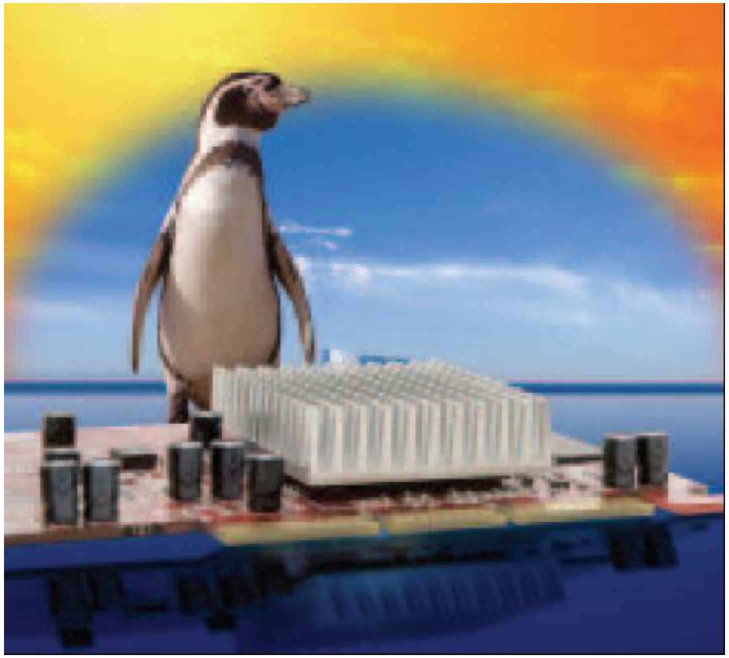
Thermal Interface Materials (TIMs) for IC Cooling

Parker Chomerics



Percy Chinoy

ENGINEERING YOUR SUCCESS.

October 22, 2008

Outline

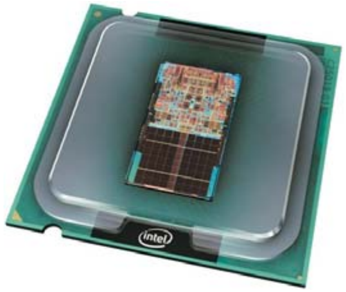
- Introduction to Thermal Interface Materials (TIMs)
- Thermal Impedance and Interfacial Contact Resistance
- TIM Design
- TIM Trends
- Summary

Thermal Challenge in Electronics

Smaller, faster, cheaper => thermal challenges

- **Heat is a major problem in electronics**
  - Limits performance (e.g. operating speed)
  - Reduces reliability (e.g. product lifetime)
  - Reduces efficiency (e.g. battery life)
  - Adds cost

- **Some perspective on the problem**
  - Leading edge microprocessors and LEDs can have hot spots of 100–1000 Watt/cm^2 with max allowable temperature of 90–125°C
  - Atmospheric re-entry of space shuttle generates 10 W/cm^2 at temperatures up to 1500°C
  - Throat of a rocket nozzle generates 100 W/cm^2 at temperatures up to 2000°C



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Thermal Management

Package level

Board level

System level

Air cooling
(natural and forced convection)

Liquid cooling

TIM Markets

Worldwide market for TIMs was $300 – 400 Million in 2007 growing at 8% CAGR

Markets Served

- **Telecommunications**
- **Information systems**
- **Consumer electronics**
- **Military/Aerospace electronics**
- **Industrial electronics**
- **Automotive electronics**
- **Medical electronics**

