Classifying and Understanding Thermal Interface Materials for Power LED Applications

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Selection of Thermal Interface Materials

- Large number of different types of TIMs available from more than 100 vendors.
- Many competing and similar materials
- Reasons:
  - Very large number of different types of applications
  - Used in categories of electronic components and electronic systems today
  - Very widely different requirements for:
    - Performance: thermal, EOL reliability, gap-filling, compliancy, temperature tolerance
    - Application process needs
    - Function: electrically-conducting, electrically non-conducting, sealing, adhesion or fastening hardware required, other
  - Very different cost tolerance for different applications
  - Dielectric materials for electrically-live semiconductors – a less-common requirement
  - Very different manufacturing process requirements, given the wide range of types of application requirements
  - Extended product life and reliability requirements for critical applications

Selection of Thermal Interface Materials

- *Maximum* performance is not the solitary method of selection for the "best" TIM.
- Performance *by what measure?*
  - The answer to this question is driven by the application requirements.
  - Choices: *thermal, electrical, dielectric, gap-filling, dispensable, EOL reliability, more…*
- What are the primary drivers for TIM material thermal performance as a very generalized statement?
  1. Clamping force applied: How much force is applied to a compliant form of TIM, to achieve the thinnest possible layer and maximum metal-to-metal contact.
  2. Surface wetting: To what degree does the TIM wet to the surfaces, to maximize heat transfer capability and eliminate all air pockets?
  3. Bulk thermal conductivity

For any one material type

- As a general statement, thermal conductivity is <u>one</u> of three primary drivers for performance for TIM materials.

Note that for some classes of TIM materials, the bulk thermal conductivity value can be quite low, including for many thermal pastes and similar compounds, as other properties are more important.

Thermal Interface Materials for Power LED Applications

- Why are TIM materials *in* particular important in LED lighting system thermal design?
  - Different type of light source and *direction of heat flow*
  - Different *heat dissipation characteristic inherent to the device*
  - Miniaturization of heat source *increases overall heat flux at the device level.*

Comparison of Light Source Technologies and Heat Loss Characteristics

Light Source Type	Heat Lost by Radiation %	Heat Lost by Convection %	Heat Lost by Conduction %
Incandescent	**> 90**	**< 5**	**< 5**
Fluorescent	**40**	**40**	**20**
High Intensity Discharge (HID)	**> 90**	**< 5**	**< 5**
LED	**< 5**	**< 5**	**> 90**

Source: J. Petroski, GELcore, "Cooling of High Brightness LEDs: Developments, Issues, and Challenges", RTI Next Generation Thermal Management Materials and Systems Conference, June 15-17, 2005

Thermal Interface Materials for Power LED Applications

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Thermal Interface Material General Outline for LED Array Applications

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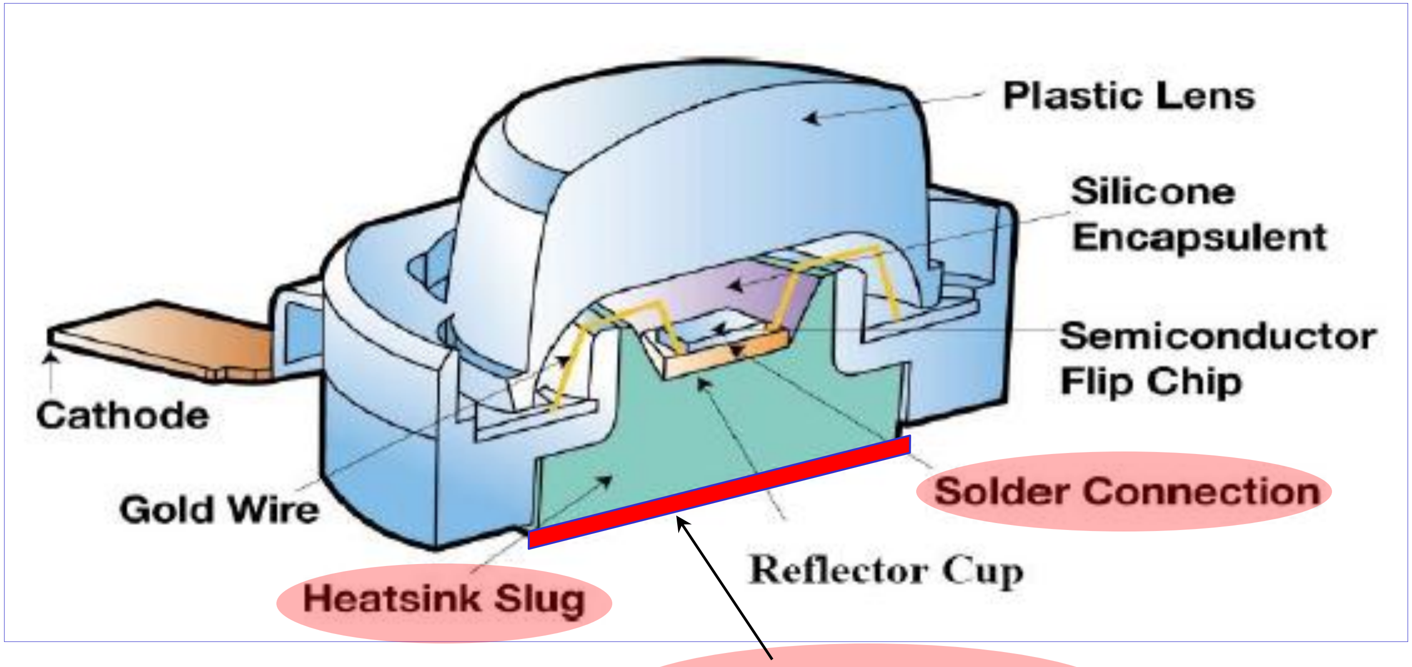
General Application Type	*Typical* TIM Materials Used	*Typical* Thickness Ranges
Attachment of LED array substrate to "heat sink slug"	**Solders, NanoFoil®**	0.05 - 0.10 mm (0.002" - 0.004")
Attachment of "heat sink slug" to finned heat sink	**Thermal Pastes, Non-Silicone Thermal Pastes, Non-Silicone Dry Thermal Paste Preforms**	0.0125 – 0.125 mm (0.0005" - 0.005")
Heat Sink to luminaire housing interior surface	**Gap-Fillers**	0.25 – 3.80 mm (0.010" - 0.150")
Heat Sink to heat pipe, other applications	**Thermally-Conductive Adhesives, Thermally-Conductive Cure-in-Place Compounds**	0.075- 0.63 mm (0.003" - 0.025")

Note: These are intended to be statements of typical usages by material type for these generalized application areas.

