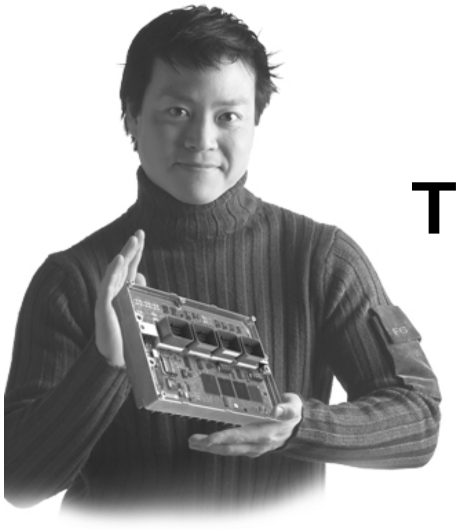
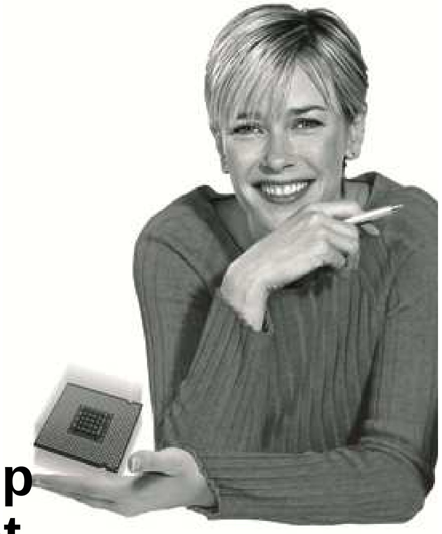


Cooling from Down Under – Thermally Conductive Underfill



7th European Advanced Technology Workshop on Micropackaging and Thermal Management

Paul W. Hough, Larry Wang
1, 2 February 2012

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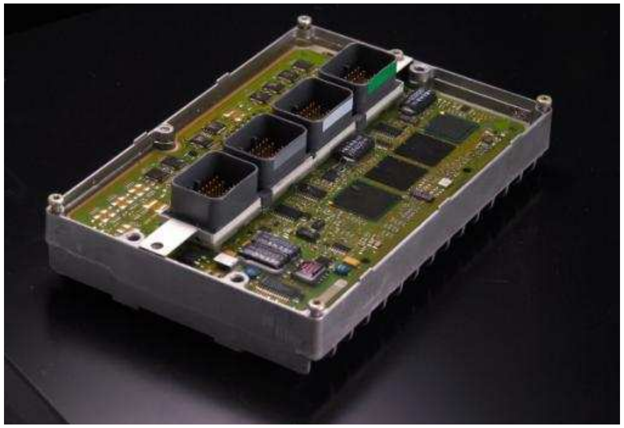
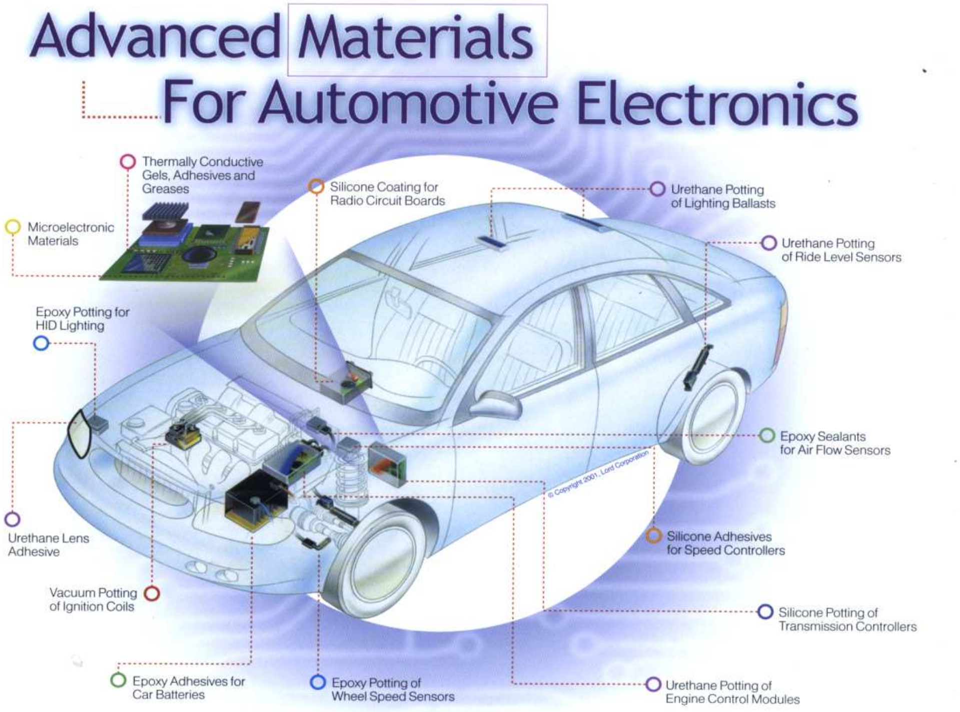
Presentation Outline

