Performance and Reliability of Bonded Interfaces for High-Temperature Packaging

PI: Paul Paret
National Renewable Energy Laboratory
June 19, 2018

DOE Vehicle Technologies Office
2018 Annual Merit Review and Peer Evaluation Meeting

Project ID: ELT080

Overview

Timeline

- Project start date: FY17
- Project end date: FY19
- Percent complete: 60%

Barriers

- Cost
- Size and Weight
- Performance and Lifetime

Budget

- Total project funding
  - DOE share: $767K
- Funding for FY 2017: $492K
- Funding for FY 2018: $275K

Partners

- Interactions/collaborations
  - Virginia Polytechnic Institute and State University (Prof. G. Q. Lu)
  - Oak Ridge National Laboratory (ORNL)
- Project lead
  - National Renewable Energy Laboratory (NREL)

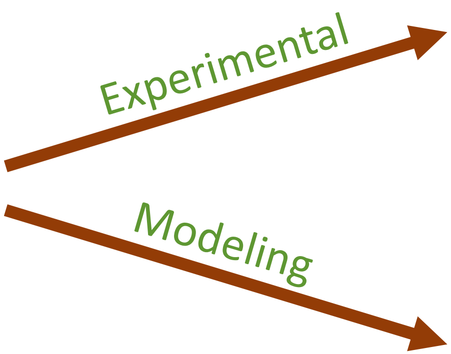
Relevance

Crack Propagation in Pressure-Assisted Sintered Silver

- Sintered silver synthesized using high pressure (30-40 MPa) exhibits excellent reliability; survived for more than 2,000 cycles

- High bonding pressure results in manufacturing complexities and catastrophic damage to devices and substrates

Pressure-less sintered silver

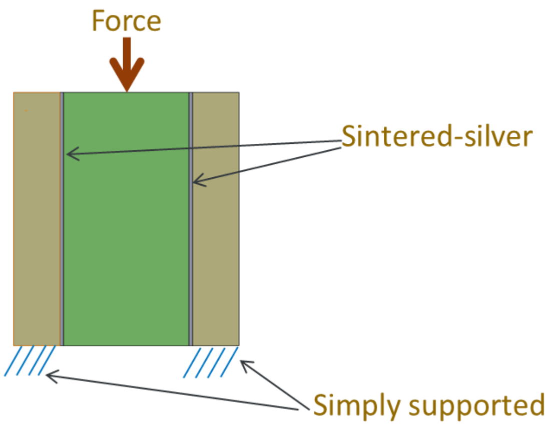


- Mechanical characterization
- Thermal cycling reliability
- Thermomechanical modeling

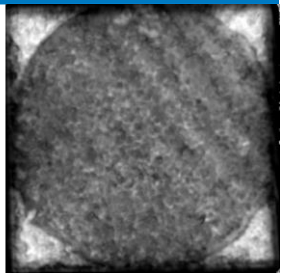
Overall Approach

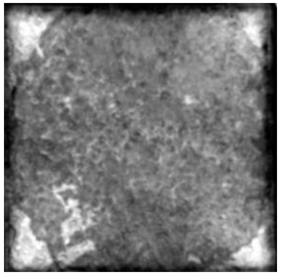
- Conduct a mechanical characterization study (stress versus strain relationship) of sintered silver
- Evaluate reliability of sintered silver under thermal cyclic loading conditions
- Develop finite element analysis models that can capture the fatigue behavior of sintered silver