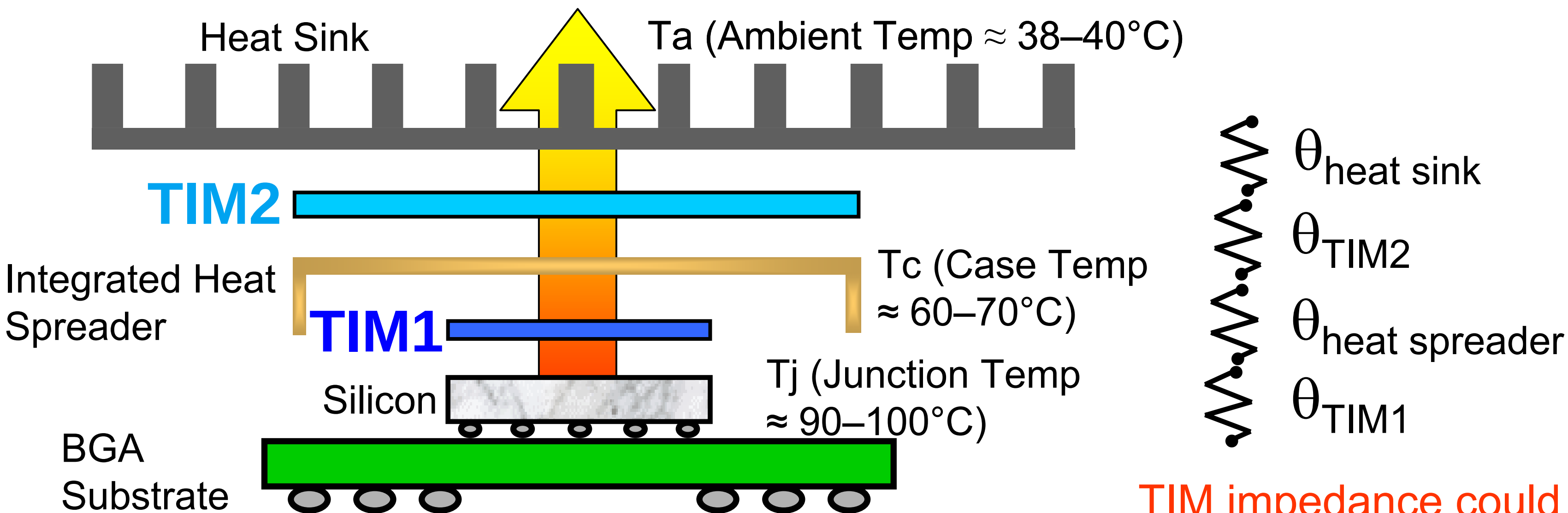




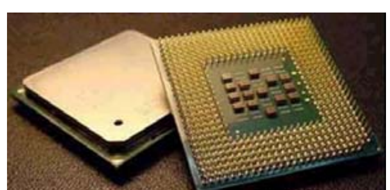

Thermal Interface Materials (TIMs)

TIMs enable heat transfer from semiconductor device (die, package) to heat spreader (heat sink, heat pipe, chassis, housing)

- Design goal is to minimize thermal impedance and keep the device junction temperature below specified limits



TIM impedance could be 20–40% of overall thermal impedance



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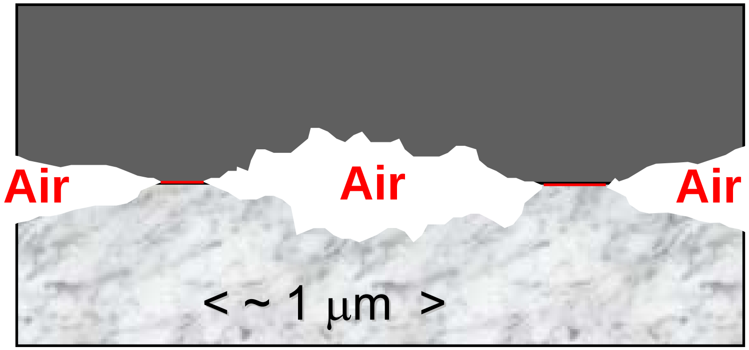
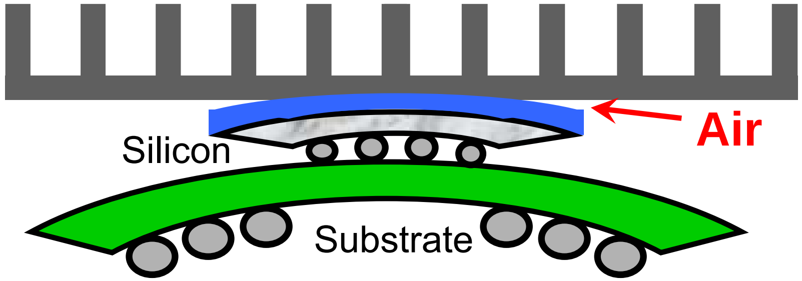
Why TIMs?
Interfacial Contact Resistance

Microscopic



Macroscopic



- Contact resistance is primarily due to surface roughness on a microscopic scale and out-of-flatness on a macroscopic scale, both of which cause air entrapment
  - Roughness of a machined surface is about 1–2 μm while that of a polished surface is 0.1–0.5μm
  - Surface flatness of 1 μm/mm is considered good
- TIMs essentially replace air with a more thermally conductive material

k_{air}= 0.03 W/m-K **k_{TIM}= 1–5 W/m-K** **k_{Al}= 230 W/m-K**

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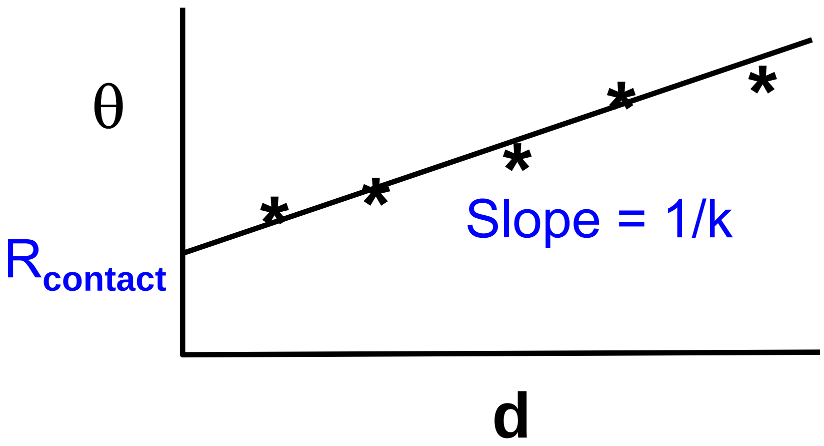
Thermal Impedance