- Introduction
- Results and Discussions
  - Characteristic properties of underfill
  - Underfill performance
  - Reliability studies
- Conclusions

Modern Electronics

- Everywhere and everything
- Powered by “chips” or “die”
- Dominating Trends
  - More functionality
  - Smaller size and space





Electronic Packaging

What is Packaging?

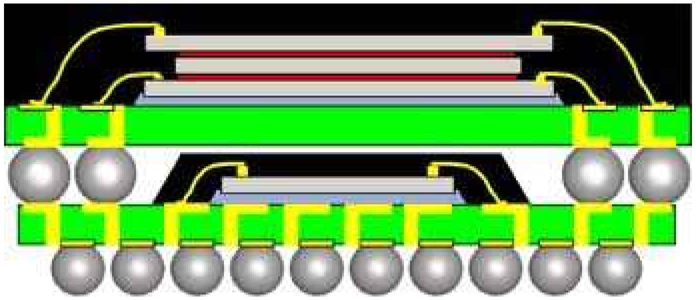
- Electrically connects the IC to the circuit board
- Protects the die from mechanical damage and contaminates
- Provides thermal distribution capability
- Allows for handling, testing, and shipping of the chip

Trends

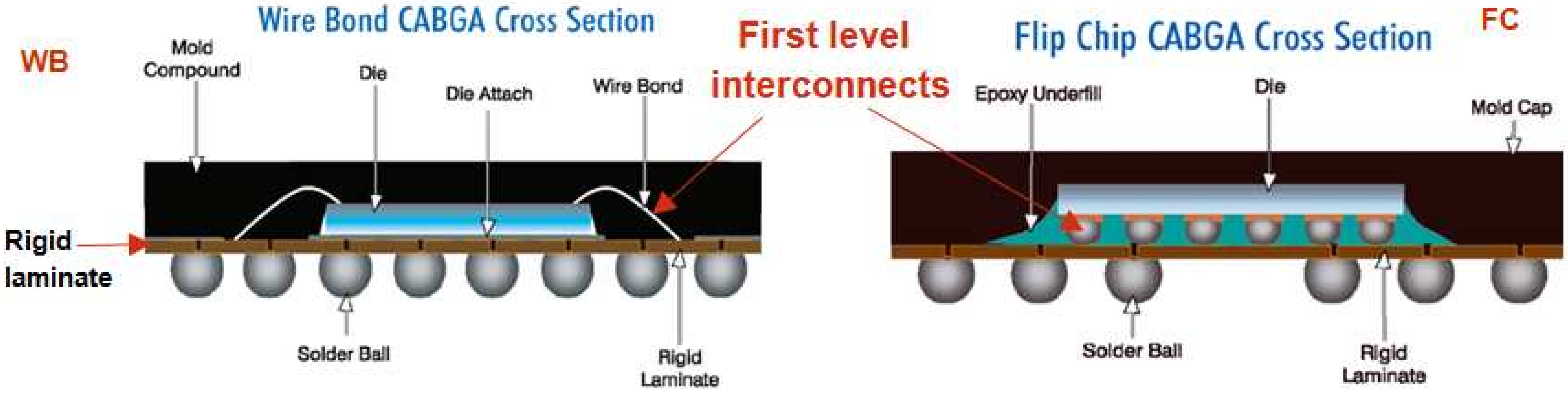
- Higher component density
- Higher operating speed
- Higher power

