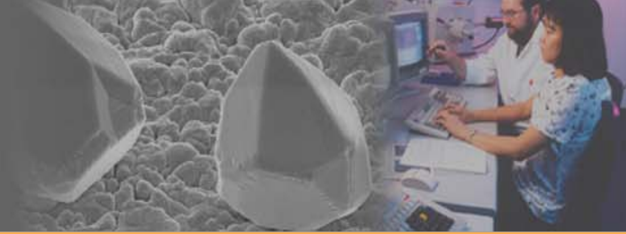
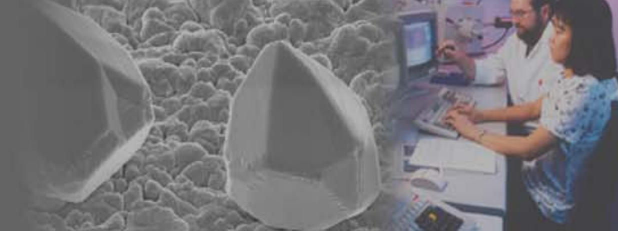
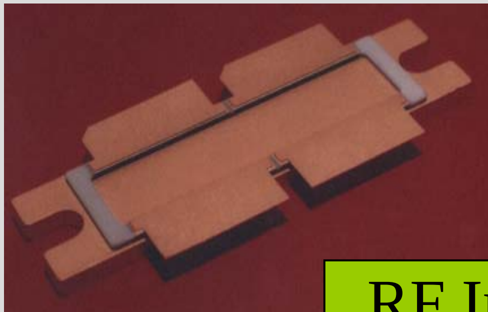


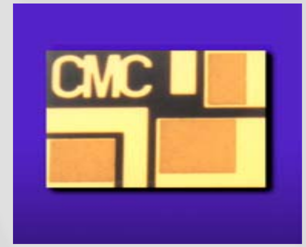
Material and Interfacial Impact on Package Thermal Performance

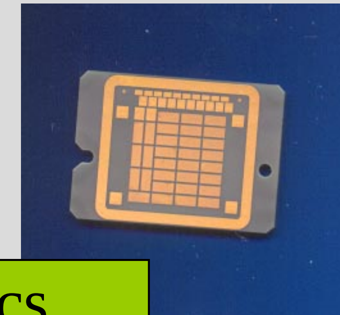
J.H. Harris, R. Enck, N. Leonardi, E. Rubel
CMC Interconnect Technologies





RF Infrastructure

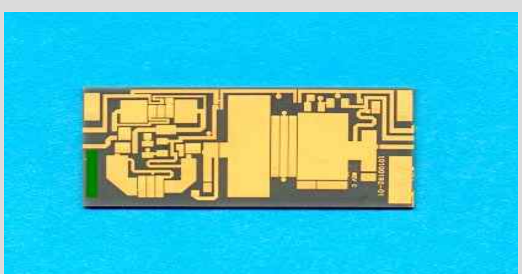




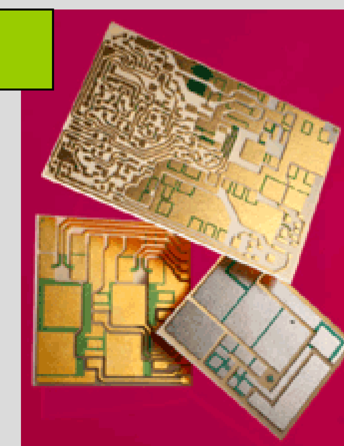
Optics

High Power Applications

Microwave



Power



CMC INTERCONNECT TECHNOLOGIES

Both materials and fabrication processes strongly impact thermal performance..

MATERIALS

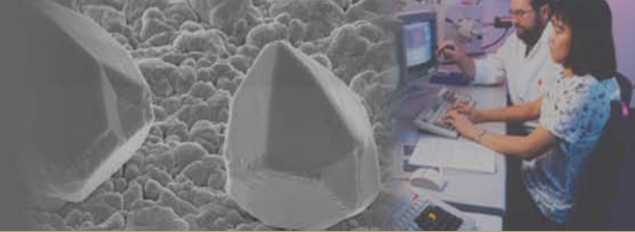
PROCESSES

High TC Components
•AlN Ceramics
• Die Attach Materials
• Diamond/Ag Composites

• Analysis
• Materials Science

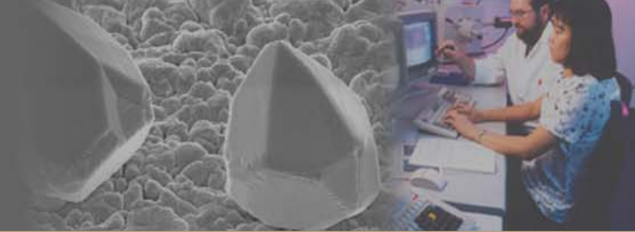
Consequences of Package Fab
• Material Changes
• Formation of interfaces

PACKAGE THERMAL PERFORMANCE



Novel High Thermal Performance Materials for Packaging Applications

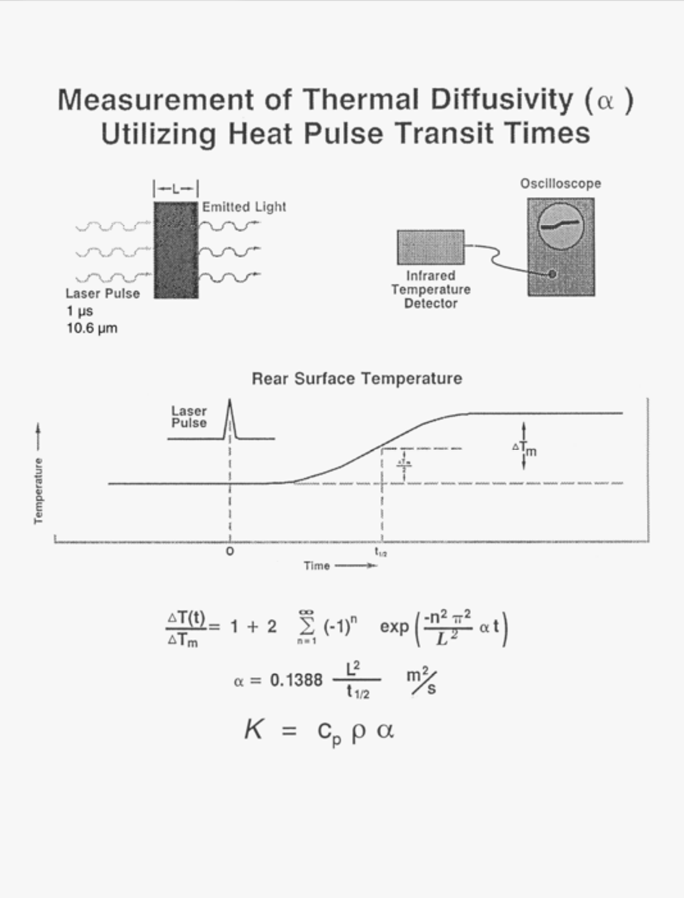
- Thermal Characterization- Laser Flash Technique
- Key Thermal Considerations for Packaging Applications- Processes
  - Material Changes during Package Fabrication
  - Thermal Impedance of Interfaces
  - Die Attach
- Conclusions