$$\theta_{TIM} = R_{contact\ 1} + R_{TIM} + R_{contact\ 2}$$

$$R_{TIM} = d / k$$



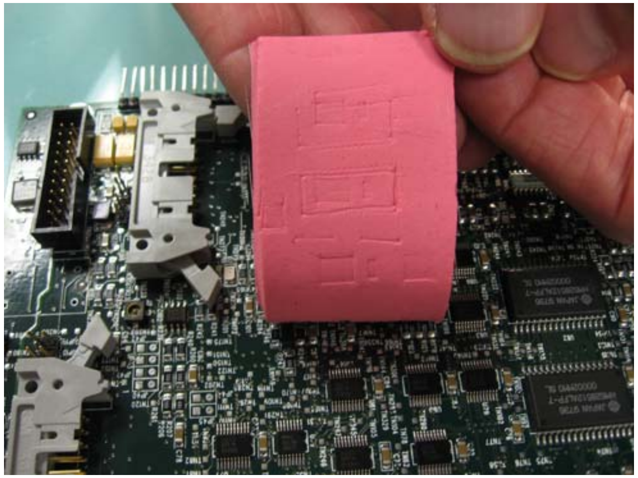
d – bondline thickness (mm)

k – thermal conductivity (W/m-K)

θ – thermal impedance (°C-cm²/W)

R – thermal resistance (°C-cm²/W)

Reducing Contact Resistance

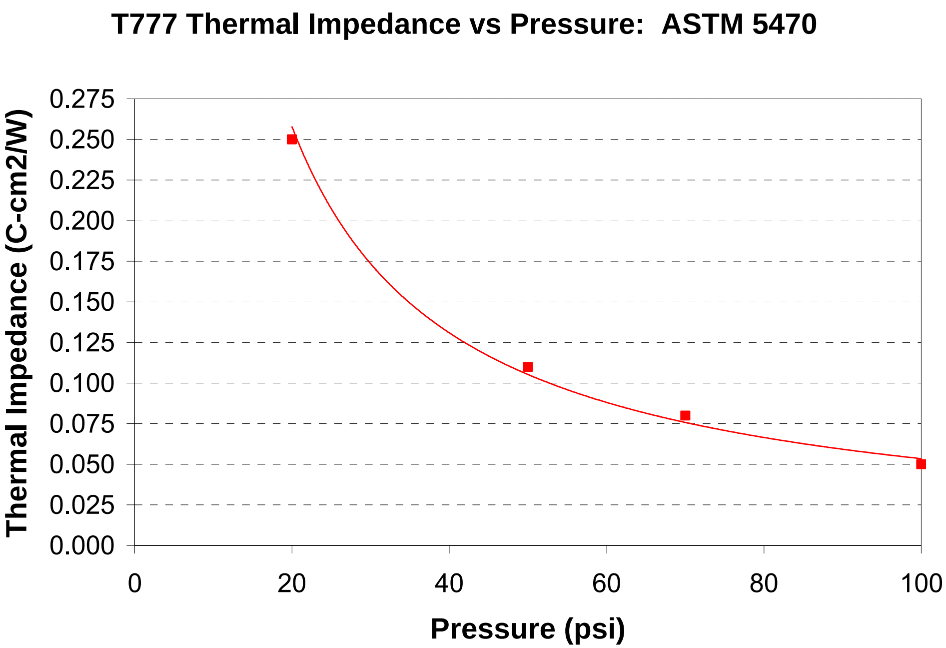


Softer TIMs conform better to surface irregularities and thus:

