Power Electronics Materials and Bonded Interfaces – Reliability and Lifetime

Keystone Project 1

PI: Paul Paret
National Renewable Energy Laboratory
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DOE Vehicle Technologies Program
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Project ID # ELT219

Overview

Timeline

- Project start date: FY19
- Project end date: FY21
- Percent complete: 15%

Barriers

- Cost
- Size and Weight
- Performance, Reliability and Lifetime

Budget

- Total project funding
  - DOE share: $175K
- Funding for FY 2019: $175K

Partners

- Interactions/collaborations
  - Virginia Polytechnic Institute and State University (Prof. G. Q. Lu)
  - Georgia Institute of Technology (Prof. Samuel Graham, Prof. Yogendra Joshi)
  - Oak Ridge National Laboratory (ORNL)
- Project lead
  - National Renewable Energy Laboratory (NREL)

Relevance

Crack Propagation in Pressure-Assisted (30- 40 MPa) Sintered Silver

- Sintered silver synthesized using high pressure (30–40 MPa) exhibits excellent reliability; survived for more than 2,000 cycles (-40°C to 150°C).
- Low-pressure sintering eases the manufacturing process and offers better protection to semiconductor devices and ceramic substrates.

High-Temperature Bonded Materials

Experimental

- Mechanical characterization
- Thermal cycling reliability

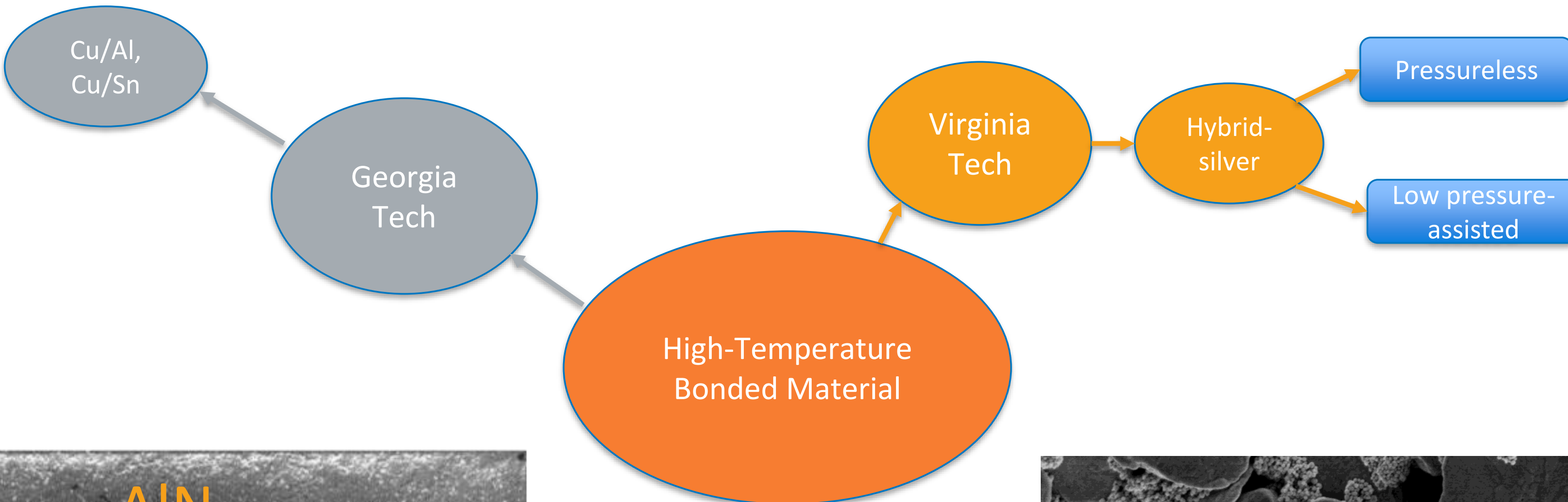
Modeling