Thermal Interface Materials for Power LED Applications

- Packaging, electrical contacts, and thermal materials for a typical LED:



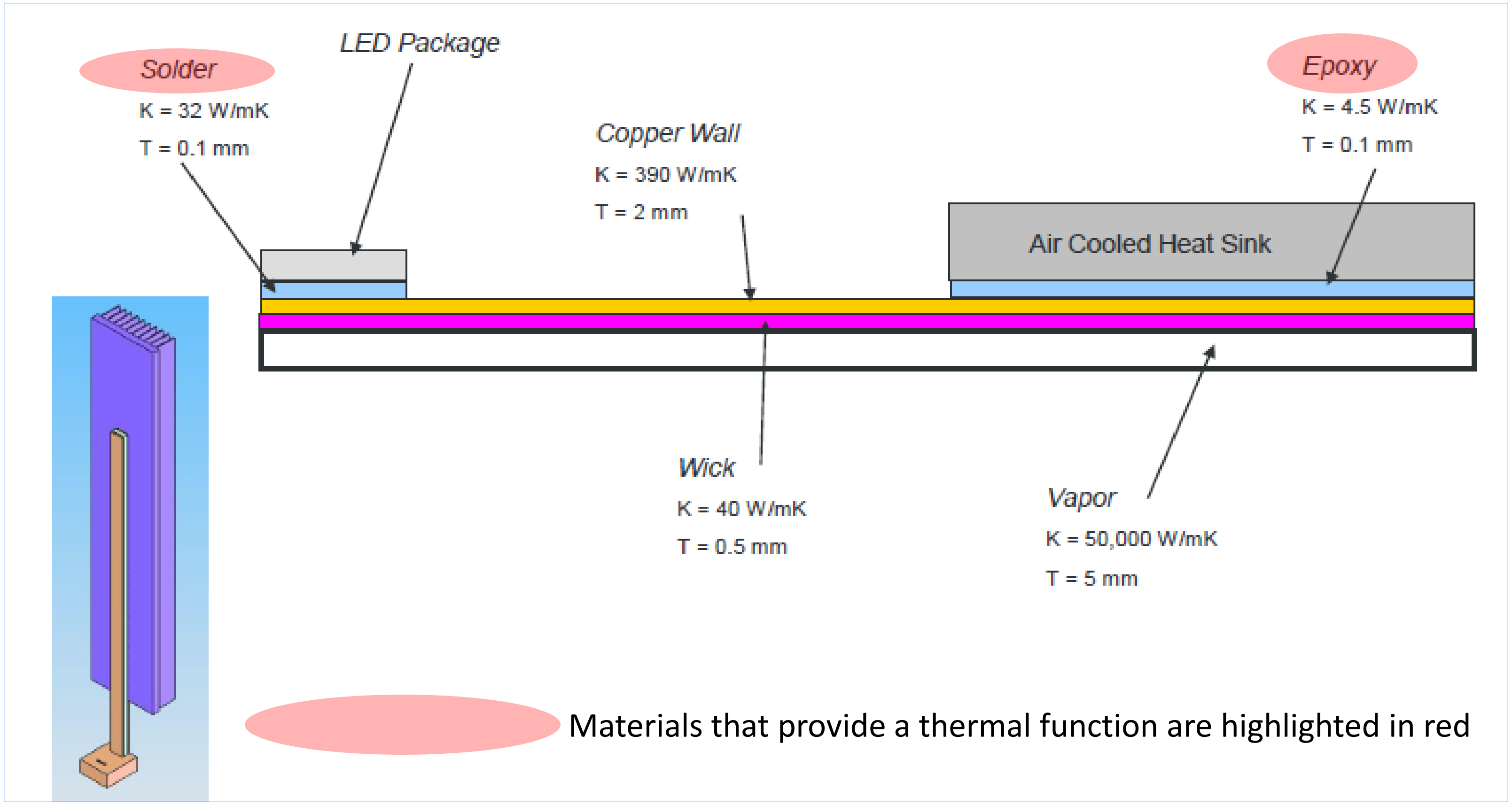
Thermal Interface Material (TIM2)

🟥 Materials that provide a thermal function are highlighted in red

Drawing: Philips Lumileds, with comments added.

Thermal Interface Materials for Power LED Applications

- Packaging, thermal materials, and heat pipe assembly for a Luminus Devices PhlatLight™ LED multichip module array for a large-screen HDTV display panel:



Materials that provide a thermal function are highlighted in red

Source: M.J. Denninger, Luminus Devices Inc., "A General Solution Framework for LED Thermal Designs", IMAPS 38th New England Symposium, Boxborough MA USA, May 8, 2008.

Thermal Interface Material Classification System

Intended use is as a method to classify and label major types of TIM materials:

- Purpose:
  - Improve understanding of major differences between types.
  - Distinguish most basic differences in material thickness, dispensability, and types of carriers:
    - *Thickness* (actually, minimum thickness) is a major determinant of thermal performance
    - *Application format* is an important difference for the assembly process:
      - Dispensable forms, such as thermal pastes, gels, some types of adhesives
      - Non-dispensable
    - *Dielectric versus non-dielectric* materials:
      - Dielectric carrier materials provide critical electrical isolation – and typically have significantly higher thermal resistance values because of the carrier material.
    - *Adhesive versus non-adhesive* materials:
      - Different formats (pre-forms, dispensed, or requiring retention fasteners)
      - Non-adhesive TIM materials require mechanical fastening of two components
      - Adhesive TIMs do not require mechanical fastening.

Thermal Interface Material Classification System

This system is intended to provide a method to classify and differentiate major TIM types:

- 11 TIM material classes, including the most common:
  - Traditional thermal pastes (also known as thermal compounds or thermal greases)
  - Adhesives, gels, and liquid forms
  - Pre-forms (pads) – *Often with very low bulk thermal conductivity, but extremely common in many different types of electronic systems, including automotive.*
- Recent developments:
  - Die attach adhesives with a high percentage of silver or other highly thermally conductive filler, typically used as a TIM1
  - Polymer-Solder Hybrids (“PSH”) combine a TIM compound with solder spheres
  - Metallic TIMs are available in several forms:
    - Low Melting-point Alloys (LMA)
    - Low melting point solders and shims and foils

      Indium shims for LDMOS RF power amplifier devices are an example.
  - Solders used as TIM1 are now recognized as functioning as a TIM:
    - Reflects reality in practice in electronics applications

      High volume reflowed indium TIM1 in microprocessors is an example.

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Thermal Interface Material Classification Outline

Table 1 of 2

Traditional TIM Material Classes

TIM Material Class	Typical Thickness Ranges	Important Subcategories	Available Reinforcing Carriers
Elastomeric Pads and Insulators	0.076 - 0.76mm (0.003" to 0.030")	**Non-Dielectric, Dielectric**	**Fiberglass Aluminum Foil Kapton**
Pressure-Sensitive Adhesives *(PSA)*,Thermally-Conductive	0.127 - 0.381mm (0.005" - 0.015")	**Non-Dielectric, Dielectric**	**Free Film Fiberglass Aluminum Foil Expanded Aluminum Kapton**
Phase-Change Materials *(PCTIM, PCM)*	0.012 - 0.254mm (0.0005" - 0.010")	**Non-Dielectric, Dielectric**	**Free Film Fiberglass Aluminum Foil Expanded Aluminum Kapton**
Gap-Fillers	0.254 - 7.62 mm (0.010" - 0.300") *(Pre-assembly thickness)*	**Film, Molded Components**	**Internal Fiberglass External Fiberglass Polyester Aluminum Foil Molded Components**
Cure-in-Place Compounds, Thermally-Conductive	N/A		**N/A**
Thermal Compounds (*Thermal Pastes, Thermal Greases)*	0.0127 - 0.127mm (0.0005" - 0.005") *(Post-assembly thickness)*	**Silicone-based, Silicone-Free**	**N/A**
Thermally-Conductive Adhesives (Dispensed)	0.0762 - 0.635mm (0.003" - 0.025")		**N/A**

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Thermal Interface Material Classification Outline

Table 2 of 2

Recent Material Development Classes and Non-Traditional Material Classes

TIM Material Class	Typical Thickness Ranges	Important Subcategories	Available Reinforcing Carriers
Die-Attach Adhesives, Highly Filled	0.051 - 1.02mm (0.002" - 0.04")	--	**None**
Liquid-Metal Alloys; Low Melting Point Metal Preforms	0.05 - 0.20mm (0.002" - 0.008")	**Preforms, Shims, Liquid Metal (RT)**	**N/A**
Polymer-Solder Hybrids *(PSH)*	0.05 - 0.20mm (0.002" - 0.008")	--	**N/A**
Solder TIMs (Reflowed, typically as TIM1)	0.05 - 0.31mm (0.002" - 0.012")	**Lead-Free, Lead-Containing**	**N/A**

Thermal Interface Materials – Why Is There a Need for New TIMs?