- reduce $R_{contact}$, and
- reduce stress on components

Higher pressures

- reduce $R_{contact}$, and
- reduce bond-line thickness



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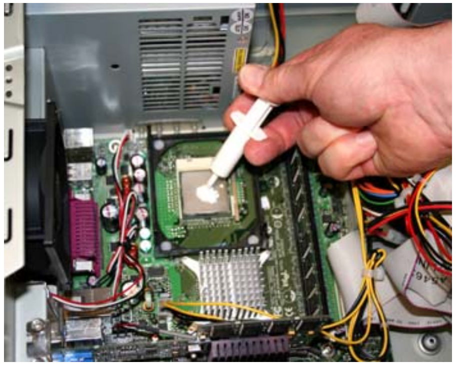
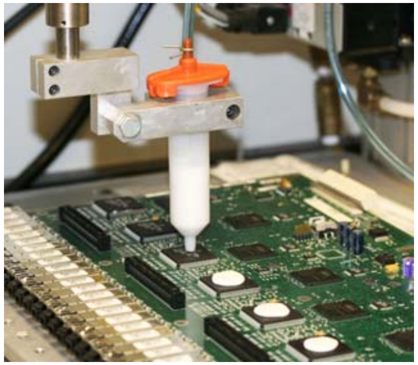
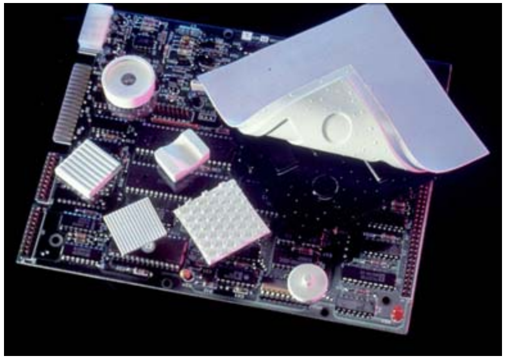
Polymer TIM Product Platforms

Thermal Grease

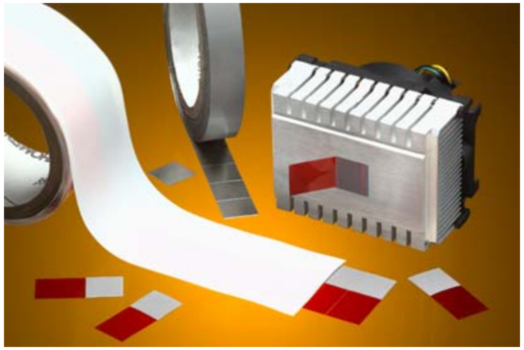




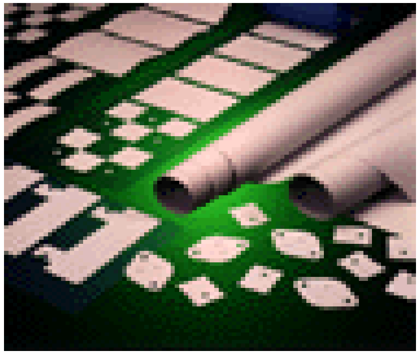
Thermal Gels



Thermal Gap Filler Pads

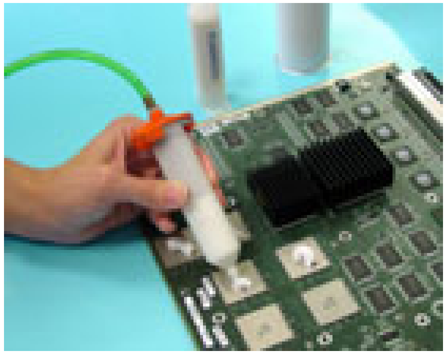


Phase Change Materials



Electrically Insulating Pads

Thermal Compounds / Adhesives



Thermal Adhesive Tapes

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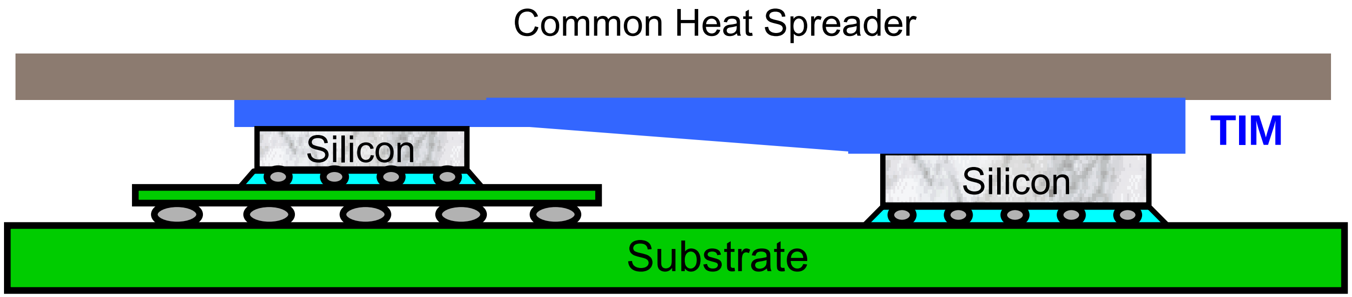
Design Variables for TIMs - 1

Thermal, Physical, Electrical, Mechanical, Regulatory

- Power dissipation – Watts, Watts/cm^2
- Allowable temperatures – $T_{junction}$, T_{case}
- Size of chip, package

