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Thermal Management Concepts

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company,
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Two approaches

- <u>Removing heat</u>
  - Dense electronics
  - High performance ICs
  - Detectors
- Preventing the transport of heat (insulation)
  - Hypersonic flight
  - Microcoolers
  - Sensors
  - Detectors

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Motivation

- Demand for more speed and capability
- Electronic and electro-optical elements
- Ever greater chip densities
- Conventional heat removal technologies
  - Convection (moving air)
  - Liquid (circulating, spray, and immersion)
  - Conduction (solid materials)

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Consequences

- Product lines are dropped
- Multicore microprocessors
  - Two and quad cores
- Optical communications
  - Active components can be separated
- High performance functionally delayed
  - Teraflop in a “coke can”

Conduction in solids

Simple metals – electrons

Non metals – thermal vibrations (phonons)

Alloys and semiconductors – combination

	Thermal conductivity, (W/m·K)
Diamond	2000-2500
Silver	429
Copper	401
Silicon	149
Polystyrene	.033
Air (200 kPa)	.026

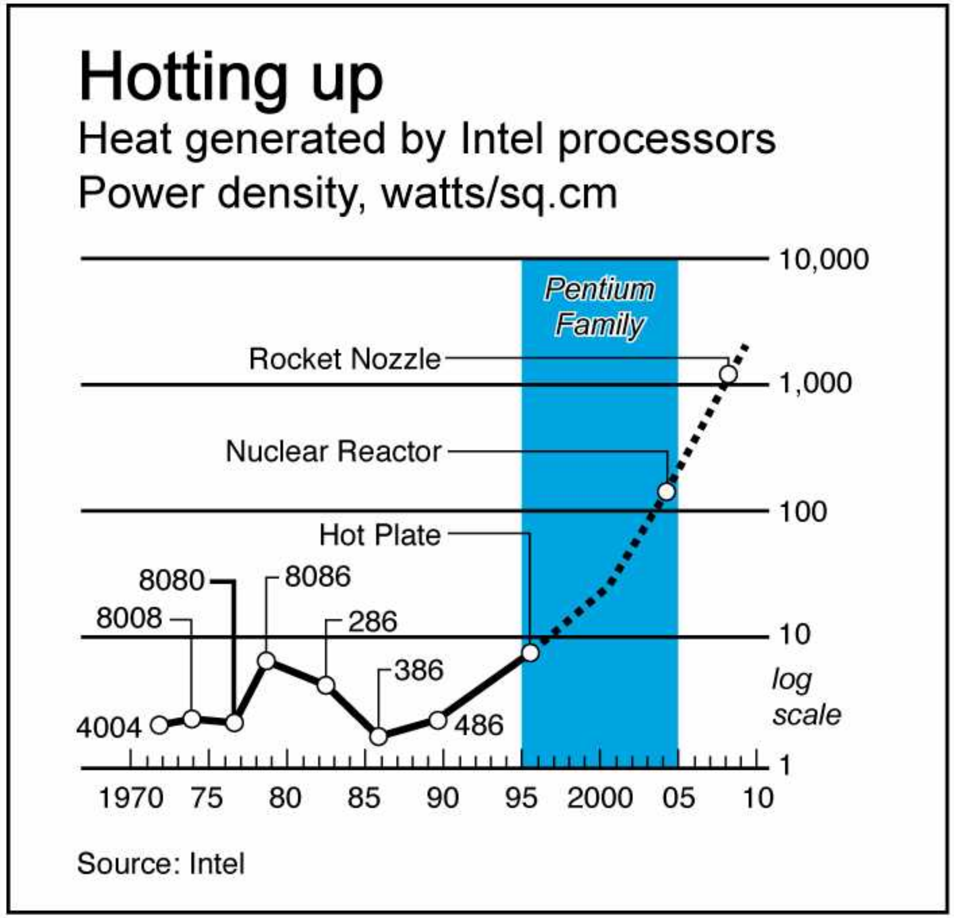
Feel the heat

Smaller chip dimensions, larger current leakage

Electronic assemblies become more compact

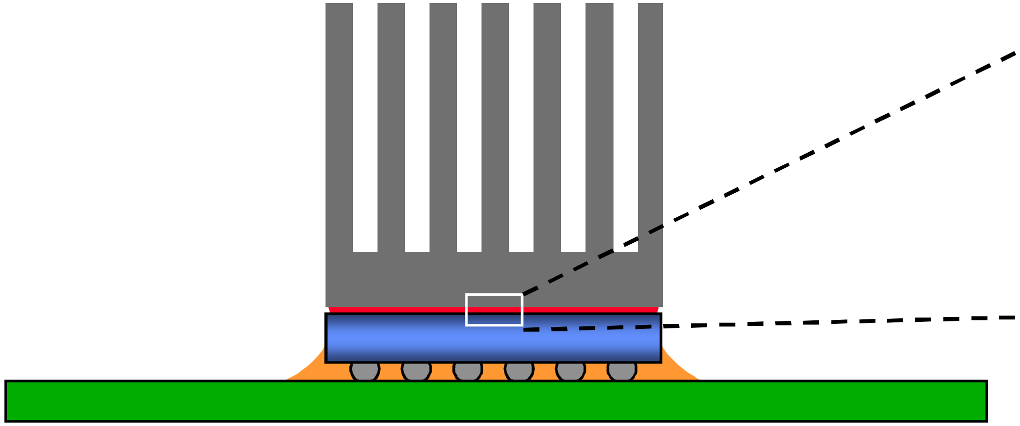
Escalating heat fluxes have become difficult to manage

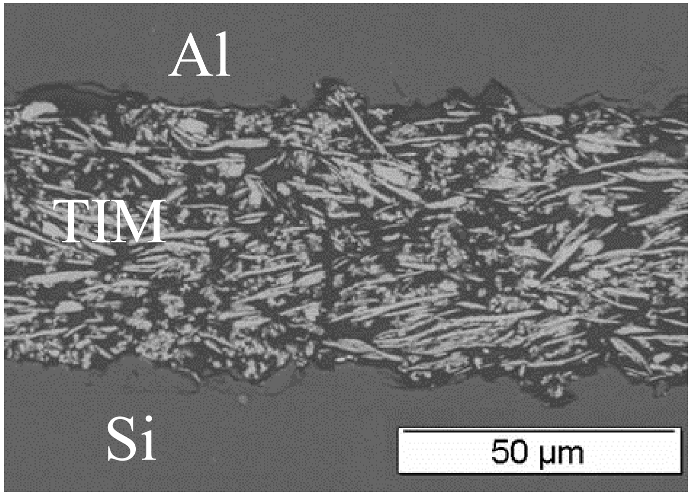
Efficient heat transfer is necessary to dissipate heat



[Economist, 2003]