- Most basic TIM material: thermal greases
  - Oldest and most common TIM, available globally from many suppliers, many formulae
  - Many thermal pastes are perceived as very low in cost
  - Some high performance thermal pastes are significantly more expensive
- Power semiconductor market has traditionally used thermal pastes
  - More than fifty years of experience worldwide with silicone oil-based thermal pastes
  - Application process is typically messy, manual, and uncontrolled
  - Traditionally disliked material at OEM assembly point
  - Major disadvantages of thermal pastes have driven decades of product development for pad forms of TIMs:
    - Pad forms simplify the application process
    - Provide a known thickness of TIM material, in place of uncontrolled manual application
    - Eliminate material waste with a pad form of specific size and outline
    - Eliminate mounting and fastener applications driven by silicone-based thermal greases.
  - Phase-change TIMs were developed and commercialized in 1984 specifically to replace thermal greases for IGBT power semiconductor modules.

Note: References to specific manufacturers of materials and testing equipment and to specific TIM materials is not intended to be an endorsement of any kind. Such information on materials is provided only as examples of material types that are commercially available in different TIM material categories.

Thermal Interface Materials – Why Is There a Need for New TIMs?

- Disadvantages of thermal greases have led to parallel development paths in power semiconductor market:
  1. Continued development of silicone-based and non-silicone thermal greases
     - Attempts to address pump-out and migration reliability problems
     - Development of specific patterns of thermal paste application by IGBT module manufacturers (e.g., Semikron, Infineon)
     - Automation of application process with screen printing, other processes.
  2. Rapid development of newer <u>pad forms</u> of alternative TIM materials:
     - Phase-change TIMs in pad forms
     - Phase-change TIMs in ingot form for automated screen printing processes
     - Dielectric phase-change TIMs for non-isolated semiconductor packages
     - Non-silicone-based “dry” thermal greases in pad forms
     - Polymer-solder hybrids
     - Metallic TIMs in pad form
  3. Development of non-silicone oil thermal pastes and metallic TIMs to eliminate oils.
- Increasing operating temperatures of semiconductor die is another factor driving temperature requirements for TIM2.

Importance of Thermal Conductivity

- Is thermal conductivity of a given material the only measure of overall thermal performance?
    - Three major factors determine overall thermal performance of a category of materials:
        - Material thickness
        - Percent of surface wetting achieved
        - Thermal conductivity
    - The highest thermal conductivity value achievable does not necessarily imply a TIM material with the best overall performance.
    - Different application requirements drive different material design and chemistries:
        - Example 1: Gap fillers are by definition very thick, as the primary purpose is to fill a very large air gap between two components:
            - Example: Top surface of a heat dissipating component in an LED luminaire “can”.
            - Gap may be 0.040”, limited clamping force
            - Only a gap-filler can meet this requirement, with a relatively dense polymeric material of modest thermal conductivity – no grease, gel, or phase-change.
            - Compressibility requirement for a limited clamping force over a large area can limit the percentage of high-conductivity filler
            - Result is a very suitable gap-filler TIM with only modest thermal conductivity.

Importance of Thermal Conductivity

- Is thermal conductivity of a given material the only measure of overall thermal performance?
  - Different application requirements drive different material design and chemistries:
    - Example 2: Phase-change compounds and PSHs function by limiting the thickness <u>under applied clamping force</u> to achieve:
      - Minimum possible thickness under highest available clamping force;
      - Maximum percentage surface wetting
      - Compound can be handled at room temperature for positioning and placement
      - Compound undergoes a phase-change transition at a designed temperature (e.g., 60°C) to a liquidus form
      - Compound formulation is designed to prevent compound run-out at temperature.
    - Example 3: Die-attach adhesives, highly-filled, used as TIM1:
      - High relative percentage of silver filler used to increase overall thermal conductivity
      - Metallic filler content may be required to achieve specified electrical conductivity
      - <u>Limit on filler percentage</u> is driven by requirements for paste dispensing and stiffness and CTE mismatch requirements within finished semiconductor package.
      - Filler percentage determines overall TIM1 thermal conductivity.

Thermal Conductivity Comparison

Relative thermal conductivity for common thermal management materials:

Material	Thermal Conductivity (W/mK) or Apparent Thermal Conductivity*
Copper (for reference)	385
Indium and other metallic TIMs	86
LMA (Liquid Metal Alloy)	20
Thermal Pastes	0.3 – 7.0
Phase-Change Compounds and PSHs	0.3 – 1.0 (typical) [Carrier (if present): 75]

* Certain pre-form materials contain an aluminum or other metallic foil carrier with compound coating on one or both surfaces.

TIM Material Categories

Solders: Direct Die Solder Attach

- Indium alloy solders are now used for high-volume TIM1 applications for server processors and processors:
  - Highly compliant for CTE matching with current copper lids for processors on organic substrates
  - Direct contact to back-side metallization (BSM) on silicon die
  - Relatively high thickness to compensate for package variation and CTE mismatch
  - Well-characterized material applied in automated processes with surrounding IP
  - Highly specific to application
- Cost and assembly process requirements may suggest that these materials are most useful in:
  - High-volume high power LED applications where process automation can be justified.
  - Very specialized power LED market applications where maximum thermal performance is required through a materials stack.

Solders: RNT Technologies

- Recently-announced materials and process development for unique metal joining process as TIM1 solder material:
    - Fluxless, lead-free joining process.
    - Joining achieved with lead-free Indium solders at room temperature using reactive multilayer foils.
    - Activation process between solder layers generated heat via a reaction within the foil.
    - Localized heat of reaction melts solder to form bond.
    - Appropriate for silicon-to-metal joining as TIM1.
    - With or without gold plating requirement.
    - Low interface thermal resistances achieved.
- Average bond line thickness achieved of 170 microns.
- Thermal impedance achieved (120 micron BLT): 0.040°C-cm^2/W

Source: RNT Technologies

Liquid Metal Alloys (LMAs)

- Significant IP developed in this area by several companies.
- Initial product offered by Thermagon in 2001 as T-LMA™
- Principal constituent alloys include bismuth-tin-indium and similar
- Phase-change at temperature, pressure.
- Suppliers include:
  - Bergquist Company
  - Laird (Thermagon, Warth)
  - Others
- Performance indicates best alternative to solder attach (DDSA) process for TIM1.
  - Refer to slides following for relative test performance comparison among LMA materials and near-metallic TIMs.
  - Refer to references for additional information.

Polymer Solder Hybrids (PSH)

- Polymer carrier with metal alloy solder spheres
  - "Dual-temperature" phase-change concept
    1. Phase-change polymeric carrier design-point temperature
    2. Metal alloy solder sphere temperature
  - Particle size, matrix, percolation performance the subject of several recent papers.
  - Should be considered to be an electrically-conductive TIM.
  - Several suppliers, including:
    - Bergquist Company
    - Parker Chomerics
    - Henkel Technologies
    - Laird (Thermagon)
    - Shin-Etsu
  - Developments include utilization of sub-micron particle sizes.