} Thermal Impedance specification

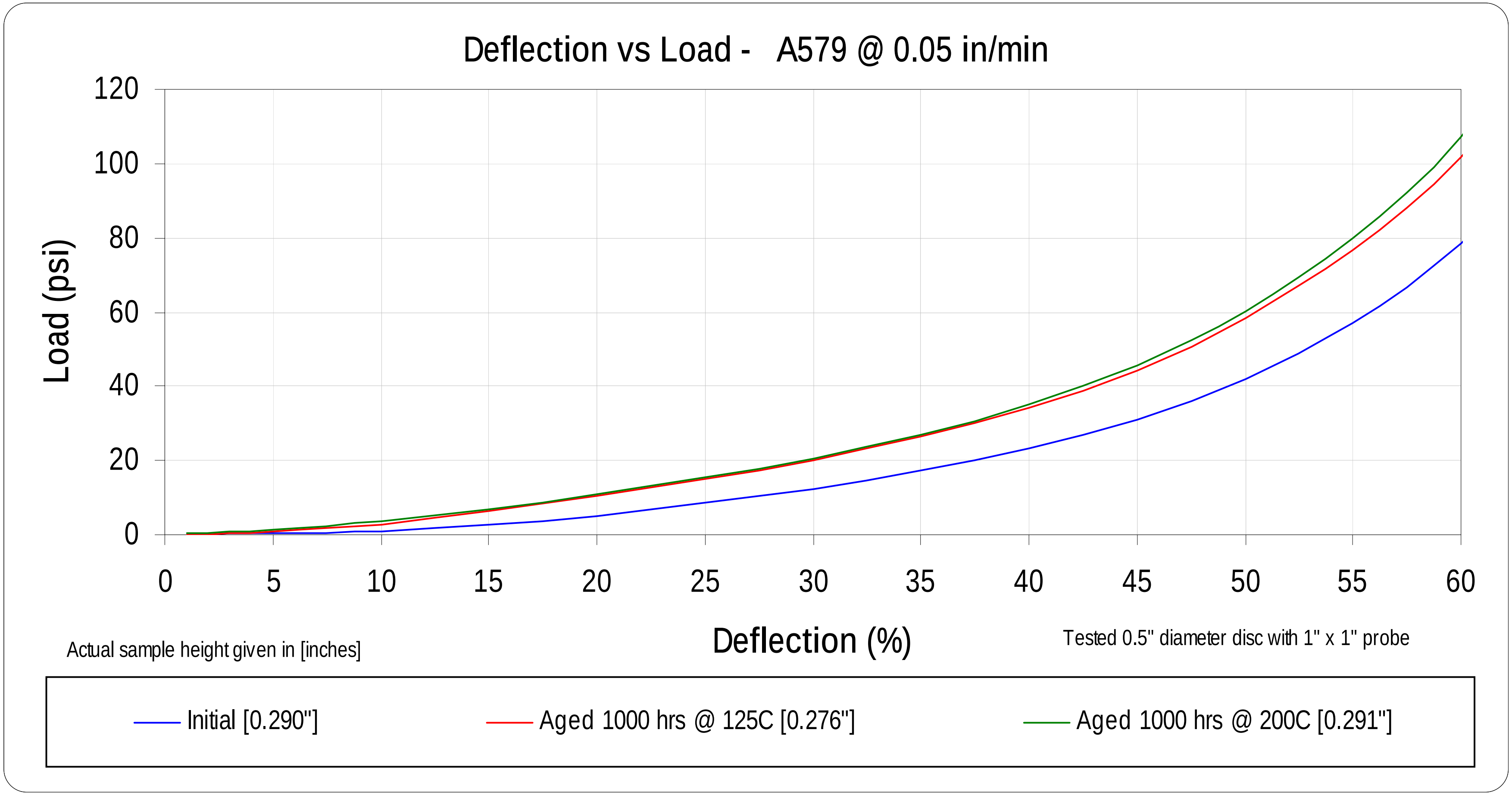
- Gap thickness between chip/package and heat spreader
  - Thin bond-line or thick bond-line TIMs
- Flatness tolerances (bow, warp, tilt)
- Single chip vs. multiple chips (co-planarity)