Thermal bondline



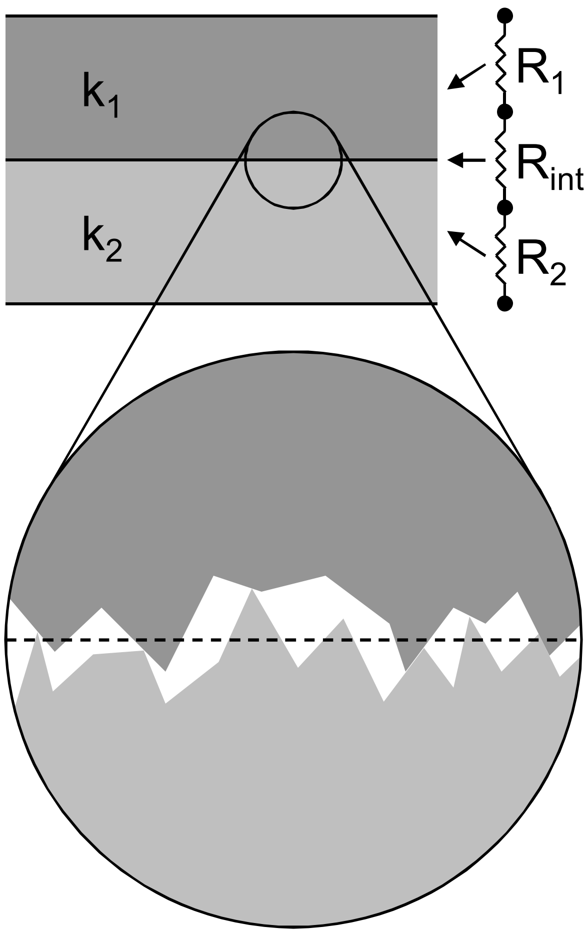


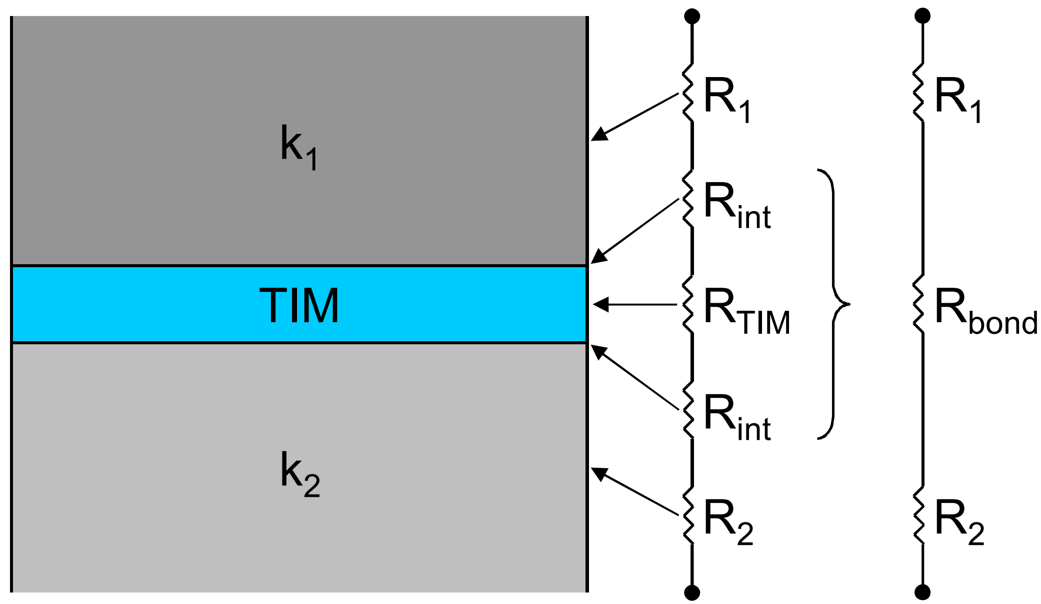
Deviation from theoretical $R_{bondline}$

- **Phonon scattering at the interfaces**
- **Incomplete wetting**
- **Voiding or delamination**
- **Processing induced heterogeneity**

Thermal Interface Materials

TIMs reduce the overall thermal resistance between a device and a heat sink by filling the gap between them

