EPO-TEK® Advances in Thermal Management

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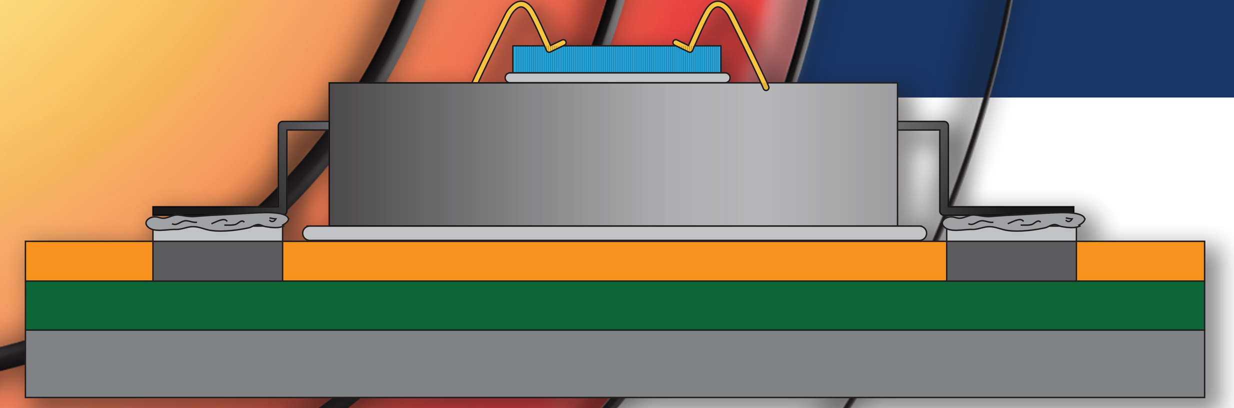


Epoxy Technology has investigated the mechanism of thermal conductivity in electrically conductive adhesives.

- Utilizing laser flash testing and SEM cross sections we determined how silver flake distribution effects thermal conductivity.
- Cure, interface, and processing play a significant role in thermal management.

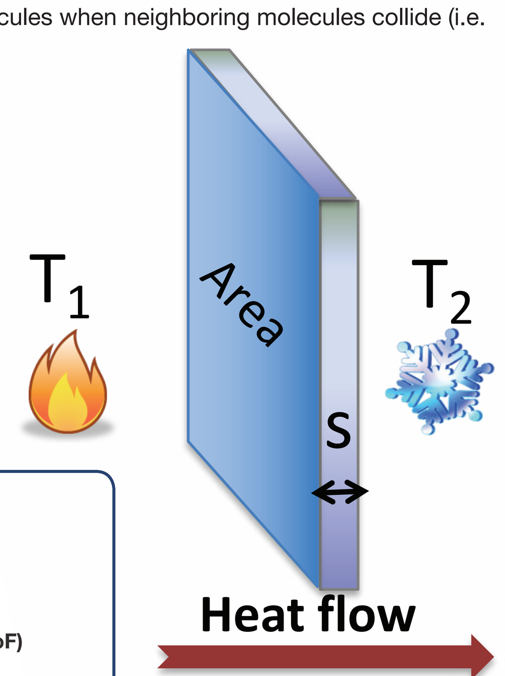
We are proposing a new laser flash sample preparation methodology.

What is Thermal Conductivity?

- Heat transfer (conduction) will take place if a temperature gradient exists in a solid (or stationary fluid) medium.
- Energy is transferred from more energetic to less energetic molecules when neighboring molecules collide (i.e. heat flows in the direction of decreasing temperature).