Die-Attach Adhesives

- Silver-filled polymeric adhesives developed primarily for die attach
- Selected DA are used as TIM1 (silicon die to package lid or other component)
- Multiple existing vendors:
  - Henkel Technologies (Ablestik and Emerson & Cuming)
  - QMI
  - DieMat Inc. (Rowley MA USA):
    - Acquired by Namics (Japan) in February 2008.
  - Others

Gels

- Cross-linked polymers requiring temperature-activated cure:
    - Example: Lord Thermoset Gelease™ family
    - Not common for LED applications

System	Filler Type	Viscosity	Thixotropic Index	Thermal Impedance (°C-cm2/W)
Gelease A	Mineral	400,000	4.4	0.77
Gelease B	Metal	57,000	4.0	0.58
Gelease C	Metal	61,000	3.6	0.39

Note Gelease is a trademark of Lord Corporation

Thermal Greases

- Most traditional TIM material:
  - Silicone-based paste format with a variety of fillers
  - Typically applied in manual application or semi-automated process
  - High-volume screen printing applications
- Typically viewed as lowest-cost TIM material of any kind.
- Referred to generally as “thermal paste”, “thermal compound”, “thermal grease”.
- User costing typically does not account for waste, clean-up, labor cost for application:
  - Low material cost does not accurately describe total applied cost.
  - Makes accurate cost comparisons to alternative TIM materials difficult.
  - Bond line thickness generally predominates in thermal impedance performance, not filler material conductivity.
  - Filler particle size is generally more critical than filler conductivity.
  - High thermal conductivity fillers may result in higher thermal impedance, not lower.[1]
  - Development of a material with greatest ease of application may outweigh thermal impedance performance as the primary development target for many TIM2 applications.
    - Example: AOS MicroFaze™ dry pad form, supplied on rolls for rapid application.

[1] *Source: Prasher, Intel ATD, “Thermal Resistance of Particle-Laden Polymeric Thermal Interface Materials”, ITS 2003*

Thermal Greases

- Large number of vendors worldwide
  - Shin-Etsu G-749, G-751: commonly referenced in North America for processors
  - Shin-Etsu SMX-7762, SMX-7783D: highest performance, high cost
  - Laird (Thermagon) T-Grease 2500
  - AOS:
    - 52137: Non-silicone thermal compound
    - MicroFaze® 3A4: Non-silicone dry pad form of thermal compound
  - Bergquist TIC-7500: highest thermal conductivity value(7.0W/mK) claimed for any thermal grease
  - Bergquist TIC-2500: thermal conductivity (2.5W/mK)
  - Bergquist TIC-1000
  - Dow Corning:
    - DC-340: Traditional market leader for older discretepower transistor applications
    - DC-5021, D-5022, D-5026
  - Electrolube HTC
  - Wacker Chemie P12

Phase-Change Materials (PCTIM)

- Phase-change TIMs (PCTIMs): Polymeric compound changes phase from a solid to a liquid at a design point temperature (typically 51°C or 60°C).
- Many TIM vendors now offer phase-change materials in pad forms
  - Designed to simply assembly practices
  - Eliminate traditional problems with silicone thermal greases
  - Well-accepted by manufacturing and process control for:
    - Ease of use in assembly, for either manual or automated placement.
    - Pre-determined volume of compound in pad form, pre-determined bond line thickness.
- Screen-printable dry format phase-change TIMs are excellent high-volume TIM2 materials:
  - Low-cost, automated process that is very suitable for power LED applications
  - High-performance phase-change compounds
  - Available from several vendors:
    - Henkel Powerstrate 51F
    - Honeywell Electronic Materials PCM-45F

Elastomeric and Dielectric Pads

- Offered by dozens of TIM vendors and resellers worldwide.
- Intensely price competitive.
- Application requirements are much simplified (compared to greases, gels, LMAs, other TIM material categories).
- Minimum performance in many thicker elastomeric pads
- Primary cost factor is cost of conversion, not cost of material production.
- Dielectric pads have a major reliability and liability component:
  - So-called “cut-through” for sharp particle protrusion into dielectric carrier such as Dupont® Kapton™ or KaptonMT™.
    - Cost of dielectric carrier materials impacts overall TIM cost.
  - UL/CSA certifications are critical – primarily referencing DuPont Kapton UL “yellow card”.

Kapton™ and Kapton MT™ are trademarks of Dupont

Pressure-Sensitive Adhesives (PSAs)

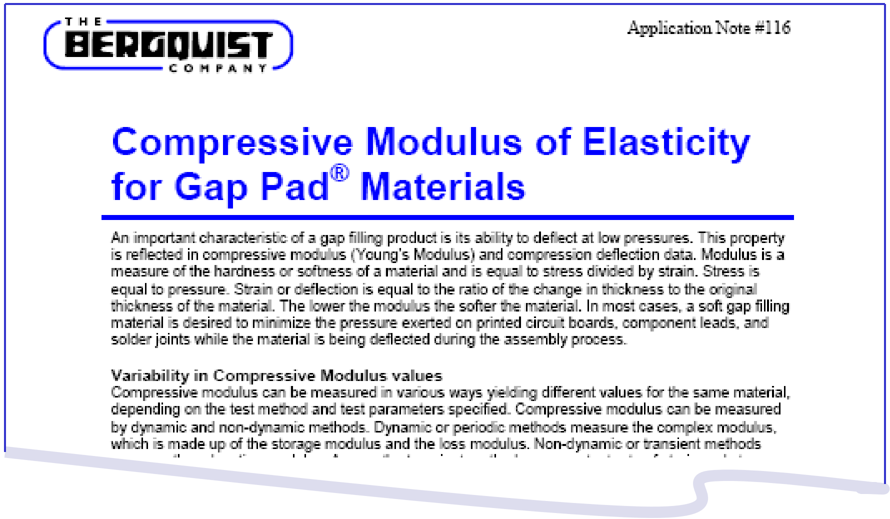
- Typically supplied as a pre-form on rolls, with release liner
- Many existing vendors
- Many performance levels for existing materials
- Application requirements are simplified.
- Presence of an adhesive coating on one or both sides severely impacts thermal impedance:
  - Primary purpose is to simply an assembly process, not maximize thermal impedance.
  - Adhesive coating eliminates need for mechanical clamping, the key factor for use.

Gap-Fillers

- General statements:
  - Purpose of these materials is to fill a large air gap between a heat source and a convenient metal surface
  - Relative high thickness precludes high performance relative to phase-change, thermal greases, LMAs, PSHs:
    - Many materials available with modest thermal performance.
    - Compressibility is an important determinant in material selection for a given application
    - Surfaces of gap-fillers may be tacky, to reduce interfacial resistance.
    - Protection of surfaces with release liners prior to application is important to prevent dust, particulate accumulation.
- Application requirements are specific to individual material types.
- Very common for power LED applications:
  - Luminaire lighting fixtures: heat transfer from LED baseplate to luminaire “can” for heat transfer to ambient air
  - Very commonly used as TIM2 for projector light sources and other power LED applications.