Electronic Packages

- Chips are the brain for almost every function
- Package designs differ by how chips are connected with other chips, components and PCB
  - Functionality , Reliability, Efficient Manufacturing
- Smaller foot print, vertically integrated
  - Wirebond, simple or complicated, layer, stack…
  - Flip chip, small or large, FCOL, FCBGA…
  - PoP, MCM, SiP, TSV

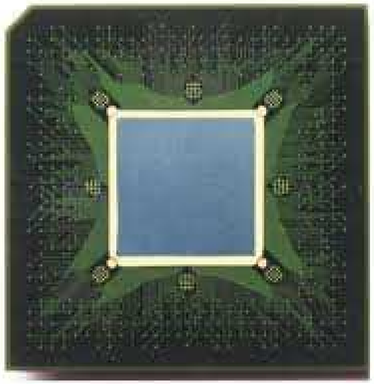


Flip Chip versus Wire Bond



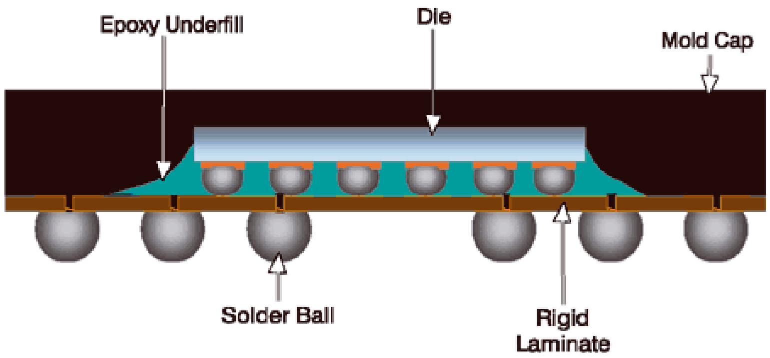
- First Level Interconnects
  - – Wire Bond versus Solder Balls
- Attachment to Substrate
  - – Wire Bond: Die attach adhesive
  - – Flip Chip: Solder balls with or without underfill

Why Flip Chip



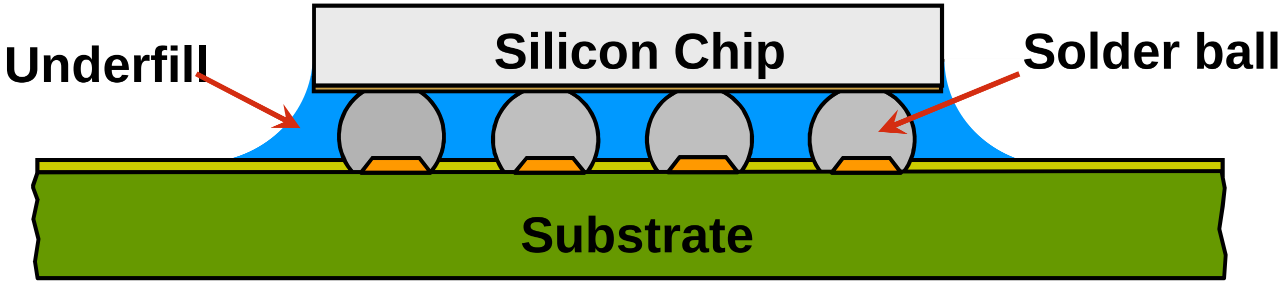
- Benefits
  - Shortest electrical path for fast signal transfer
  - Smallest footprint, higher I/O, and small form factor
  - All electrical connections are made in one reflow step
- Disadvantage
  - Smaller size, inflexible geometry, susceptible to stresses
- Flip Chip Packaging
  - Bare top – smaller chip and minimal thermal problem
  - Molded package – FCBGA, for large chip with low thermal demand
  - Thermal interface material on top – large power chip, high demand for heat dissipation