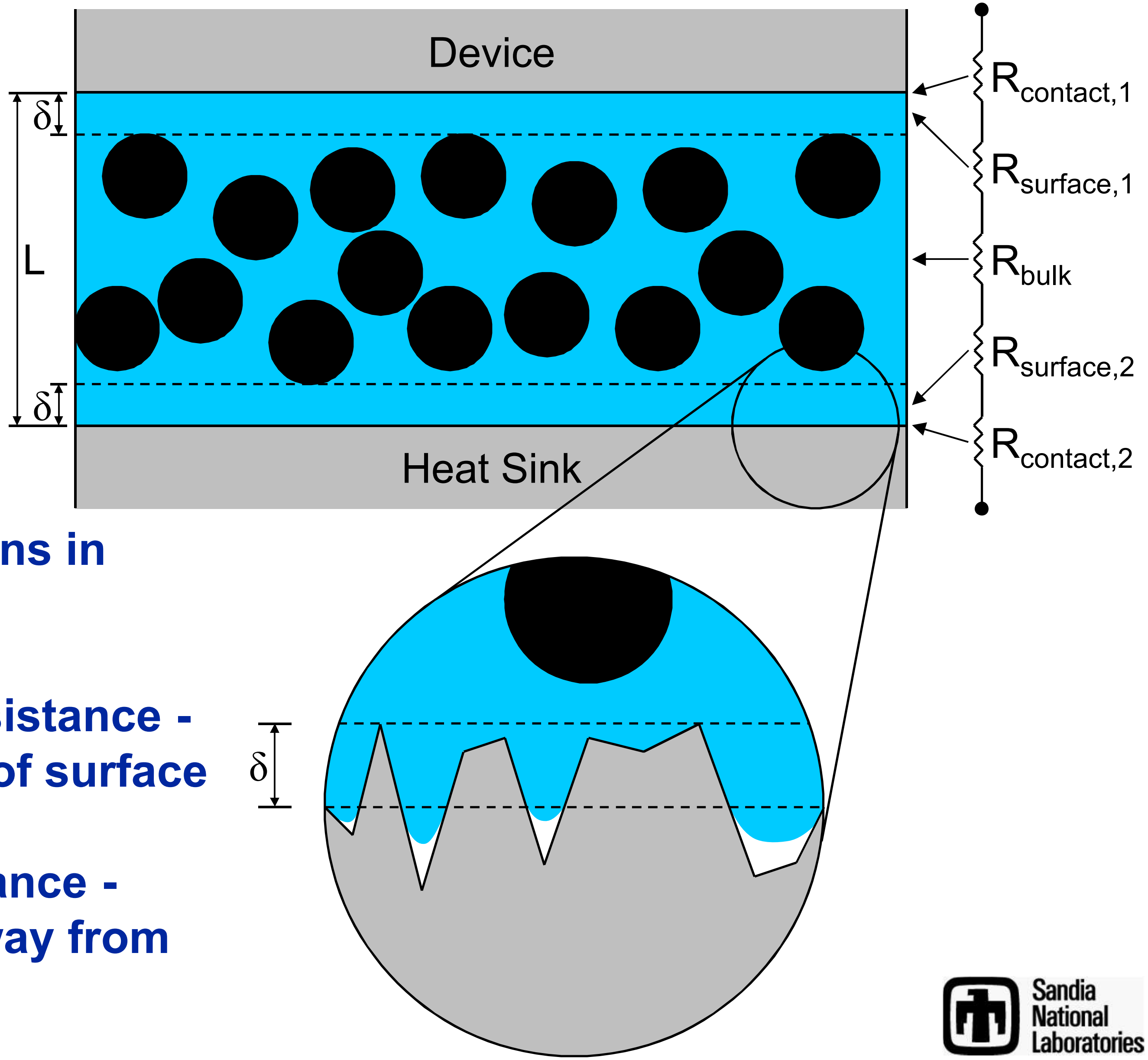




$$R_{bond} = R_{\text{int}} + R_{TIM} + R_{\text{int}} =$$

$$2R_{\text{int}} + L / k_{TIM} = \frac{(\Delta T)_{TIM}}{q_y}$$

Material/Processing challenges

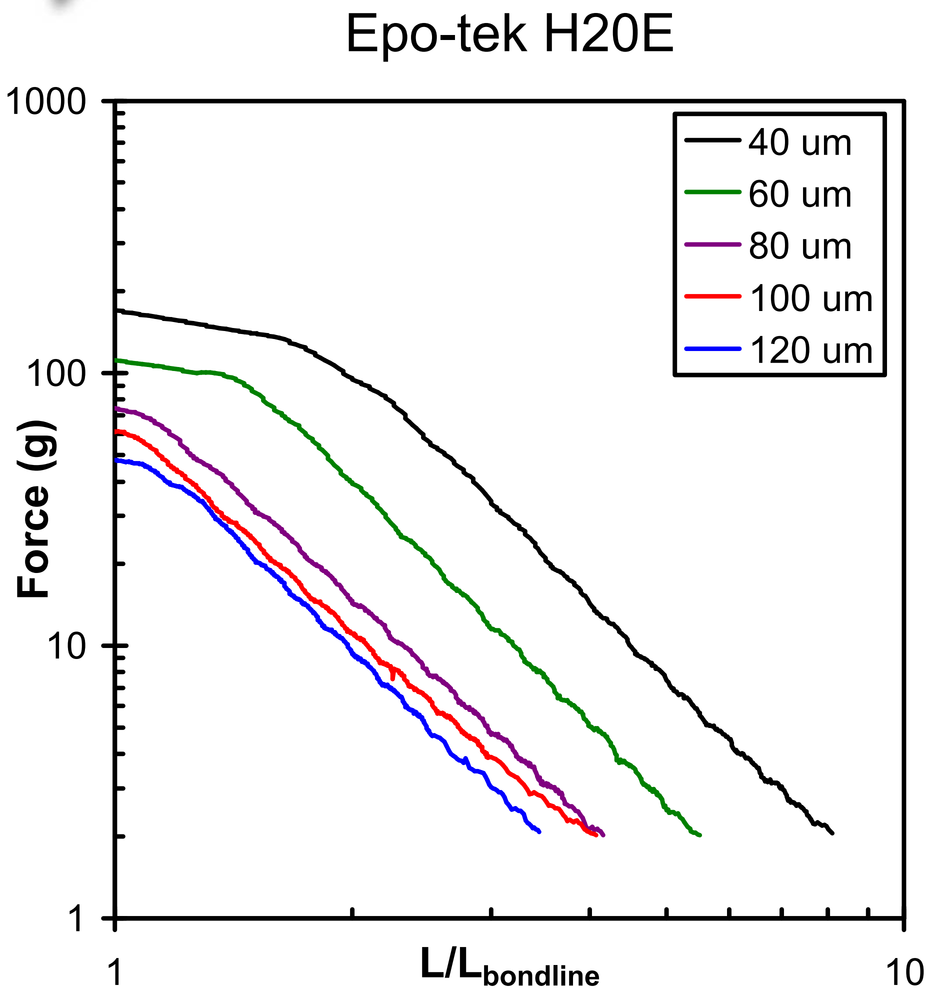


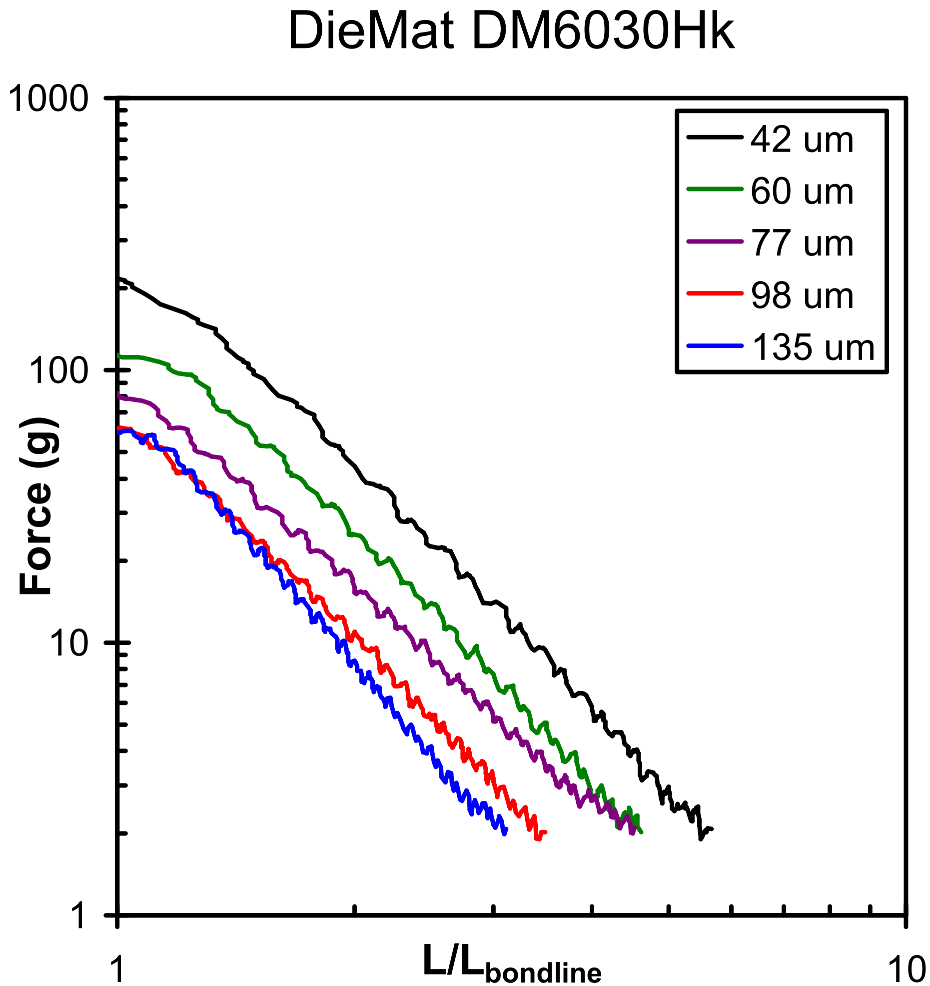
Theoretical reductions in thermal resistance

Increase contact resistance - incomplete wetting of surface

Surface layer resistance - filler segregation away from interface

Squeeze flow data





Larger force for thinner bondlines suggests filler compaction
Squeeze out of excess material causes slope change at small thickness