Gap-Fillers

- Compressibility is a key characteristic of gap-filler:
  - Ability to deflect at low pressures
  - Minimum pressure is important
  - Relative high thermal conductivity is important because of the relatively thick nature of a gap-filler
  - Young’s Modulus of material is strongly affected by use of a high percentage of the high thermal conductivity filler constituent.
- Review compressibility information provided by vendors for details
  - Example: Bergquist Company Application Note 116:



THE BERGQUIST COMPANY

Application Note #116

Compressive Modulus of Elasticity for Gap Pad® Materials

An important characteristic of a gap filling product is its ability to deflect at low pressures. This property is reflected in compressive modulus (Young's Modulus) and compression deflection data. Modulus is a measure of the hardness or softness of a material and is equal to stress divided by strain. Stress is equal to pressure. Strain or deflection is equal to the ratio of the change in thickness to the original thickness of the material. The lower the modulus the softer the material. In most cases, a soft gap filling material is desired to minimize the pressure exerted on printed circuit boards, component leads, and solder joints while the material is being deflected during the assembly process.

Variability in Compressive Modulus values

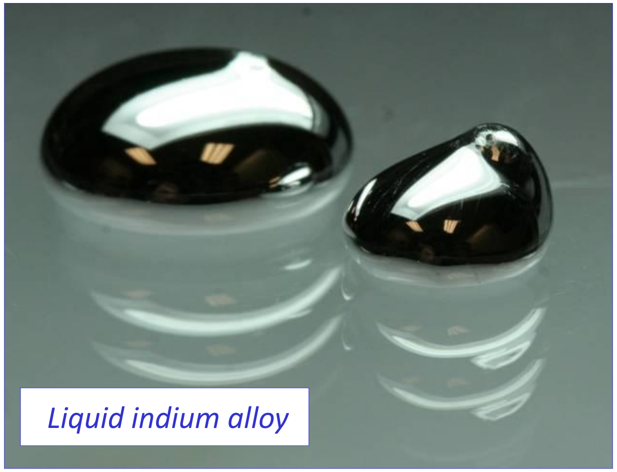
Compressive modulus can be measured in various ways yielding different values for the same material, depending on the test method and test parameters specified. Compressive modulus can be measured by dynamic and non-dynamic methods. Dynamic or periodic methods measure the complex modulus, which is made up of the storage modulus and the loss modulus. Non-dynamic or transient methods

Nanomaterials

- Nanotechnologies and nanomaterials applied to TIMs:
  - Substantial public discussion of nanomaterials for TIM and thermal applications over 2003 – 2009.
  - Few materials commercialized to date.
- Many university and research development programs to evaluate forms of nanomaterials which may offer:
  - High thermal conductivity as stand-alone TIM materials in various forms
  - Use of nanomaterials as high thermal conductivity constituents in TIM materials such as thermal greases and compounds.
- Current US programs to develop significant improvements in TIM material performance:
  - Three programs are utilizing arrays of carbon nanotubes grown on a carrier with a liquid metal or metal infiltration
  - One program utilizing large number of micro copper springs
  - Performance results currently equal to existing metallic TIM materials and reflowed indium solders.
  - Manufacturability continues to be a major challenge, as is testing equipment resolution.

Liquid Metal Alloys

- Commercial LMA products:
  - Designed with retention mechanism as a pad form of material. Examples:
    - Enerdyne Solutions Indigo™
    - Indium Corporation Indalloy 19 – applied in solid form, phase-change at 60°C
    - Others
  - Liquid metals, designed for phase-change at 10°C:
    - Indium Corporation Indalloy 51
    - Indium Corporation Indalloy 46L
    - Gallium
    - Thermal conductivities to 86W-mK
    - Proprietary retention mechanism available



Liquid indium alloy

Photograph: Indium Corporation

Metallic Thermal Interface Materials

- Soft metal alloys (“SMA-TIM”):
  - Flat foils and preforms used as TIM2:
    - Typical products used in many traditional applications
    - Referred to historically as “solder shims” in RF device applications for RF amplifiers
    - Traditional flat foils
    - Available in flat sheet form, flat sheet preforms, preform “window frames”
  - Indium Corporation Heat-Spring®
    - Compressible metallic TIM materials
    - Available in die-cut preforms
    - Available in several versions and several thicknesses
- Advantages:
  - Stability – No silicone oils, no bake-out or pump-out issues
  - High thermal conductivity and low bulk resistance—less sensitive to thickness change
  - High X-Y heat spreading capability as a metal
  - Inherent gap-filling capability for co-planarity issues: +/- 75um
  - Complies with CTE mismatch for different substrates and heat sink materials

Heat-Spring® is a registered mark of Indium Corporation

TIM Material Performance Testing Procedures

Categories and Purposes for TIM Material Performance Testing

- Three major categories of TIM test methodologies:
  1. Laboratory tools designed specifically to provide comparative data with control over individual performance determinants and all variables:
     - Clamping force
     - Surface finish, flatness, parallelism
     - Power input per unit area
     - Thickness
     - Ambient temperature
     - All other variables removed
     - ASTM D 5470-06 and transient test equipment types.
     - Most custom test stands follow a calorimeter principal, similar to ASTM D 5470-06
  2. Thermal test vehicles specifically designed to provide in-situ application results:
     - Typically designed for single high-volume microprocessor package or power device.
     - Many variables enter into test parameters.
     - TTVs are typically only available as highly-specialized packages, custom designed by an OEM or IC manufacturer for in-house use in a tightly-controlled environment.
     - TTVs are typically not available commercially.
  3. Transient and dynamic test techniques
     - Very accurate, high repeatability in–situ testing