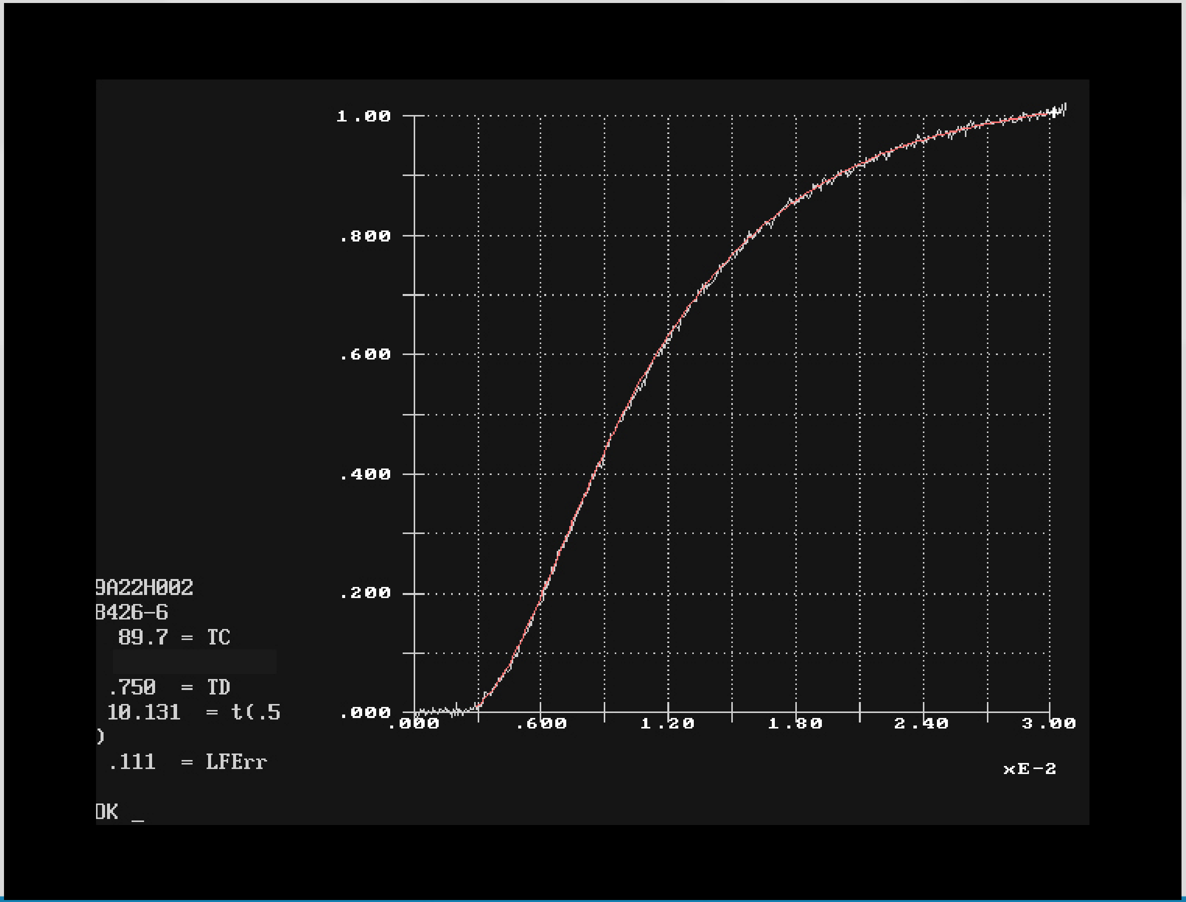
Laser Flash Thermal Diffusivity Measurement

Laser Flash Thermal Diffusivity Measurement-Schematic

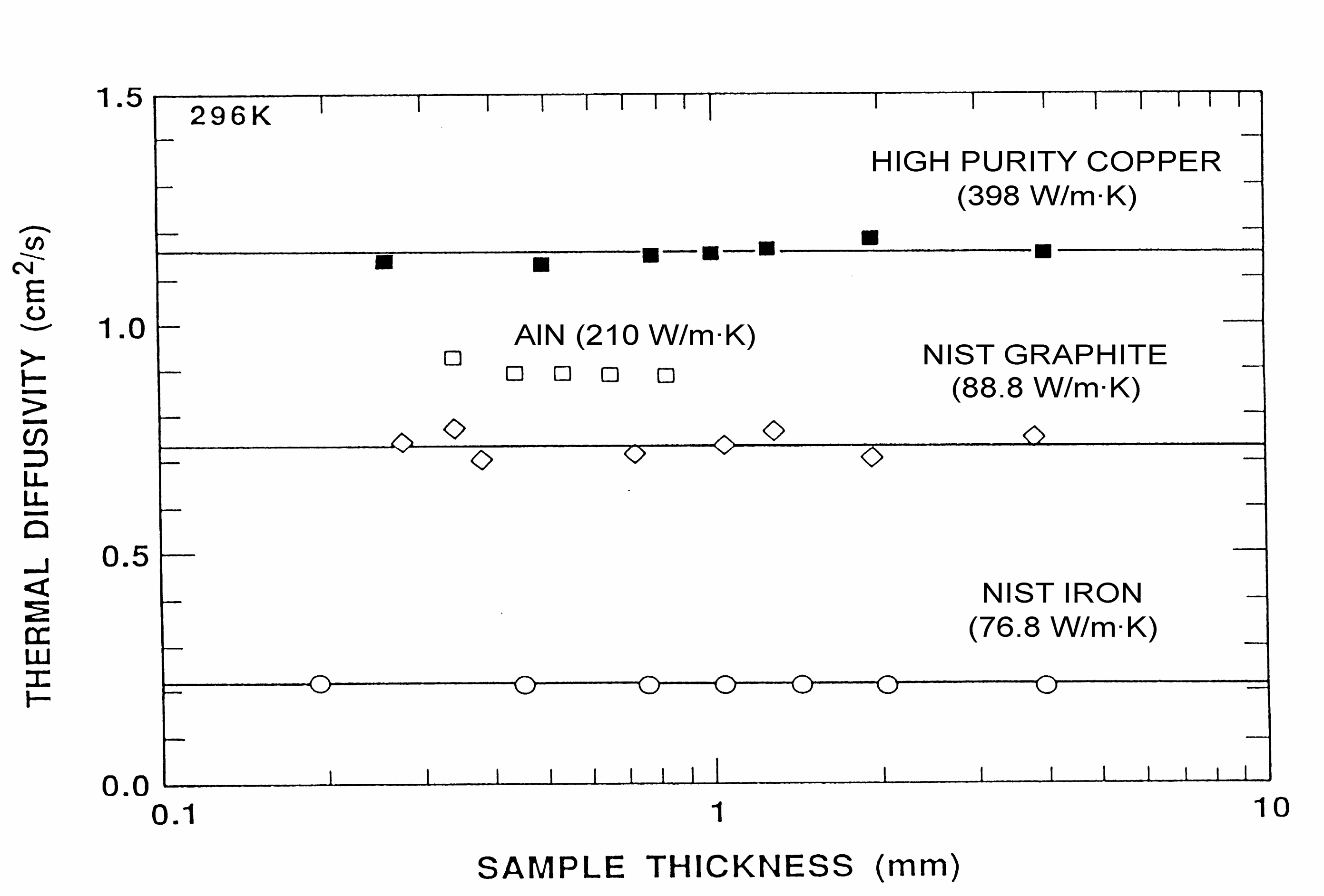
- Short laser pulse heats a shallow layer of the sample surface
- Temperature on the backside of the sample is monitored vs. time
- T vs. time curve is fit to 1D Heat Flow equation- Thermal Diffusivity is measured