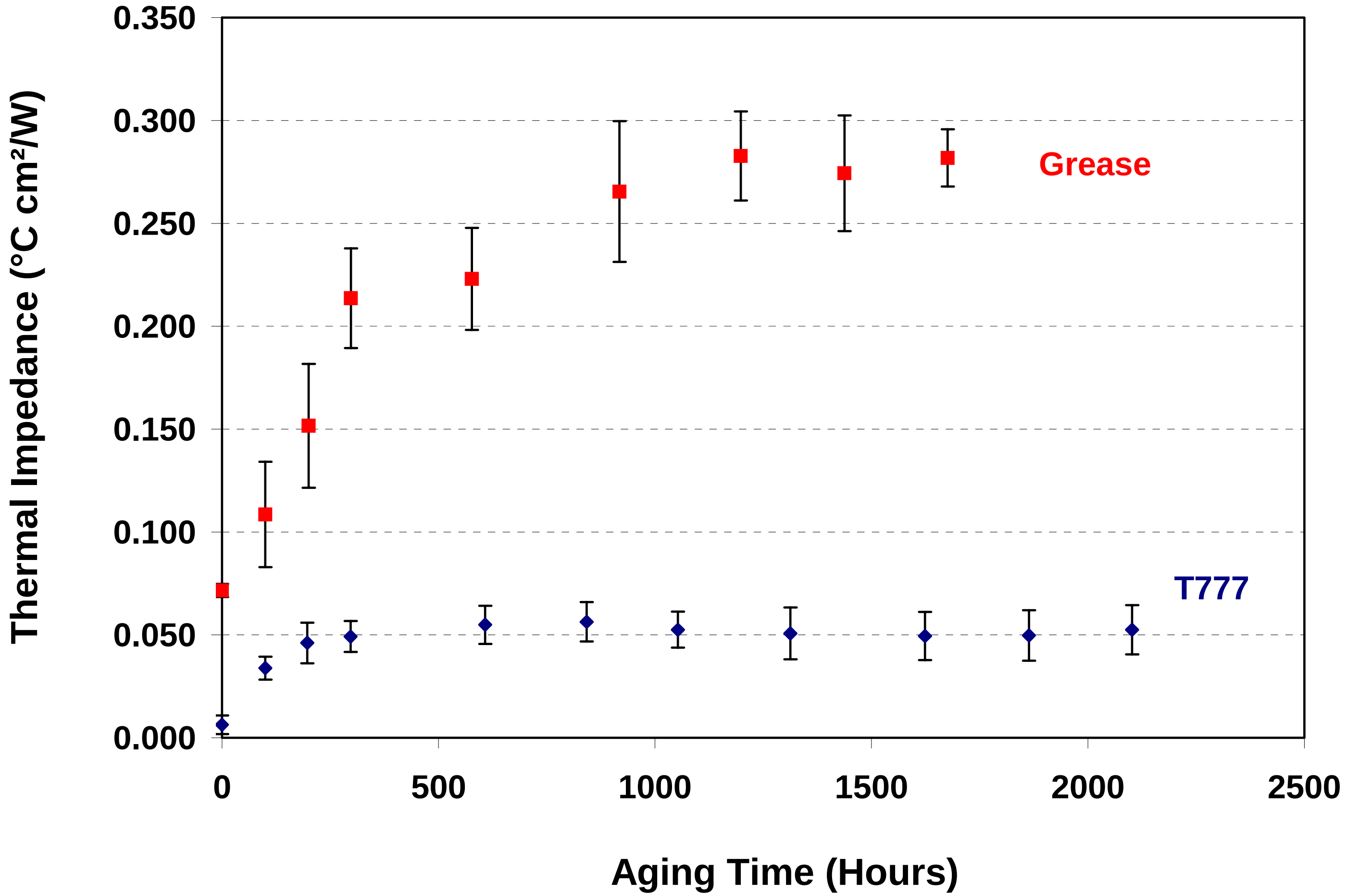
Design Variables for TIMs - 2

- Contact pressure
    - Impacts bond-line thickness and interfacial contact resistance
- Compression-Deflection characteristics
- Electrical isolation requirement – Volts/mm
- Attachment of heat spreader with mechanical fastener (screw, clip) or TIM – adhesion strength requirements
- Method of Application – pick-and-place, dispense, stencil
- UL rating
- RoHS compliance
- Out-gassing requirements – TML, extractable silicones
- Re-workability
- Storage, shelf-life
- Others ……..

Deflection Curve for Heat Aged 579



Long Term Reliability: T777 vs. Grease
(Uniform heating, 120°C)