1. ASTM D 5470-06

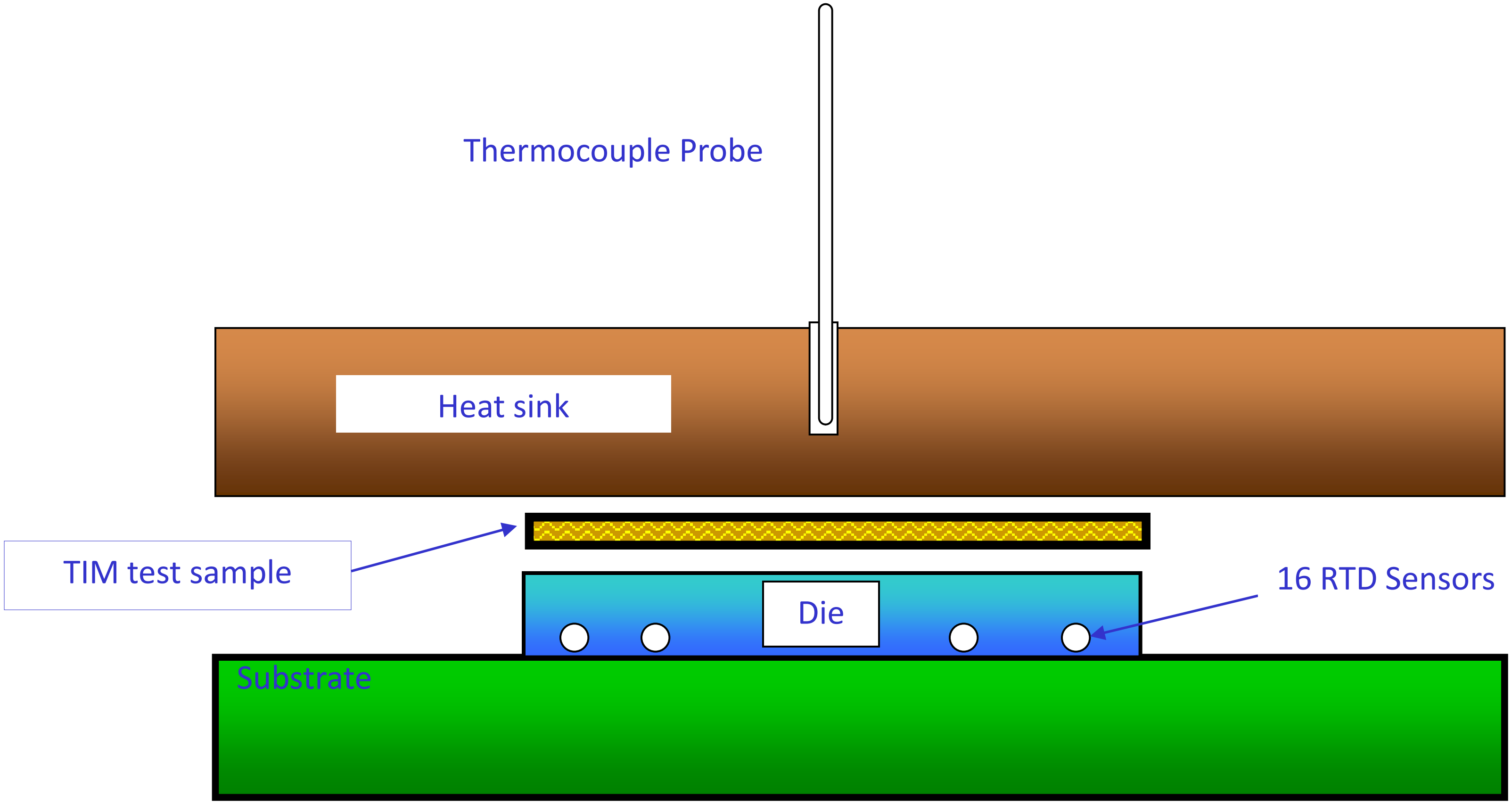
- ASTM D 5470 was developed and published in 1984.
- Primary authors (both now retired):
  - Mike DeSorgo, Parker Chomerics, USA
  - Herb Fick, The Bergquist Company, USA
- Newest methodology revision released in 2006 as ASTM D 5470-06.
- Source: ASTM International, West Conshohocken PA USA

  Website: **www.astm.org**
  Email inquiries: **service@astm.org**
- Primary intended purpose:
  - Thermal impedance and thermal conductivity test methodology for use with rigid and semi-rigid thermal interface materials (electrically insulating and non-insulating).
  - Latest modifications address testing for non-rigid materials (i.e., PCTIMs, greases).
- Use of a test stand designed to follow latest revision (ASTM D 5470-06) for many materials requires modification of test stand:
  - Mechanism to measure sample thickness under pressure.
  - Containment systems for liquidous and other non-rigid, non-uniform materials.
- ASTM D 5470-06 is a test methodology using the calorimeter principle.

1. ASTM D 5470-06

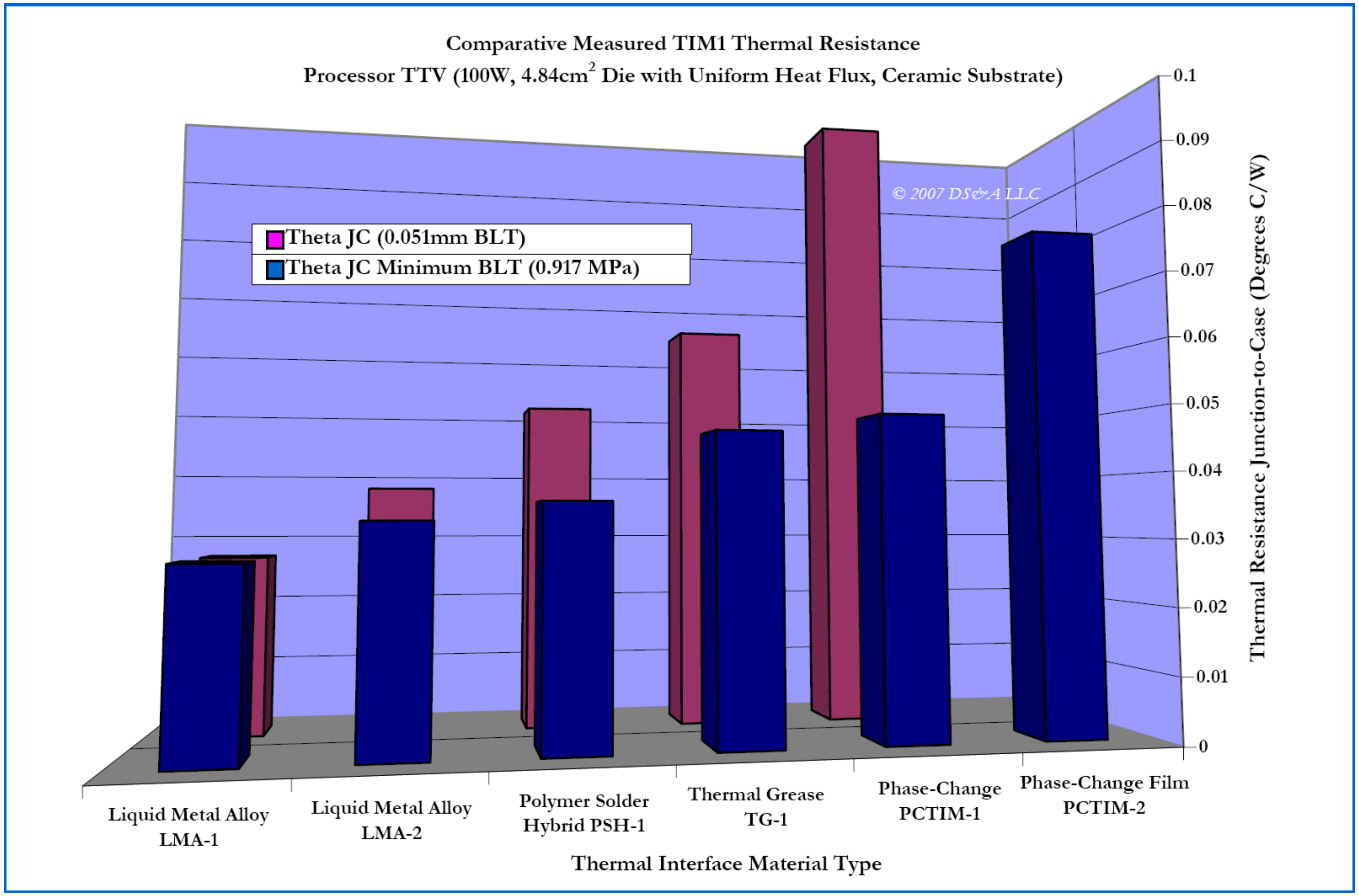
- ASTM D 5470 does not attempt to describe specific details of test stand construction, such as:
  - Thickness measurement equipment
  - Test head material, finish, flatness
  - Data collection system
  - Measurement of heat loss, not transmitted through specimen material.
  - Mechanical or pneumatic press for application of clamping force.
- This point is often not well-understood by users of TIM material data sheet values and, in fact, by some users of D 5470-06 test stands.
- Insulation and guard heater is suggested; use of insulation on RTDs, RTD lead wires, other test head components is not specifically proscribed.
- Variations in comparability and repeatability of test results are driven by:
  - Variation in test system design from company to company
  - Inappropriate modifications to meet requirements for heat path insulation, material thickness.
  - User knowledge and understanding of test stand use and calculation requirements.