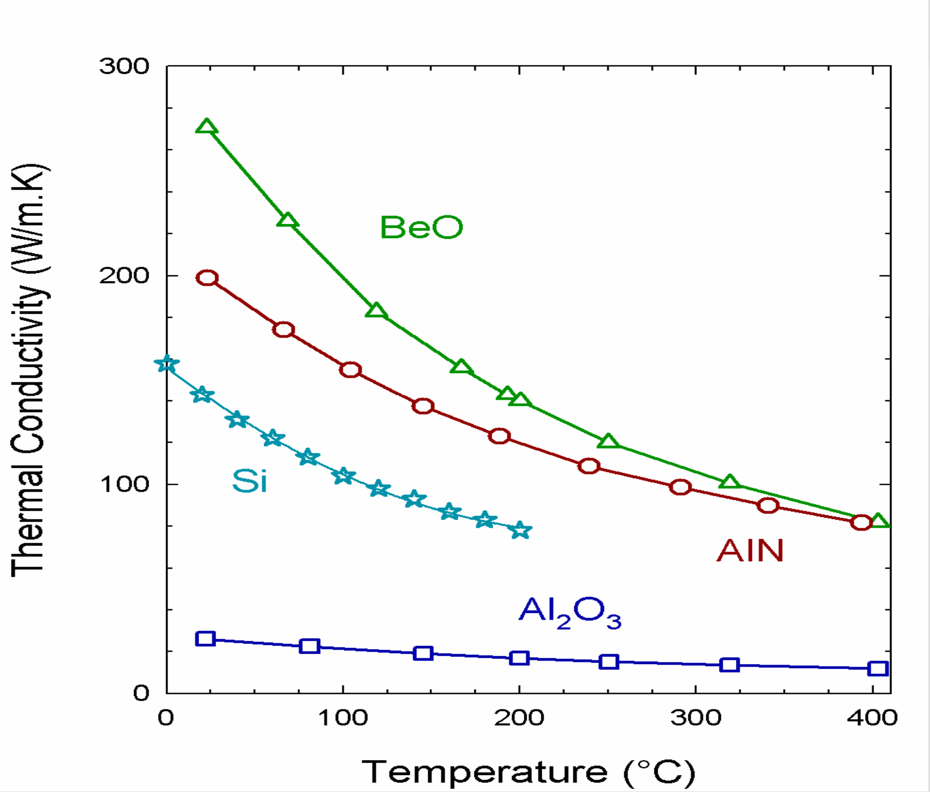
Laser Flash Thermal Diffusivity Measurement- T vs. Time



