Automotive Electronic Material Challenges

Co-Leaders

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End Of Project Report
March 17, 11am – noon ET

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Automotive Material Challenges

- Participants
- Summary
- Objectives, Schedule and Tasks
- Fundamental Question
- Thermal Interface Materials
- Standards Review
- Recommendations

Acknowledgments

Company	Team Members
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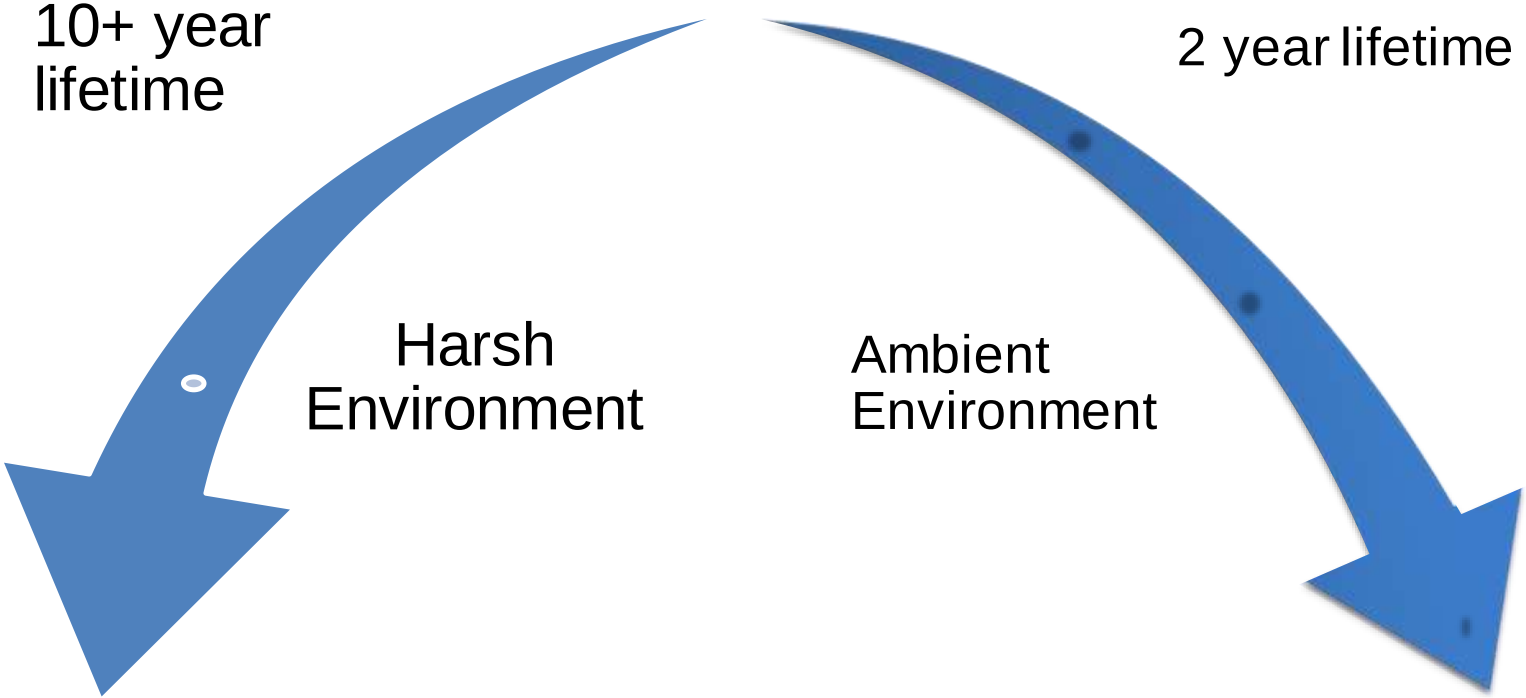
Integrated Service Technology (IST)	Jeffrey Lee, Dem Lee

Project Summary

- **Problem**
  - **For passenger compartment automotive electronics lack of proper materials/interface understanding is impacting long term reliability predictions**
- **Opportunity**
  - **Predict and understand functional performance of small geometries in harsh environments through measurement of material and interface properties**
- **Goal**
  - **Measure functional performance of small geometries through understanding a combination of material properties and interface properties. Gaps and recommendations will be identified and closed, where possible in the project timeframe.**
  - **End goal is to have the necessary information to <u>predict reliability of technology to reduce design cycles</u>. This would optimize reliability and reduce costs for the industry as a whole.**

