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Thermal Interface Materials and Testing Methods for Semiconductor Test

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Overview: Thermal Interface Materials

A. Thermal interface materials (TIM) are critical for adequate heat transfer: semiconductor to environment.

- Function is to transfer heat across an interface between a heat source and a heat sink or cold plate.
- Testing and evaluation of TIMs is critical to proper selection for a specific application.
- Thousands of different TIM materials to choose from, for widely varied application requirements.

B. Basic application steps:

1. Determine TIM type required:
   a) Mechanical fasteners for attachment, or adhesive?
   b) Electrically isolating or other atypical requirement?
2. Does the TIM selected meet the required thermal resistance value? Assembly process? Shipping?
3. Suitable for semiconductor test -- the *most challenging application requirements for TIMs are found in semiconductor test*.
4. Does the TIM selected meet product life, reliability, and cost requirements?

C. Recent Developments in TIMs

Importance of Thermal Resistance: Power Semiconductor Example

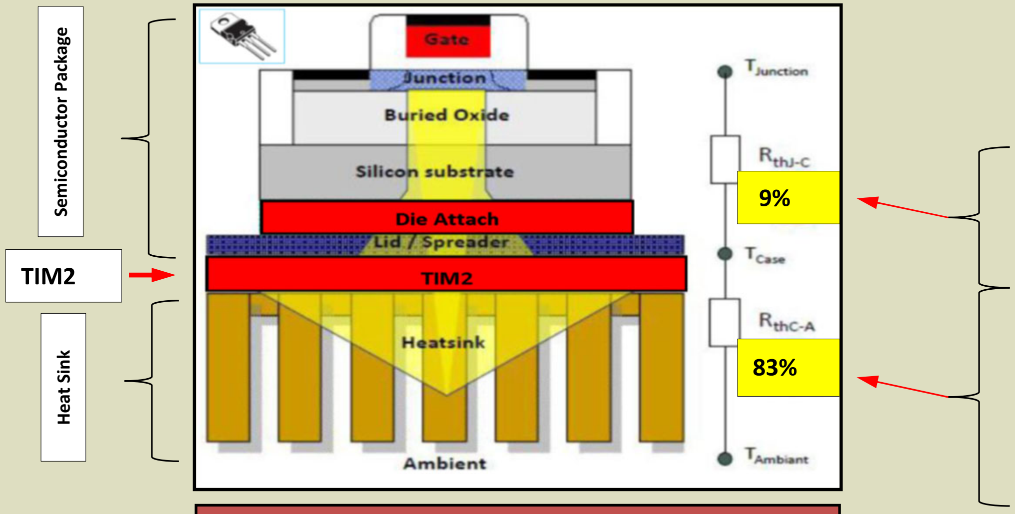
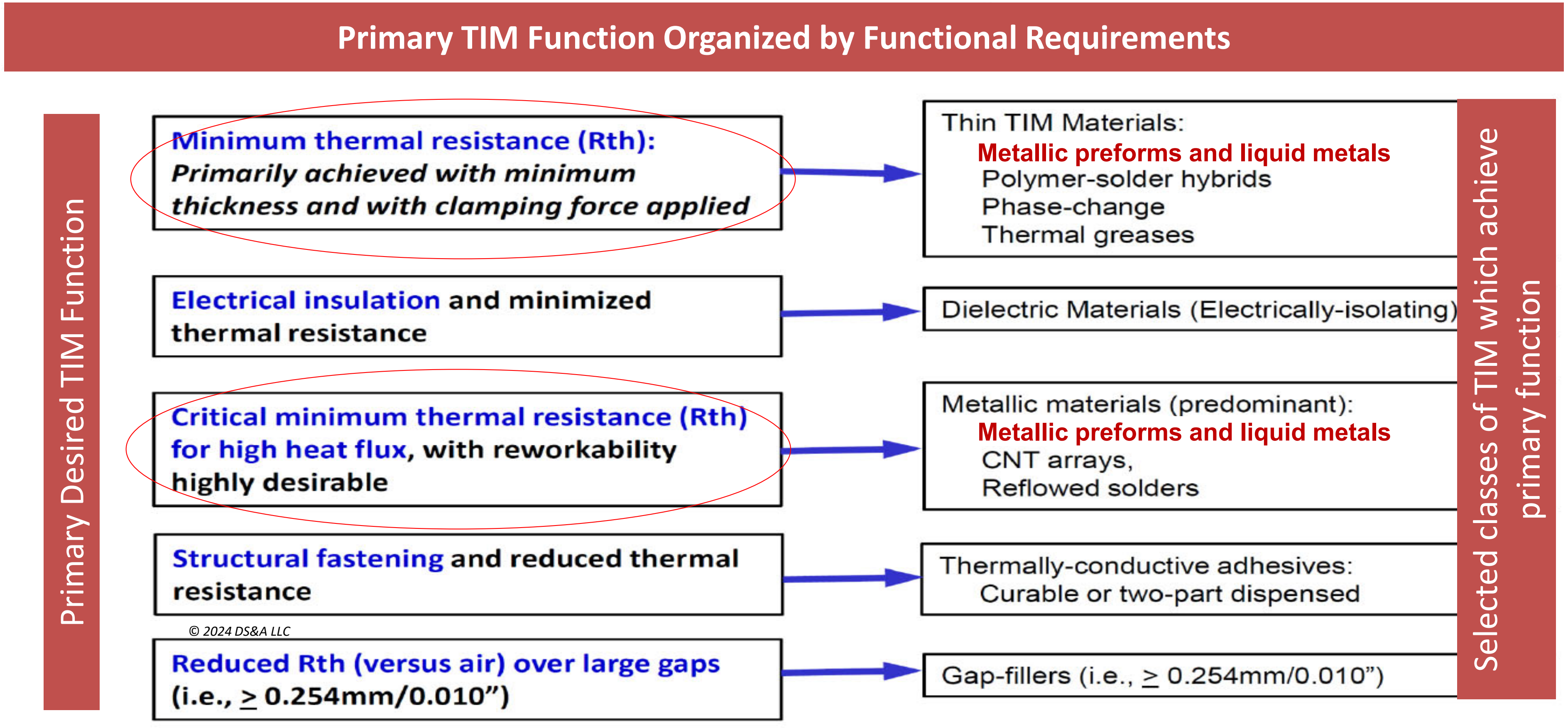


Figure 2 – TO-220 Thermal Resistance Stack

Empirical Analysis, TO-220 Package Materials Thermal Resistance Contribution			
Material Layer	BLT (µm)	λ (W/mK)	Percent of Total (%)
Die (Si)	100	150	6
Die Attach (Solder)	20	50	3
Substrate (Cu)	200	380	2
TIM2 (Thermal Grease)	100	5	71
Heat Sink (Al)	2000	180	10
Other	-	-	8
Total	-	-	100

Data Source: Berliner Nanotest und Design GmbH (Germany). Used with permission.