TC vs. Thickness



TC vs. Temperature

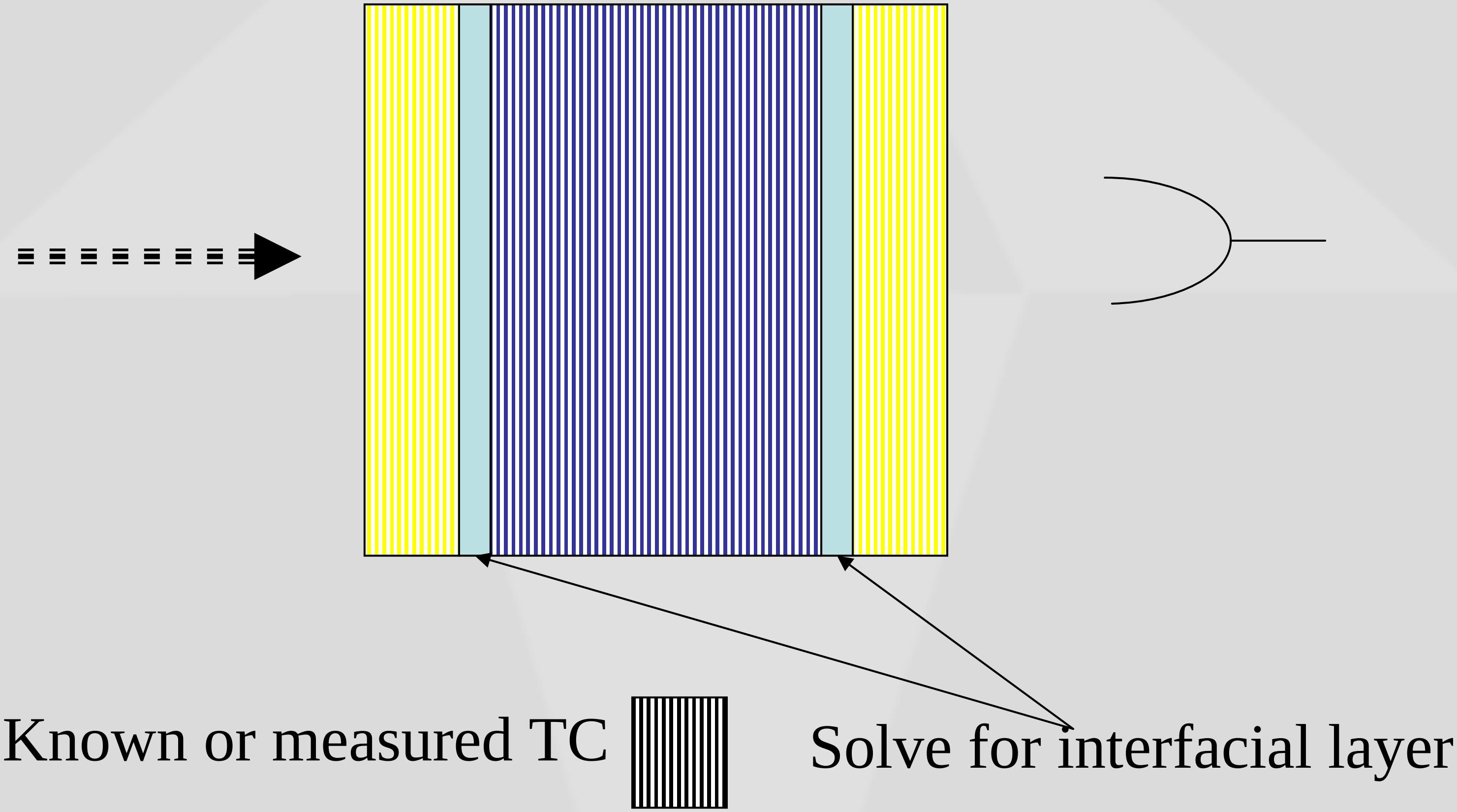


ANALYSIS

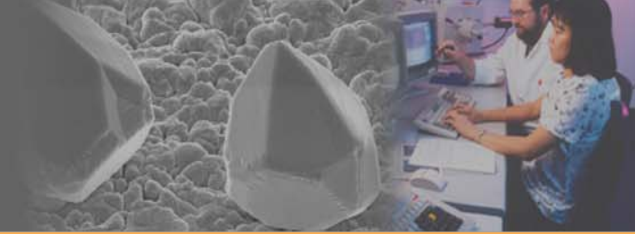
CMC INTERCONNECT TECHNOLOGIES

Thermal Characterization of Interfaces

Five Layer “Sandwich” Model*



*Taylor and Lee, 1975



Material Changes During Fabrication

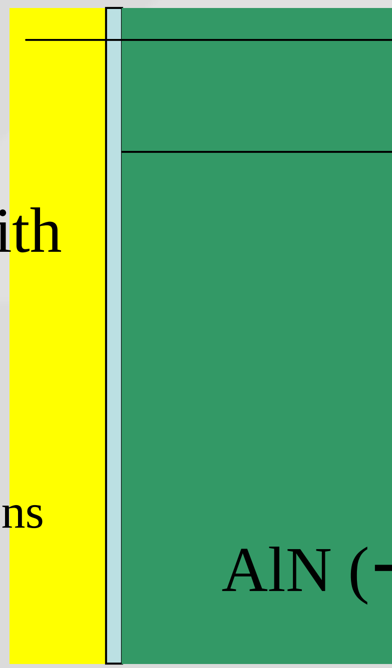
Copper Reactively Bonded to Aluminum Nitride Ceramic

Copper Reactively Bonded to AlN

(→ Processed at 1000 ° C)

Copper
(→ Cu with
Ti,Al)

250 microns



AlN (→ Al at interface)

Ti (→ TiN)

1.124 mm

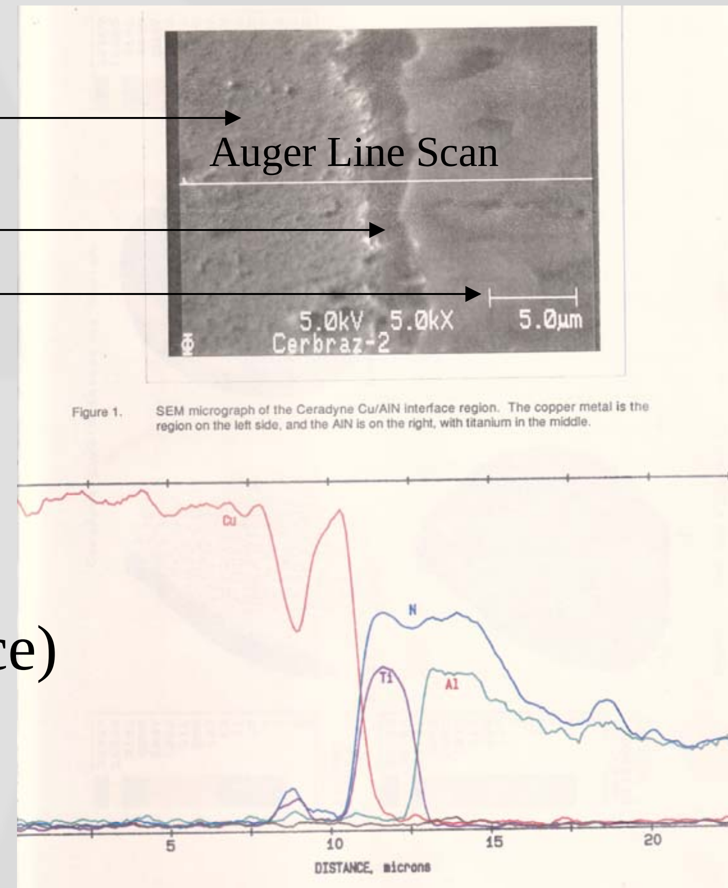
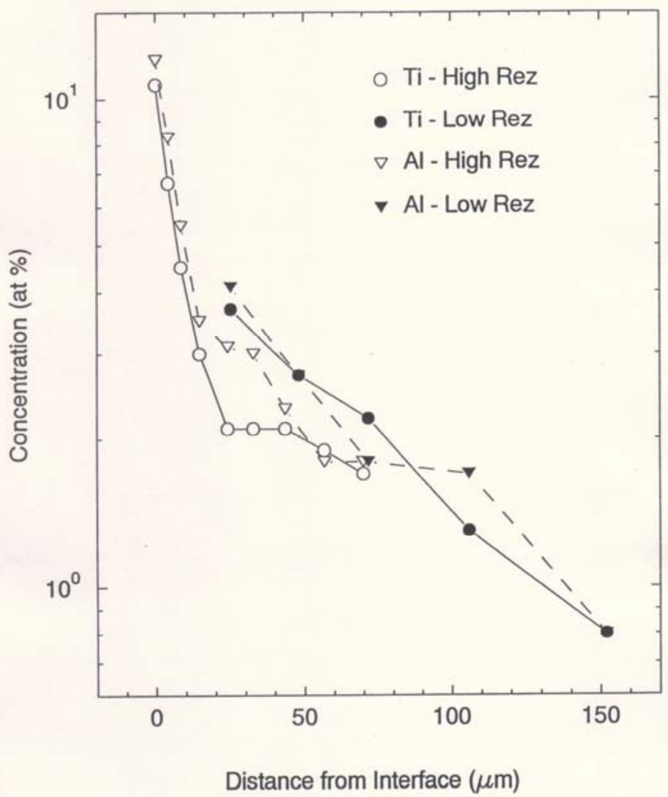


Figure 1. SEM micrograph of the Ceradyne Cu/AlN interface region. The copper metal is the region on the left side, and the AlN is on the right, with titanium in the middle.