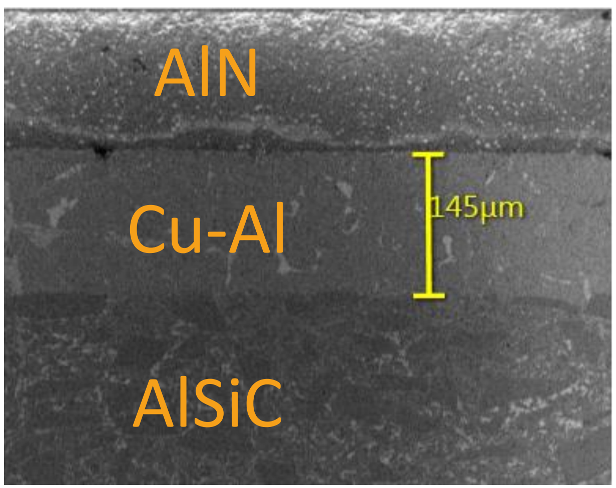
- Thermomechanical modeling

Overall Approach

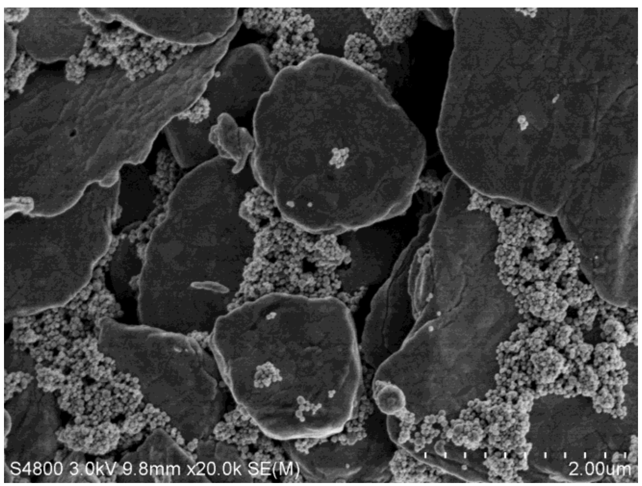
- High-temperature bonded materials
  - Investigate synthesis/bonding procedures.
  - Conduct mechanical characterization study (stress versus strain relationship).
  - Evaluate reliability under accelerated thermal cyclic loading conditions.
  - Develop finite element analysis models that can capture the material fatigue behavior.
  - Create lifetime prediction models correlating experimental cycles-to-failure data with modeling results.

Approach – Materials





Cu-Al bond – SEM image[1]



Hybrid-silver – SEM image[2]

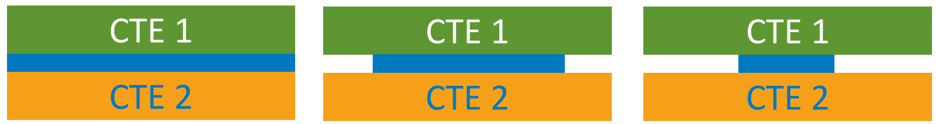
SEM: scanning electron microscope
[1] Courtesy – Darshan Pahinkar (Georgia Tech)
[2] Courtesy – G Q Lu (Virginia Tech)

Cu : Copper, Al : Aluminum, Sn : Tin
AlN : Aluminum Nitride
AlSiC: Aluminum Silicon-Carbide

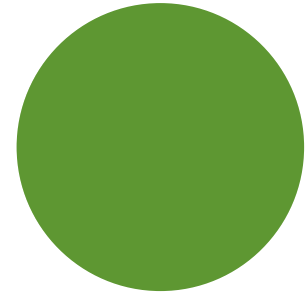
Approach – Reliability Evaluation

Copper – Invar Coupons

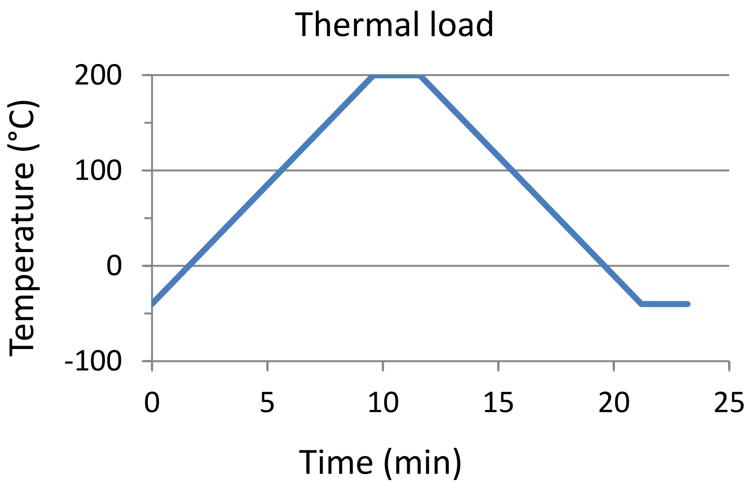
Side Views

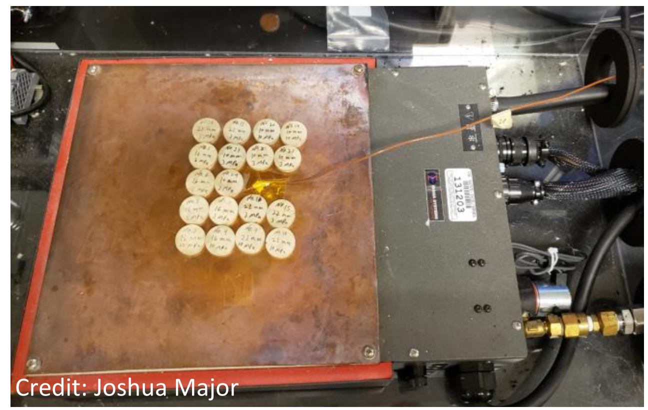


Top View



Φ 25.4 mm





Thermal platform for thermal cycling

- Subject CTE-mismatched samples bonded with the material of interest to thermal cycling from -40°C to 200°C.
- Obtain C-SAM images of the bond material at periodic cycling intervals.
- Estimate crack growth rate from C-SAM images through image analysis.

