Performance and Reliability of Bonded Interfaces for High-Temperature Packaging




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Overview

Timeline

- **Project Start Date:** FY14
- **Project End Date:** FY16
- **Percent Complete:** 10%

Barriers and Targets

- Cost
- Weight
- Performance and Lifetime

Budget

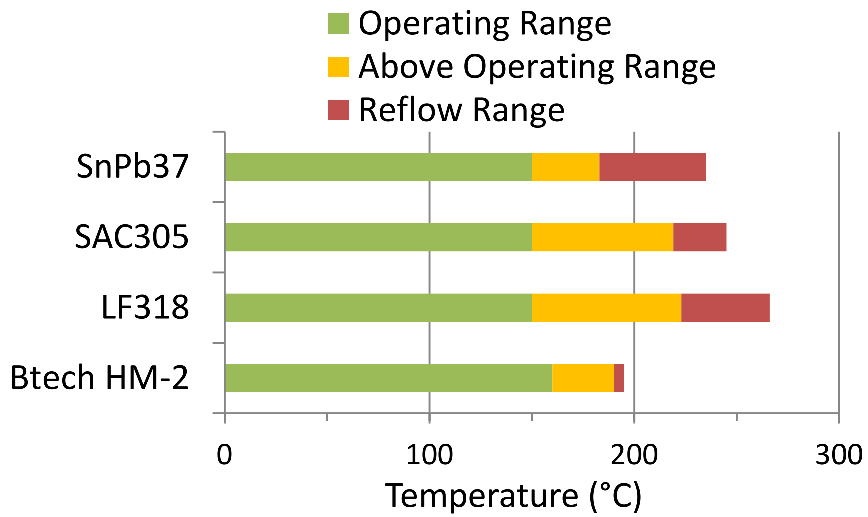
- **Total Project Funding:**
  - DOE Share: $500K
- **Funding for FY14:** $500K

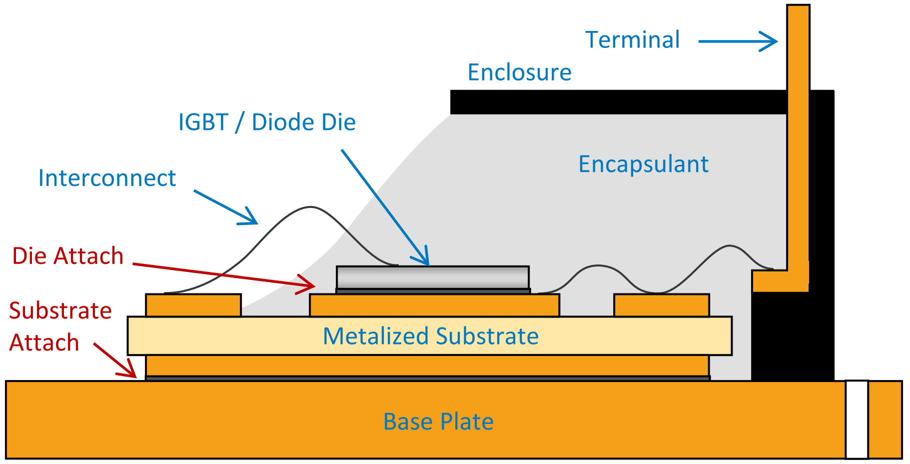
Partners

- Interactions / Collaborations
  - Heraeus, Henkel, General Motors, Oak Ridge National Laboratory (ORNL) (Andrew Wereszczak)
- Project Lead
  - National Renewable Energy Laboratory (NREL)

Relevance

- Current automotive power electronics are transitioning from silicon to wide bandgap (WBG) devices to meet cost, volume, and weight targets.
- Packaging designs must improve to take advantage of WBG devices' higher junction temperatures (>200°C).
- Current bonded interface materials (BIMs) do not meet packaging requirements:
  - Continuously operate above 200°C
  - Meet RoHS standards (lead-free)
  - Exhibit thermal fatigue resistance
  - Provide high thermal conductivity.

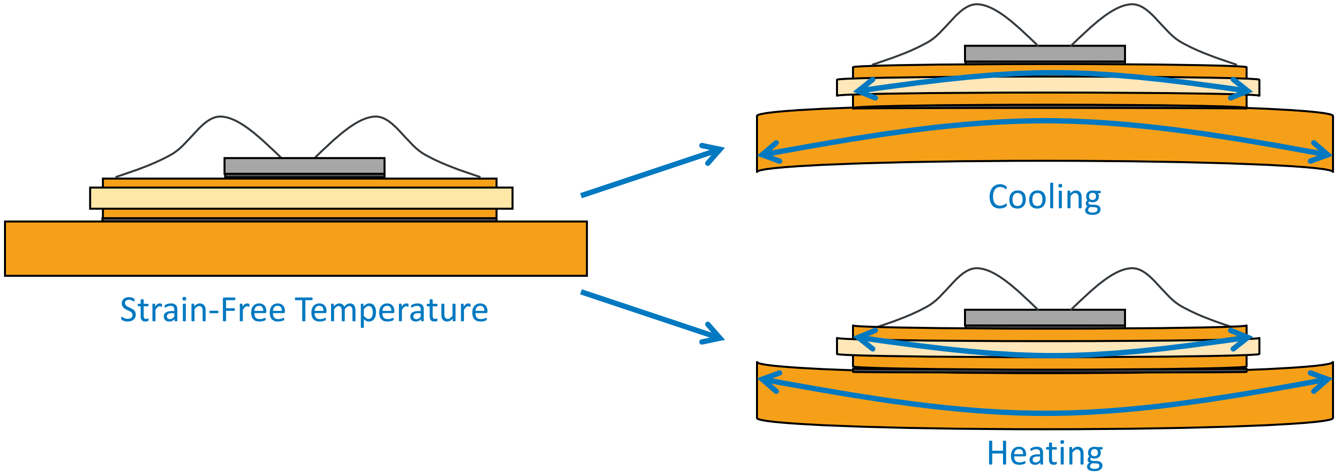




Traditional Power Electronics Package

Relevance

- As operating temperatures increase, the coefficient of thermal expansion (CTE) mismatch between the substrate and the base plate causes delamination initiation and propagation in the joining layer.