Thermal Interface Materials: Function Identification and Matching



Thermal Interface Materials: Functions and Terminology

Proper use of terminology is important:

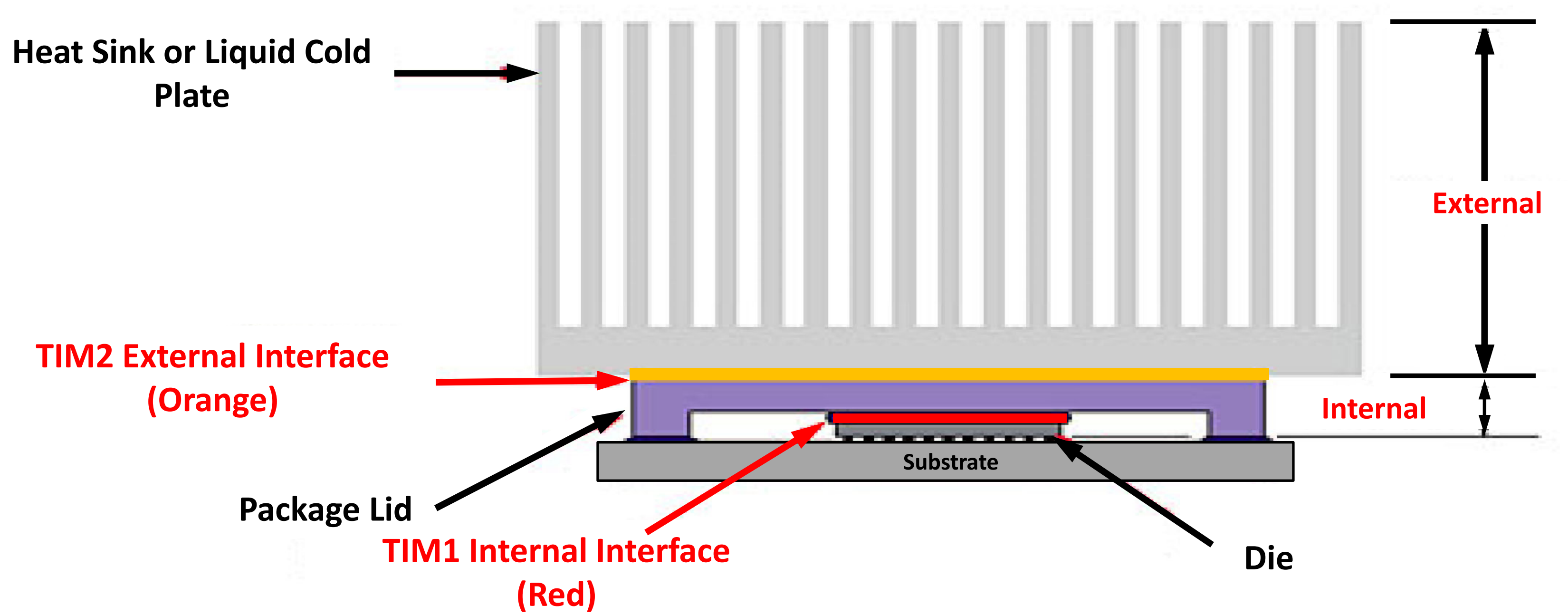
- Intel/AMD use of *reflowed indium solders* for TIM1 (within the semiconductor package) is a separate category of TIM application.
  - The term "Solder TIM (STIM)" is only appropriate to these specific uses.
  - The term "Solder TIM" is *not appropriate* for use in other TIM applications and only creates confusion, as a reflowed solder will require a retention mechanism.
  - A *Solder TIM* is distinct and has different requirements than a *liquid metal* TIM.
- Die attach materials are for die attach and are *not* categorized as TIMs.
  - A very small percentage of die attach materials have been used within packages as a TIM1.
  - Some academics have confused *die attach* in the EU as TIM1 – incorrect.
- All TIM applications *external to the semiconductor package* are what is termed as "TIM2" in industry.

Note: All solders and die attach materials generally have thermal characteristics and provide a heat flow path -- but are not considered in the general terminology usage as thermal interface materials (TIMs). Solders and die attach materials are selected by different criteria as the primary function is electrical interconnect.

Thermal Interface Materials: Functions and Terminology

Proper use of terminology is important:

- All applications *external to the semiconductor package* are TIM2:



Note: The earlier term adopted as "TIM 1.5" was replaced with "TIM 0" twenty years ago. The three standard terms are TIM0, TIM1, TIM2.
Source: Boteler, L., "Thermal Design of Power Electronics," US Army RDECOM Army Research Laboratory, APEC 2019 Conference, Tutorial (March 2019).

Thermal Interface Materials: Performance

Selecting an appropriate thermal interface material:

- Clamping force uniformly applied is intended to achieve:
  - Maximized surface wetting;
  - Thinnest possible TIM thickness (to minimize influence of bulk thermal conductivity);
  - Metal-to-metal contact for surfaces.
- Degree of surface wetting achieved is critical to overall performance, to minimize contact thermal resistance at each of two contact surfaces.
  - Contact resistance dominates overall TIM bulk resistance for many materials.
  - Achieving the thinnest possible thickness with highest clamping pressure is critical to achieving minimum thermal resistance.
- Relatively good bulk thermal conductivity is needed when only limited clamping force is available.

TIM Test Methodologies: Overview

Performance Property	Property Parameter	Method/Value
Thermal Resistance	Through-plane (primary) bulk + contact = total thermal resistance	ASTM D 5470-17 (Steady-state, unidirectional controlled heat flow) JEDEC JESD 51-14 (In-situ, Transient with structure function calculations from electrical resistances) Thermal Test Vehicle (TTV, in-situ)
Thermal Conductivity	Homogeneous, bulk (isotropic)	ASTM D5470-17 (Steady-state) JEDEC JESD 51-14 (Transient) Laser flash (Homogeneous materials) 3Ω Characterization
	Non-homogeneous, bulk (through-plane)	ASTM D5470-17 (Steady-state, unidirectional flow) JEDEC JESD 51-14 (Transient) 3Ω Characterization
	Non-homogeneous, bulk (in-plane)	Nanotest LaTIMA (Steady-state, in-plane flow) Scanning pulsed laser

Note: Not all test methods are suitable for testing certain categories of TIMs such as anisotropic and/or non-homogeneous structures (examples are compounds coated on a dielectric carrier or multilayer TIMs.)

TIM Test Methodologies: ASTM D 5470-17 and Transient

ASTM D 5470-17 and transient methods are the primary test methods for determining bulk thermal conductivity and thermal resistance values.

- *TIM vendor data sheet values should be developed utilizing ASTM D 5470-17* for comparative values generated under:
  - *Controlled surface conditions*
  - *Unidirectional heat flow conditions*
  - *Parallel contact surfaces*
  - *Precisely known clamping forces*

ASTM D 5470 Purpose: Develop comparative test data under identical conditions with all extraneous factors (such as die warpage or non-co-planar contacting surfaces) removed.

- Use of JESD 51-14 transient methodology *follows after* ASTM D 5470 testing. Goal is to develop *in-situ* performance test values with a specific package surface, clamping mechanism, other variables.
- Transient methods use electrical characteristics of a DUT, such as a power semiconductor, in-situ.
- These two methods are complementary: *One does not replace the other*.