Fourier's Law expresses conductive heat transfer as

$$q = k\,A\,dT / s$$

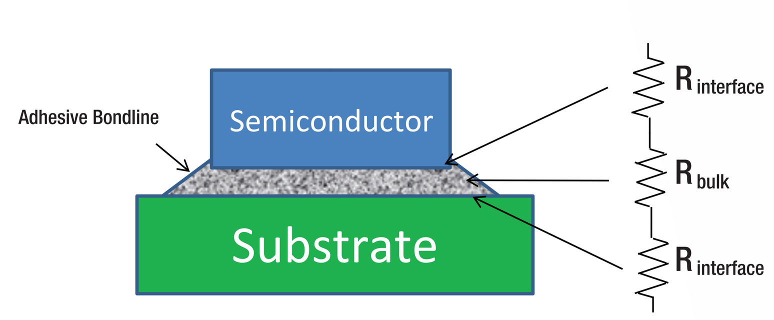


- **q** = heat transferred per unit time **(W, Btu/hr)**
  - remember 1 Watt= 1 Joule/sec **(power= energy/unit of time)**
- **A** = heat transfer area **(m2, ft2)**
- **dT** = T1-T2, the temperature difference across the material **(K or oC, oF)**
- **s** = material thickness **(m, ft)**
- **k** = thermal conductivity **(W/m.K or W/m oC, Btu/(hr oF ft2/ft))**
  - A bulk material property that determines the rate of heat transfer for a given geometry

Thermal Resistance is an object (device dependent) property.

The thermal resistance between two points is defined as the ratio of the difference in temperature to the power dissipated; the unit is °C/W

Low Thermal Resistance in Device



$$R_{adhesive} = 2R_{interface} + R_{bulk}$$

For effective heat transfer, the adhesive must have:

- Low bulk resistivity (high bulk ThK)

AND

- Maintain low resistance at both interfaces

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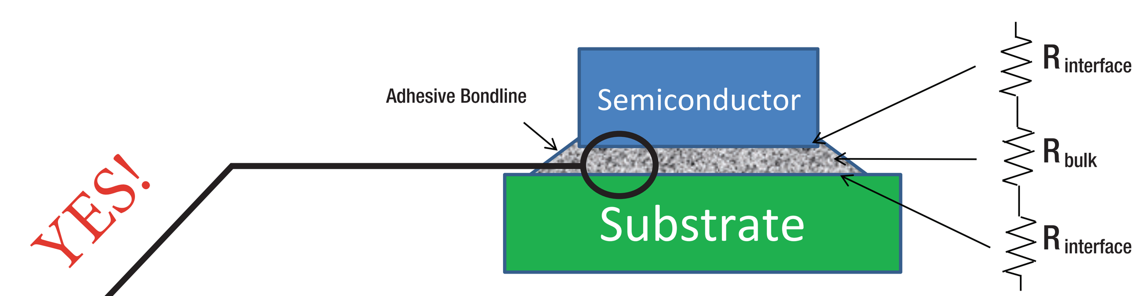
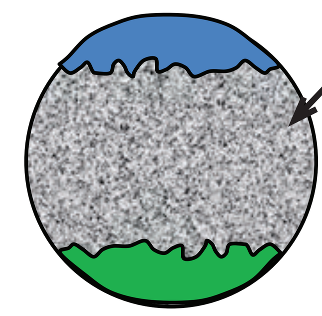
Can the Resistance in Device Ever be Similar to the Bulk Resistance?



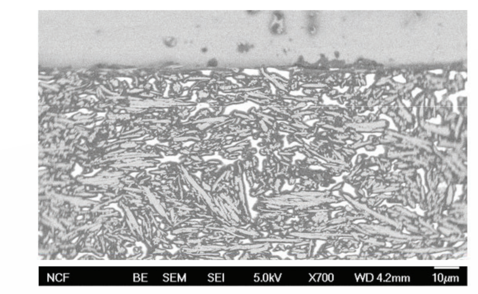
Ideal Case



$$R_{adhesive} = 2R_{interface} + R_{bulk}$$

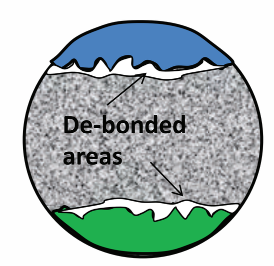
- Adhesive wets both substrates well. No voiding at interfaces.
- Filler particles are uniformly distributed across bondline all the way to the interfaces.
- Adhesion is good and material is complaint enough to absorb any stresses from CTE mismatches. No delamination occurs.
- Resin is properly cured and fillers make good conductive pathway.
- $2R_{interface}$ is very, very low.