The Challenge



Electronics
Technology
and Materials

10+ year
lifetime

2 year lifetime

Harsh
Environment

Ambient
Environment

Automotive Electronics
Requirements

Consumer Electronics
Requirements

Project Objectives

While keeping automotive requirements in mind…

- Identify dominant failure mechanisms
  - Focus on particular materials or categories of materials and/or components.
- Prioritize key properties for predictive modeling of reliability and performance
- Identify existing test methods for small geometries and relevant interfaces
- Recommend future projects to develop new test methods

Failure Mode Examination

Component/ Sub-assembly/	**Material**	**Failure Mode**	**Consumer Spec**	**Automotive Spec**	**Spec DIFFERENCES**	**Governing Material Property(ies) or the Physics of the failure as typically understood**
Lead-less Device (BGA, QFN, …)	Pb-Free Solder joint	Thermal Cycle Fatigue	IPC 9701A	-40 / +85C	Temp range - Total cycles	Alloy Type. Solder alloy properties: Temperature dependent Youngs Modulus, yield strength; creep and visco-plastic constitutive models; CTE
		Fracture (Drop)	For component JEDEC 22-B110 JEDEC 22-B111 For module IEC 60068-2-27 IEC 60068-2-31	For component AEC Q100 (Shock Test)/ Q101 / Q200 For module ISO 16750 - Shock / Drop	2 falls per DUT (ISO) ?	IMC properties (Intermetallic). Solder alloy (yield strength defines stress transfer) + IMC properties: fracture Strength, Youngs Modulus; CTE
		Fracture (Vibration)	For component JEDEC 22-B103B For Module IEC 60068-2-64	For component AEC Q100 / Q101 / Q200 For module ISO 16750 - Vibration		
	Component lead	Tin whisker	JEDEC 22-A201A -40~85c , 1000Cycle 55c/85% , 1000hr	AEC Q100 / Q005 JEDEC 201A -40~85c , 1500cycle 55c/85% , 4000hr	500 more cycles; 3000 more hr	Tin Alloy Type
	EMC	Delamination				Adhesion strength (to chip and leadframe)
		Thermal Cycle Fatigue				CTE, E --> stresses applied to solder interconnections *(low EMC iNEMI project)*
		Fracture (material degradation)				Fracture strength
	Wire bond	Thermal Cycle Fatigue	are the reliability tests same for component as listed above		Temp range - Total cycles	Yield strength (plastic deformation to be avoided)
		Kirkendall voiding/ IMC growth			Slightly higher operating temp ?	Activation energy (known)
		Joule heating/electromigration			Slightly higher operating temp ?	Activation energy (known) (Joule heating: Currents above 1A; Electromigration: 10^5 (Al) - 10^6 (Cu) A/cm^2)
	Die attach	Delamination				Adhesion strength
	Leadframe/EMC	SIR				Cleaning issue
Thermal interface materials	Adhesive	Cracking, Delamination	Thermal Cycling	Thermal Cycling		Delamination Adhesion strength / Thermal conductivity (thermal resistance measurement)
	Thermal Pad	bake out /dry cracks	Humidity	Humidity		Hardening
	Pre-cured Gel					Hardening
	Thermal Grease	Pump-out				Pump-out
Lens fixturing (camera, display)	Adhesive					Delamination
Lens seal (Camera, display)	Adhesive	Moisture intrusion				
	Gasket					

Fundamental Question

- **Do we focus on the materials that go into the assembly/module or focus on the characteristics of the materials that go into the component.**

- **What is weak link? Is it the components that are failing? Is it the solder, thermal interfaces?**

Choices list:

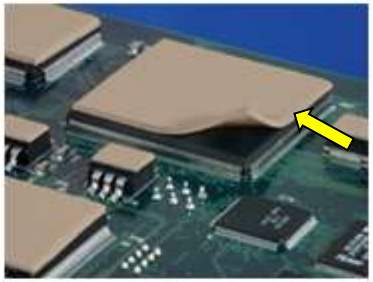
➡**1. *Thermal Interface Materials – chosen here***

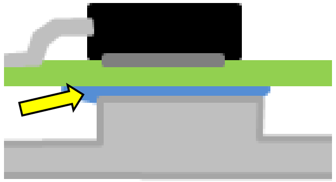
2. Adhesives

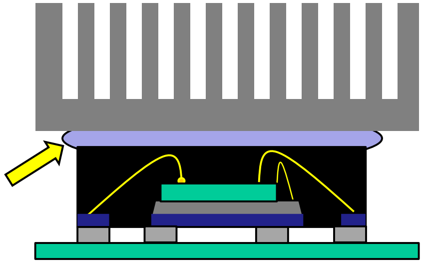
3. Solder joints

Thermal Interface Materials background

- **Reduce the temperature of ICs in electronics by transferring heat from the device to a heat sink**
- **Material types**
  - **"Sil" pads**
  - **Grease**
  - **Gap Filler gels and pastes**
  - **Phase Change material**
  - **Adhesive**
    - **Secondary function of securing assemblies**
- **Automotive Applications of TIM**
  - **Microprocessor cooling**
  - **LED cooling**
  - **Power Electronics and Battery cooling**