CTE (x 10^{-6} / K)
Silicon: 2.6
AlN: 4.5
Si_3N_4: 3.2
Copper: 16.5
Aluminum: 22.7
Sn63/Pb37 Solder: 24.7
Silver: 19.5

- Sintered-silver reliability has not been documented at 200°C conditions for the substrate attach layer.
    - ORNL and NREL's prior experience with sintered-silver processing will generate recommended practices for synthesis of reliable interfaces.

Milestones

2013			2014								
Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep

Model stress intensity factor with finite element analysis and fit V-K* curve to FY13 sintered-silver results.

Go/ No-Go

Process shear test samples.

Process CTE mismatched disk samples with various diameter bond pads.

Key Deliverable

Perform accelerated life testing and reliability characterization.

ORNL

NREL

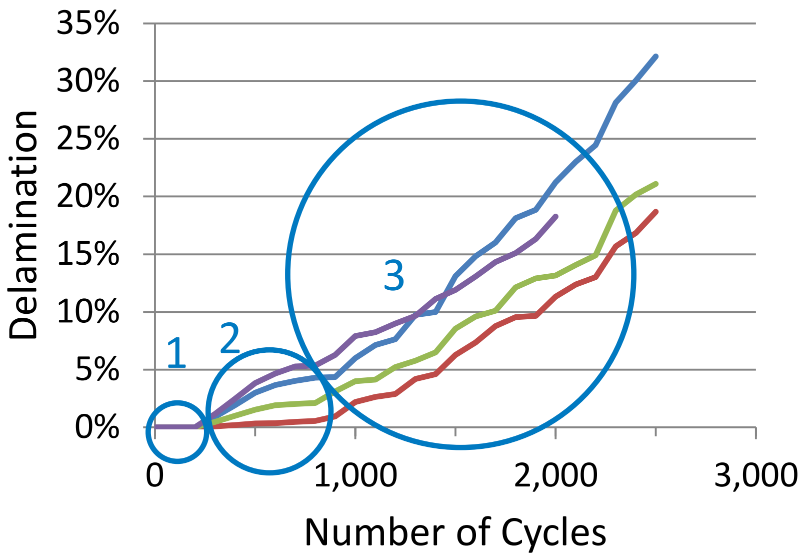
Go/No-Go: Can threshold before delamination initiates be defined?

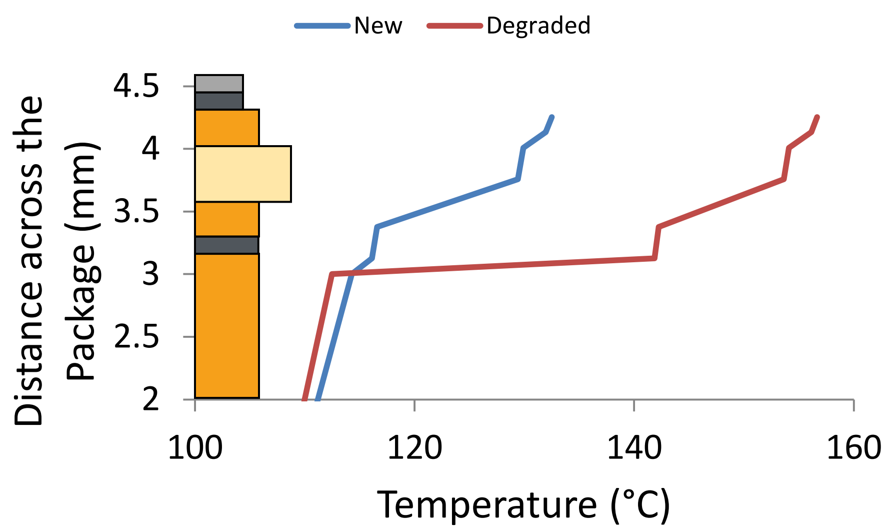
Key Deliverable: Publish delamination initiation findings for sintered-silver.

*V= da/dN, Crack Growth Rate, (mm/cycle) – K = Stress Intensity Factor

Strategy

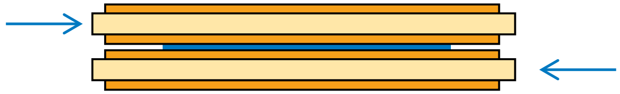
- Subject samples to shear tests for development of stress-strain curves.
- Focus on optimizing and understanding key synthesis parameters for sintered-silver.
    1. Identify threshold at which stress intensity factors are sufficient to cause delamination initiation.
    2. Evaluate the crack region where a transient delamination rate occurs.
    3. Evaluate the crack region where a constant-slope delamination rate occurs.
- Develop stronger experimental correlation between interface patterning/ degradation and junction temperature rise.



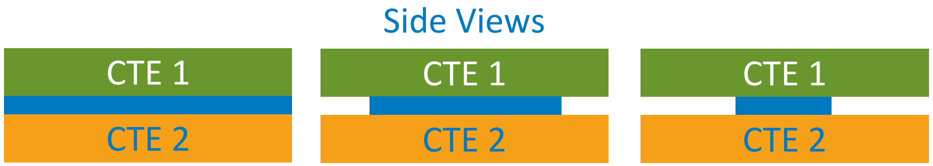


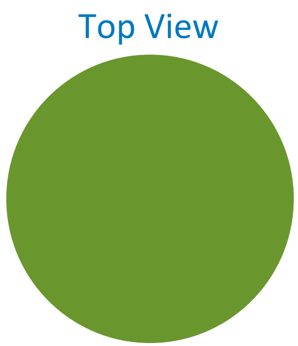
Strategy

- Synthesize and shear test initial samples for mechanical characterization of sintered-silver.
  - Attempt to measure residual stress at room temperature.
  - Estimate stress-strain curves.
  - Use information to model plastic deformation.
- Sintered-silver is bonded between two direct bond copper substrates.