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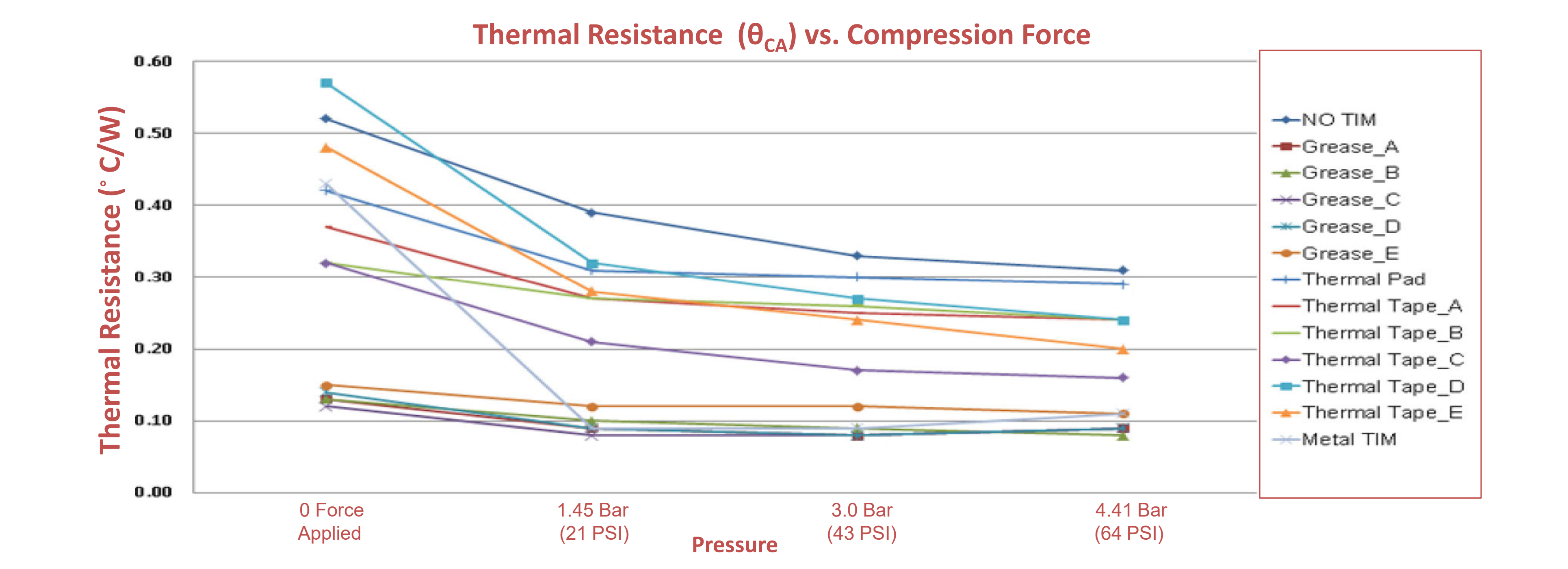
TIM Test Methods: ASTM D 5470-17

ASTM D 5470-17 test methodology -- Example of comparative test data generated:

- Application of specified pressures significantly improves thermal resistance of many TIM types;
- Properly-designed test stand provides apples-to-apples comparative data, all factors equal.

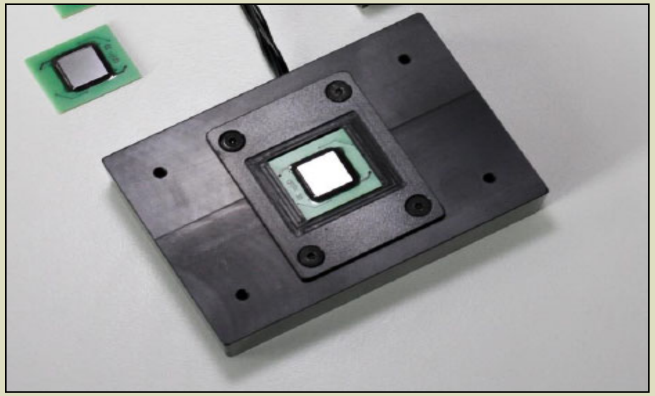


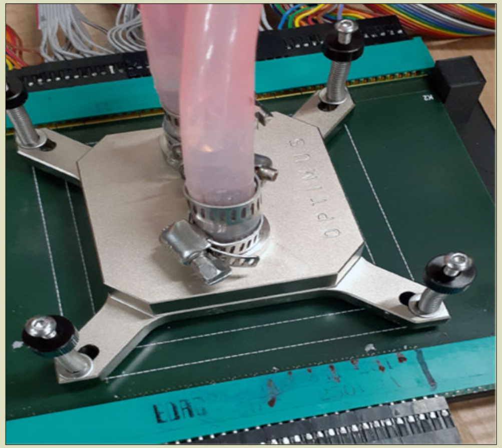
Note: Specific TIM materials are not identified by vendor and vendor product identification. "Metal TIM" is indium metal flat foil.
Source: Ng Hooi Hooi, Thermal Test Solutions, Inc.; "Introduction to Thermal Interface Materials," BiTS Test Workshop, Mesa AZ USA, March 5-8. 2017.

TIM Test Methods: Thermal Test Vehicles (TTV)

Thermal test vehicles are used for examining TIM performance in in-situ applications to measure:

- Performance of a TIM2 with a production semiconductor package;
- Performance of a TIM0 or TIM1 in contact with a die, to evaluate performance:
  - Given specific die warpage
  - With contact to lid (TIM1) or liquid cold plate/heat sink assembly (TIM0)
  - When well-designed, a tool that can provide very useful and detailed analytical capabilities for *in-situ* measurement for applications with a specified package type.





Sources: (Left) Berliner Nanotest und Design GmbH; (Right) Indium Corporation (with liquid cold plate applied to bare die TTV on engineering test board (ETB). (Photograph, DS&A LLC, January 16, 2024.)

Thermal Interface Materials: General Categories

Table A: General Functions and Categories of Thermal Interface Materials *Adhesive Types*		
Primary Function	**Material Category**	**General Statements**
Adhesive TIM attachment Heat sink or cold plate fastening Reduced thermal resistance Device to heat sink/cold plate Shock dampening Specialized gap-filling adhesives	**Thermally-conductive adhesives***: Pressure sensitive preforms Curable or two-part dispensed	• Generally very poor thermal performance • Providing adhesive attachment of a heat sink or other component • No mechanical fasteners required
Minimum Rth with: Fastening Heat spreading (modest) CTE control (modest)	**TIM1 Materials:** Die-attach adhesives as TIM1	• Relatively high bulk thermal conductivity, low thermal resistance • Applied die to heat spreader

Notes: Generally, available as liquid-dispensed adhesive compounds and as die-cut preforms with adhesive, one or two surfaces.
Source: DS&A LLC.

Thermal Interface Materials: General Categories

Table B: General Functions and Categories of Thermal Interface Materials *Medium Rth Thermal Performance**		
Primary Function	**Material Category**	**General Statements**
Reduce thermal resistance (Θ_{CS} or Rth) versus air over large gaps (i.e., $\geq$ 0.254mm/0.010")	**Gap-fillers**	• Very thick materials to fill large air gaps between two surfaces • Relatively low thermal performance due to moderate bulk thermal conductivity and significant thickness
Large-area heat dissipation, temperature control, temperature modulation	**Graphite, Elastomeric Sheets**	• Wide range of available materials • Wide range of thermal performance, cost
Electrical insulation with minimized thermal resistance	**Electrically-Isolating**	• Relatively uncommon, higher cost • Lower thermal performance due to dielectric layer

Notes: Gap-filler TIMs are available as die-cut preforms and as liquid-dispensed compounds. ** Generally, available with and without adhesive layer one surface, for die-cut preforms.*
Source: DS&A LLC.

Thermal Interface Materials: General Categories

Table C: General Functions and Categories of Thermal Interface Materials *High Rth Performance*		
Primary Function	**Material Category**	**General Statements**
Minimum thermal resistance (Rth) *Achieved with minimum thickness and with clamping force applied*	**Thin TIM1/TIM2 Materials**: Thermal greases Phase-change Polymer-solder hybrids, solders	• Low thermal resistance • Use requires mechanical fasteners to apply consistent, constant pressure.
Minimum Rth, heat spreading, with CTE control	**TIM1 Materials**: • Gels, Phase-change, thermal greases, VA-CNT# • Reflowed indium solders for CTE mismatch control and high effective thermal conductivity	• Relatively low Rth and high bulk thermal conductivity • Between die and heat spreader • Multiple material types available for TIM1 evaluation

Notes: Thermal greases, Phase-change TIMs are available as die-cut preforms and as dispensed compounds. # Many continuing development programs for new materials in these categories.
Source: DS&A LLC.