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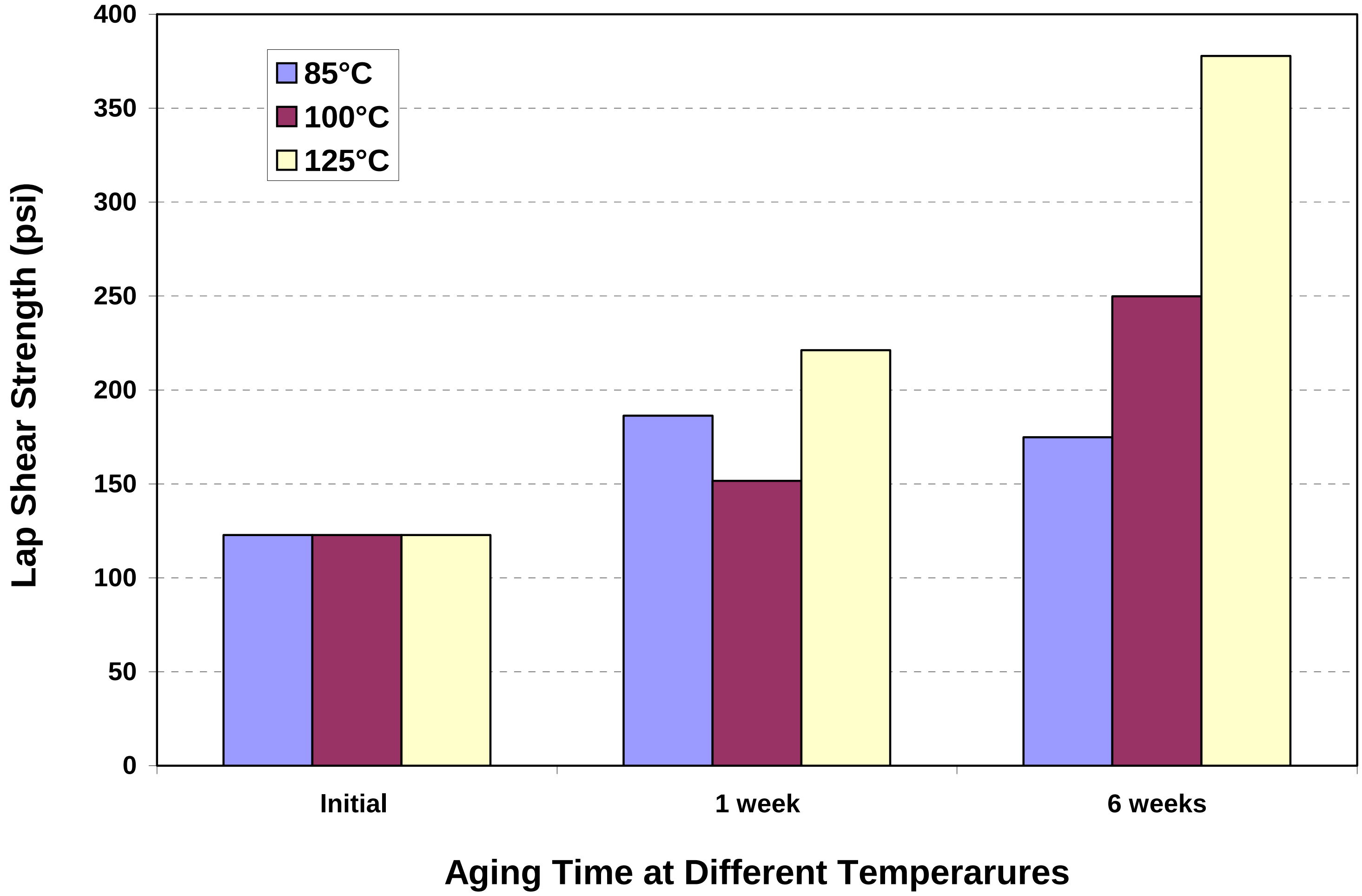
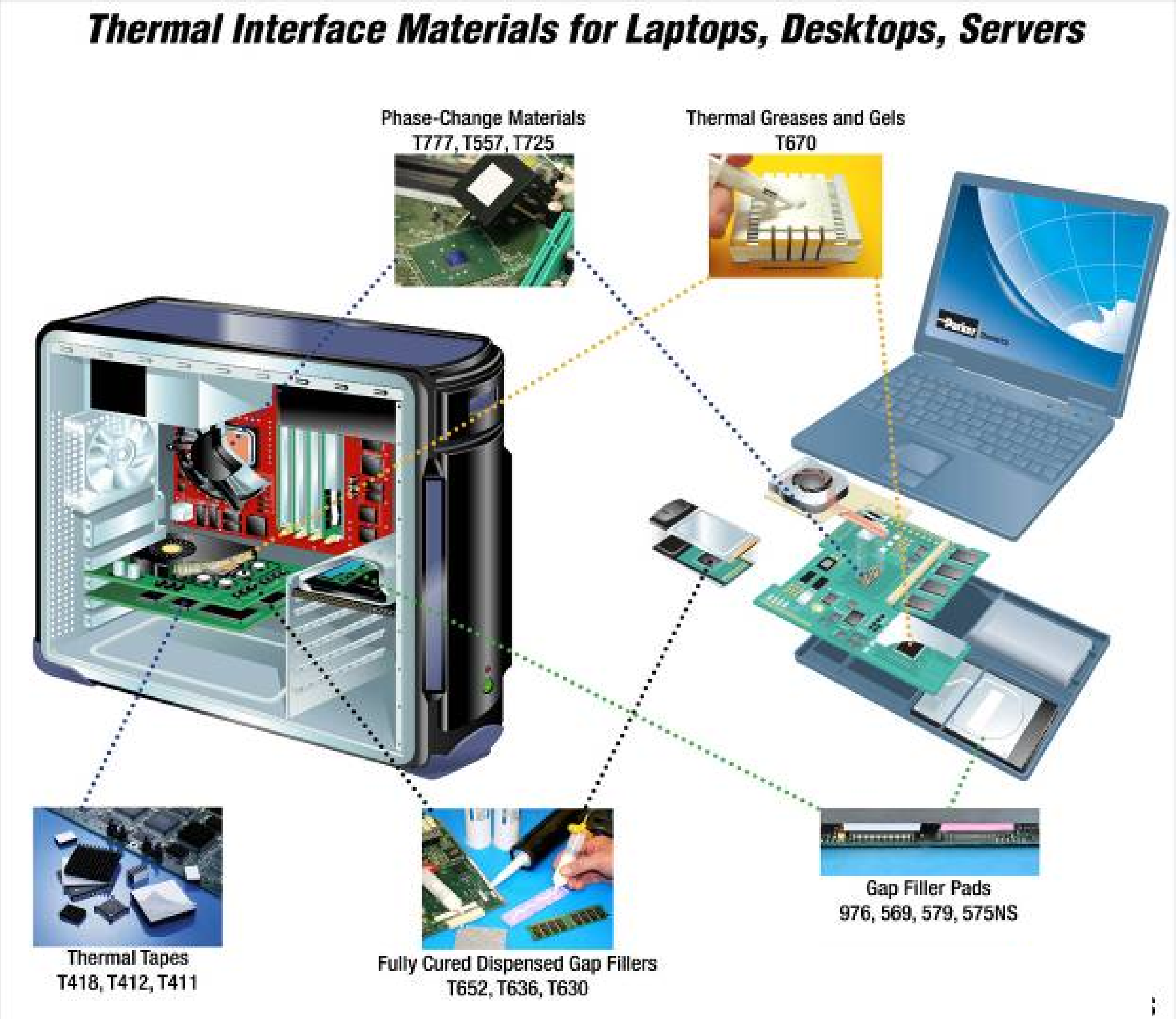
T418 Lap Shear Strength after Aging