H20E Bondline – Ideal Case



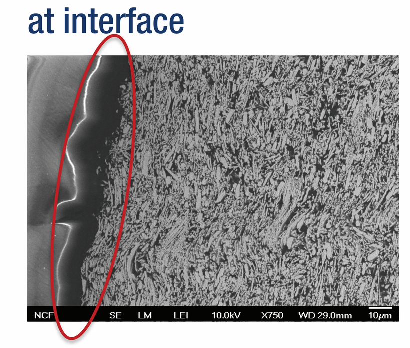
Why is Resistance at the Interface Often So Different from the Bulk Resistance?

1. Delamination

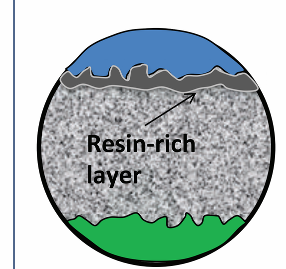


- Many highly filled adhesives have poor adhesion due to low resin component.
- Highly solvent-loaded systems can shrink a lot during cure, causing delamination.
- Stresses caused by CTE mismatches between Die and Substrate may also lead to delamination.
- Air is one of the best thermal insulators: ThK = 0.024W/mK.
- $2R_{interface}$ is much higher than R_{bulk}

Delaminated region at interface

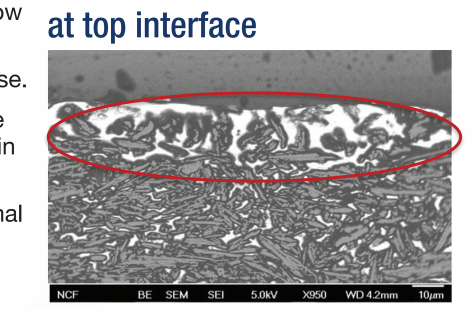


2. Filler Settling

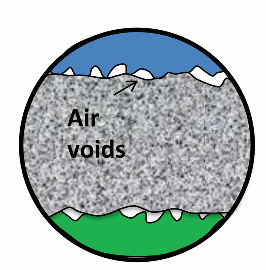


- Many highly Ag filled adhesives use low viscosity resins/lots of solvent.
- Ag is much more dense than resin base.
- Low viscosity bases allow Ag to settle to the bottom of the bondline and resin base to rise to the top.
- Base resin is another very good thermal insulators: ThK = 0.35W/mK.
- $R_{interface}$ is much higher than R_{bulk}

Resin-rich area at top interface

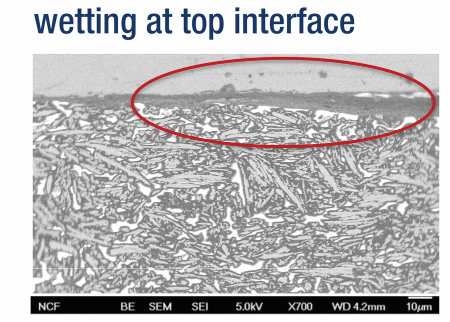


3. Poor Wetting

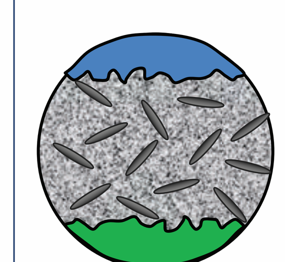


- Adhesive does not fully wet the surface of the substrate.
- Air is one of the best thermal insulators: ThK = 0.024W/mK.
- $2R_{interface}$ is much higher than R_{bulk}