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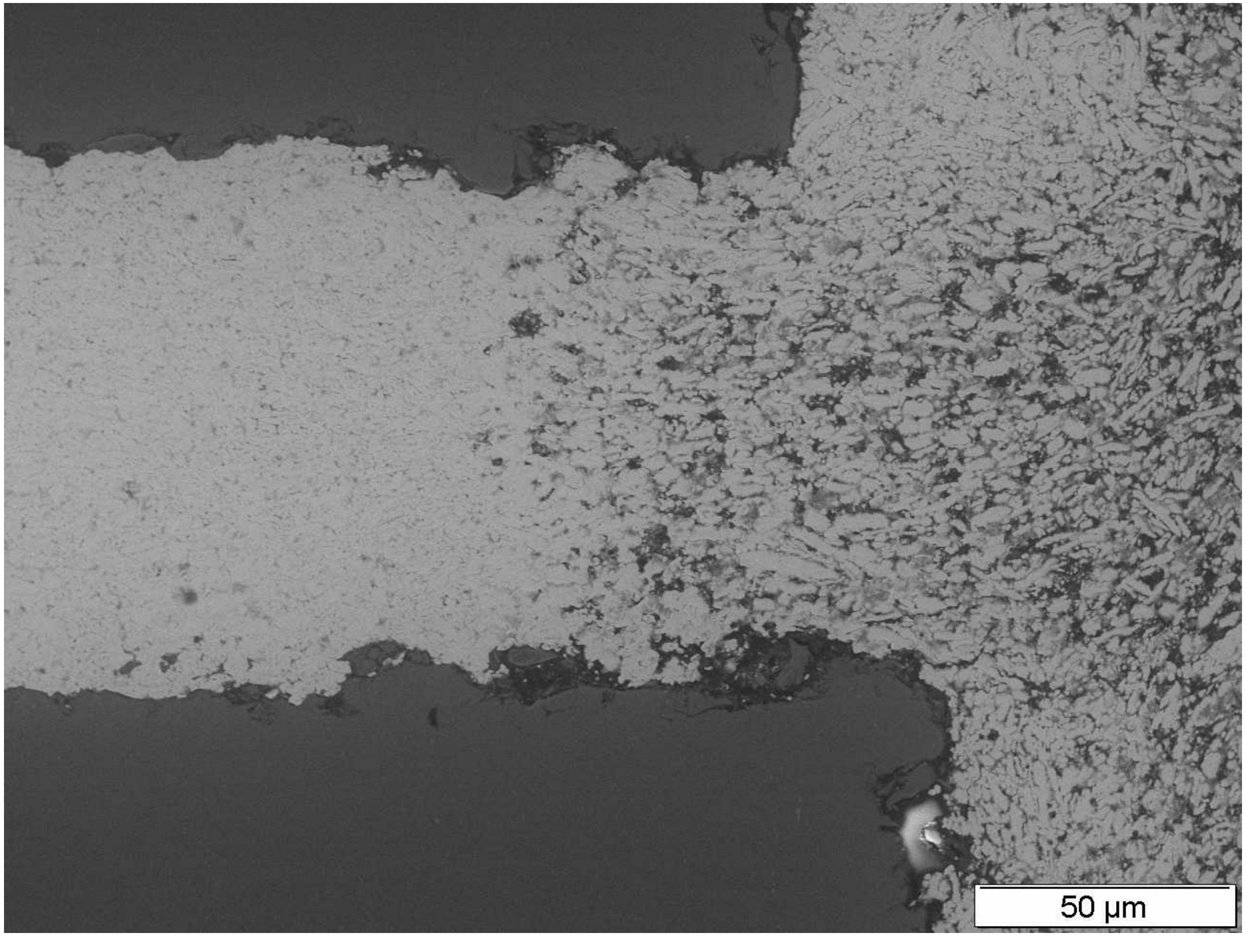
Controlled squeeze flow



Material - DM6030Hk

Particles near center are highly compacted, squeeze out of epoxy is evident at edge