Thermal Interface Materials: General Categories

Table D: General Functions and Categories of Thermal Interface Materials *Highest Rth Performance*		
Primary Function	**Material Category**	**General Statements**
Critical minimum Rth for high heat flux; reworkability highly desirable	**Carbon-Based Arrays:** Carbon Fiber-based Arrays: Vertically-aligned Carbon Fiber Arrays (VA-CNF)	• Lowest Rth commercially available currently • Higher cost • Require mechanical fastening
	Carbon Nanotube-based Arrays: Vertically-Aligned Carbon Nanotube Arrays (VA-CNT)#	• Lowest Rth projected, as commercial products (future) • Higher Cost • Require mechanical fastening
Critical minimum Rth for high heat flux; reworkability highly desirable, with CTE control	**Metallic Preforms, Liquid Metals**	• Lowest Rth available currently • Variety of metal alloys, patterns • Higher cost • Require mechanical fastening

Notes: Thermal greases, Phase-change TIMs are available as die-cut preforms and liquid-dispensed compounds. # Development materials at present.
Source: DS&A LLC.

TIMs: Development Specifications for Semiconductor Test

High Performance TIM Material Target Specifications *for Test*	
Material Attribute	**Goal[1]**
Material Stability	No constituent run-out, no mechanical pump-out. Dimensionally stable; no moisture sensitivity during processing or normal operation in specified ambient environmental conditions. No fretting.
Silicone Stability	No silicone content; no dry-out, no silicone oil separation; zero measurable separation by weight (TGA).
Surface Wetting	TIM provides sufficient surface contact to approach 100% surface wetting in clamped condition, including expected warpage and specified surface conditions.

Notes: 1. Generalized statements, applicable to all levels of TIM (TIM0, TIM1, TIM2).

TIMs: Development Specifications for Semiconductor Test

High Performance TIM Material Target Specifications *for Test*	
Material Attribute	**Goal[1]**
Thermal Performance	Target and stretch goals for thermal resistance to meet system maximum heat load and heat flux.
Outgassing	No permissible outgassing per NASA, aerospace applications requirements; no outgassing for medical, optical, optoelectronic applications and systems
Environment	Suitable for shipment, storage, processing, operational temperatures (ambient, junction/module)
Cost	Budget goals met with volume manufactured TIM.

Notes: 1. Generalized statements, applicable to all levels of TIM (TIM0, TIM1, TIM2).

TIMs: Development Specifications for Semiconductor Test

High Performance TIM Material Target Specifications *for Test*	
Material Attribute	**Goal[1]**
Conformability	**Same TIM conforms to different die sizes, lid sizes without damage or change in performance.[2]** **TIM conforms to 90 bending and wrapping around test head/socket lid configuration. [2]**
Particulates	**No permissible loss of particulates, fibers.[2]** **No residue visible, remaining on DUT after contact; no detritus.[2]**
Durability	**Tested cycling survival through X number of repeated contact-and-release cycles. [2]**

Notes: 1. Previous statements are applicable to all levels of TIM (TIM0, TIM1, TIM2).
2. Statements specific to semiconductor test and liquid immersion systems.

Well-Performing TIMs

What is meant by “well-performing”?

- Bulk thermal conductivity is *not* the sole determinant as “best” material for a given application.
- A TIM in a given high-performance design must be assessed against a defined list of specialized criteria in addition to bulk thermal conductivity alone.
- These specialized criteria typically include, for example:
    - Higher operating temperature range;
    - Minimized thermal resistance, with 100% surface wetting;
    - Higher dielectric properties with improved thermal resistance;
    - Resistance to extreme mechanical stress due to power cycling;
    - *No* compound run-out and no dry-out due to temperature – or due to mechanical stress
- *Prioritization of these requirements* may alter thermal performance in the final TIM selection.

Well-Performing TIMs

What is meant by “well-performing” *for semiconductor test applications:*

- *Durability during repeated contact-and-release cycles (which TIMs are not normally designed to survive in traditional applications).*
- *Durability, resistance to cracking, flaking during folding and attachment to test head apparatus.*
- *Zero residue on DUT following contact-test-release.*

Important:

- These are very challenging requirements – *contrary to what most TIM types are designed for;*
- Most TIM types cannot meet these semiconductor test requirements.
- Silicone oil separation due to pump-out, run-out, and bake-out are major failure mechanisms for silicone thermal grease and silicone-based TIMs types;
- The majority of TIM types are silicone-based and therefore not applicable.

Well-Performing TIMs

Newer materials available include:

- Vertically-oriented carbon fiber arrays in an organic carrier material
- High bulk thermal conductivity graphene-enhanced graphitic materials
- High bulk thermal conductivity metallic thermal interface materials

These TIM categories require mechanical fastening with relatively high clamping force to:

- Achieve minimum thickness
- Maximize surface wetting
- Maximize thermal performance.

Improvements:

- Significant (> 5 - 10X) bulk thermal conductivity improvement required to impact thermal performance.
- Silicone oil and silicones are a primary challenge for reliability, toxicity, chemical constituents, and shelf life of existing TIM materials – not widely recognized or accepted across the electronics industry.

Recent TIM Developments

Patterned Metallic TIMs

Flat metallic foils have been used as TIM materials for decades:

- Typically indium metal or copper shims
- Telcom, military, and aerospace applications for RF devices and discrete power semiconductors.
- Indium Corporation introduced a family of "Heat-Spring®" patterned metallic foils:
- Increased compliancy and no significant increase required in metal thickness.
- Increased range of material options recently introduced:
  - Additional alloys
  - *Taller patterning* to accommodate warpage
  - Different base alloy thicknesses
- Flat indium foils TIMs have historically been used for RF, diode laser, and semiconductor test markets.
- Modified versions continue to be developed to meet specific semiconductor test requirements:
  - Additional alloys and additional pattern variations to adapt to differing test requirements;
- High temperature testing and high temperature storage testing for these types of materials has been the subject for continuing research.[1]

Notes: "Heat-Spring" is a Registered Mark of Indium Corporation. US Patent 7,593,228-B2. 1. Koh, Y. J.; Kim, S.H.; Sohn, E.S.; Khim, J.Y.; Amkor Technology Korea Inc., "Thermal Performance of Advanced TIMs for High-Power FCLBGAs," IEEE ECTC Conference 2022, San Diego CA USA, May 31, 2022.