C-SAM: C-mode scanning acoustic microscope

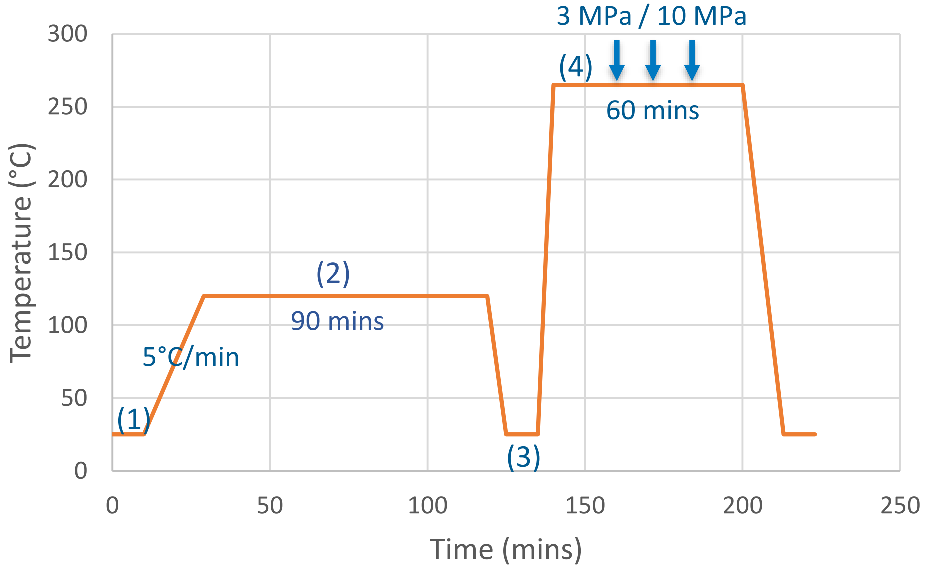
CTE: co-efficient of thermal expansion

Milestones

Month / Year	Description of Milestone or Go/No-Go Decision	Status
December 2018	Conduct accelerated thermal cycling on circular coupons with hybrid sintered silver as the bonded material.	Completed
May 2019	Conduct accelerated thermal cycling on circular coupons with nano sintered silver as the bonded material.	Ongoing
August 2019	Develop a crack propagation model of sintered silver material.	Ongoing
September 2019	Fabricate samples with alternative high-temperature bonded materials for mechanical characterization.	To be started

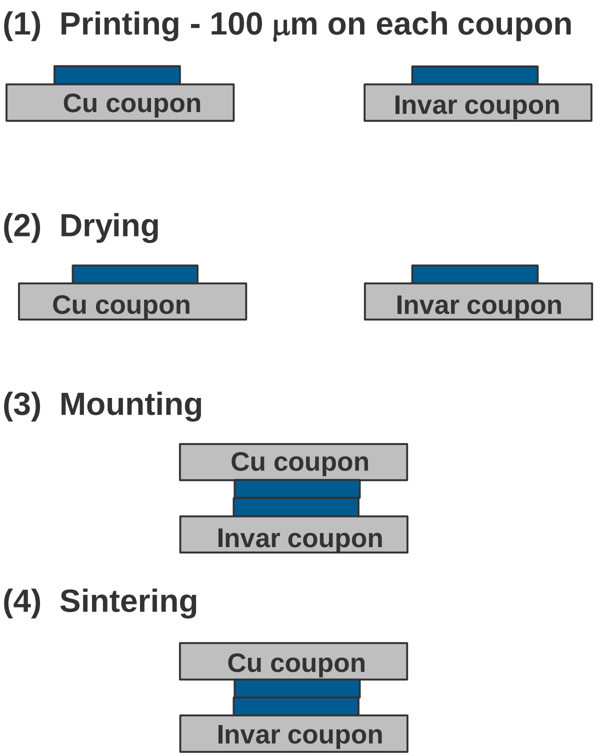
Technical Accomplishments and Progress

Synthesis of low pressure-assisted samples – hybrid silver (Virginia Tech)