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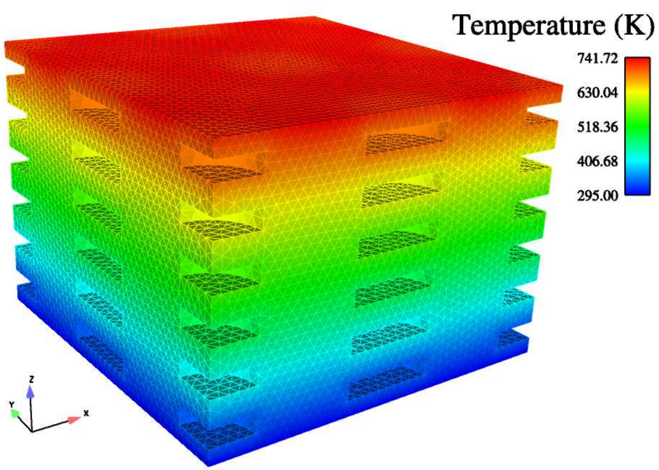
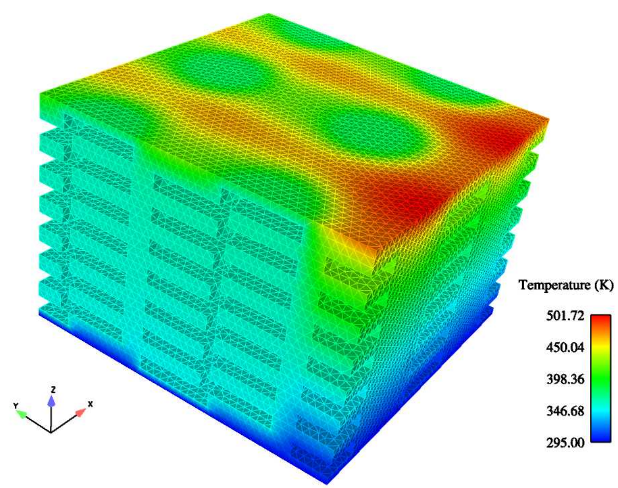
Modeling Heat Conduction in Thermal Interface Materials with Micro-Disks

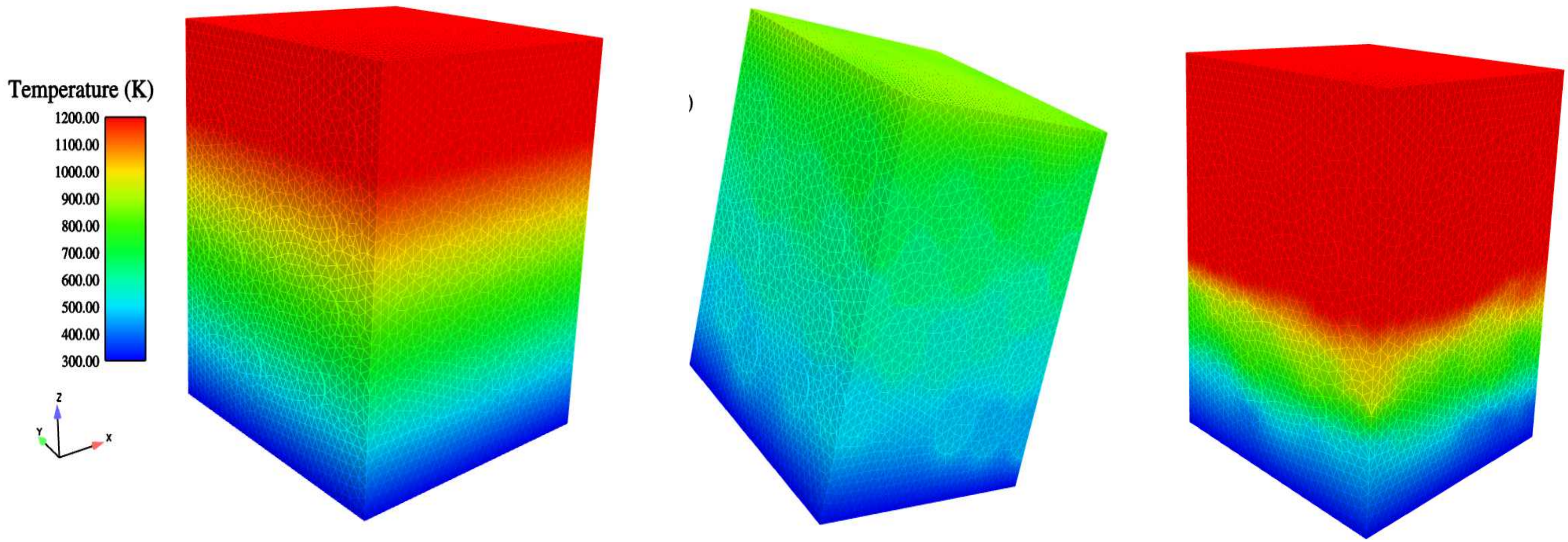
- Perform thermal analysis for TIMs with stacks of micro-disks (20 μm in diameter and 4 μm high; volume fraction = 55%).
- 5 cases studied, w/ interfacial resistance, preliminary results are :
  (matrix: *k* = 0.21 W/m-K; filler: *k* = 0.42 W/m-K)
  (1) bcc, distributed evenly: *k* = 0.225 W/m-K;
  (2) bcc, closely packed in z-direction: *k* = 0.286 W/m-K;
  (3) shifted bcc, no disk-to-disk contact: *k* = 0.396 W/m-K;
  (4) shifted bcc, some contact: *k* = 0.635 W/m-K;
  (5) stacked & 100% disks contact: *k* = 1.25 W/m-K.