Approach – Mechanical Characterization

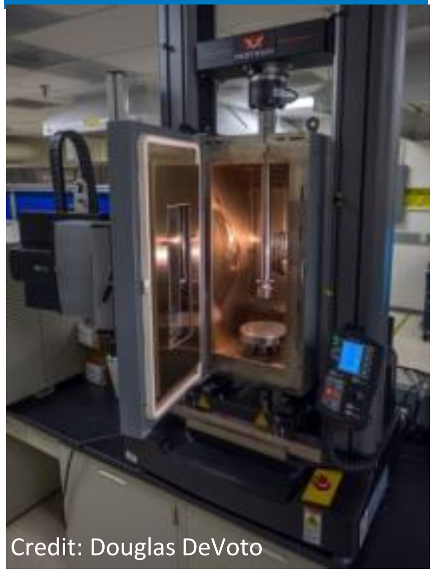


Double Lap Sample

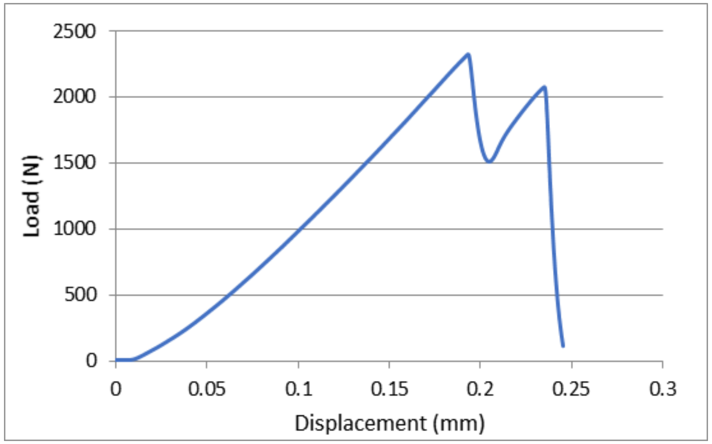




Shear Testing



- Shear testing was conducted at multiple displacement rates and temperatures
- Peak shear stress values were recorded
- Both nano-silver and hybrid/nano-micron silver were included in the study
- Impact of variation in sintering pressure was investigated on hybrid-sintered silver