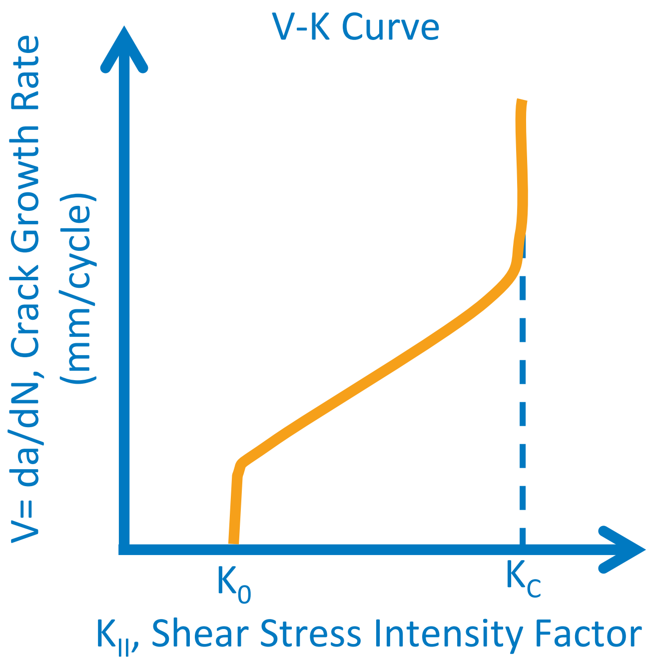
- Process CTE-mismatched disk samples with various diameter bond pads to validate stress intensity factor relationship with delamination initiation.
  - The stress intensity factor is a function of the loading amount, deformation mode, and the region of interest relative to the crack tip deformation.
  - Crack tip deformation can propagate through three modes:
    - Tension
    - Shear
    - Tearing.





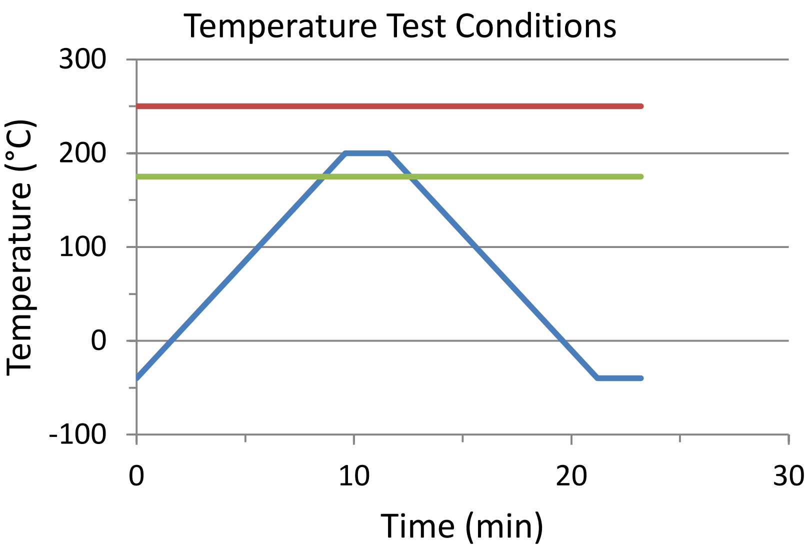
Strategy

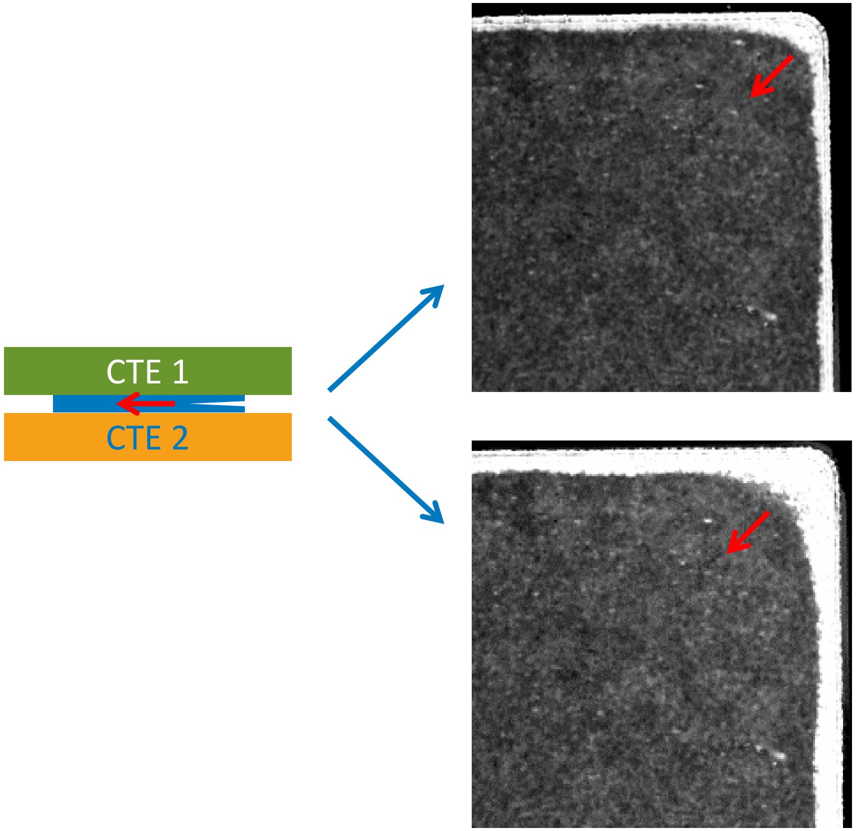
- Identify threshold at which stress intensity factor is sufficient to cause delamination initiation.
  - Model stress intensity factor with finite element analysis and correlate with FY13 sintered-silver results.
  - Fit V-K curve to FY13 sintered-silver results.