Auger Analysis of Ti, Al Diffusion into Copper



AlN ←|→ Cu

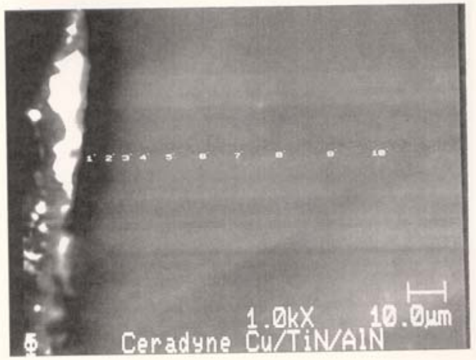
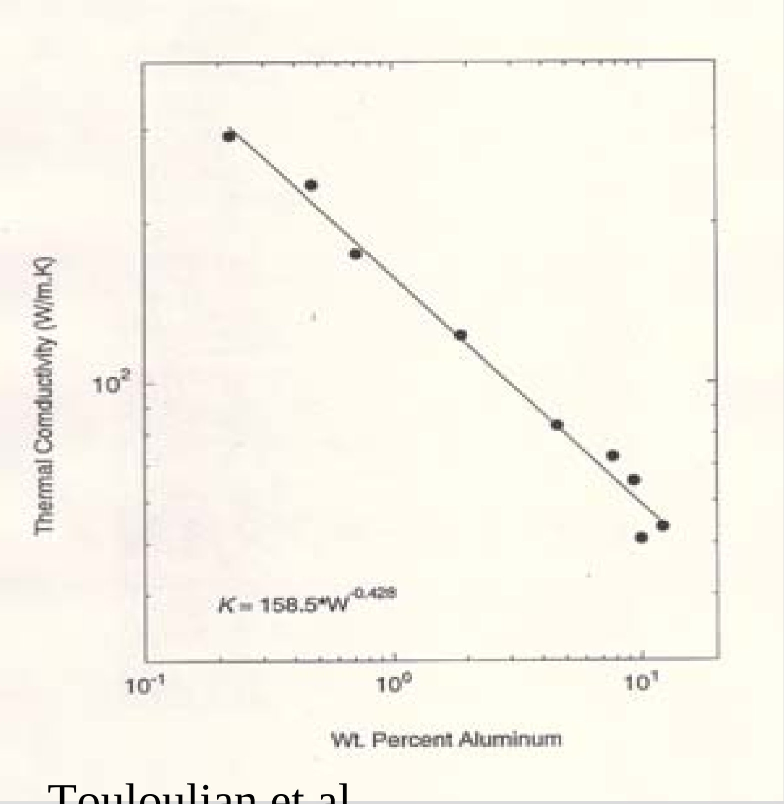


FIGURE 1

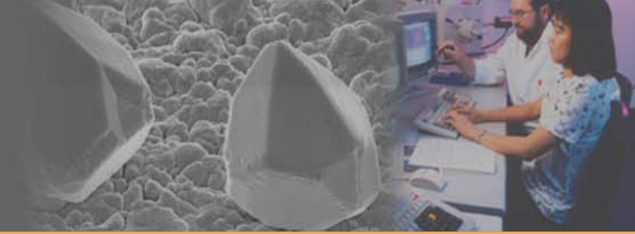
		Atomic %	
	Copper	Titanium	Aluminum
Area 1	35.4	44.8	19.8
Area 2	77.3	10.7	12.0
Area 3	85.1	6.7	8.3
Area 4	90.0	4.5	5.5
Area 5	93.5	3.0	3.5
Area 6	94.8	2.1	3.1
Area 7	95.0	2.1	3.0
Area 8	95.6	2.1	2.3
Area 9	96.3	1.9	1.8
Area 10	96.5	1.7	1.8

Copper TC vs. Dissolved Al

- TC can degrade rapidly with dissolved impurities (Ti, Al in Copper)
- Electron/ Impurity Potential scattering mechanism



Touloulian et al.



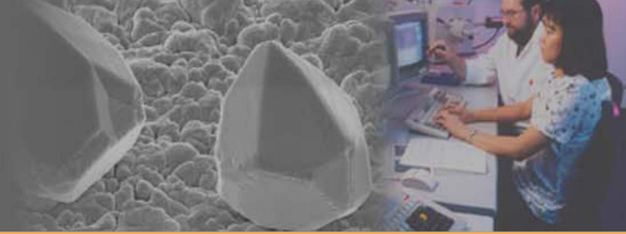
Thermal Properties of Cu Reactively Bonded to AlN

Percent of Total Thermal Resistance Contributed by Each Type of Layer

Sample	Two Metal Layers	Two Interface Layers	AlN Layer	1 D TC (W/m-K)
Reactive Bonded	**40** **(185 W/m-K)** **Measured**	15 (5 W/m-K) From Model	45 (230 W/m-K) Measured	179
Pure Cu Prediction	25 (376 W/m-K)	19 (5 W/m-K)	57 (230 W/m-K)	225

Laser Flash Measurement, Layer Model (5)

CMC INTERCONNECT TECHNOLOGIES

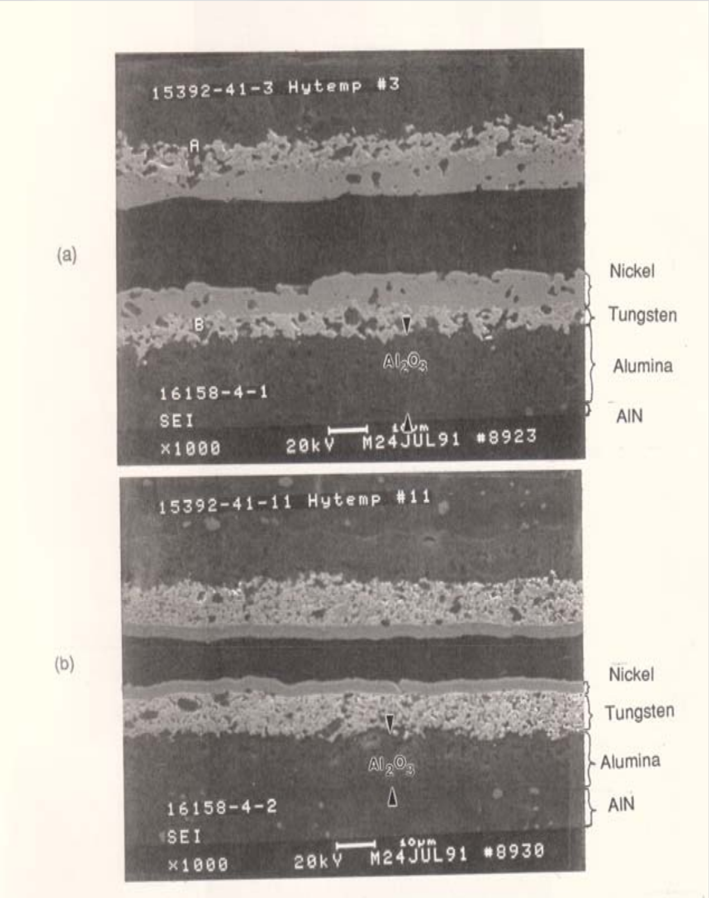


Thermal Impedance of Interfaces

- Tungsten Thick Film on Aluminum Nitride Ceramic
  - Post fire oxide bonding thick film
  - Co-fire
- Die Attach Materials
  - AuSi, AuSn
  - Silver Filled Epoxy