Low pressure-assisted sintering profile

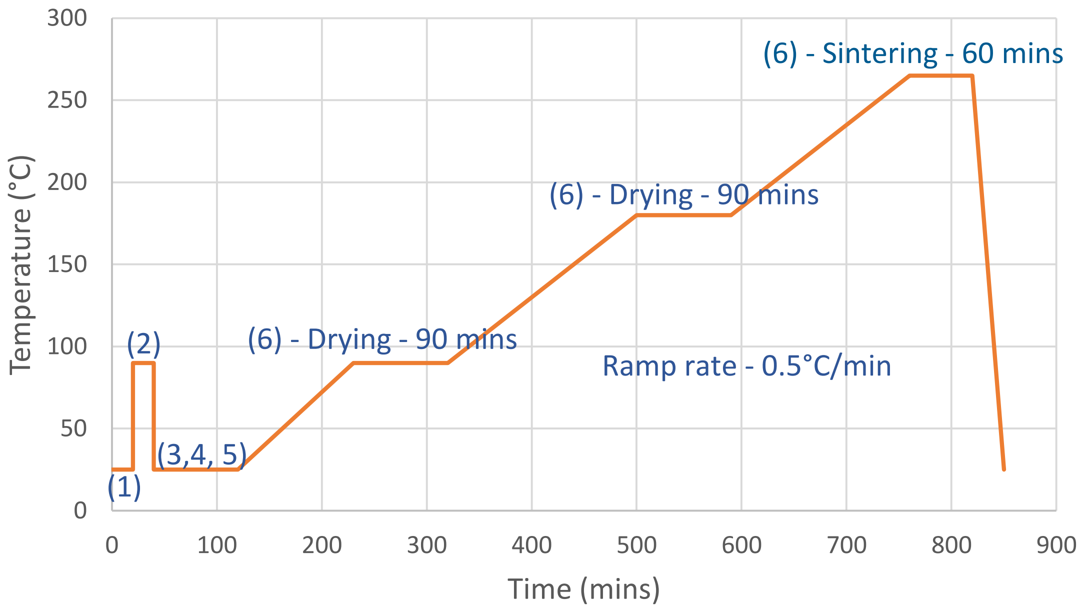
Bonding procedure



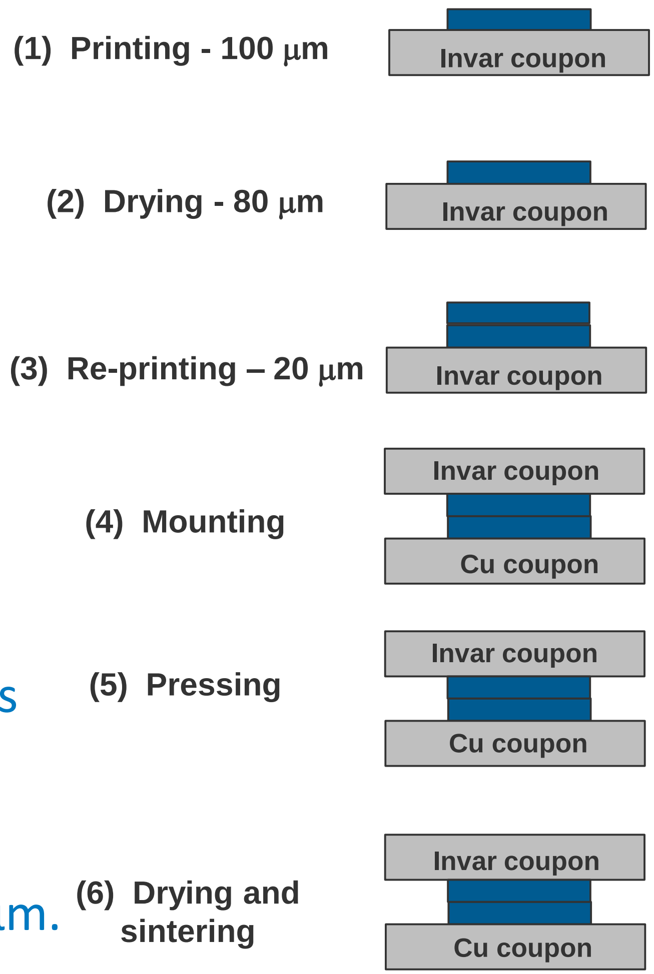
- Paste was applied to each of the coupons, which were then joined together before sintering.
- Final bond line thickness averaged between 115 μm and 137 μm.

Technical Accomplishments and Progress

Synthesis of pressure-less samples – hybrid silver (Virginia Tech)