Strategy

- Subject samples to accelerated temperature testing:
  - -40°C to 200°C thermal shock
  - 175°C and 250°C temperature elevation.
- Monitor delamination rates through acoustic microscopy.

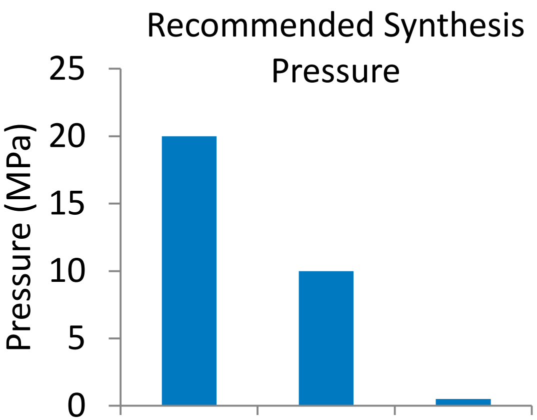




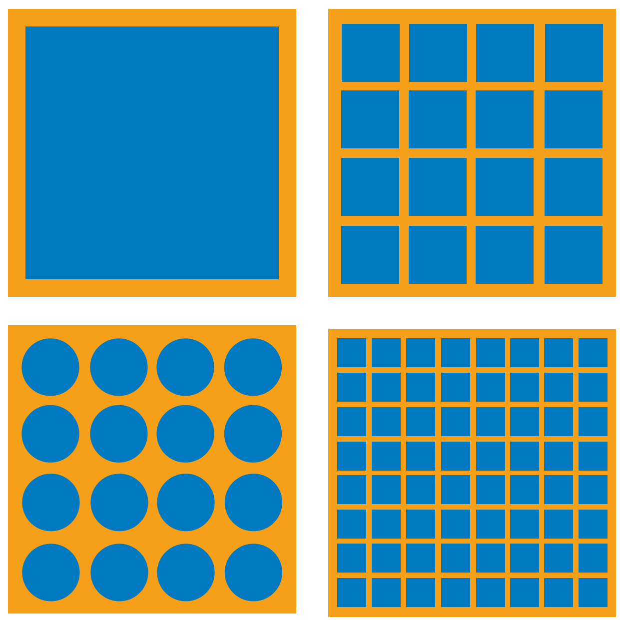
Strategy

- Evaluate the delamination rate of sintered-silver test coupons under various pressure requirements, bond areas, pad geometries, and surface-plating materials.

Evaluate low- and no-pressure sintered-silver materials.

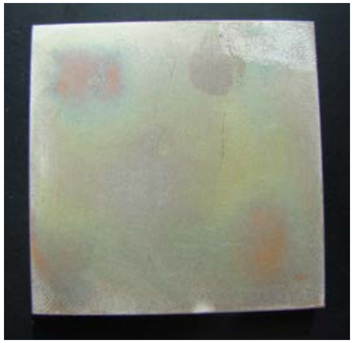


Optimize pad geometries for a large-area bond pad.

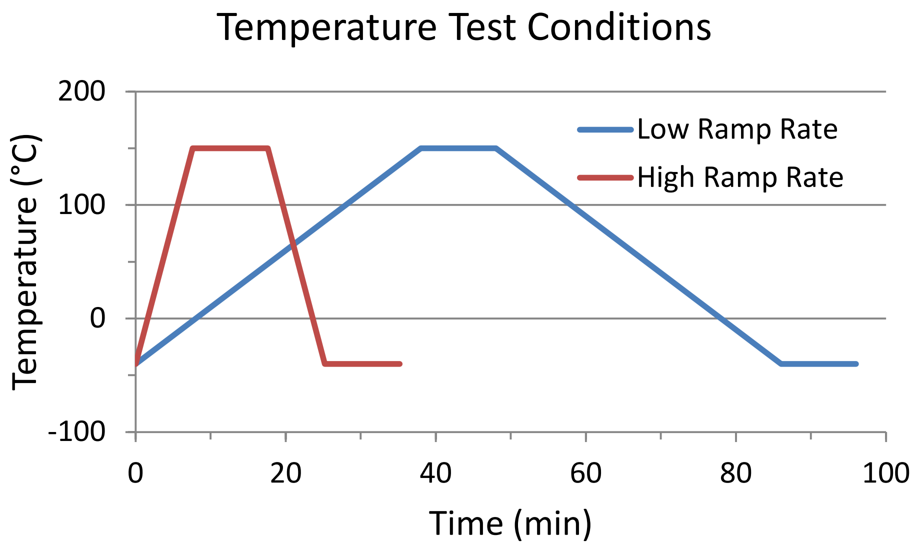


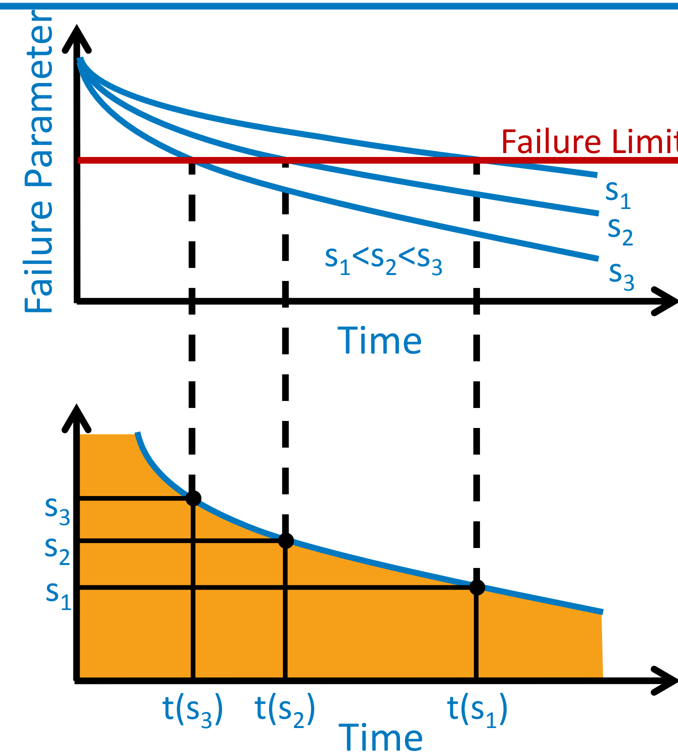
Recommend industry standard practices for plating.