Patterned Metallic TIMs

Bulk thermal conductivity and suggested maximum operating temperatures for metallic TIMs:

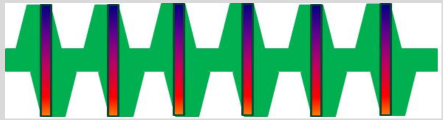
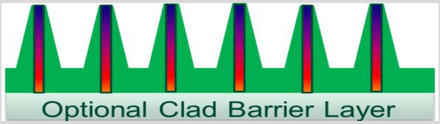
Maximum Bulk Thermal Conductivity and Suggested Operating Temperature for Metallic TIMs		
Metallic TIM Composition	Bulk Thermal Conductivity (W/mK)	**Suggested Maximum Operating Temperature (°C)**
52In/48Sn Indalloy 1E	34	100
80 In/20 Sn	53	110
100 In	86	125
In/Al Clad	-	125
Sn, "Sn+"	73	200
100 Pb	35	250
100 Cu	395	750

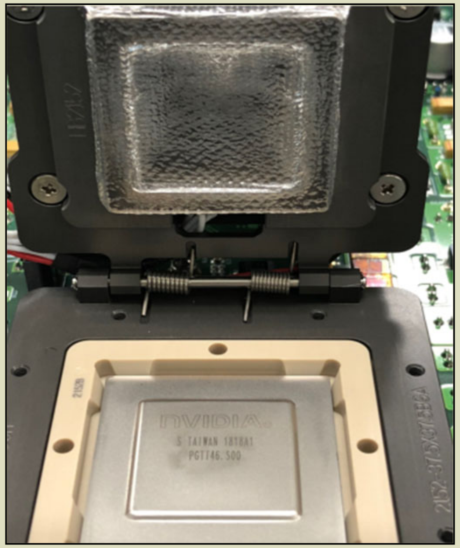
Table shows suggested values for selected metals and alloys; other alloys are possible.

- Characteristics of interface surfaces may affect maximum temperature.

*Notes: * "Indalloy", "Sn+" are Indium Corporation products. Data Source: R. Jarrett, Indium Corporation , Utica NY USA; Bulk conductivity values, G. Wilson, Indium Corporation, Milton Keynes UK.*

Patterned Metallic TIMs

Available Patterns for Indium Heat-Spring® Metallic TIMs	
Pattern Type	**Configuration**
Pattern 1: Designed for interfaces with tight surface control for roughness and parallelism.	
Pattern 2: High-profile variant for surfaces w/non-co-planar surfaces or greater warpage. 2X compressibility.	
Pattern 3: Single-sided pattern for clad multiple insertion applications and large surface area applications.	



Example (above):
Heat-Spring® HSK pattern, Al (25µm thickness)

Alloy: 90In10Ag

Clamping force applied: 70 PSI

Tj: 125˚C

Device power: 400 - 700W

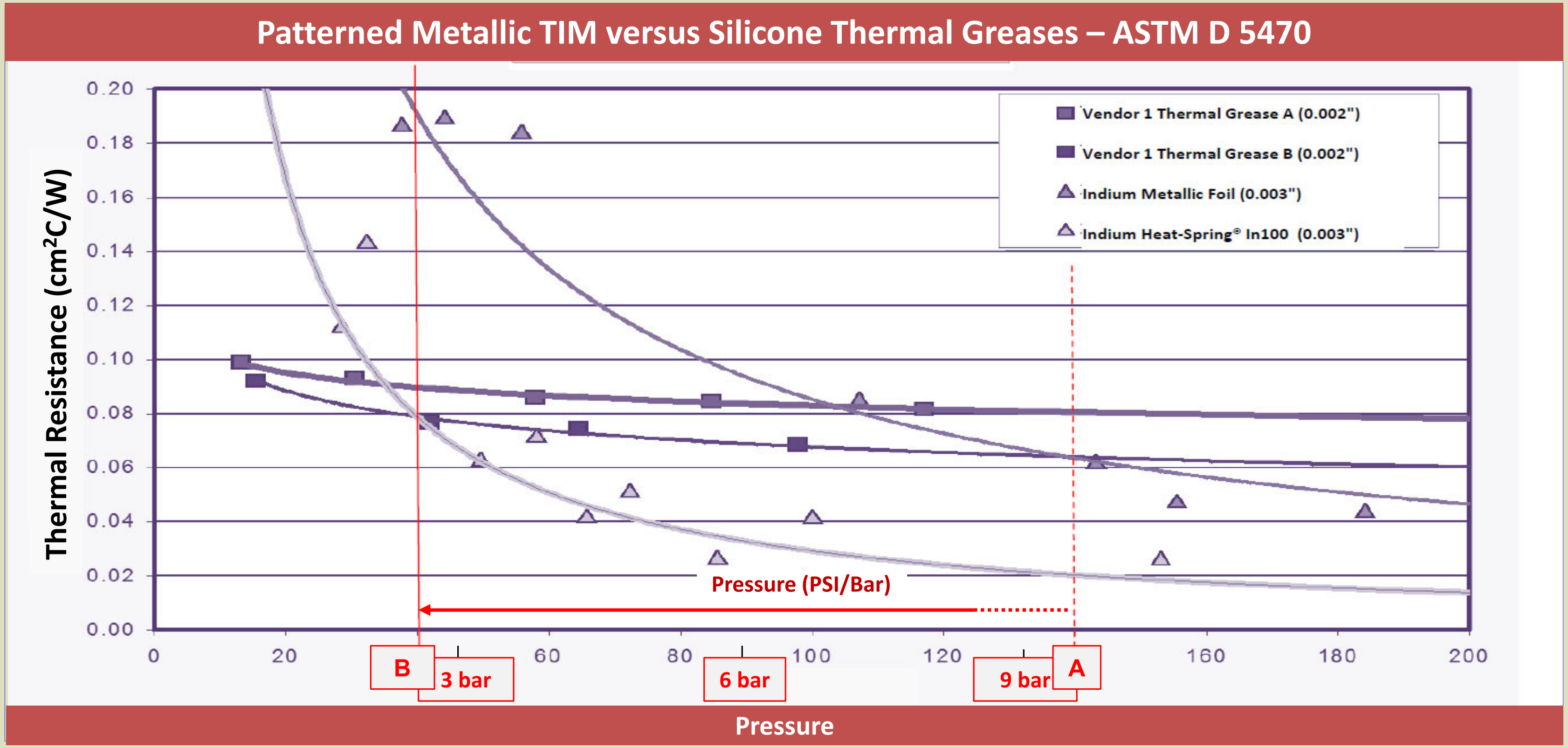
Burn-in hours: 500 (167 chipsets tested)

Data Source: G. Wilson, Indium Corporation, Milton Keynes UK; M. Lazic, Indium Corporation , Clinton NY USA. US Patent 7,593,228-B2 “Heat-Spring” is a registered mark of Indium Corporation.

Patterned Metallic TIMs

Comparative test data: indium flat foils vs. Indium "Heat-Spring" patterned In100 foil and thermal greases:

- Improvement: Patterning vs. flat indium foils, greases at > 40PSI (Note force reduction from points A to B)



Data Source: Indium Corporation. DS&A LLC Model 101 ASTM D5470-12 Test Stand. "Heat-Spring" is a registered mark of Indium Corporation.

