivity of 2.94 W/(m°C).
Conclusions regarding TIM

- Acceptable TIM performance on a CPU does not mean the same will be seen on an IGBT module

- Datasheet values may seem like a good indicator, but they do not eliminate proper verification in your actual application

- A dedicated, optimized thermal interface material outperforms general purpose solutions that are available to end users of power modules
Thank you!