Flip Chip CABGA Cross Section



Why Underfill

- Protects flip chip and solder joints for reliability
  - CTE mismatch between silicon chip, solder balls, and substrate
  - Stress from assembly process
  - Stress from thermal cycling during real life usage
  - Stress from mechanical torture – drop, impact, vibration
  - Environmental Protection: moisture, liquids, gases, etc
- Significant improvement in reliability
- Balance the benefit and costs (design, materials, processing time and cost, etc)



Thermal Interface Materials Background

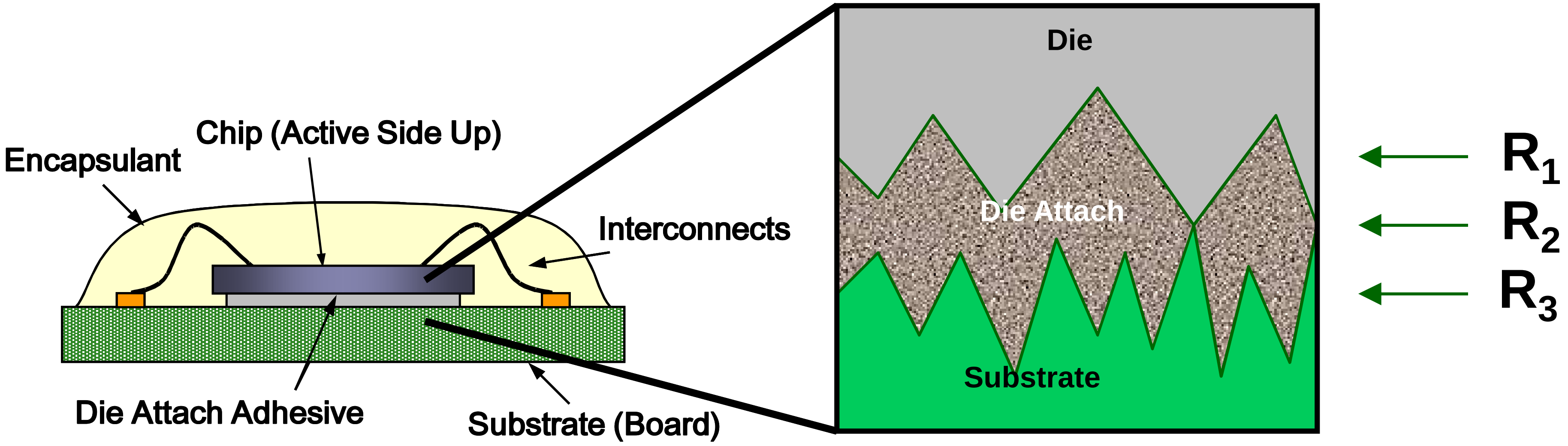
What is a TIM?

- A compliant material that efficiently and reliably facilitates heat transfer between components of a package

What are the key properties?

- High thermal conductivity
- Low interfacial thermal resistance
- Processability
- Package reliability
- Adhesive strength
- Room Temperature Stability
- Reworkability
- Ionic Purity