Computer Applications of Chomerics TIMs



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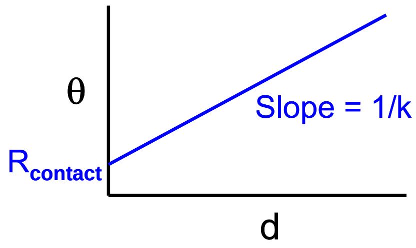
Microprocessor Power Trends

- Transistor density continues to double each technology node
  - 45nm ramping up in 2008 → 32nm ramp-up in 2010
- Clock frequency continues to increase (3GHz) for high-speed performance, but ….
  - … running into power consumption and heat dissipation limitations
  - Multi-core processors
- Thermal challenges dominate microprocessor design and architecture
  - Performance per Watt is key design parameter
- ITRS and iNEMI roadmaps show continuing increase in max power for high-end microprocessors
  - >160W for servers/netcom, >100W for desktop, >40W for mobile
- Multi-core processors (dual core, quad core) slowing down the trend of increasing *max* power, but ….
  - *… hot spots* are a growing challenge, power density > 200 Watts/cm^2

TIM Trends



- Low thermal impedance
  - High thermal conductivity
  - Thin bond line
  - Low contact resistance – softness / compliance, surface wetting
- High reliability
  - End-of-Life performance – TIM degradation over time
  - Reduced pump-out => move from grease to gels, PCMs
- Low cost
  - Total cost of ownership – improved TIM may need smaller heatsink
- Adhesion strength
  - High adhesion strength for tapes, adhesives
  - Low adhesion strength on some surfaces for ease of rework
- Automated Application Process
  - Dispense, pick-and-place
- Custom Integrated Assemblies
  - Thermal + EMI shielding/RF absorbing solutions

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Summary

- Thermal challenges dominate chip and package design
- Increased power density of ICs and system reliability are continuing to drive innovation in TIMs
- Thermal impedance is the key metric of TIM performance, not just at time=0 but at end-of-life
- Decisions on TIM selection should not be based just on piece-part cost but rather total cost of ownership
- Maturing market will drive higher functionality solutions, e.g. TIM + EMI shield or RF absorber
- Collaboration of TIM manufacturers with designers at OEMs, ODMs, CEMs is essential to ensure steady stream of new TIMs that meet tomorrow's IC cooling needs