Plating Material	Ag, Au
Cleaning	None, substrate cleaning, pre-oxidation

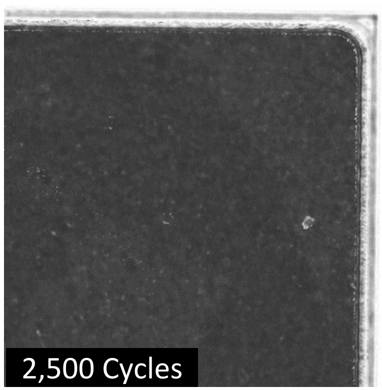

Poor Ag Plating

Prior Temperature Cycling

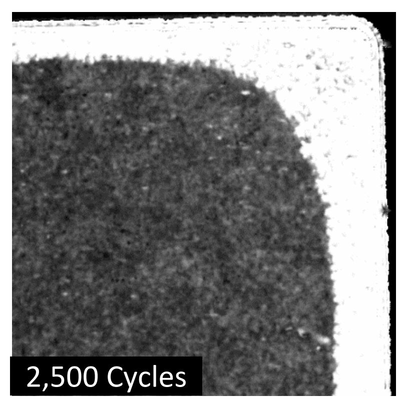




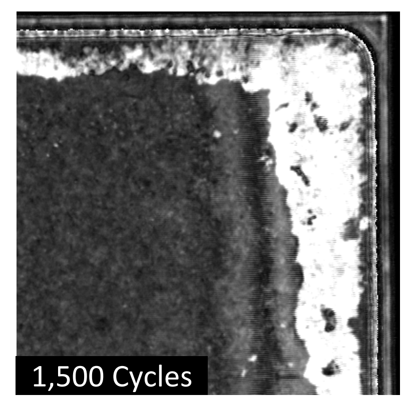
- Thermoplastic film embedded with carbon fibers, sintered-silver, and Sn63/Pb37 solder were subjected to accelerated thermal cycling.