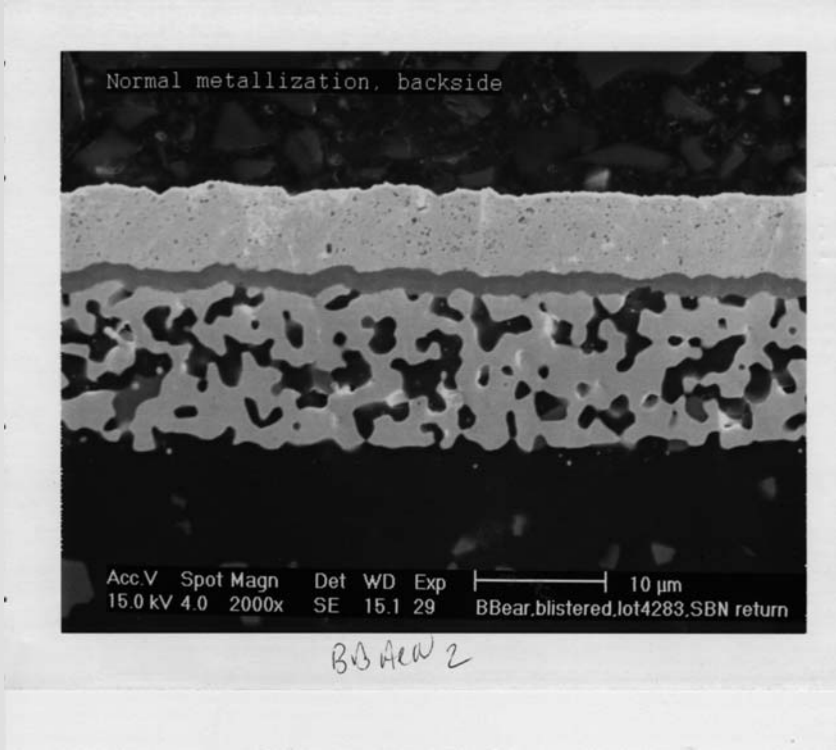
Tungsten Post Fire Thick Film on AlN

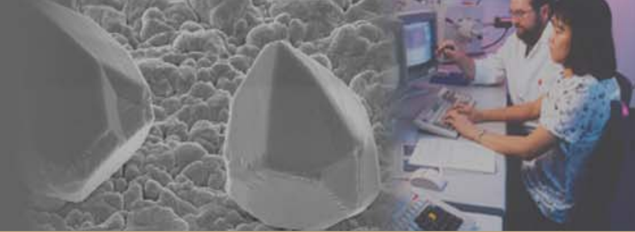
- Tungsten- Metal Oxide containing paste
- Oxide reaction with AlN to form bonding layer
- Porous oxide layer between the metallization and the high TC ceramic



Tungsten Co-fire Thick Film on AlN

- Metal and Ceramic are co-sintered at 1825C
- Intimate contact between the metallization layer and the ceramic

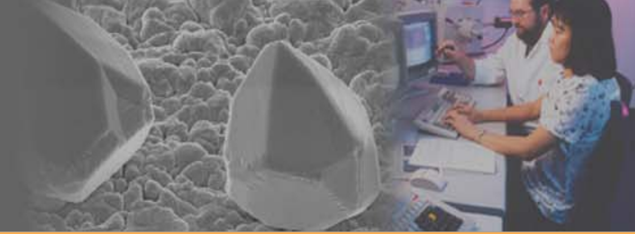




Thermal Properties of Tungsten Bonded to AlN

Percent of Total Thermal Resistance Contributed by Each Type of Layer

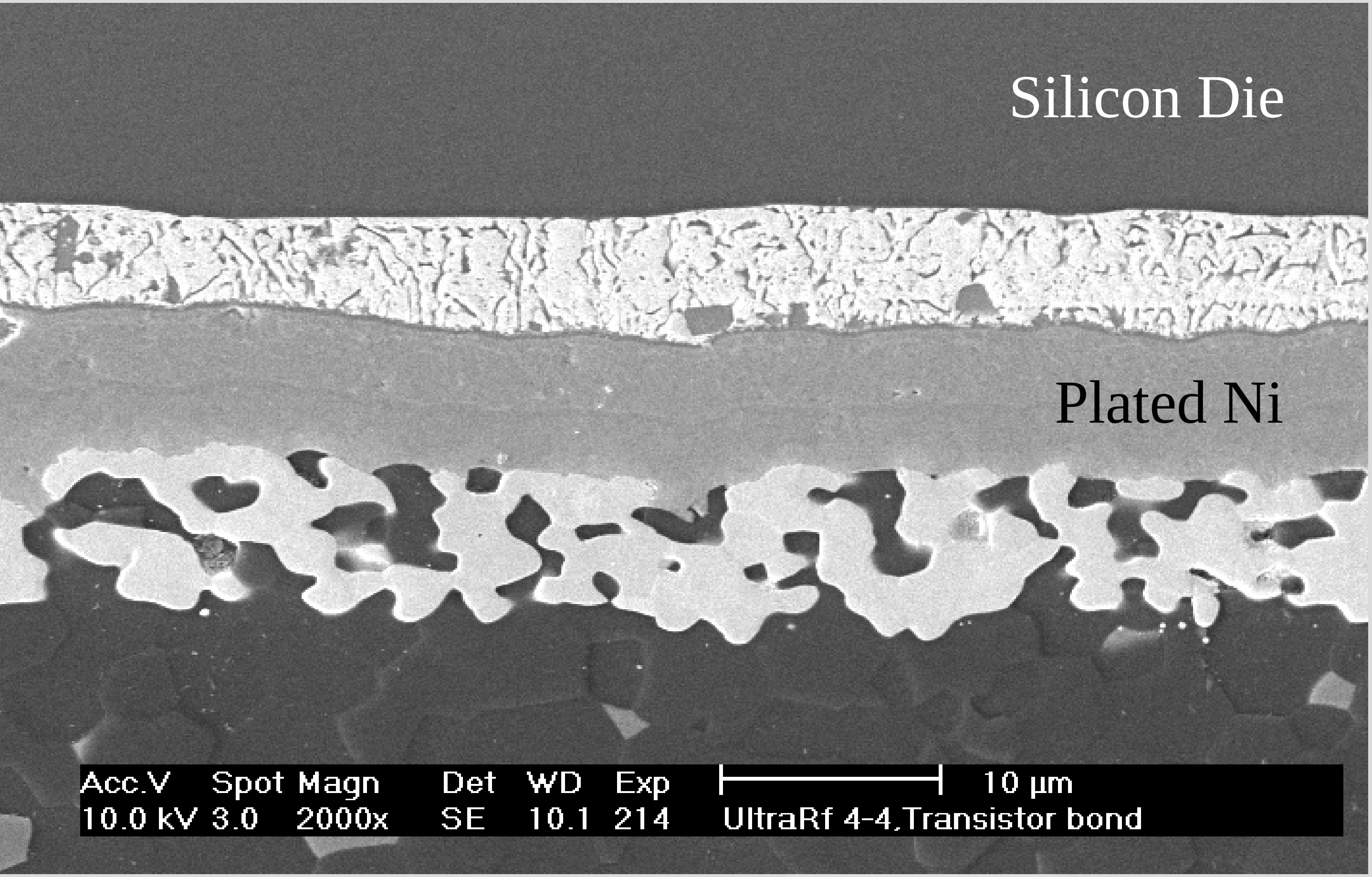
Sample	Two Metal Layers	Two Interface Layers	AlN Layer	1 D TC (W/m-K
Thick Film Post-Fire	1 (180 W/m-K) 12 microns Measured	71 (3 W/m-K)	28 (190 W/m-K) 540 microns Measured	57
Co-Fired	3 (179 W/m-K) 18 microns Measured	0	97 (183 W/m-K) 1234 microns Measured	183