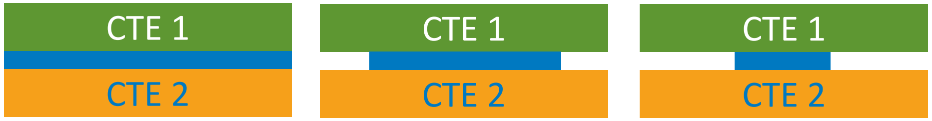


Shear Test Output

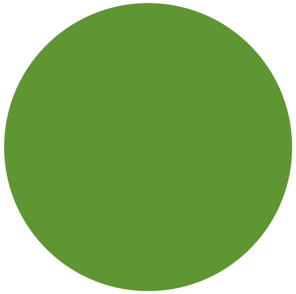
Approach – Reliability Evaluation

Copper – Invar Coupons

Side Views

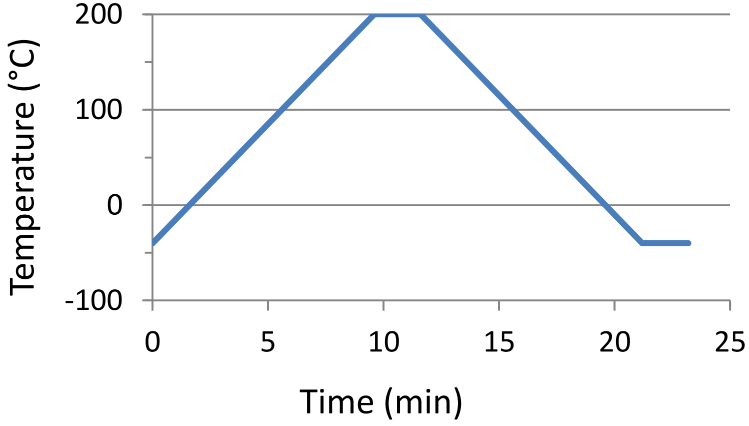


Top View



Φ 25.4 mm

Thermal load

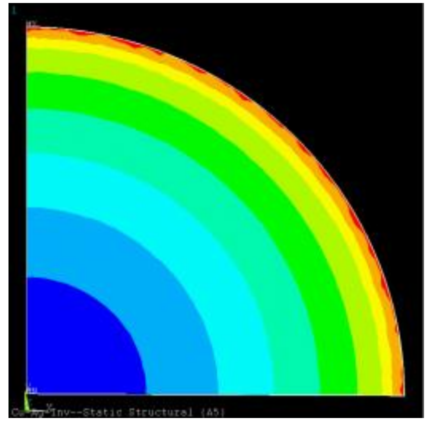


- Main output from accelerated testing would be cycles-to-failure

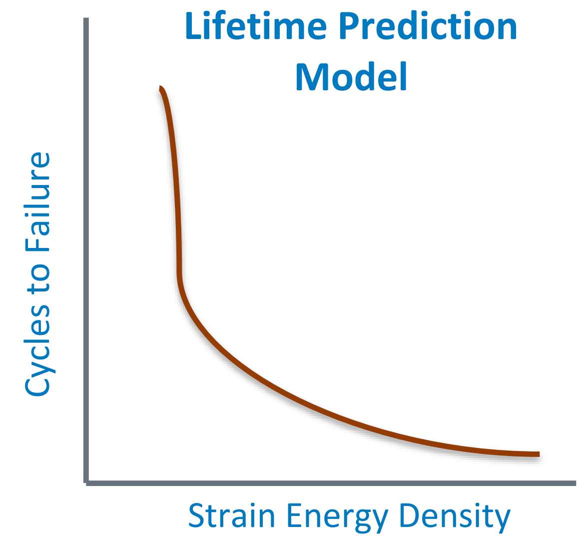
CTE – co-efficient of thermal expansion

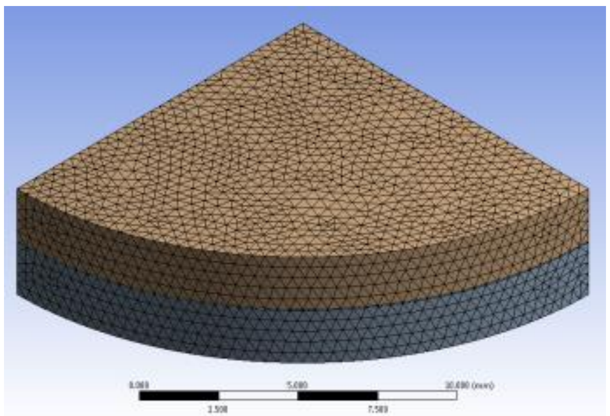
Approach – Thermomechanical Modeling

Continuum Mechanics



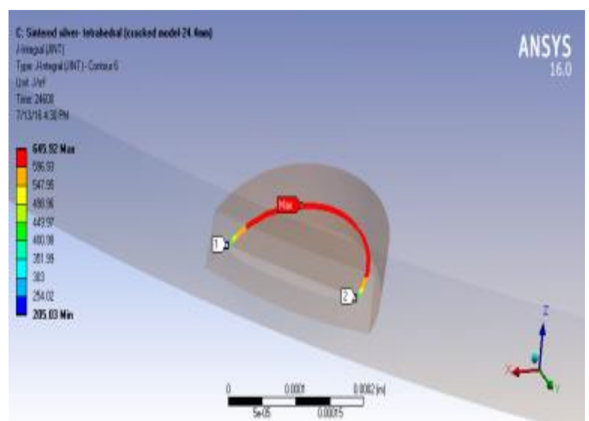
Strain Energy Density Contour Plot



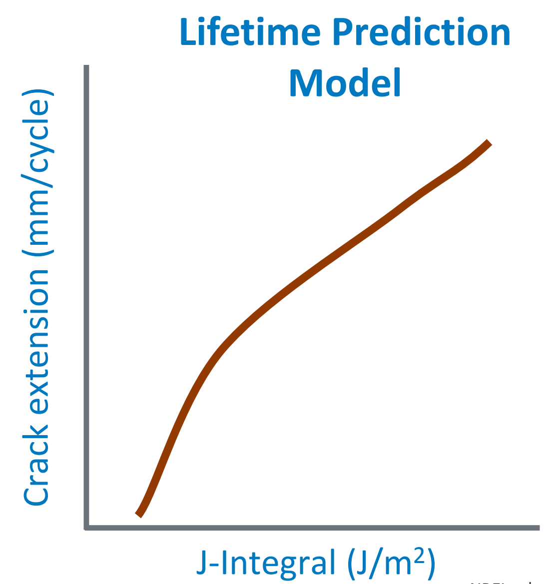


Φ 25.4-mm Sample

Fracture Mechanics



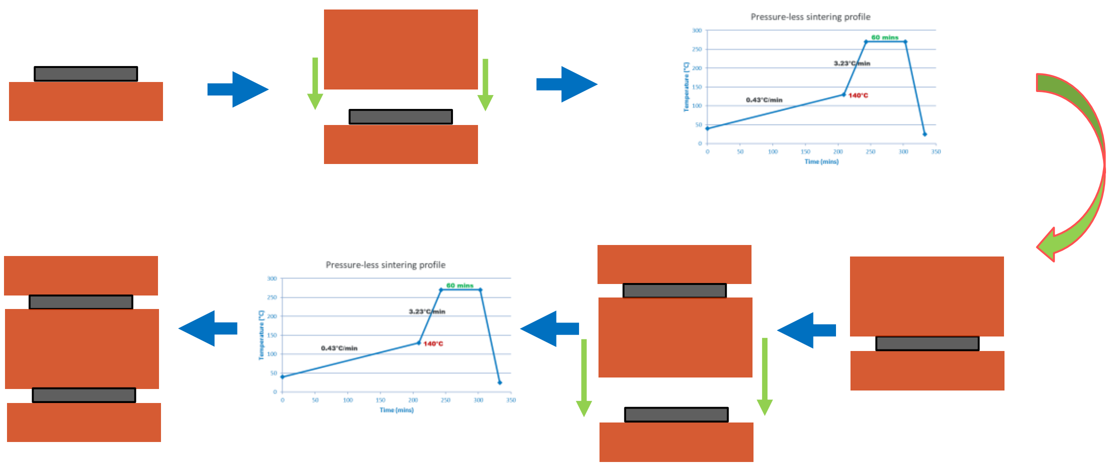
J-Integral Plot

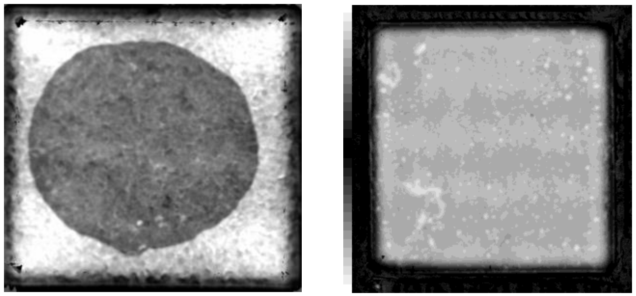


Milestones

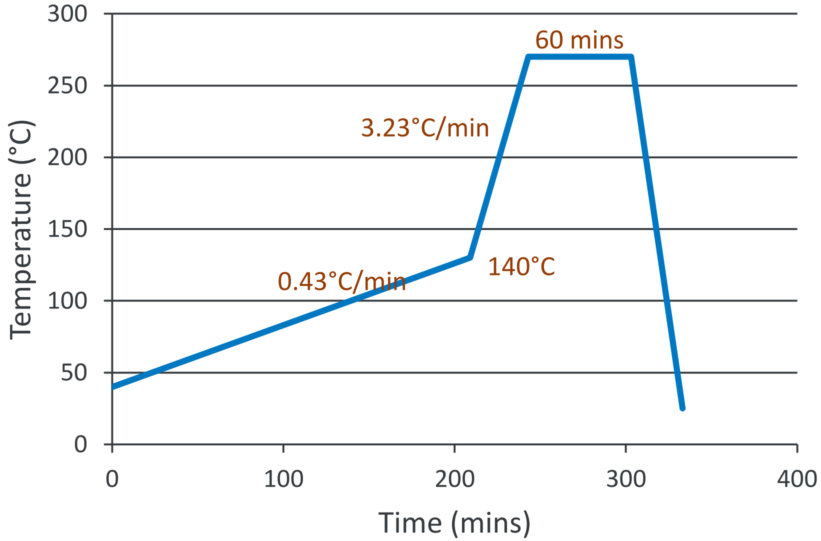
Month / Year	Description of Milestone or Go/No-Go Decision	Status
December 2017	Conduct thermomechanical modeling simulations to obtain strain energy density and J-integral values	Completed
May 2018	Complete mechanical characterization tests on double-lap samples Select a constitutive model for sintered silver from the resulting stress-strain curves **(Go/No-Go)**	Ongoing
August 2018	Conduct accelerated thermal cycling tests on round coupons to obtain cycles-to-failure **(Go/No-Go)**	Ongoing
September 2018	Formulate a lifetime predictive model correlating modeling outputs and experimental results	Ongoing
January 2019	Develop a preliminary crack propagation model of sintered silver material with the appropriate constitutive model as input	To be started
August 2019	Conduct additional accelerated tests to validate the lifetime prediction model; use these results to improve the accuracy of the lifetime prediction model	To be started