2. Thermal Test Vehicle (TTV) Configuration



2. Thermal Test Vehicles (TTVs) for Precision In-Situ Testing

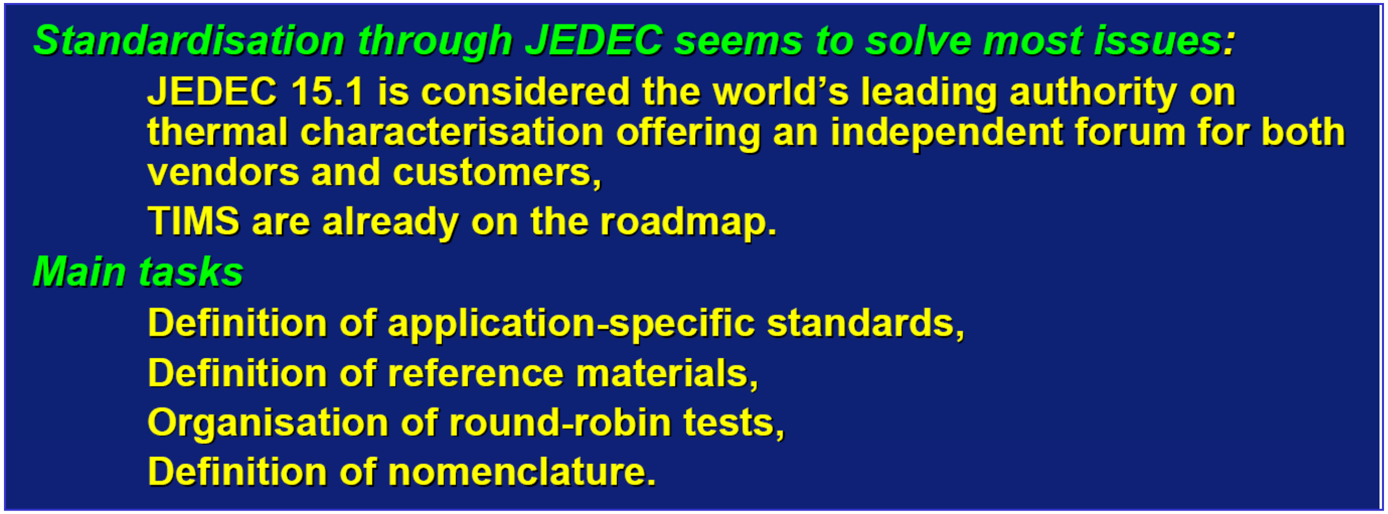
- Comparative results for recent high performance TIM materials – increased pressure:



Source: DS&A LLC (2007, 2010)

3. Development of Dynamic and Transient Test Methodologies

- Descriptions of reasoning and goals provided in Electronics Cooling Magazine (November 2003).
- Proposed by Clemens Lasance as a function of JEDEC JC15.1 committee:



Standardisation through JEDEC seems to solve most issues:

JEDEC 15.1 is considered the world's leading authority on thermal characterisation offering an independent forum for both vendors and customers,

TIMS are already on the roadmap.

Main tasks

Definition of application-specific standards,

Definition of reference materials,

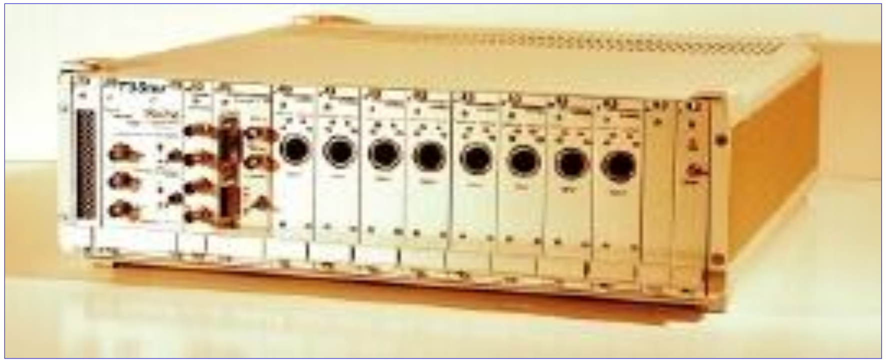
Organisation of round-robin tests,

Definition of nomenclature.

Source: C. Lasance, C.T. Murray, D. Saums, M. Rencz, "Challenges in Thermal Interface Material Testing", Proceedings of IEEE 22nd Semitherm Conference, Dallas TX USA, March 13-15, 2006.

3. Transient Testing Techniques for In-Situ Testing

- Transient testing techniques for thermal interface material testing measure temperature increases as a function of time:
  - Utilizes temperature sensors in a fixture
  - Thermal transient of the fixture is measured
  - Mathematical computations referred to as structure functions
  - Cumulative structure function yields the sum of thermal capacitances.
  - Changes in slope represent either specific material or increase in cross-sectional area, or both.
  - Thermal resistance value derived from slope for TIM specimen
  - Thermal conductivity value is proportional to slope.
  - Output from system can be:
    - Thermal resistance and impedance
    - Thermal conductivity
- Extremely capable test instrument, useful for package characterization.
- PowerLED test module available.



MicReD Ltd. T3ster™ Transient Tester System Unit

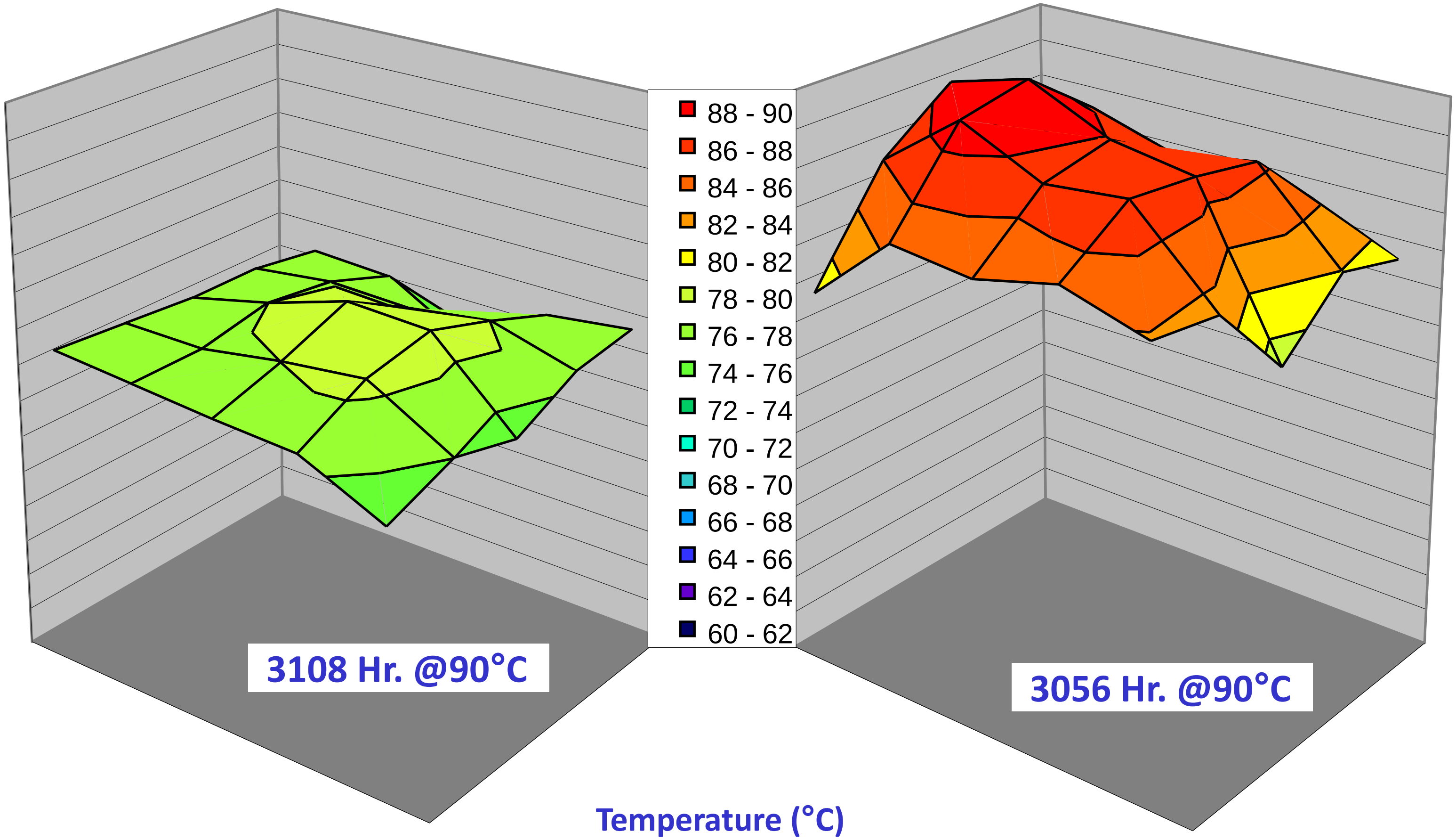
Photograph: MicReD Ltd. (Mentor Graphics), Budapest, Hungary