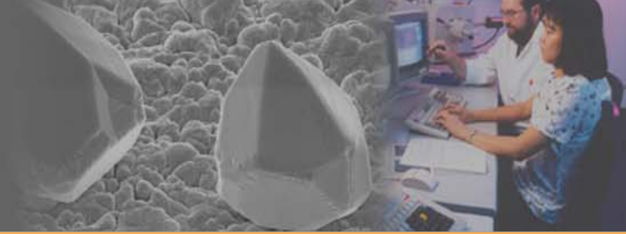


Application to other areas in packaging….

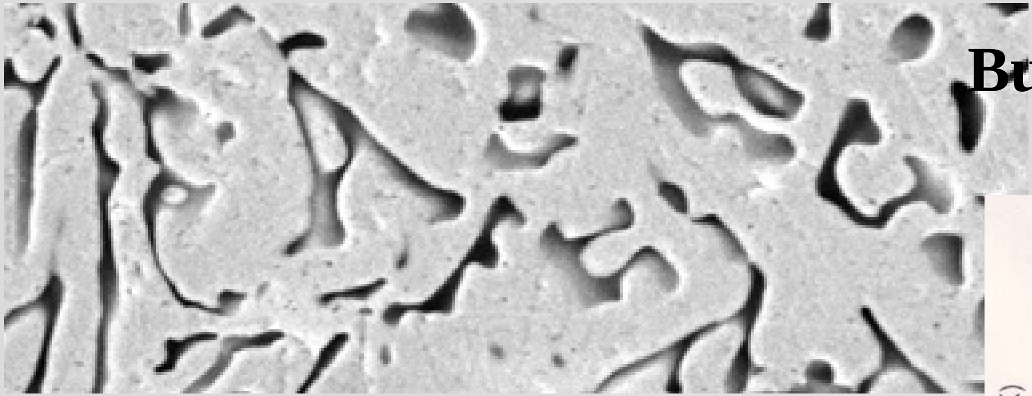
Package Type or Application	Material Changes or Interface Issue	Impact	Solution
GaAs MMIC, FET, semi-conductor laser	Ni diffusion into gold during AuSn die bond	Thermal conductivity decrease, wire bond issues	Control Au grain size to limit Ni diffusion, restrict die bonding time, Pt or Pd barrier layers
Silicon LDMOS and Bipolar for RF Power	Nickel silicide interface layer formation during AuSi die attach	Thermal barrier, die attach failure (brittle layer)	Plate with nickel cobalt to inhibit nickel silicide formation

Eutectic Die Attach: AuSi, AuSn

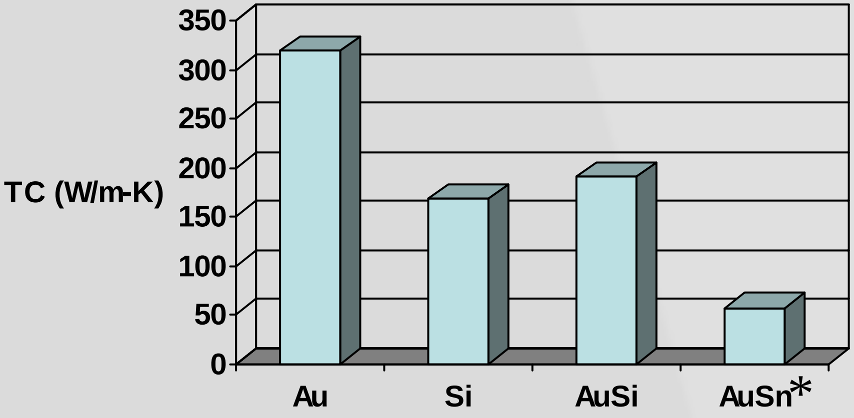


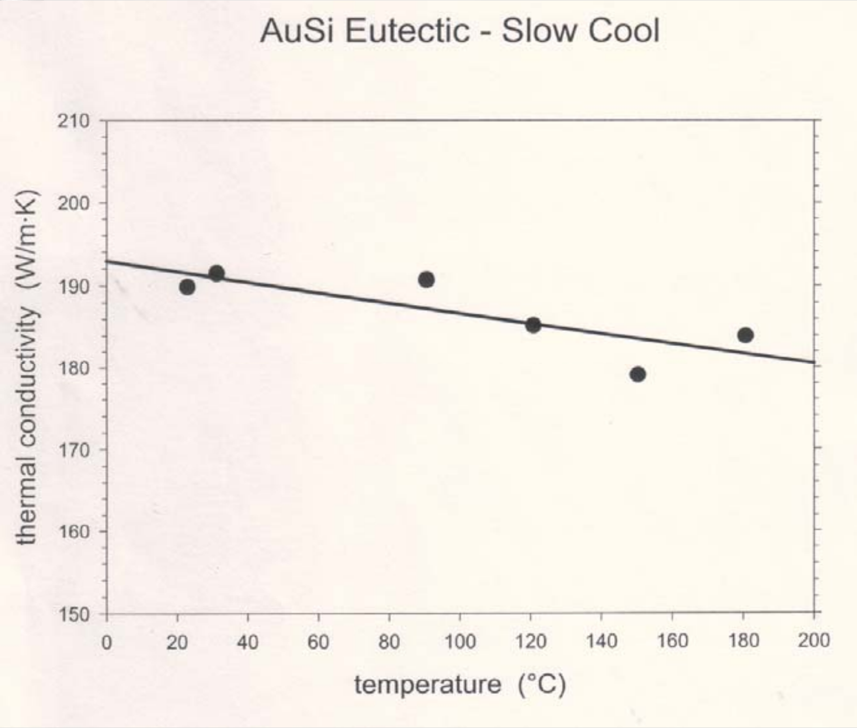


AuSi, AuSn Die Attach



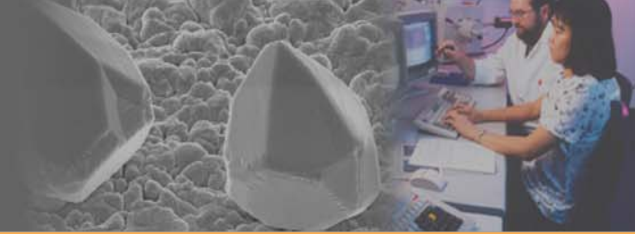
Bulk AuSi Sample ($Au_{82}Si_{18}$)