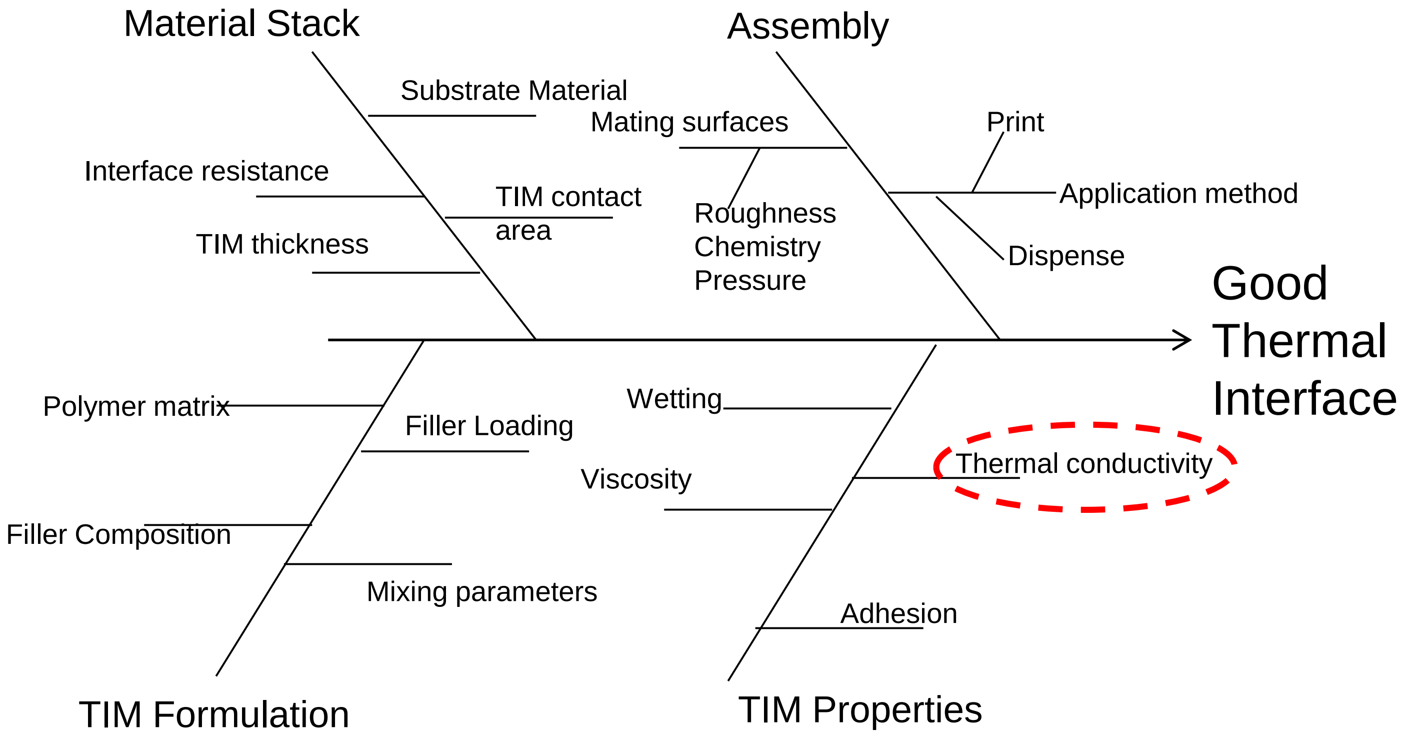


TIM Characterization Drivers

- **Provide users of interface materials with the right information to optimize material selection with respect to performance and cost**
- **Improve understanding of characterization methods used by developers of TIM materials**
- **Understand of the respective differences in use of such methodologies.**