Thermoplastic



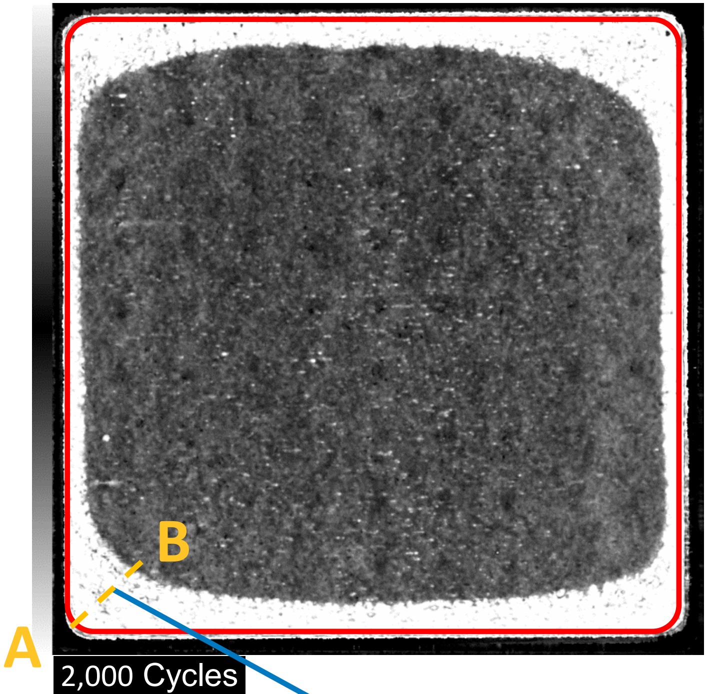
Sintered-Silver

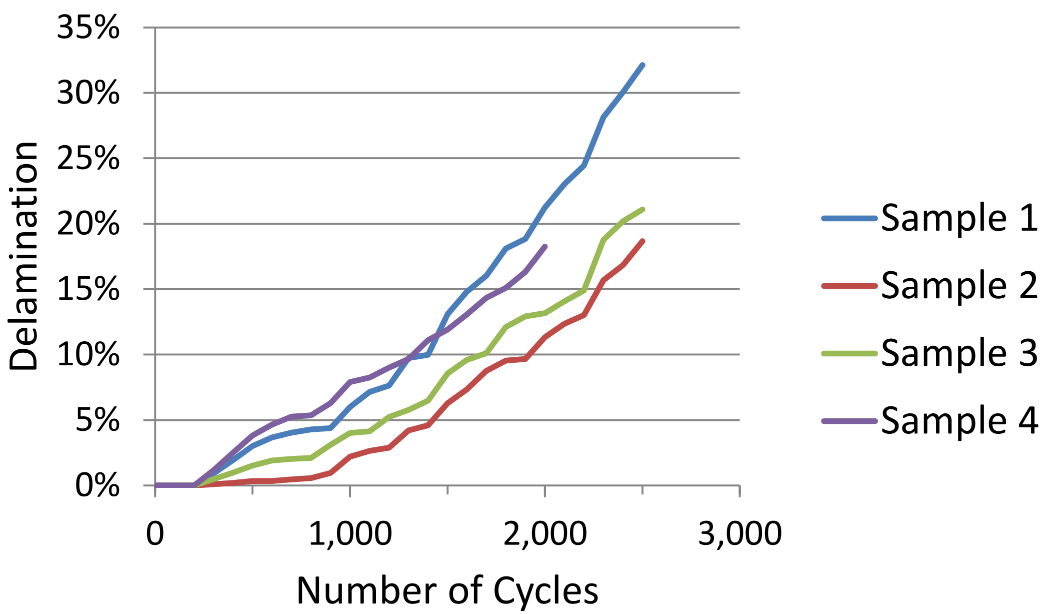


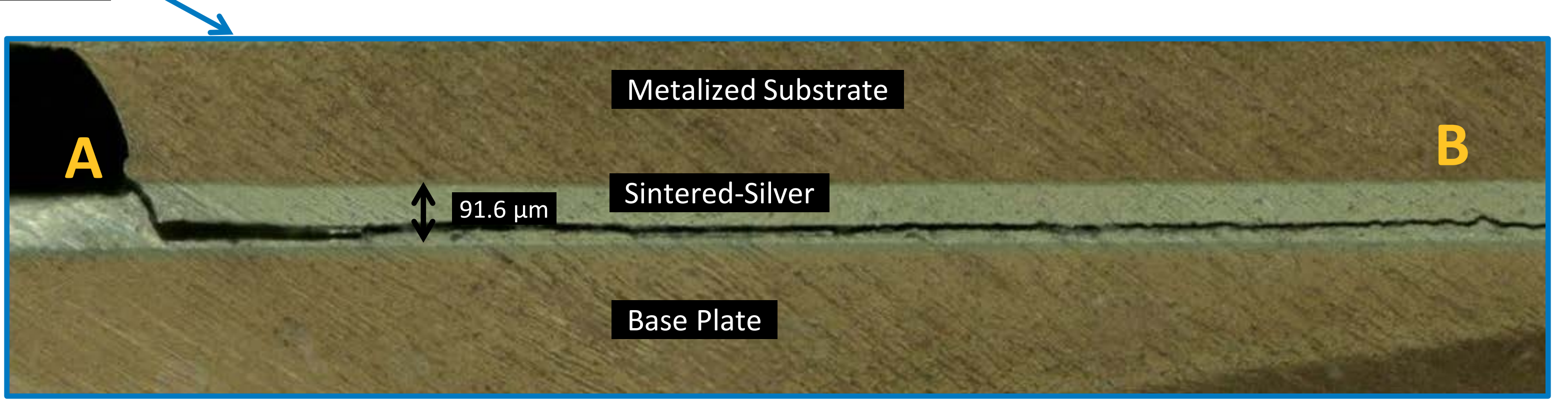
Solder

Sintered-Silver Evaluation

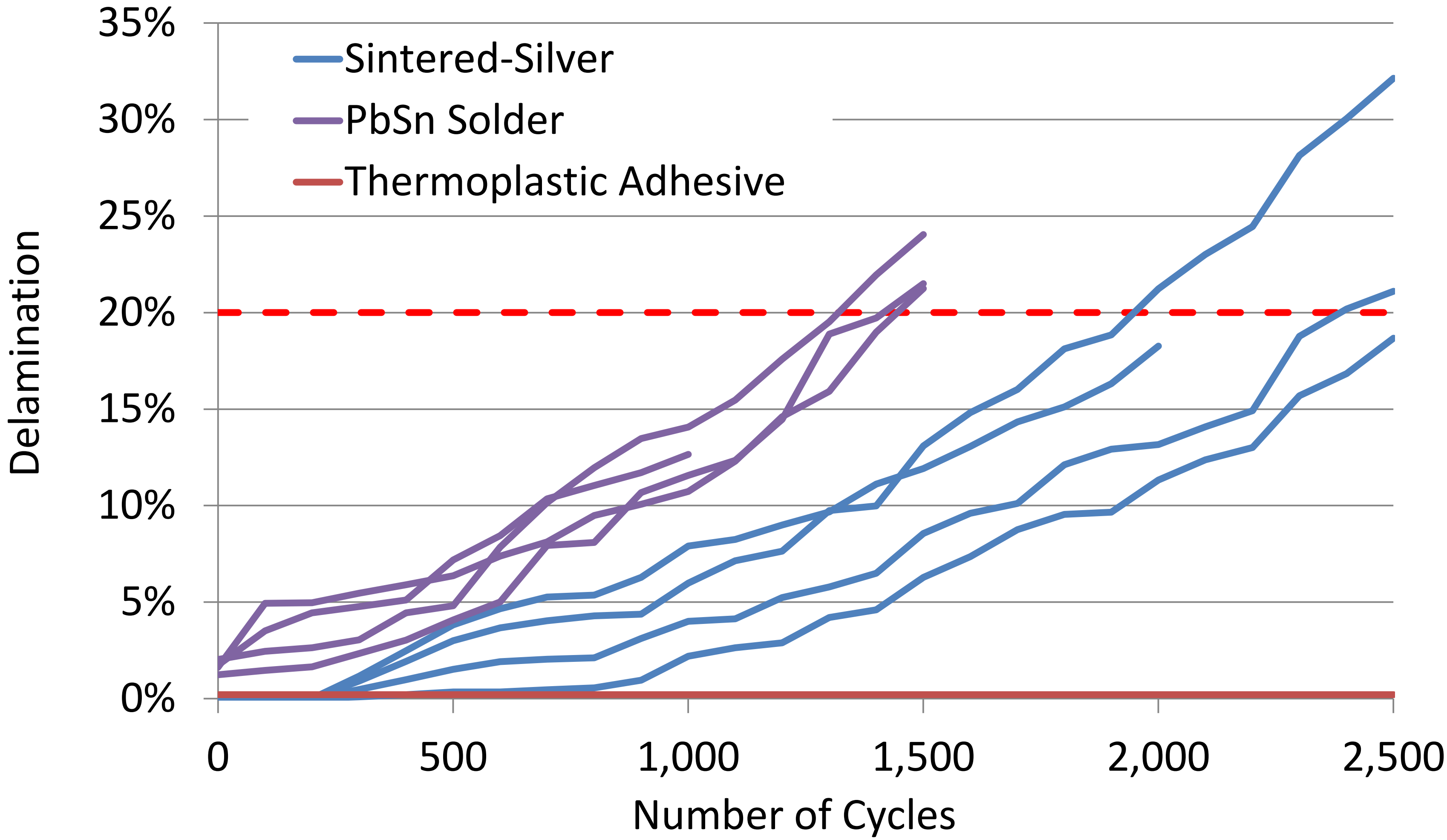
- After 2,500 thermal cycles, perimeter fracturing reached 19% to 32%.