Preliminary CALORE Analysis of 3 Heterogeneous Interface Materials

Polymer only | *Polymer w/ metal spheres* | *Polymer w/ voids*



	Adhesive Polymer Only	w/ Metal Spheres	w/ voids
Max. T	1491 K	882 K	2124 K
Min. T	295 K	295 K	295 K

Bulk TIM sample - results

ID	Material	ρ (g/cm^3)	Cp (J/gK)	α (cm^2/s)	λ (W/mK)	λ_{vendor} (W/mK)
Epoxy 1	Unfilled epoxy	1.13	1.3	0.0013	0.2	-
TIM 1	Ag-flake filled epoxy 1	3.13	0.51	0.0113	1.8	29
TIM 2	Ag-flake filled epoxy 2	2.84	0.45	0.0830	10.6	17
TIM 3	5% Nanocomposite of TIM 1	2.76	0.61	0.0051	0.6	-

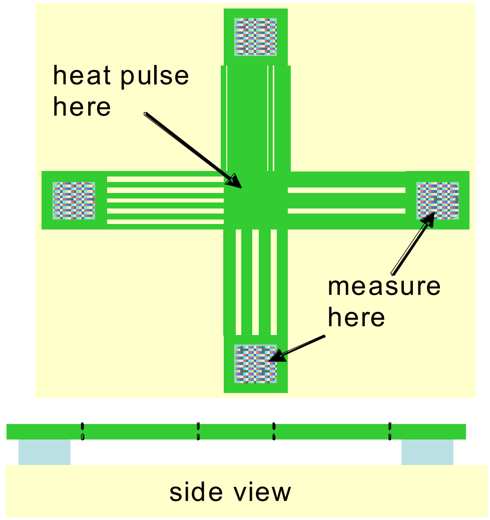
Preparation:

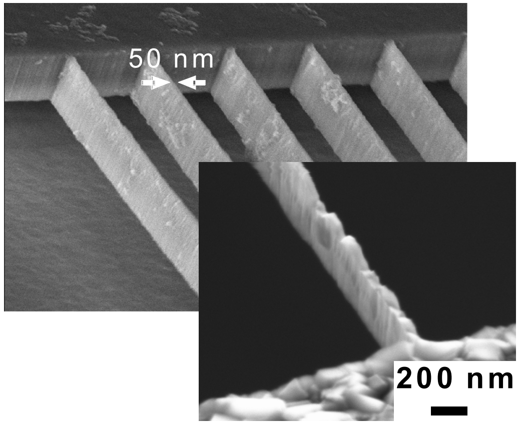
- 3 samples of each tested, average is shown
- Au/Pd and graphite overcoat layers
- λ deviation 10-30%

Results:

- All filled materials provide improvement over unfilled epoxy
- Both commercial epoxies λ_{exp} lower than on data sheet λ_{vendor}
- No discernable benefit to addition of 5% nanoparticles for bulk λ

Experiments with controlled interfaces





A proposed thermal transport test structure. Legs form bottlenecks with dimensions greater than and less than the phonon mean free path.

Lithographically defined structures with dimensions comparable to phonon mean free paths.

Summary

- Thermal demands are bringing Moore's law to a halt
- Heat transfer at the interface plays dominate role
- Processing effects
- Filler contact resistance

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Any questions