MATERIALS

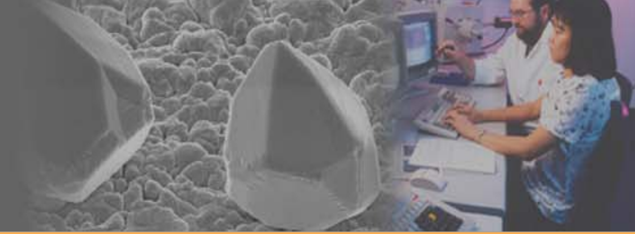
* Literature, Olsen and Berg



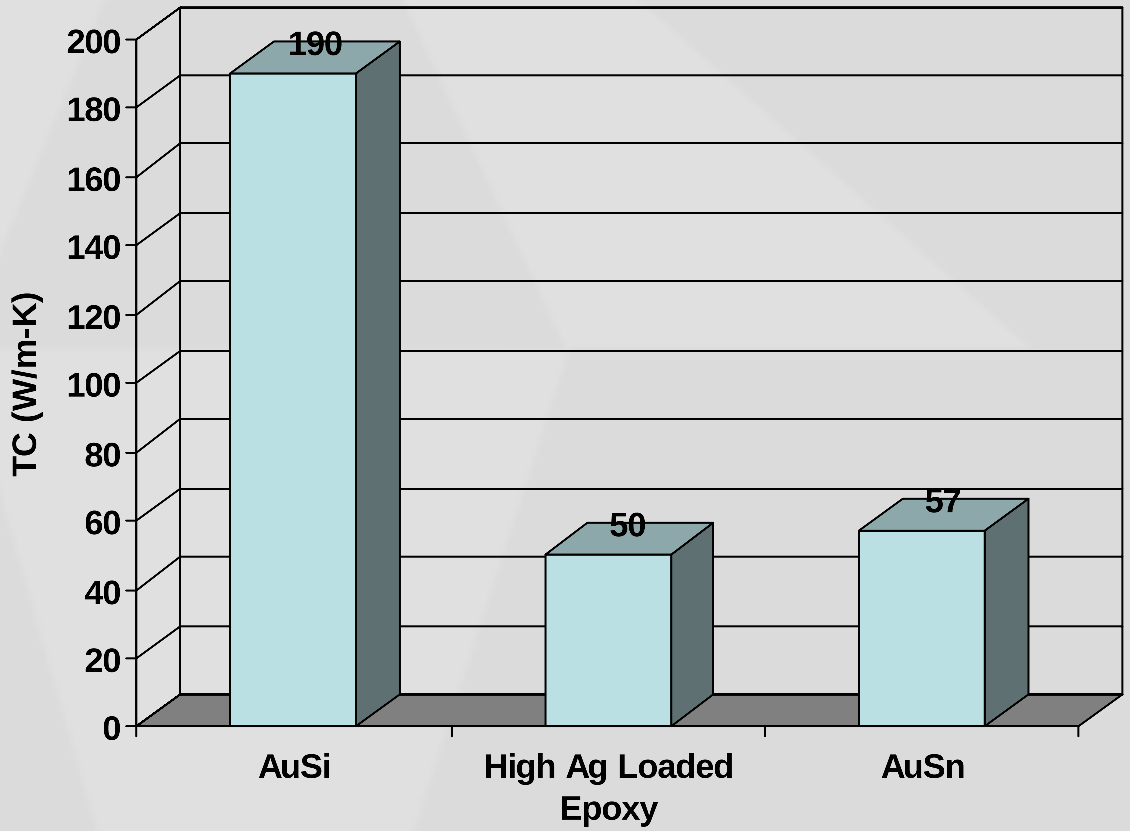
AuSi Thermal Conductivity- Controlling Factors

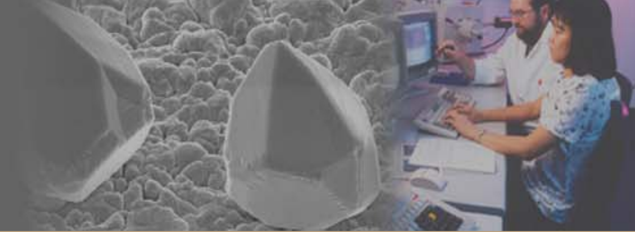
- Microstructure/Phase
  - Au_5Si (Fast cooled, metastable phase), TC= 15 W/m-K
  - Slow cooled Au/Si eutectic, TC = 190 W/m-K
- Silicon Dissolved in the Au Phase
  - 0.27 at. % Si in Au Solubility at Eutectic Temperature Johnson (1987)
  - In practice, function of cooling rate, Au grain structure

CMC INTERCONNECT TECHNOLOGIES



Thermal Conductivity Evaluation- Silver Filled Epoxy





Both materials and fabrication processes strongly impact thermal performance……….

MATERIALS

PROCESSES

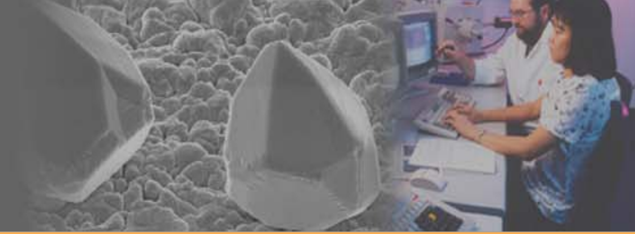
High TC Components
• Copper conductors
• AlN Ceramics
• Die Attach Materials

• Analysis
• Materials Science

Consequences of Package Fab
• Material Changes
• Formation of interfaces

PACKAGE THERMAL PERFORMANCE

(Electrical Performance, Mechanical Properties, Reliability)



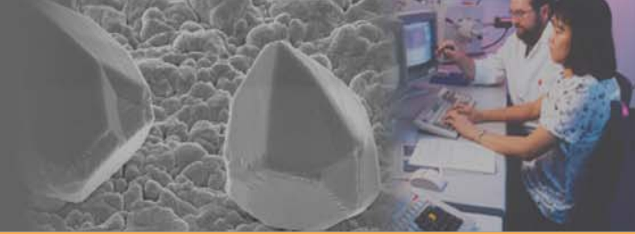
Packaging Technical Base

Electrical and Mechanical Engineers

Materials Science

↓

Thermal Conductivity Measurements
SEM/ Microstructural Analysis
Auger Spectroscopy
Phase analysis and equilibrium



Key Thermal Considerations for Packaging Applications- Summary

- Packages are constructed from heterogeneous "collection" of diverse materials
- Material alterations during fabrication and material interface formation have a profound effect on thermal performance
- **Material choice: Thermal Conductivity, Bonding Characteristics and Sensitivity to Fabrication Processes**