Key Properties: Thermal Conductivity and Thermal Resistance

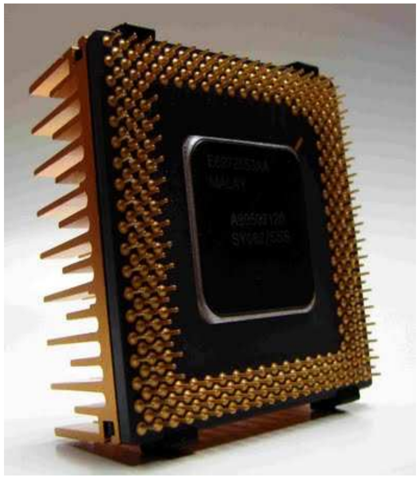


$$\frac{BLT}{EffectiveTC} = R_1 + \frac{BLT}{BulkTC} + R_3$$

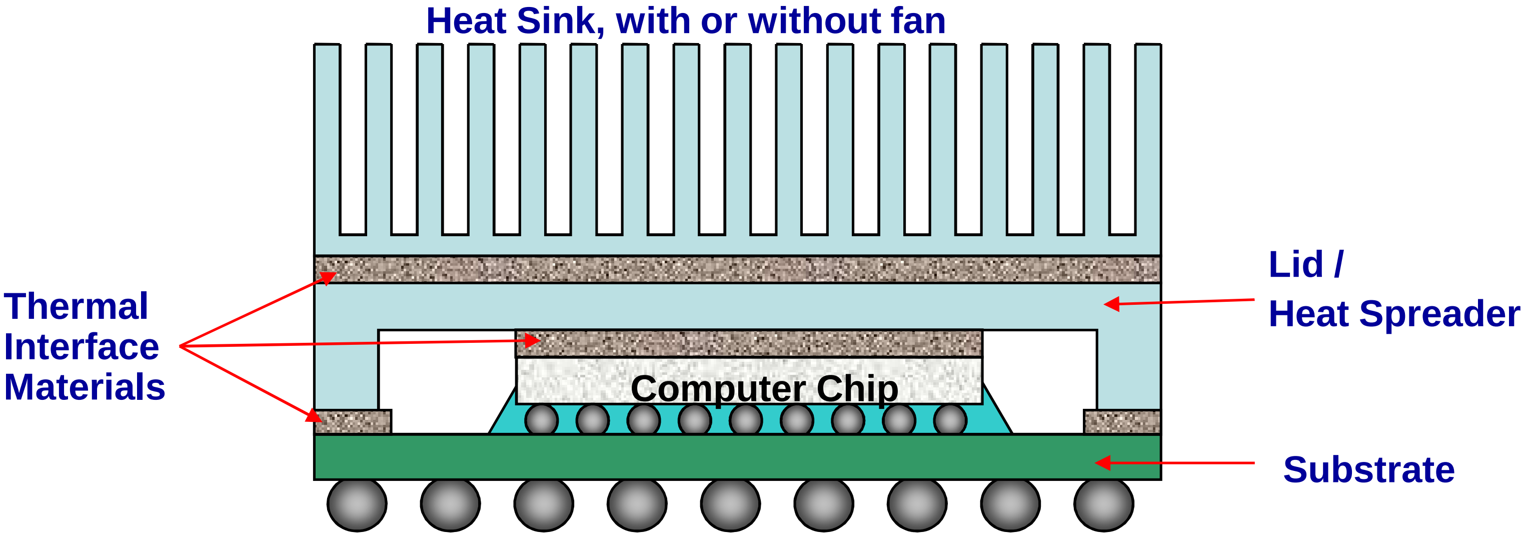
TC: thermal conductivity
R1:interfacial resistance (Die/Adhesive)
R2:resistance of Adhesive
R3 :interfacial resistance (Adhesive/Substrate)

Flip Chip Thermal Dissipation

- Flip chip heat dissipation primarily through top side
- Design depends on the thermal demand:
  - Bare chip: radiate to air
  - Molded packages: radiate via molding material to air
  - Non-molded: utilize TIM and heat spreader/sink
  - Microprocessor: utilize TIM + heat spreader/sink + fan