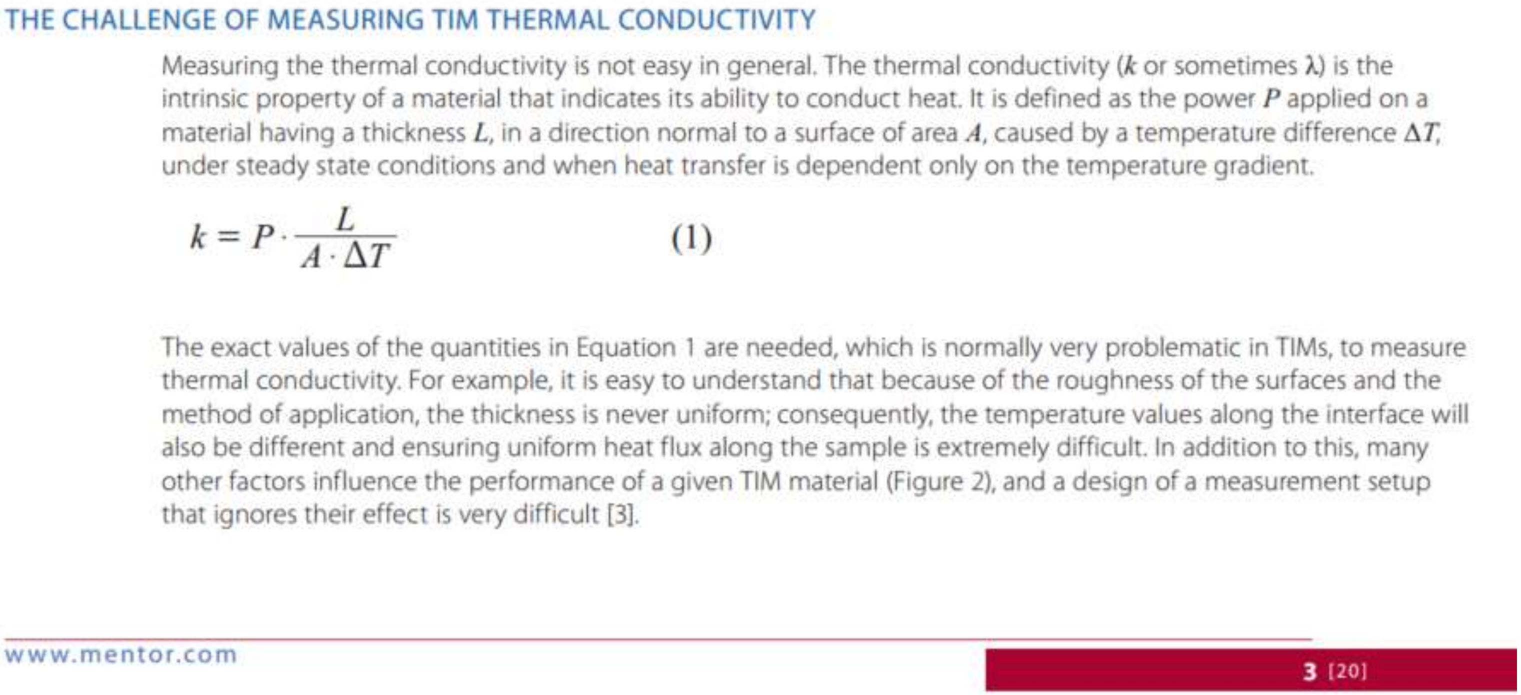
Source: Lasance et al, Challenges in Thermal Interface Material Testing 22nd IEEE SEMI-THERM Symposium

TIM performance is driven by multiple factors



Motivation

- **Thermal conductivity happens to be the most commonly reported value in datasheets and one of the most critical parameter in material selection for its application**



THE CHALLENGE OF MEASURING TIM THERMAL CONDUCTIVITY

Measuring the thermal conductivity is not easy in general. The thermal conductivity (k or sometimes λ) is the intrinsic property of a material that indicates its ability to conduct heat. It is defined as the power P applied on a material having a thickness L, in a direction normal to a surface of area A, caused by a temperature difference ΔT, under steady state conditions and when heat transfer is dependent only on the temperature gradient.

$$k = P \cdot \frac{L}{A \cdot \Delta T} \qquad (1)$$

The exact values of the quantities in Equation 1 are needed, which is normally very problematic in TIMs, to measure thermal conductivity. For example, it is easy to understand that because of the roughness of the surfaces and the method of application, the thickness is never uniform; consequently, the temperature values along the interface will also be different and ensuring uniform heat flux along the sample is extremely difficult. In addition to this, many other factors influence the performance of a given TIM material (Figure 2), and a design of a measurement setup that ignores their effect is very difficult [3].

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3 [20]

NEW METHOD FOR CHARACTERIZING THERMAL INTERFACE MATERIALS IN AN IN SITU ENVIRONMENT

ANDRAS VASS-VARNAI, MicReD PRODUCT MANAGER, MENTOR GRAPHICS

Challenge

- Thermal conductivity will be influenced by
  - TIM Thickness
    - Depends on application method
    - Increases as clamping force relaxes over time
    - Depends on substrate surface flatness
  - Wetting of TIM to surfaces
    - Roughness of substrates
    - Cleanliness of substrates
    - Material compatibility
  - Assembly pressure and thermal filler contact

….Problems increase with higher thermal conductivity (the future direction) because contact resistance becomes larger.