Air pockets/poor wetting at top interface

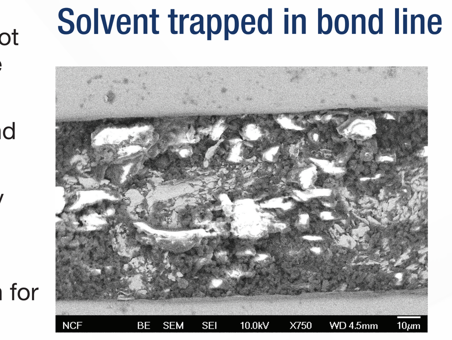


4. Trapped Solvent/Unreacted Species



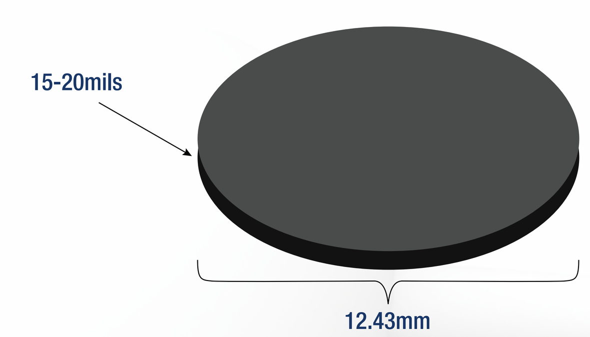
- Many highly filled adhesives use a lot of solvent or diluents to achieve the high filler loading.
- Trapped solvent plasticizes resin and prevents proper cure.
- Filler particles are not pulled closely enough together to form a good conductive pathway.
- Rbulk in device is much higher than for properly cured material.

Solvent trapped in bond line



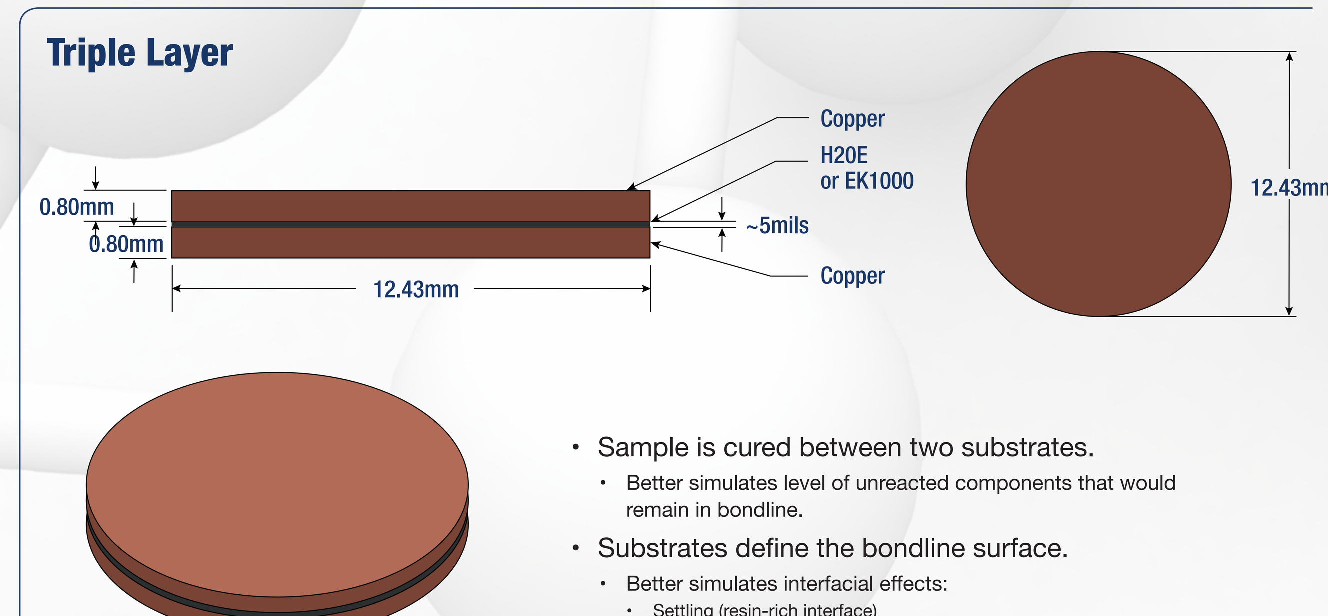
Industry Standard Laser Flash Sample vs Triple Layer Sample

Typical Bulk ThK Sample Geometry



- Only measures R_{bulk}
- Sample is cured in open format:
  - Low molecular weight components & solvents can escape during cure, inflating results.
- Surfaces are often sanded flat for testing:
  - Resin-rich surface layers may be removed, inflating results.
- Sample is much thicker than most bondlines.
- No interfacial effects (Rinterface) are taken into account.