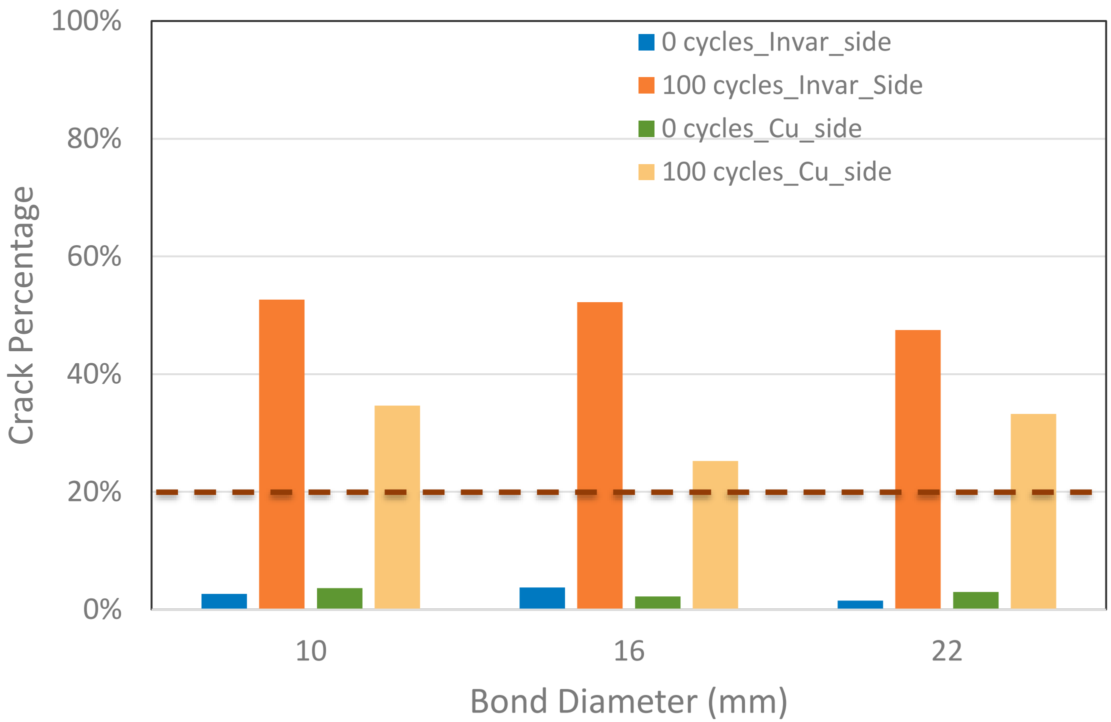
Bonding procedure



- Evaporation of solvents under the drying process tend to leave voids and cracks in the bond.
- No sintering pressure was applied.
- Final bond line thickness averaged around 100 μm.

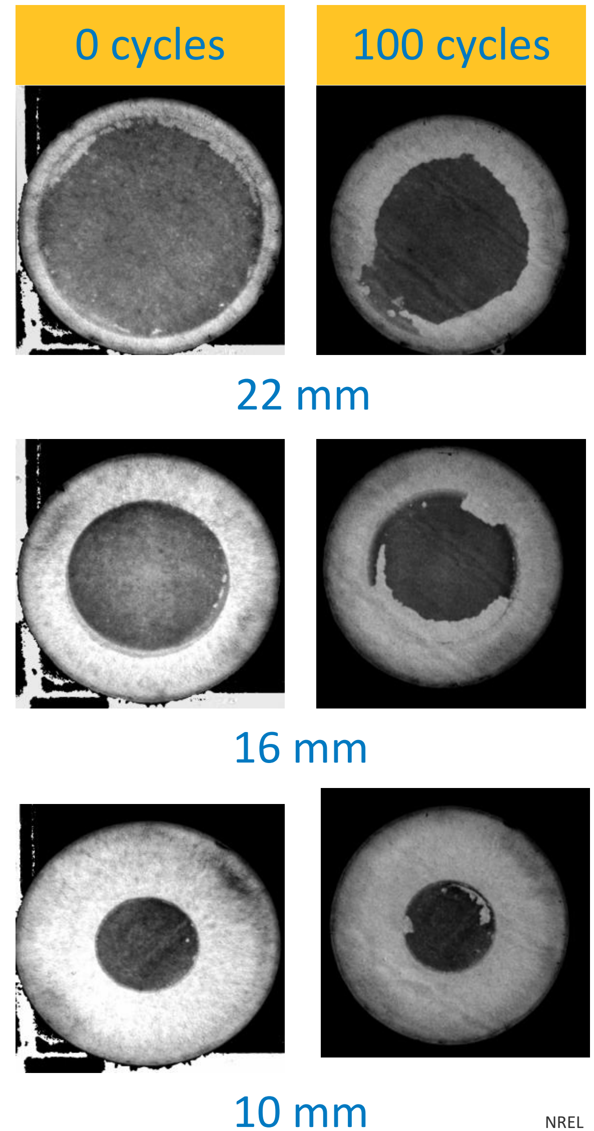
Technical Accomplishments and Progress

Thermal cycling of pressure-assisted samples (3 MPa)



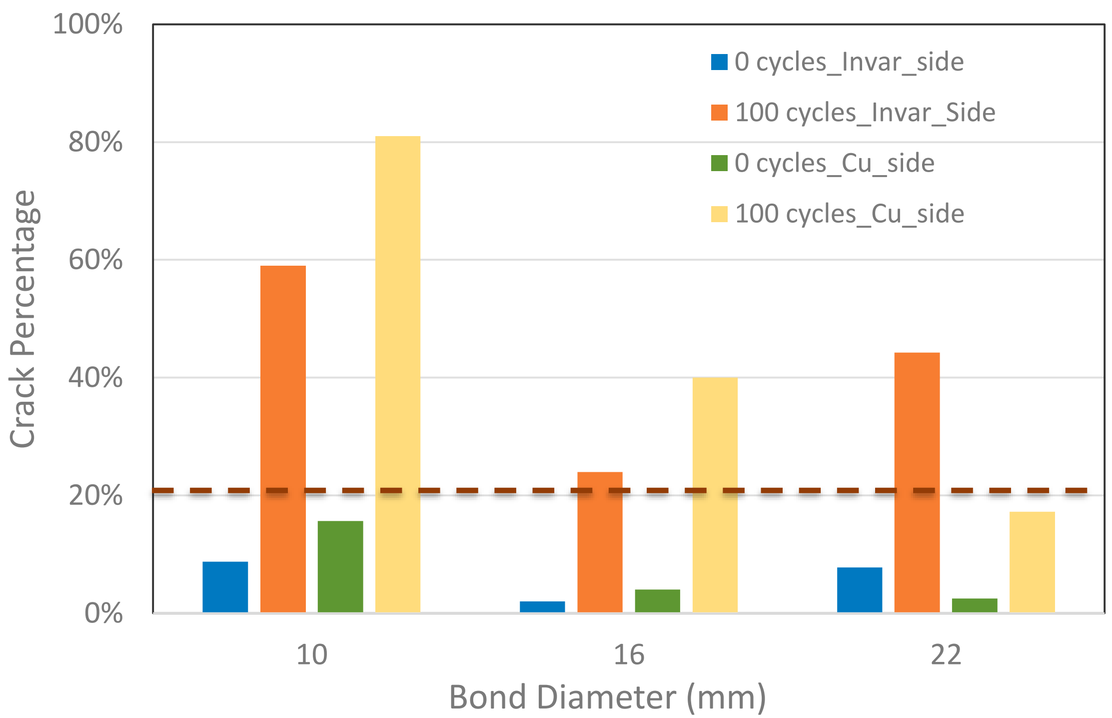
- Four samples were cycled for each diameter case.
- Failure (> 20% crack growth) may have occurred within 50 cycles.
- Crack growth rate was higher on the Invar side.