Reference: Lasance et al, Challenges in Thermal Interface Material Testing 22nd IEEE SEMI-THERM Symposium

Review of existing test standards

ASTM D5470 – 12

Standard Test Method for Thermal Transmission Properties of Thermally Conductive Electrical Insulation Materials

- **D5470 defines the standard test structure and method for measuring thermal conductivity**
  - **Test method is shown to have 18% variation**
  - **There is no standard test equipment available on the commercial market**
  - **Clamping force ranges are provided for TIM stack**
    - **10PSI to 500PSI, depending on TIM hardness**

Key takeaways from the review

- Pressure described in ASTM standard only allows for comparison of materials within categories
- Increased pressure will minimize thermal resistance BUT also will reduce bondline thickness, meaning that the interfacial resistance plays a greater role in the total heat transfer
- There is no standard TIM assembly pressure for automotive electronics
  - In use Assembly pressure will be driven by
    - Mechanical tolerances
    - Strength of components
    - Heat transfer requirements
      - Eg. High power device vs low power
- End user may want to compare performance of grease vs adhesive or gap pad. How can data sheets be compared (if different pressures used…)

Key takeaways from the review –contd.

- TIM performance will vary with temperature
- For Automotive Passenger compartment applications, temperatures will primarily be driven by the power output of devices
  - This is similar to Consumer applications
  - Passenger compartment Automotive ambient temps are -40C to 85C or 110C
- Heat dissipation can be uneven across a device
  - How can test method account for uneven heating?

Key Takeaways from the review – contd.

- **Surface cleanliness influences the results and is not specified in standard test method**
  - **The storage history of the metal block determines the quality of the metal-TIM interface**
  - **TIM to Heatsink interaction at interface influences performance**

Recommendations

The end-user is most interested in making sure the data from different vendors can be compared on equal basis

- same testing setup / equipment,
- standardized testing protocol.

At a minimum, material formulators/suppliers should be encouraged to report:

- thermal conductivity (material property, as a function of TIM thickness)
- thermal resistance
- detailed test protocol used (in lieu of an updated test standard)

Recommendations

1. Standardized test fixtures
    1. Cleanliness /Surface quality of metal plates must be specified.
    2. The interaction of the TIM with the metal plates must be understood and described in order to get consistent and comparable results

2. Standardize data package

    The data package must include

    1. Measurements at 3 or 4 TIM thicknesses
    2. Measurements at 3 or 4 temperatures
    3. Well defined substrates (e.g., Aluminum Alloy vs. Cu plates); well characterized substrate surface roughness

Proposed Next Steps

- Need for test lab to develop details of standardized test fixtures
- Need for material suppliers to work together to develop a standardized data package

- Ideally, these results would be provided to standards development organizations (such as ASTM or IPC) for integration

Contact Information

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NIST
National Institute of Standards and Technology

NIHON SUPERIOR CO., LTD.