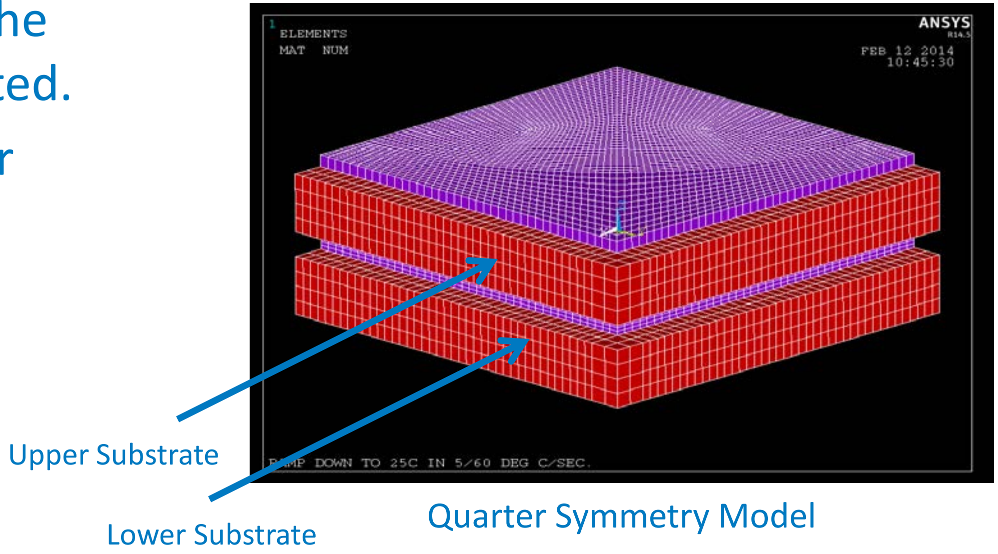
BIM Degradation Summary



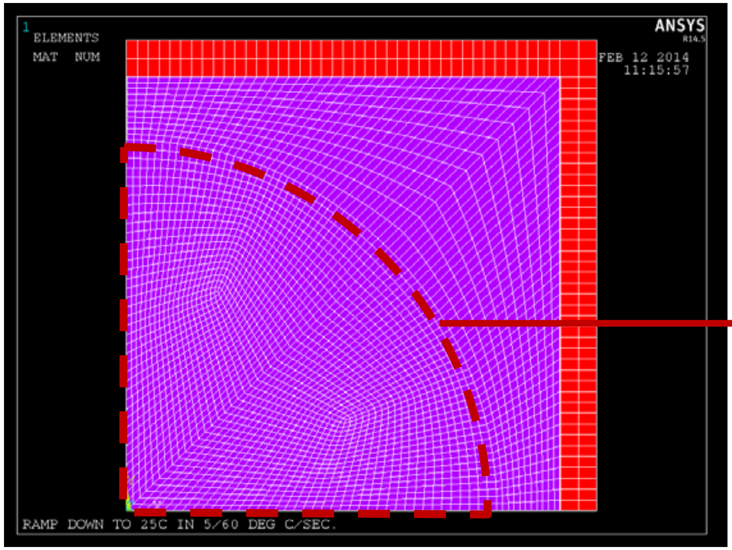
DeVoto, D., Paret, P., Narumanchi, S., Mihalic, M., 2013, "Reliability of Bonded Interfaces for Automotive Power Electronics," InterPACK2013-73143, Proceedings of the 2013 InterPACK Conference, July 2013, Burlingame, CA.

Interface Modeling

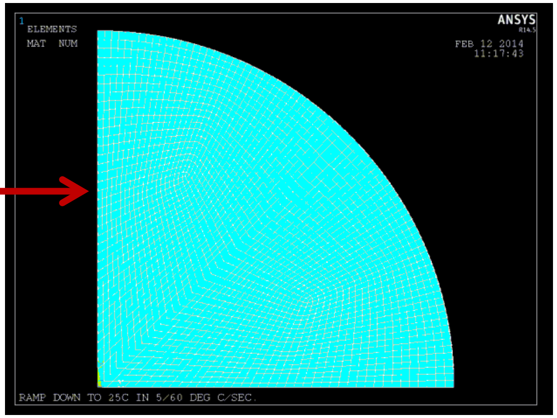
- A quarter symmetry model of the substrate test sample was created.
- Material parameters for a linear elastic analysis were applied to various layers of the model.
- Temperature is first raised to 275°C, then lowered to room temperature.