C-SAM images of sintered silver from Cu side

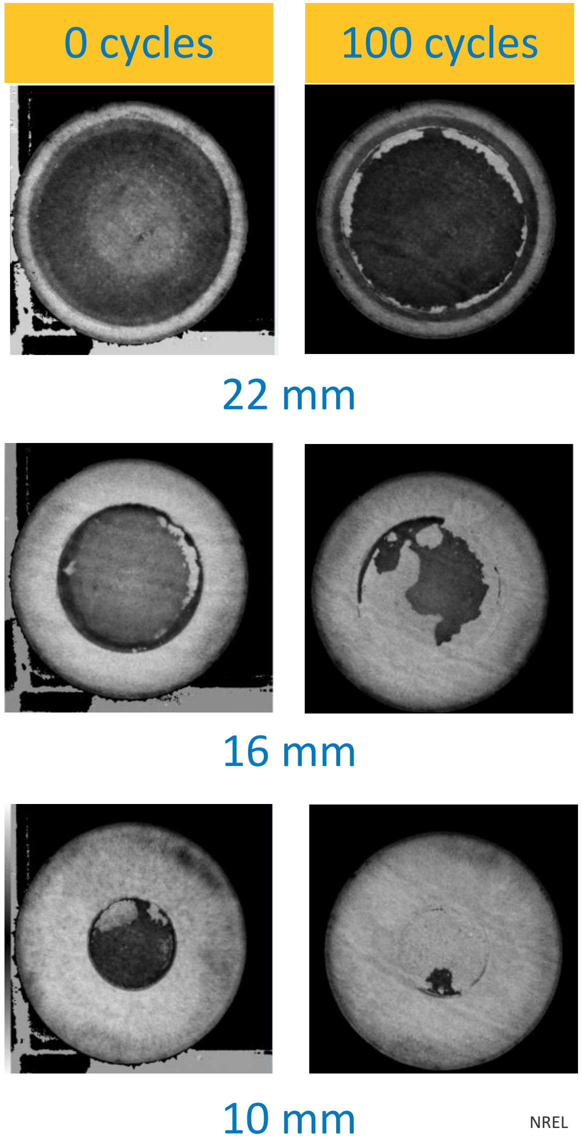


Technical Accomplishments and Progress

Thermal cycling of pressure-assisted samples (10 MPa)



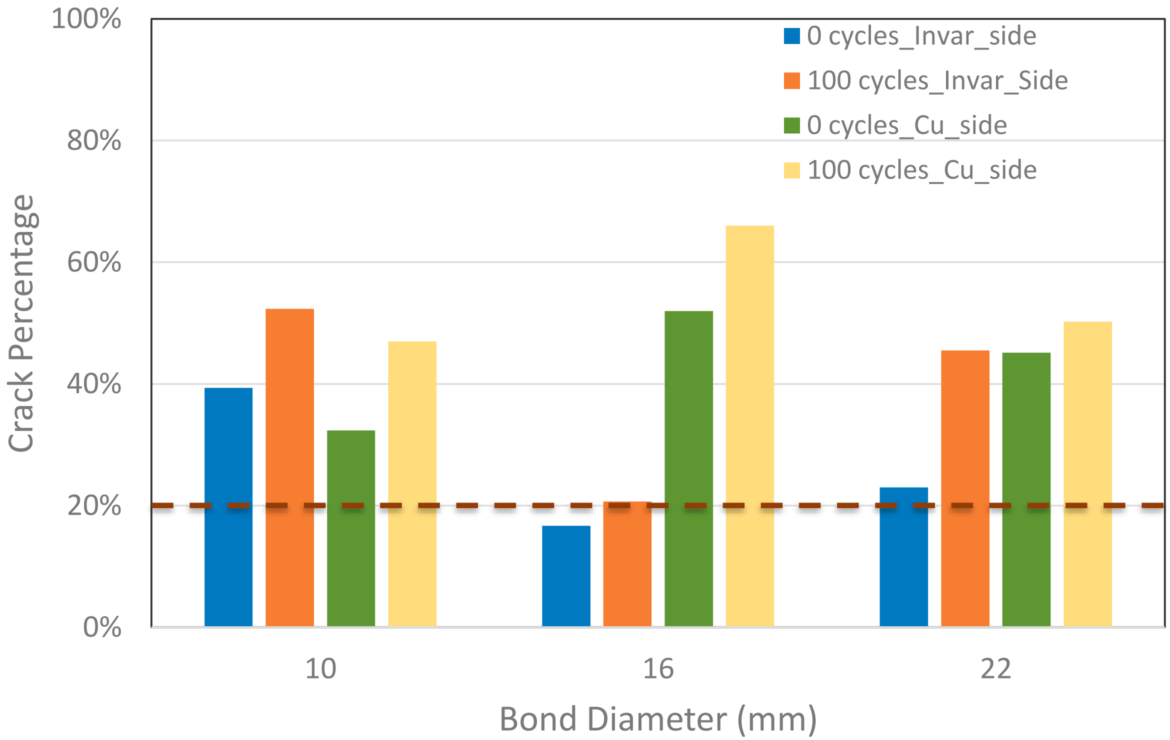
C-SAM images of sintered silver from Cu side