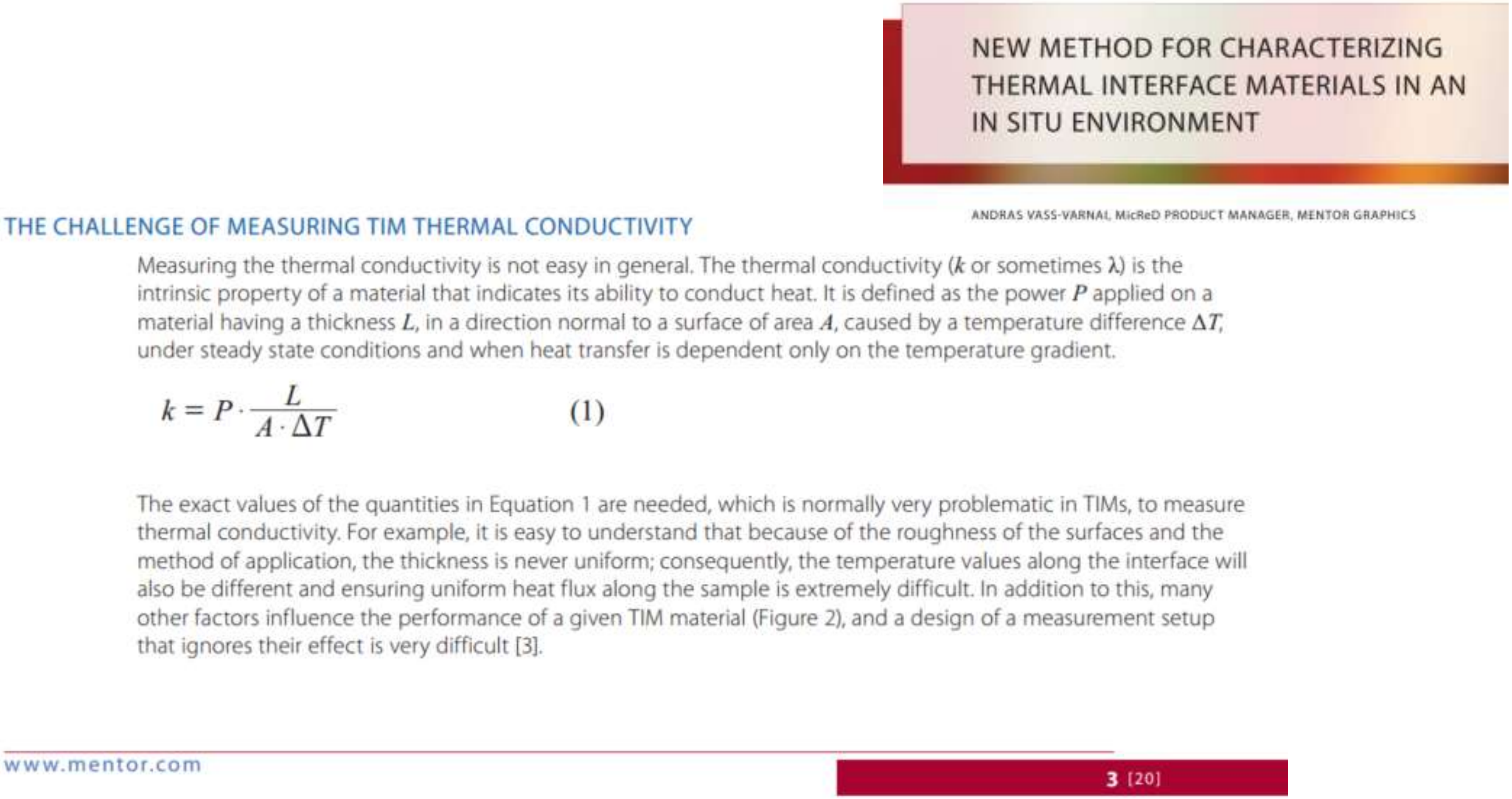
Project Schedule and Tasks

TASK LIST	Q1			Q2			Q3			Q4			Q5		
Identify dominant failure mechanisms (@ interface)	🟩	🟩	🟩	🟩											
Identify materials/categories to focus on	🟩	🟩	🟩	🟩											
Prioritize key properties for predictive modeling of reliability and performance					🟩										
Identify tests/test methods for small geometries for selected materials/categories **(May result in a recommendation to develop a method)**						🟩	🟩	🟩	🟩						
Identify relevant interface properties/ test methods							🟩	🟩	🟩	🟩					
Develop Gap Analysis and Recommendations											🟦	🟦			

Test Method Comparison
Drop/Mechanical Shock

Consumer		Automotive	
Component	Module	Component	Module
JEDEC 22-B110 2 – 10 drops in each of 6 directions depending on “state” of application	IEC 60068-2-27	[IC] AEC Q100 JESD22-B**104** (# shocks: 5x 6 directions) + Y1 plane only, 5 pulses, 0.5 msec duration, 1500 g peak acceleration. TEST before and after at room temperature.	ISO 16750 - Shock / Drop test 3 DUTS w/ each 2 drops for 1m drop height onto concrete/steel
JEDEC 22-B111 Board level drop test of components for handheld electronics	IEC 60068-2-31	[PASSIVE] AEC Q101 JESD22-B**103** + 20 Hz to 2 KHz to 20 Hz (logarithmic variation) in >4 minutes, 4X in each orientation, 50 g peak acceleration. TEST before and after at room temperature.	
		[DISCRETE] AEC Q200 SMD components: MIL-STD-202 Method 213 ; Figure 1 of Method 213 : Condition F Leaded components: MIL-STD-202 Method 213; Figure 1 of Method 213. Condition C	