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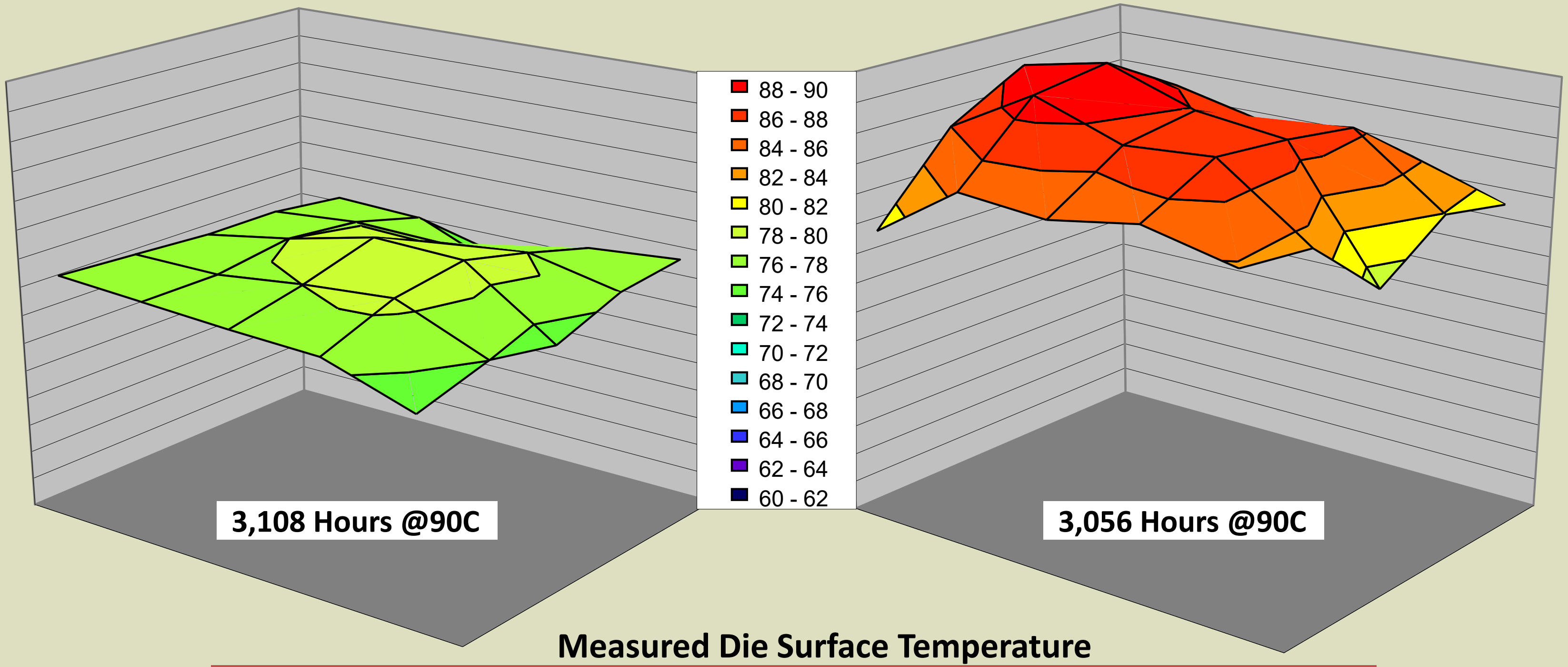
Patterned Metallic TIMs: Reliability

Patterned Indium Alloy Metallic TIM **Baseline: High-Performing Silicone Thermal Grease**



Measured Die Surface Temperature

Thermal Test Vehicle Comparative 3,000-Hour Reliability Bake Test

Note: Measured die surface temperature at time zero was shown to be approximately equivalent. Above test data taken after 3,000-hour bake test. Increased die surface temperature for Figure 4B reflects increased thermal resistance due to dry-out of silicone oil in the tested premium silicone-based thermal grease.

Data source: R. Jarrett, Indium Corporation, Utica NY USA. Die thermal test vehicles: Provided by Intel Corporation.

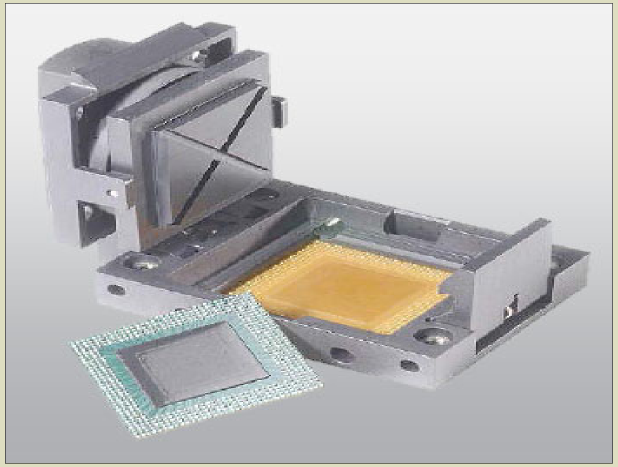
Metallic TIM Types: New Developments

Examples: Relative bulk thermal conductivity values, development metallic TIMs of different types:

Bulk Thermal Conductivity Values – Metallic TIMs			
Basis[1]	**Category**	**Type (Typical Intended Usage)**	**Value (W/mK, Typ.)**
Indium Based	Solid	Solder TIM (TIM1)	70-86
		Compressible TIMs (Patterned, TIM2)	86
	Phase-Change	Phase-change metal alloy TIMs (TIM2)	40-50
Indium/Gallium[2]	Hybrid Liquid Metal	Indium® m2TIM™ (TIM1)	40-50
		Liquid metal pastes (TIM0, TIM1, TIM)	15-25
Gallium Based[2]	Liquid	Liquid metal TIMs (TIM0, TIM1)	20-45

Notes: 1. Primary metal by percentage. 2. Generalized statements regarding intended usages shown in parentheses. Multiple materials available from suppliers.
Source: Adapted from: Miloš Lazić, Indium Corporation, "Advanced Gallium-Based Thermal Interface Materials," IMAPS New England Symposium 49, Boxborough MA USA, May 2, 2023.

Graphitic Materials



Semiconductor test carrier and socket

NeoGraf "Flexible" graphite, highly anisotropic:

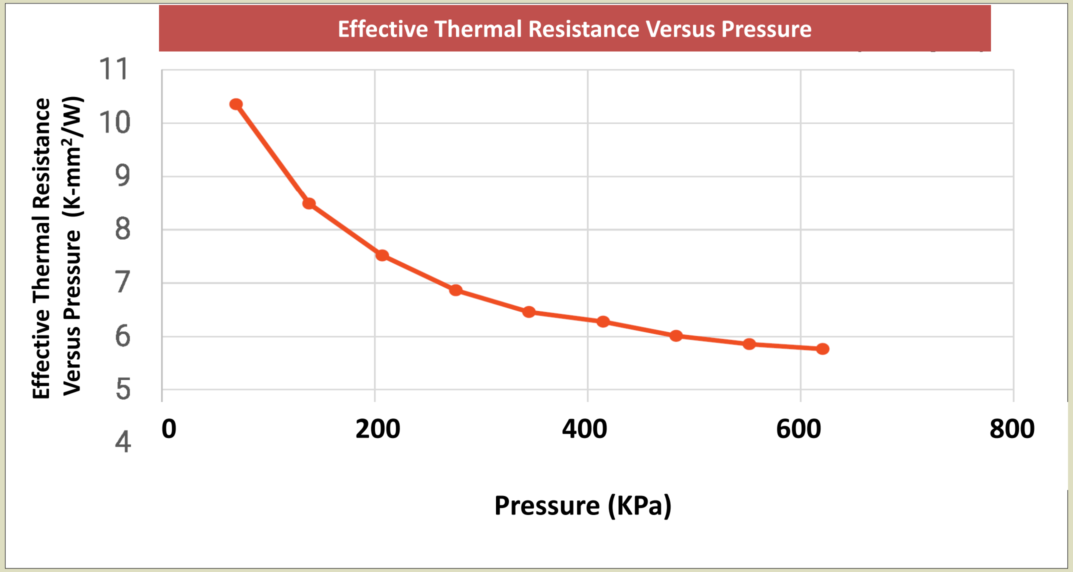
- Bulk thermal conductivity:
  - In-plane (X-Y): 1200-1800W/mK
    Through-plane (Z): 1-8W/mK
- Thermal performance improves with higher pressures
- No silicone prone to pump-out or separation – and flexible
- No phase-change temperature required
- Maximum temperature, certain compressible graphite films: 125°C
- Maximum temperature, many traditional graphite films: 400°C
- Disadvantages:
  - Typical minimum thickness: 0.127mm (0.005")
  - Some types are subject to conductive particle flaking
- Development material - compressible to limited degree: NeoGraf eGraf® TG-768
- NeoGraf, Panasonic PGS, Kaneka are leading suppliers.