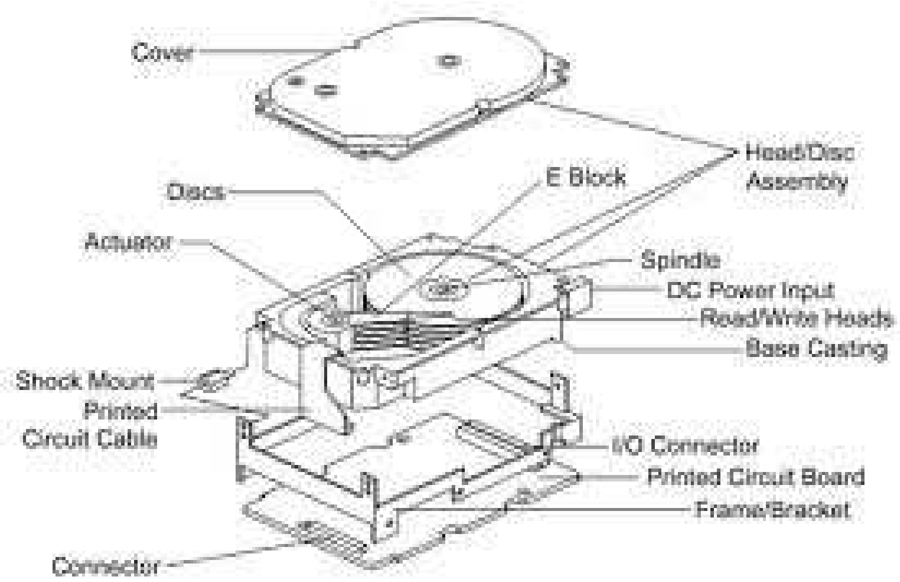


Intel Microprocessor



Confined Space

- Miniaturizing: both at chip level and package level
- Limited space: inside and/or outside of package
- Hermetic package: no air movement
- More heat built-up but no way to escape



TIM or Underfill or Both?

- Traditionally TIM and Underfill are separate materials
  - Incorporated on opposite sides of the chip
- TIM
  - Paste like, no strength (gel) or low-medium strength (adhesive)
  - High thermal conductivity (1 – 30+ W/mK)
  - Can be electrically conductive
- Underfill
  - Low viscosity liquid
  - High rigidity and strength
  - Electrically insulative
  - Almost a thermal barrier (<0.4 W/mK)

Motivation

Design an underfill for flip chip in confined space

- ♦ Processing capability
  - – Good flow to small stand off, <25 microns
  - – Rapid cure
- ♦ Performance
  - – High thermal conductivity
  - – Optimum modulus for solder ball and chip
  - – High reliability
- ♦ Environmentally benign
  - – Non-anhydride for health and safety concerns
  - – Good moisture resistance

Formulation Development

- Resin system – the carrier
  - Epoxy resins
  - Non-anhydride curing agents
  - Contribute to low viscosity, fast flow speed, rapid cure, Tg, modulus, high temp strength
- Fillers – the enabler yet a limitation factor
  - Control/affect several key properties
  - Trade-offs
    - Thermal conductivity
    - CTE
    - Modulus
    - Viscosity, flow speed
- Additives

Results and Discussions

- Underfill basic properties and processing
- Underfill characterization
- In-package performance
  - Processing
  - Reliability Performance

Underfill Basic Properties

Property	ME-543
Resin chemistry	Epoxy/Amine
Filler Type	Ceramic
Filler particle size, average	5 µm
Viscosity at 25 °C	21,000 cps
Density	2.2 g/cc
Work life, 25 ℃	36 hrs
Gel Time, 150 ℃	3 min
Cure Schedule	15 min at 165 ℃