Thermal Conductivity



NEW METHOD FOR CHARACTERIZING THERMAL INTERFACE MATERIALS IN AN IN SITU ENVIRONMENT

ANDRAS VASS-VARNAI, MicReD PRODUCT MANAGER, MENTOR GRAPHICS

THE CHALLENGE OF MEASURING TIM THERMAL CONDUCTIVITY

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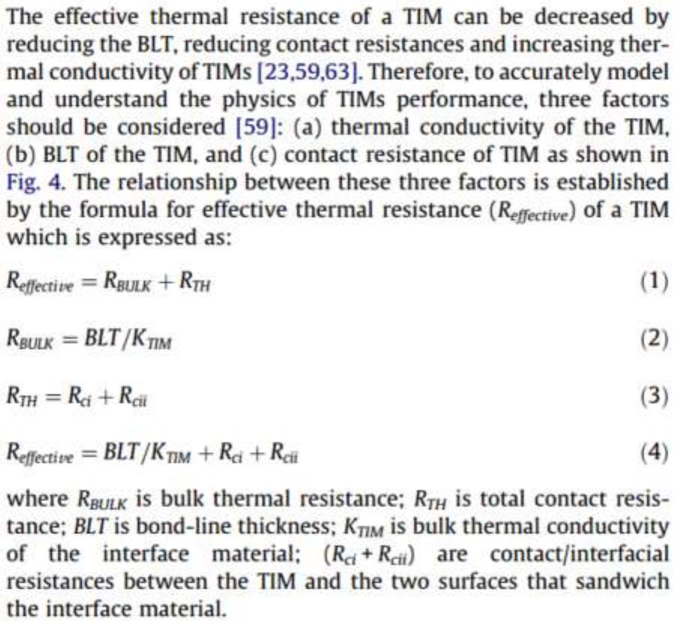
$$k = P \cdot \frac{L}{A \cdot \Delta T} \qquad (1)$$

The exact values of the quantities in Equation 1 are needed, which is normally very problematic in TIMs, to measure thermal conductivity. For example, it is easy to understand that because of the roughness of the surfaces and the method of application, the thickness is never uniform; consequently, the temperature values along the interface will also be different and ensuring uniform heat flux along the sample is extremely difficult. In addition to this, many other factors influence the performance of a given TIM material (Figure 2), and a design of a measurement setup that ignores their effect is very difficult [3].

Additional references



The effective thermal resistance of a TIM can be decreased by reducing the BLT, reducing contact resistances and increasing thermal conductivity of TIMs [23,59,63]. Therefore, to accurately model and understand the physics of TIMs performance, three factors should be considered [59]: (a) thermal conductivity of the TIM, (b) BLT of the TIM, and (c) contact resistance of TIM as shown in Fig. 4. The relationship between these three factors is established by the formula for effective thermal resistance ($R_{effective}$) of a TIM which is expressed as:

$$R_{effective} = R_{BULK} + R_{TH} \tag{1}$$

$$R_{BULK} = BLT/K_{TIM} \tag{2}$$

$$R_{TH} = R_{ci} + R_{cii} \tag{3}$$

$$R_{effective} = BLT/K_{TIM} + R_{ci} + R_{cii} \tag{4}$$

where R_{BULK} is bulk thermal resistance; R_{TH} is total contact resistance; BLT is bond-line thickness; K_{TIM} is bulk thermal conductivity of the interface material; $(R_{ci} + R_{cii})$ are contact/interfacial resistances between the TIM and the two surfaces that sandwich the interface material.

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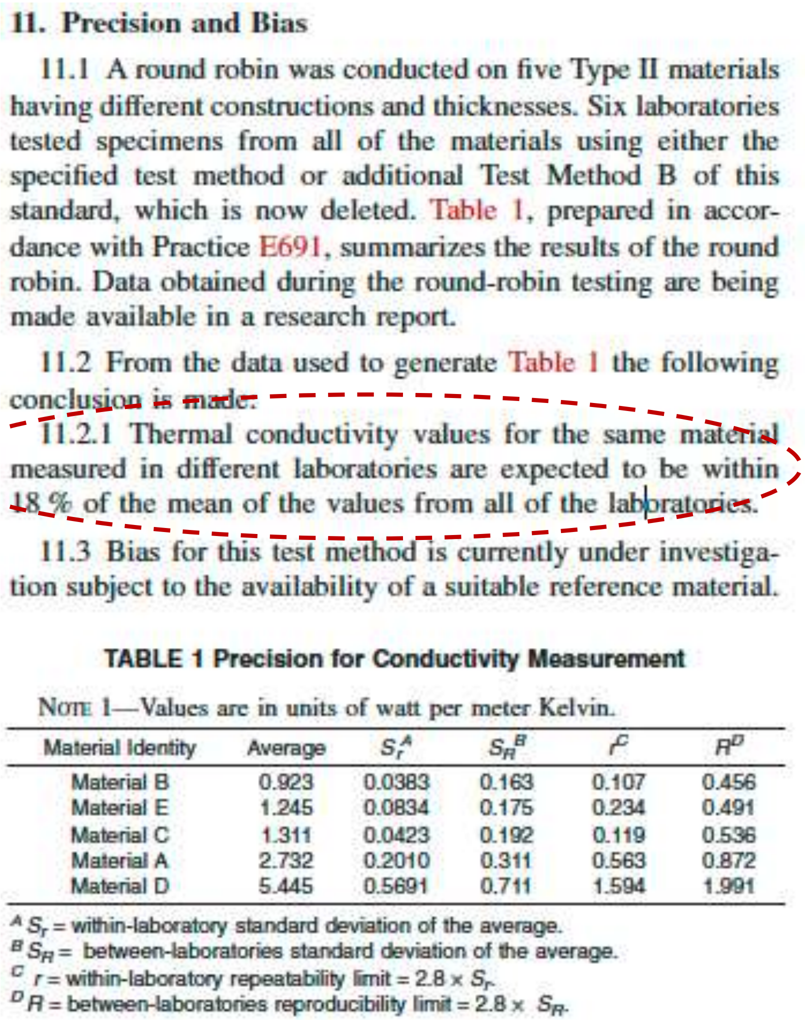
ASTM D5470-12 standard notes