- Samples that had more than 20% initial crack (at 0 cycles) are not included in the graph.
- Failure occurred within 50 cycles.
- Crack growth rate was dictated by the initial crack percentage.

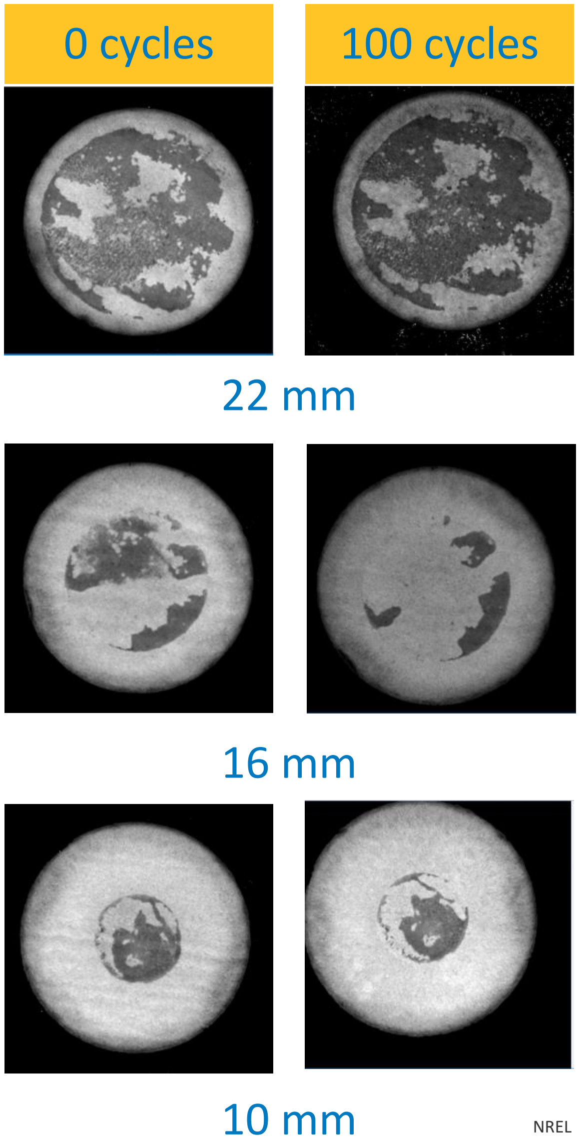
Technical Accomplishments and Progress

Thermal cycling of pressure-less samples (hybrid silver)