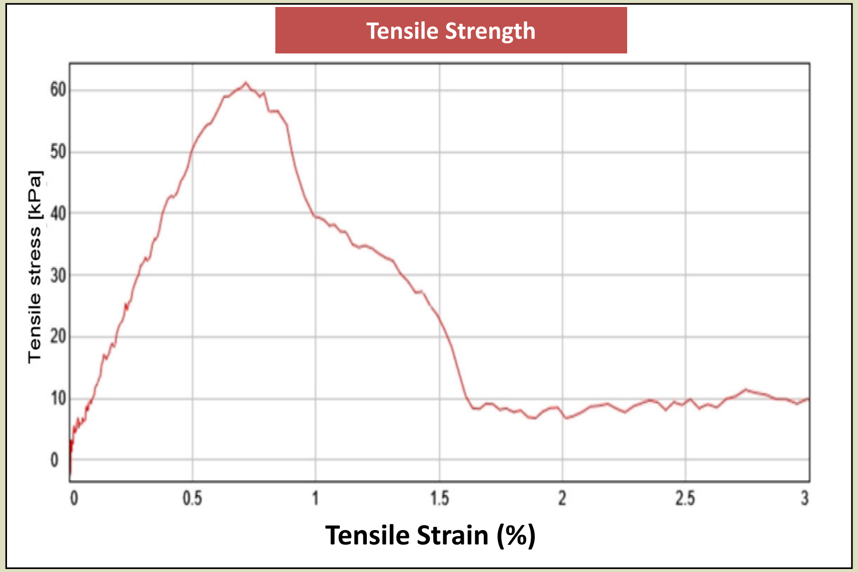
Source, text and photograph: NeoGraf Solutions LLC data sheets. Note that certain "compressible" graphite films are impregnated with resins that affect maximum operating temperatures, depending on supplier. Refer to individual product data sheets for specific values.

Graphene-enhanced Graphitic Materials

New TIM developments include graphene-enhanced performance of graphite films:

- SHT "FrostSheet" is an example of such a newly-developed thermal material





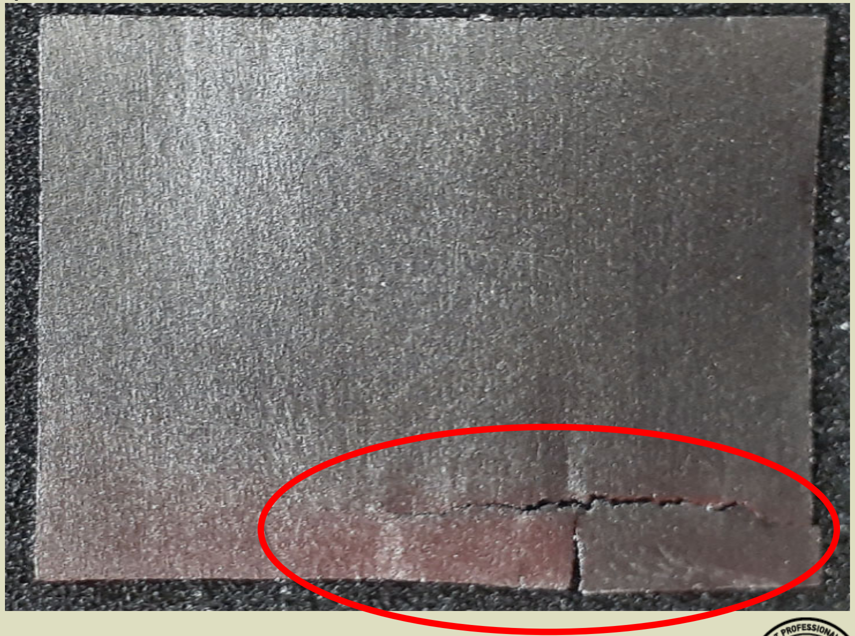
- Effective thermal resistance (per vendor data): 20 K-mm2/W (@100KPa)

Source: Murugesan, M.; Martinson, K.; Enmark, M.; Zhang, H.; Liu, J.; Almhem, L., "Applications of High Thermal Conductivity Graphene Enhanced Thermal Interface Materials," SHT AB, IMAPS France Thermal and Micropackaging Workshop 2023, Poitiers, France, March 8-9, 2023.

“Graphene-Enhanced” Graphitic Materials

Graphene-enhanced performance of materials such as graphite films:

- SHT FrostSheet is an example of such a newly-developed thermal material;
- Such materials include developments for both TIMs and heat spreaders;
- SHT FrostSheet and GT-TIM GT-90SPRO data sheet values:
  - Bulk through-plane thermal conductivity: 90+/- 10 W/mK
  - Thickness: 300µm (0.012”)
  - Fragile, relatively thin graphite materials
  - Subject to easy handling damage
  - No testing to date for repeated contact/release cycling for use in semiconductor test.

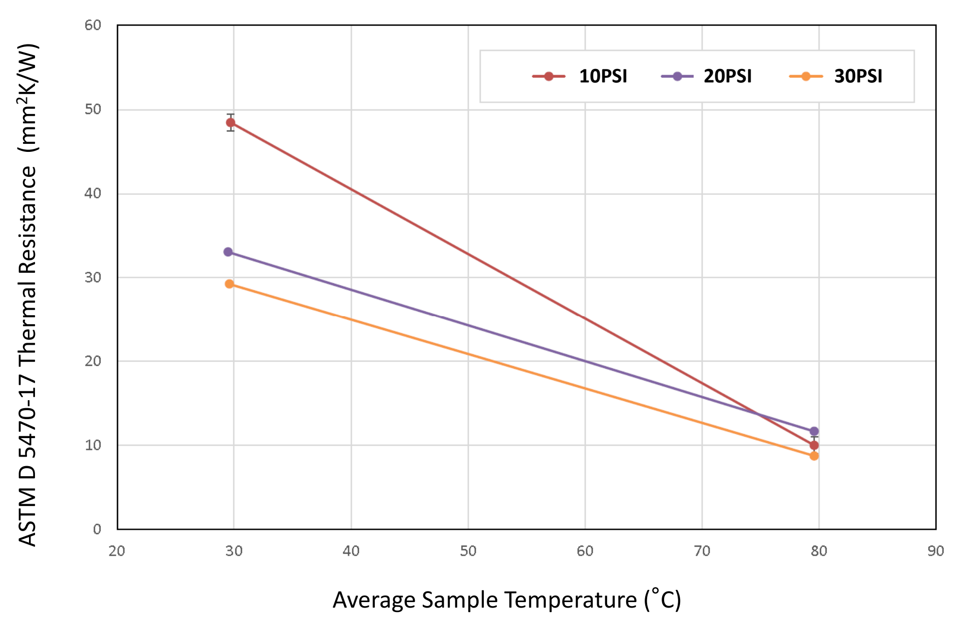


Source: Murugesan, M.; Martinson, K.; Enmark, M.; Zhang, H.; Liu, J.; Almhem, L.; Super High Tech AB, “Applications of High Thermal Conductivity Graphene Enhanced Thermal Interface Materials,” IMAPS France Thermal and Micropackaging Workshop 2023, Poitiers, France, March 8-9, 2023.
Photograph: Super High Tech AB (Göteborg, Sweden) “FrostSheet” enhanced graphite film: DS&A LLC (January 16, 2024).