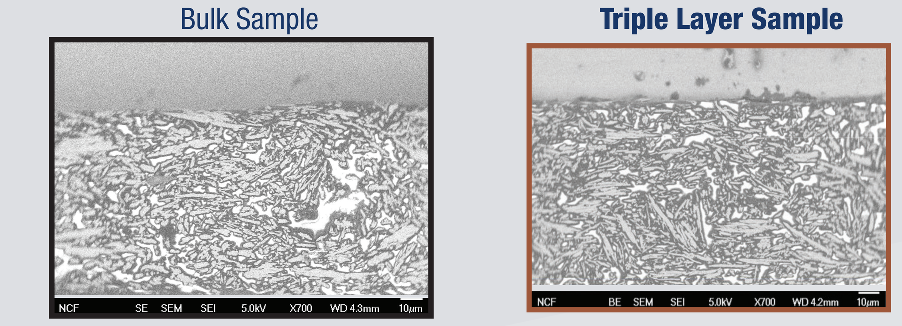
Triple Layer



- Sample is cured between two substrates.
  - Better simulates level of unreacted components that would remain in bondline.
- Substrates define the bondline surface.
  - Better simulates interfacial effects:
    - Settling (resin-rich interface)
    - Voiding
    - Poor wetting
    - Delamination
- Sample thickness is similar to typical bondlines.

H20E Bondline Cross-sections

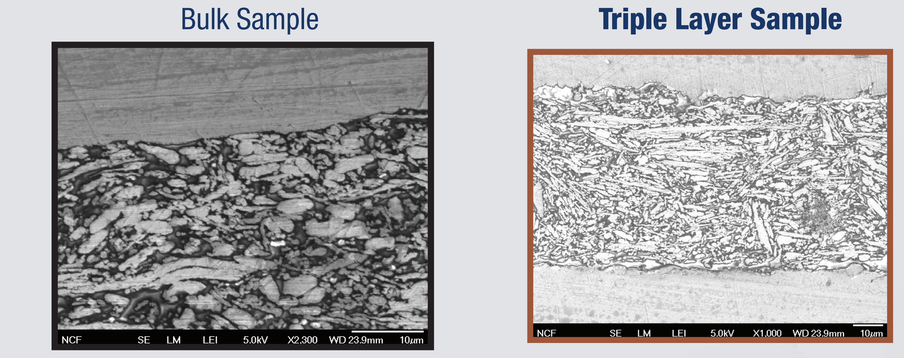
Bulk Sample | Triple Layer Sample



- In both the bulk and triple layer samples, there is very uniform distribution of Ag flake throughout the sample.
- Triple layer sample shows no evidence of air voids, delamination or resin–rich layers at the interface.
- It is not surprising that ThRes in device reflects the bulk ThK.

EK1000 Bondline Cross-sections

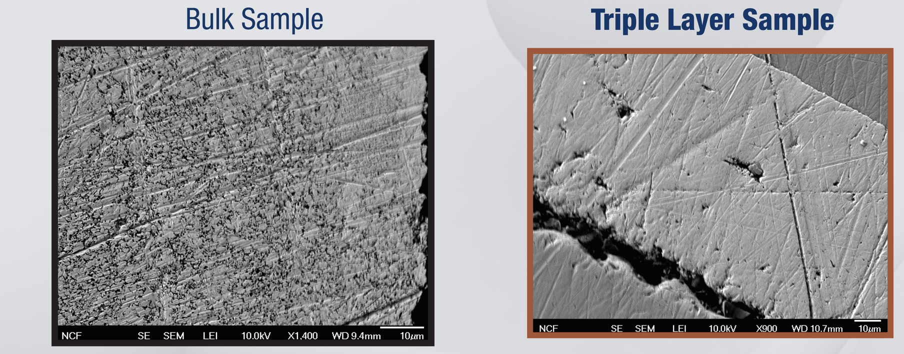
Bulk Sample | Triple Layer Sample



- In both the bulk and triple layer samples, there is very dense and uniform distribution of Ag flake throughout the sample.
- Triple layer sample shows no evidence of air voids, delamination or resin–rich layers at the interface.
- It is not surprising that ThRes in device reflects the bulk ThK.