TIM Material Life and Reliability Testing

Why is Life Testing Important?

- Thermal resistance performance over time, temperature, and CTE expansion/contraction is critical to performance of very thin TIM materials.
- Traditional problems with silicone-based thermal greases are well-documented:
  - “Pump-out” in thermal and power cycling
  - Migration of silicone oils, causing dry-out
- Newer material developments continue to target these traditional problems.
- Example of results shown (next page):
  - Compressible metallic TIM comparison to silicone thermal grease
  - In-situ application test using microprocessor TTV (silicon die backside surface to heat sink surface)
  - 3,000-hour bake test in clamped condition

TTV Profile Comparison: Bake 3000 Hours



SMA-TIM

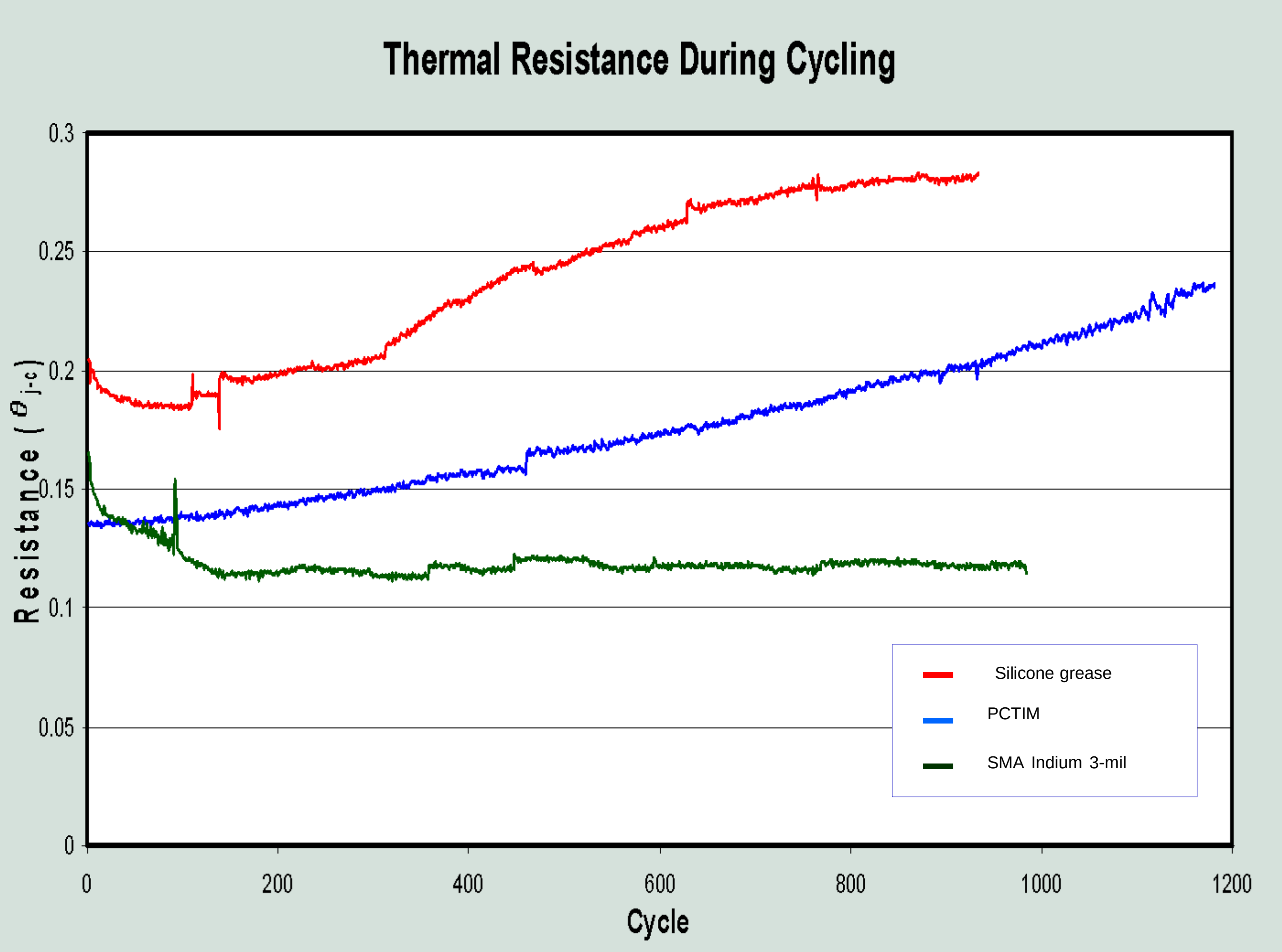
Baseline Grease

Data source: Indium Corporation

End of Line Performance

- End of Line Thermal Resistance
  - TTV testing
    - Assembly repeatability (variability in TTV)
    - Thermal profiling and uniformity
    - Performance against baseline thermal grease
  - In-situ testing – replicate exact applications conditions:
    - Assembly repeatability
    - Performance against baseline thermal grease or other qualified TIM

Power Cycling Test Results: 3-Mil SMA vs. Thermal Grease, PCTIM



Data source: Indium Corporation

Thermal Test Equipment Vendors

Analysis Tech
John Sofia, President
Wakefield MA USA

Thermal Impedance Test Stand

MicReD Ltd.
Subsidiary of Mentor Graphics Corporation
Budapest, Hungary
Marta Rencz, CEO
Gabor Farkas, Technical Director:
Web: www.micred.com

Transient Thermal Impedance Test Instrument
MicReD T3str™ TIM Test Stand

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Email: farkas@micred.com

Thermal Engineering Associates, Inc.
Bernie Siegal, President
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Web: www.thermengr.com

Thermal Impedance Test Stand

Email: bsiegal@thermengr.com

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