Quarter Symmetry Model



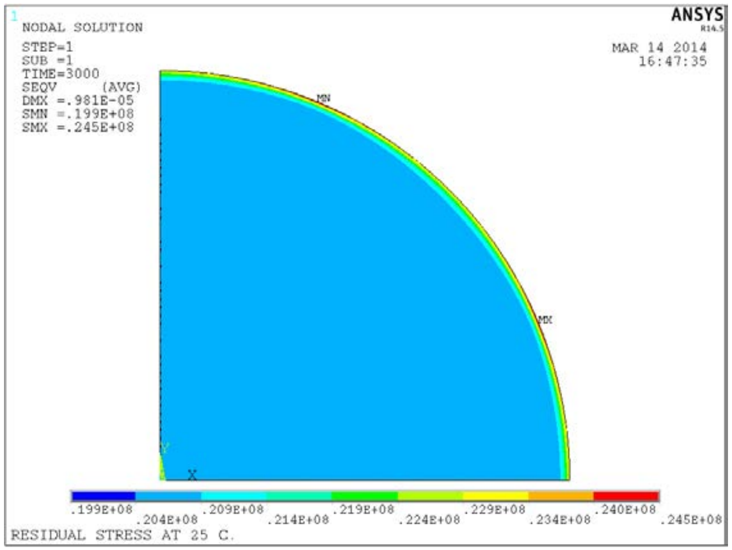
Model – Top View



Sintered-Silver Layer – 5 mm Radius

Interface Modeling

- Six linear elastic simulations were performed and incorporated variations in thickness and diameter of the sintered-silver joint.



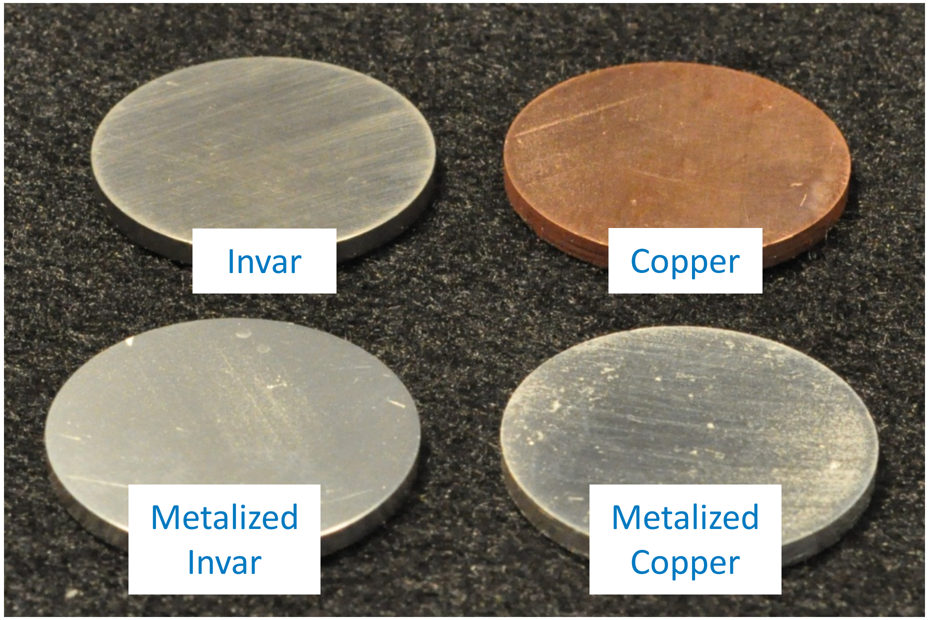
von-Mises Stresses in Sintered-Silver Layer

Thickness (µm)	Diameter (mm)	von-Mises Stress (MPa)
25	10	24.5
25	9	24.9
25	8	25.5
25	7	26.1
25	6	26.8
50	10	27.5

- Stress increased with decrease in diameter of the sintered-silver joint for the same substrate size.
- Stress increased as thickness was increased from 25 µm to 50 µm.

Coupon Synthesis

- Invar and copper were selected for round test coupons.
  - Coupon dimensions are 25.4 mm in diameter, 2 mm in thickness.
  - Materials were chosen for CTE mismatch.
  - Surfaces were blanchard ground and metalized with silver.



Invar and Copper Test Coupons

Responses to Previous Year Reviewers' Comments

- This is a new start for FY14.

Collaboration and Coordination

- Partners
  - **ORNL** (Federal): technical partner on sintered-silver samples
  - **Heraeus** (Industry): sintered-silver material guidance
  - **Henkel** (Industry): sintered-silver material guidance
  - **General Motors** (Industry): technical guidance

Proposed Future Work (FY14)

- Synthesize and shear test initial samples for mechanical characterization of sintered-silver.
- Process CTE-mismatched disk samples with various diameter bond pads to validate stress intensity factor relationship with delamination initiation.
- Focus on optimizing and understanding key synthesis parameters for sintered-silver.
- Develop stronger experimental correlation between interface patterning/ degradation and junction temperature rise.

Proposed Future Work (FY15)

- Evaluate the delamination rate of sintered-silver test coupons under various pressure requirements, bond areas, pad geometries, and surface plating materials.
  - Evaluate low- and no-pressure sintered-silvers.
  - Optimize pad geometries for a large-area bond pad.
  - Recommend industry standard practices for plating.

Summary

- **DOE Mission Support:**
  - BIMs are a key enabling technology for compact, lightweight, low-cost, reliable packaging and for high-temperature coolant and air-cooling technical pathways.
- **Approach:**
  - Synthesis of sintered-silver bonds, thermal temperature cycling, bond inspection (acoustic microscope), and stress intensity factor versus cycles-to-failure models.
- **Accomplishments:**
  - Established a procedure for the material and degradation characterization of sintered-silver.

Summary

- **Collaborations**
  - ORNL, Heraeus, Henkel, GM
- **Future Work**
  - Synthesize and shear test initial samples for mechanical characterization of sintered-silver.
  - Process CTE-mismatched disk samples with various diameter bond pads to validate stress intensity factor relationship with delamination initiation.
  - Focus on optimizing and understanding key synthesis parameters for sintered-silver.
  - Develop stronger experimental correlation between interface patterning/degradation and junction temperature rise.

NATIONAL RENEWABLE ENERGY LABORATORY

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