Claimed 140W/mK Formulation Bondline Cross-Sections

Bulk Sample | Triple Layer Sample



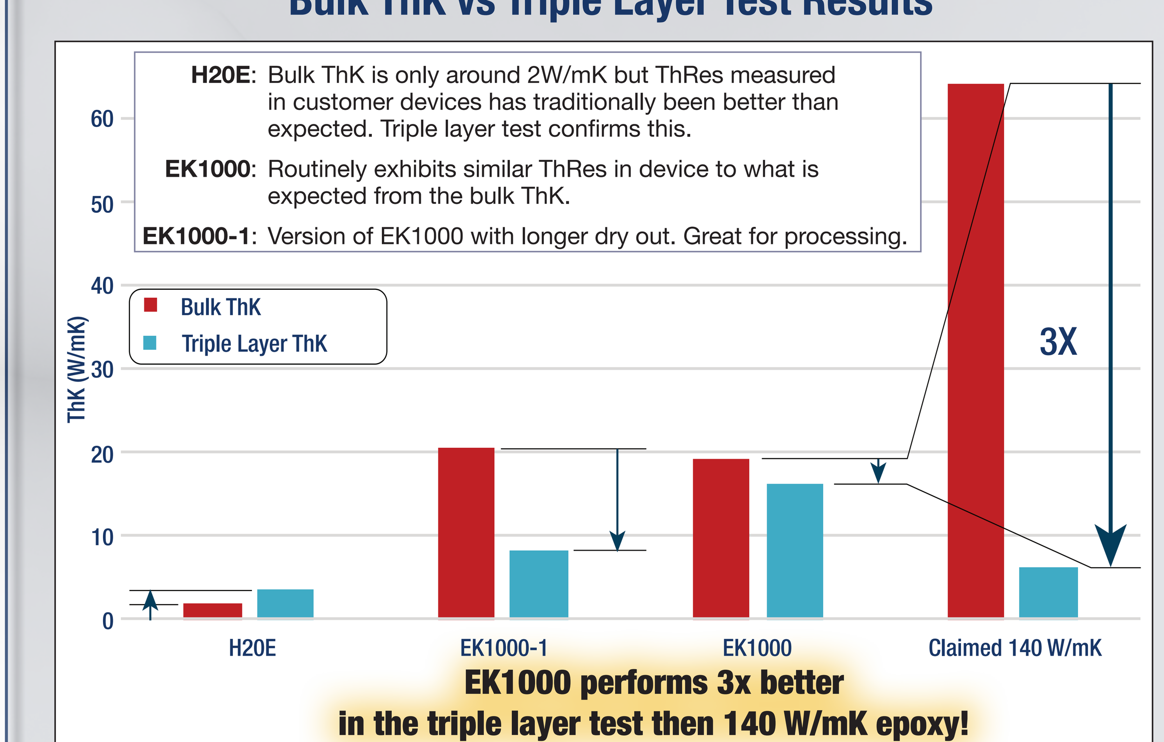
- In both the bulk and triple layer samples, the conductive filler does appear to have sintered.
- Sintering appears to be more complete in the triple layer sample.
- There appears to be only a very low level of resin binder remaining in either the bulk or triple layer sample.

Triple Layer Samples

Ideal Area | Delaminated Area | Trapped Solvent

- The triple layer samples show a wide variety of conditions.
- Some areas showed close to ideal bondlines with very good interfaces.
- Other sections showed large areas of delamination – possibly from shrinkage due to sintering and solvent removal.
- Still other portions of the sample showed huge areas consistent with trapped solvent.
- **The areas with air gaps, delamination and trapped solvent are likely the cause of the very poor ThRes results in the triple layer test.**

Bulk ThK vs Triple Layer Test Results



- While we did not obtain the full 140W/mK for our bulk ThK results, our average value of 63.3W/mK was still extremely high.
- But, triple layer ThK results ranged from only 4.8 – 7.5W/mK

Conclusion

Interface Matters!

- High bulk ThK really is **not** a good predictor of thermal management in device
- The triple layer test method **does** appear to give us far more insight into which products will perform well
- The EPO-TEK® EK1000 family of products continues to outperform many products with claimed higher bulk ThK when evaluated in device