Phase-Change Materials

Phase-change compounds have been manufactured for use as TIMs for more than thirty years and are well-known for TIM2 applications:

- Compounds and pre-forms are available with phase-change temperatures from 45°C to 60°C:
  - Purpose of the phase-change temperature is to achieve thickness change to minimize resistance, at a given pressure (graph)
- Bulk thermal conductivity values are available in a wide range (depending on formulation): 0.6W/mK – 8W/mK
- Not typically utilized for semiconductor test, PCM dispensed compounds and pre-forms will be subject to marking of the DUT (as operating test head temperature approaches the designed phase-change temperature).
- Certain new materials are available that may offer promise for single-side carrier coatings:
  - Aluminum (dead soft)
  - Durable graphite films (certain manufacturers)
  - Dielectric films (i.e., DuPont™ Kapton® MT, MT+)
- Application of a TIM pre-form with single-side coating to face the test head prevents marking or detritus on the DUT.



Source, Graph: Berliner Nanotest und Design GmbH (Berlin, Germany). Well-known phase-change preform TIM (8µm initial thickness, prior to application of pressure).

PCM-Coated Graphite Films and Reliability Testing

Current development of phase-change coated graphite film carriers, developed by Streuter Technologies:

- Data sheet test values per ASTM D 5470.
- Decades of proven compound coating and manufacturing processes for TIM materials, to date;
- Streuter Technologies is now offering different versions of this product type:
  - Single-side phase-change coating on film graphite film for semiconductor test applications;
  - Single- and double-sided coatings in different thicknesses, as required;
  - Multiple combinations of options in performance and durability testing:
    - Carrier (20-, 32-, 40-, 70-micron thicknesses)
    - Coating thickness and custom footprint/offset compound coatings
    - Phase-change temperature (52°C, 60°C)
  - Very high degree of surface wetting achieved – addressing surface warpage and roughness.
  - Certain graphite films are highly durable and have passed significant 90-degree bend testing over tens of thousands of bend cycles – appropriate for semiconductor test.

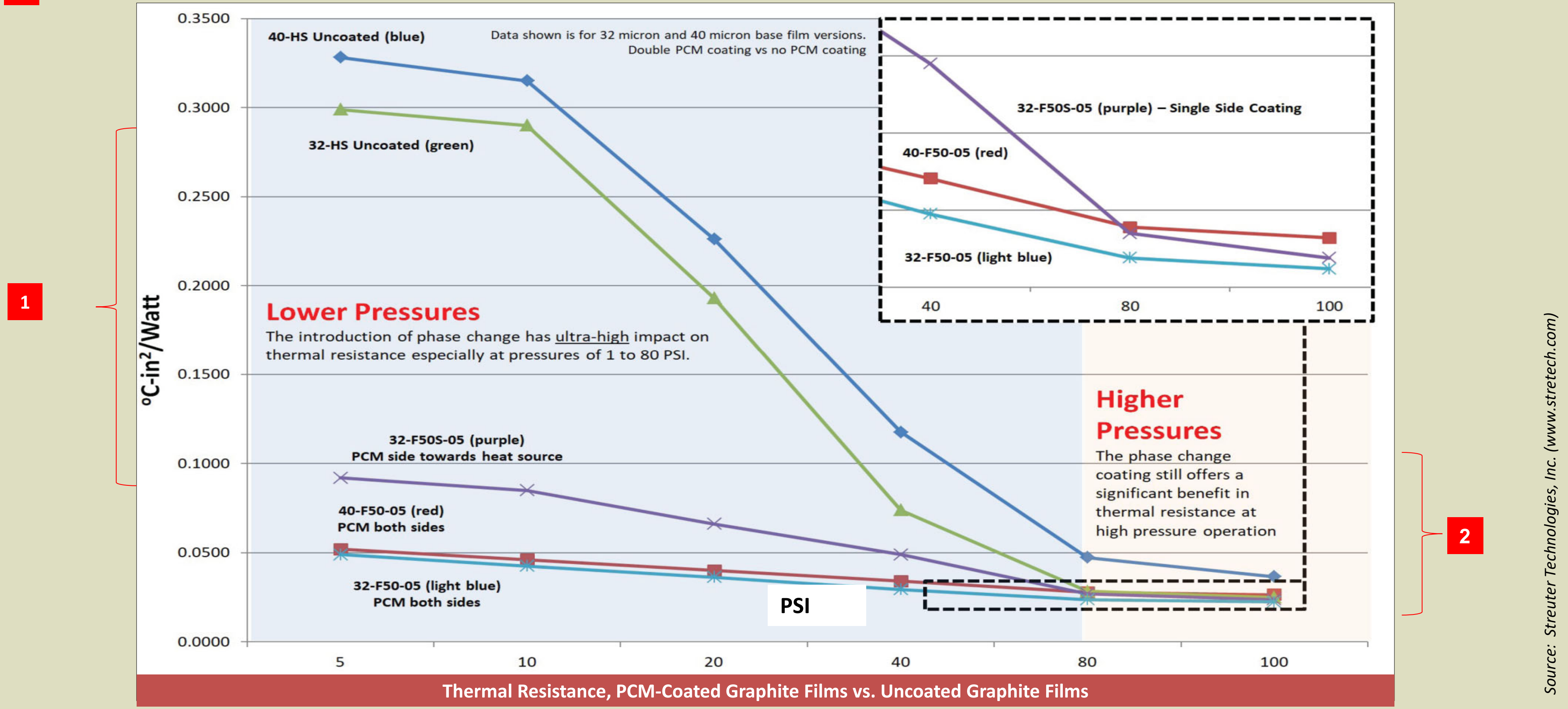
Source: Streuter Technologies, Inc. (www.stretech.com)

TestConX 2024

TIMtel "Graphenol" PCIM-Coated Graphite Films

1 32micron graphite film: 71% Improvement at low pressure (5 PSI), single-side coating vs. uncoated

2 40micron graphite film: 70% Improvement at medium (40 PSI) pressure, double-side coating vs. uncoated



Carbon Nanotube Materials

Developments with vertically-aligned carbon nanotube TIMs (VA-CNTs):

- Advantages:
  - Perceived high bulk thermal conductivity of CNTs
- Disadvantages:
  - Significant difficulties in developing a manufacturable TIM product
  - Development materials in some cases have very low bulk thermal conductivity
  - High perceived manufacturing cost
- Fujitsu:
  - Tested values to date for bulk thermal conductivity (Z): 10-20W/mK

Summary

TIMs are critical to efficient heat transfer from a semiconductor source.

- Understanding TIM types and TIM testing methodologies are both critical to evaluation of different types.
- Specialized TIM materials can be characterized as *well-performing* when measured against challenging requirements for critical applications.
- Selection of a specialized TIM is not based solely on maximum bulk thermal conductivity.
- *Semiconductor test has highly specialized and unusual requirements* that are not requirements for TIMs in other semiconductor industry segments.
- Few TIM manufacturers focus on semiconductor test requirements and develop specialized TIMs for use.
- A range of metallic thermal interface materials have been developed and described, for specialized applications requiring performance and reliability in semiconductor test.
- Other types of graphitic TIMs are also in development which may be applicable to semiconductor test.

Notes

- ASTM D 5470-12, issued by ASTM International, is available for purchase and download at www.astm.org.
- Heat-Spring® is a Registered Mark of Indium Corporation, Clinton NY USA.
- Kapton® is a Registered Mark of DuPont de Nemours, Wilmington DE USA.
- Other trademarks and Registered Marks are the property of their respective owners.

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