Underfill Processing

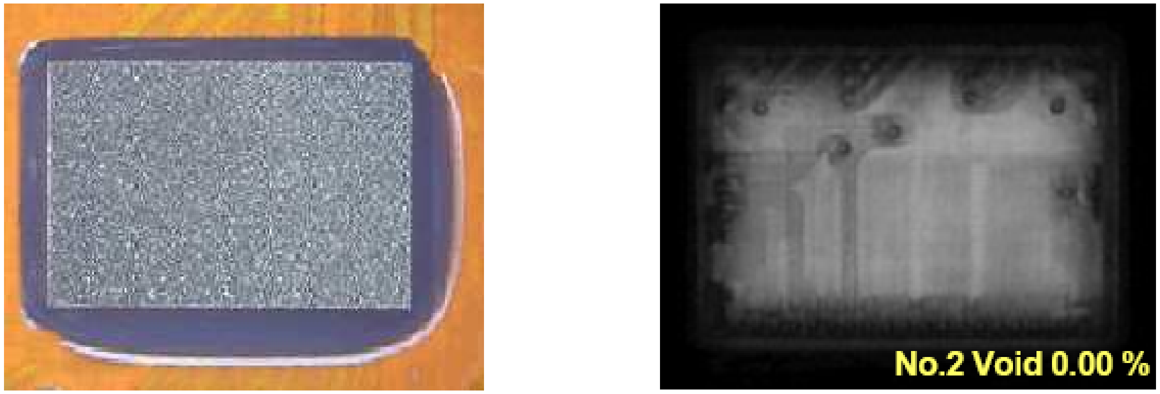
Property	ME-543
Viscosity at 25 ℃	21,000 cps
Viscosity at 90 ℃	200 cps
Dispensing method	Line dispense or jetting
Substrate pre-heat	90-105 ℃
Underfill temperature	Ambient
Post-dispense staging	Optional, 90-100 ℃
Cure method	In-line oven or box oven
Cure Schedule	15 min @ 150 ℃
Minimum gap height	< 25 µm
Flow speed, 90 ℃, 50 µm	
6.4 mm flow distance	8 seconds
12.7 mm flow distance	35 seconds
25.4 mm flow distance	120 seconds

Underfill Characterization

Property	ME-543
Thermal Conductivity, W/mK	1.2
DSC Cure Profile	
Onset, ℃	118
Peak, ℃	130
Enthalpy, J/gm	172
Glass Transition, Tg, ℃	135
CTE α1 (<Tg), ppm/℃	27
CTE α2 (>Tg), ppm/℃	95
Elastic Modulus (<Tg), GPa	5.5
Elastic Modulus (>Tg), GPa	0.43
Thermal stability, temp @ 1% wt loss	340 ℃

Customer Device Test

- ME-543 underfill in customer hard drive device
- 2 x 3 mm flip chip on flex circuit
- Jetting dispense, fast, accurate, and consistent
  - fast flow, full coverage, void free
  - Self filleting, with no creep on top of chip
  - Fast cure in production in-line oven



Optical and X-ray images of underfilled flip chip device

ME-543 In-Package Performance

- Dissipating heat through underfill layer to flex substrate
- Additional copper traces in flex conduct the heat out of hard drive hermetic package
- Thermal performance
  - Chips operate at lower temp for better efficiency
  - Permit future designs to increase functionality on the same chip

ME-543 Reliability

- Reliability tests by customer in a hard drive device
- Performance
  - Biased temperature/humidity BTH, 168 hrs 85℃/85%R H
    - 0/45 failure
  - High Temp Operation Life HTOL, 1000 hrs 125 ℃
    - 0/45 failure
  - Thermal cycling test, -55 to 125 ℃ , 500 cycles
    - 0/45 failure
  - Thermal shock test, -55 to 125 ℃, 3000 cycles
    - 0/45 failure

Summary & Conclusions

- A thermally conductive underfill has been developed with novel chemistry, optimum material properties and processing characteristics
- Innovative approach allows heat dissipation through underfill layer in a confined space in the hermetic package
- Proprietary ceramic fillers enable high thermal conductivity of 1.2 W/mK and maintain electrical insulation
- Fine particle size fillers for flip chip devices with stand-off heights of < 25 µm
- Fast and uniform flow for a void-free coverage with no separation or striation throughout the flow front.
- Excellent device reliability both in test assembly and in customer device

Thank You!

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A Global, Market-Focused Company,
Creating & Delivering Value to Our Customers

Questions?

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