11. Precision and Bias

11.1 A round robin was conducted on five Type II materials having different constructions and thicknesses. Six laboratories tested specimens from all of the materials using either the specified test method or additional Test Method B of this standard, which is now deleted. Table 1, prepared in accordance with Practice E691, summarizes the results of the round robin. Data obtained during the round-robin testing are being made available in a research report.

11.2 From the data used to generate Table 1 the following conclusion is made:

11.2.1 Thermal conductivity values for the same material measured in different laboratories are expected to be within 18 % of the mean of the values from all of the laboratories.

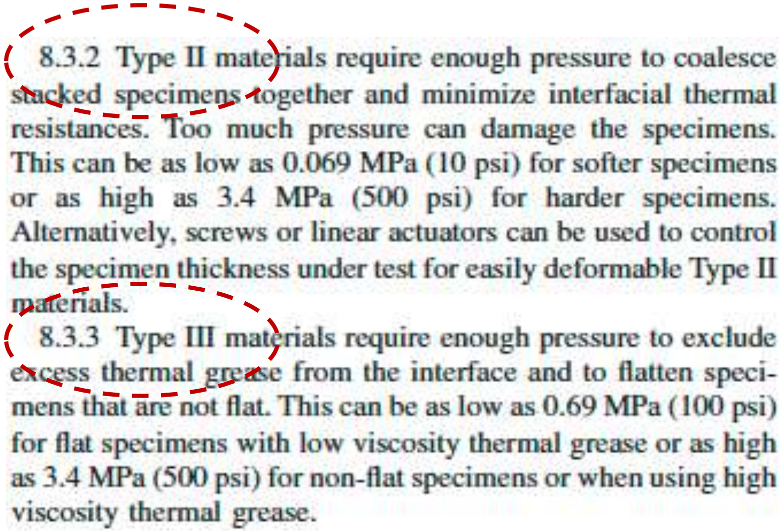
11.3 Bias for this test method is currently under investigation subject to the availability of a suitable reference material.

TABLE 1 Precision for Conductivity Measurement

NOTE 1—Values are in units of watt per meter Kelvin.

Material Identity	Average	S_r^A	S_R^B	r^C	R^D
Material B	0.923	0.0383	0.163	0.107	0.456
Material E	1.245	0.0834	0.175	0.234	0.491
Material C	1.311	0.0423	0.192	0.119	0.536
Material A	2.732	0.2010	0.311	0.563	0.872
Material D	5.445	0.5691	0.711	1.594	1.991

[A] S_r = within-laboratory standard deviation of the average.
[B] S_R = between-laboratories standard deviation of the average.
[C] r = within-laboratory repeatability limit = 2.8 × S_r.
[D] R = between-laboratories reproducibility limit = 2.8 × S_R.



8.3.2 Type II materials require enough pressure to coalesce stacked specimens together and minimize interfacial thermal resistances. Too much pressure can damage the specimens. This can be as low as 0.069 MPa (10 psi) for softer specimens or as high as 3.4 MPa (500 psi) for harder specimens. Alternatively, screws or linear actuators can be used to control the specimen thickness under test for easily deformable Type II materials.

8.3.3 Type III materials require enough pressure to exclude excess thermal grease from the interface and to flatten specimens that are not flat. This can be as low as 0.69 MPa (100 psi) for flat specimens with low viscosity thermal grease or as high as 3.4 MPa (500 psi) for non-flat specimens or when using high viscosity thermal grease.

Lasance et al, Challenges in Thermal Interface Material Testing 22nd IEEE SEMI-THERM Symposium