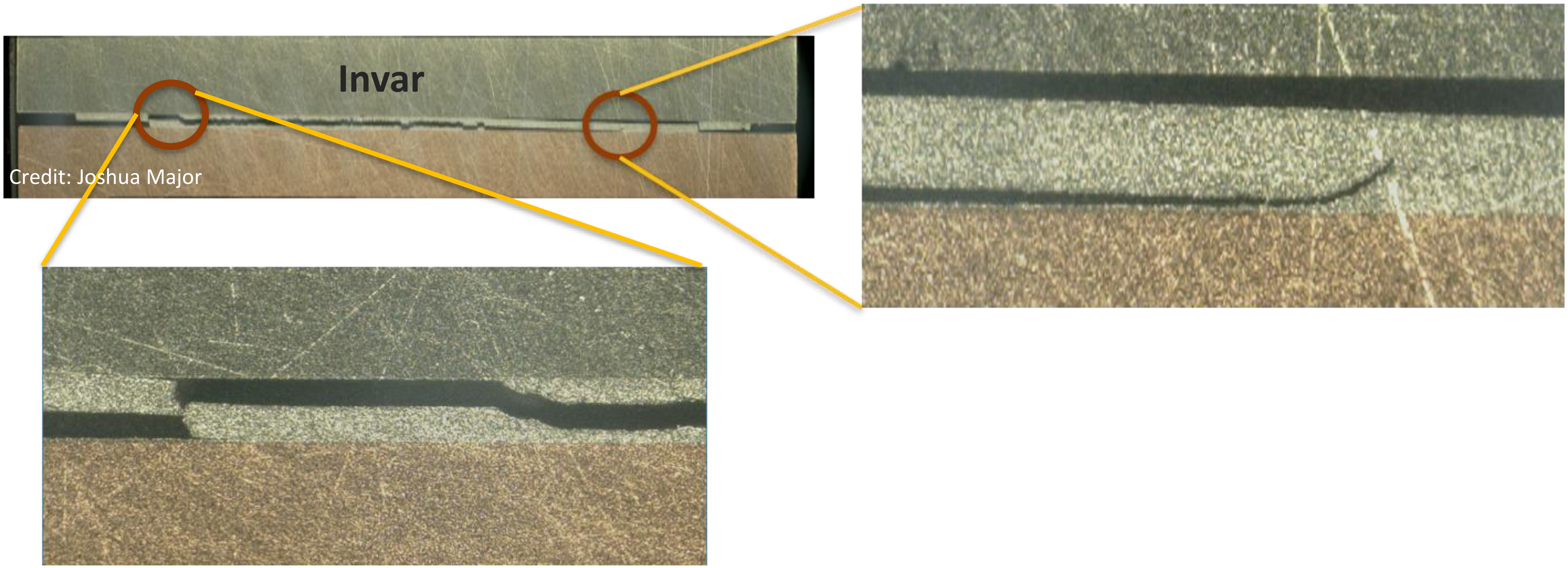


- Initial crack in most of the samples was more than 20% of the total bond area.
- Lack of sintering pressure led to poor densification of the micron-sized silver flakes and nano-silver particles.
- The lower crack growth rate may be due to the existing cracks providing stress relief under thermal cycling.

C-SAM images of sintered silver from Cu side



Technical Accomplishments and Progress



Cross-sectional Microscopic Images of Crack Propagation in Sintered Silver

- Mode of crack propagation was found to be a combination of cohesive and adhesive failure mechanisms.
- Presence of different crack modes possibly indicates the strong impact of both global (Cu and Invar) and local (silver and Invar) CTE mismatch .
- Multiple cracks observed explain the difference in C-SAM images/crack percentage calculations from Cu and Invar side.

Responses to Previous Year Reviewers' Comments

- The project is a new start in FY19.

Collaboration and Coordination

- Virginia Tech: technical partner on the synthesis of sintered silver bonds
- Georgia Tech: technical partner on the synthesis of Cu-Al bonds
- ORNL : technical guidance
- Private industries in power electronics

Remaining Challenges and Barriers

- Developing void-free, round, large-area bonded coupons for reliability evaluation with a pure pressure-less sintering process is not trivial.
- Reliability of sintered silver under thermal cycling from - 40°C to 200°C needs to be compared against other high-temperature bonded materials.
- The correlation between circular and square footprint samples established through modeling is to be experimentally validated.

Proposed Future Research – FY19

- Synthesize void/crack-free circular coupons with nano-silver as the bonding material.
- Complete accelerated thermal cycling on circular coupons under different temperature profiles.
  - -40°C to 200°C
  - -40°C to 175°C
  - -40°C to 150°C
- Develop a 2-D crack propagation model for sintered silver under thermal cycling.
- Submit a manuscript to a journal capturing the various findings of the project, including both modeling results and experimental data.

"Any proposed future work is subject to change based on funding levels"

Proposed Future Research – FY20

- Conduct mechanical characterization and reliability evaluation of alternative high-temperature bonded materials.
  - Sintered copper
  - Cu-Al
  - Cu-Sn

- Perform thermomechanical modeling of high-temperature bonded materials to obtain theoretical parameters such as strain energy density and J-integral.

- Develop lifetime prediction models correlating modeling outputs with experimental crack growth data.

"Any proposed future work is subject to change based on funding levels"

Summary

- DOE Mission Support
  - Reliability evaluation of bonded materials is a critical research area for enabling low-cost, lightweight, and reliable power electronics packages that can operate at high temperatures.
- Approach
  - Synthesis of sintered silver bonds, mechanical characterization, reliability evaluation, thermomechanical modeling, and lifetime prediction models
- Accomplishments
  - Investigated the reliability of a hybrid sintered silver (a mixture of nanoparticles with micron-sized silver flakes) under a high-temperature thermal cycling load.
  - Failure (crack growth to more than 20% by area) occurred within 50 or 100 thermal cycles.
  - Microscopic images of sample cross-section revealed the failure mechanism to be a combination of adhesive and cohesive cracking.
- Collaborations
  - Virginia Tech
  - Georgia Tech
  - ORNL
  - Power electronics industry partners

Acknowledgments

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EDT Task Leader

Sreekant Narumanchi
Sreekant.Narumanchi@nrel.gov

Phone: (303)-275-4062

Team Members

Joshua Major (NREL)
Douglas DeVoto (NREL)
G Q Lu (Virginia Tech)
Samuel Graham (Georgia Tech)
Yogendra Joshi (Georgia Tech)

EDT – Electric Drive Technologies

For more information, contact

Principal Investigator
Paul Paret
Paul.Paret@nrel.gov
Phone: (303)-275-4376

Thank You

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