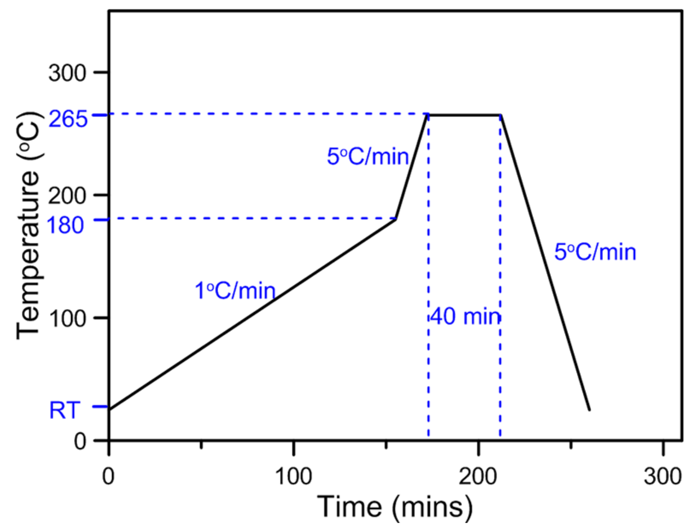
Synthesis of double-lap samples





C-mode scanning acoustic microscope (C-SAM) images of sintered silver bond regions in double-lap samples





Sintering profiles of nano-silver (left) and hybrid-silver (right)

Technical Accomplishments and Progress

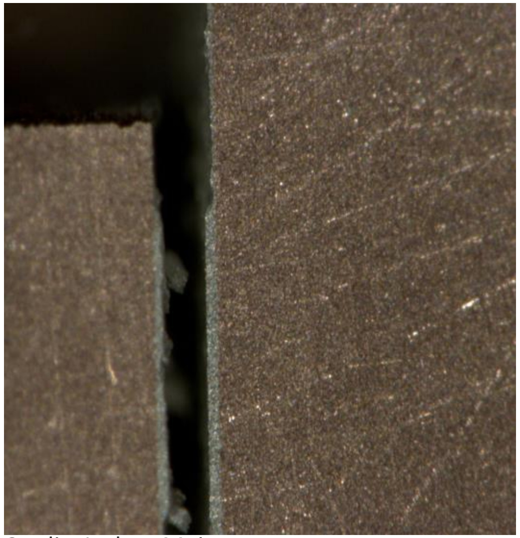
Observation of Failure Mechanism – Nano-silver

Credit: Paul Paret

Cross-section view

Credit: Joshua Major

Interface before failure



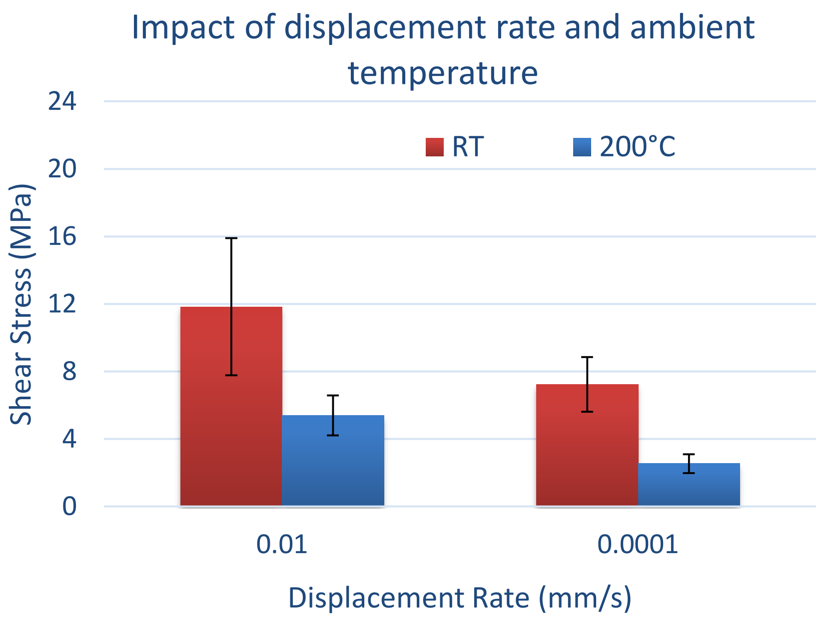
Credit: Joshua Major

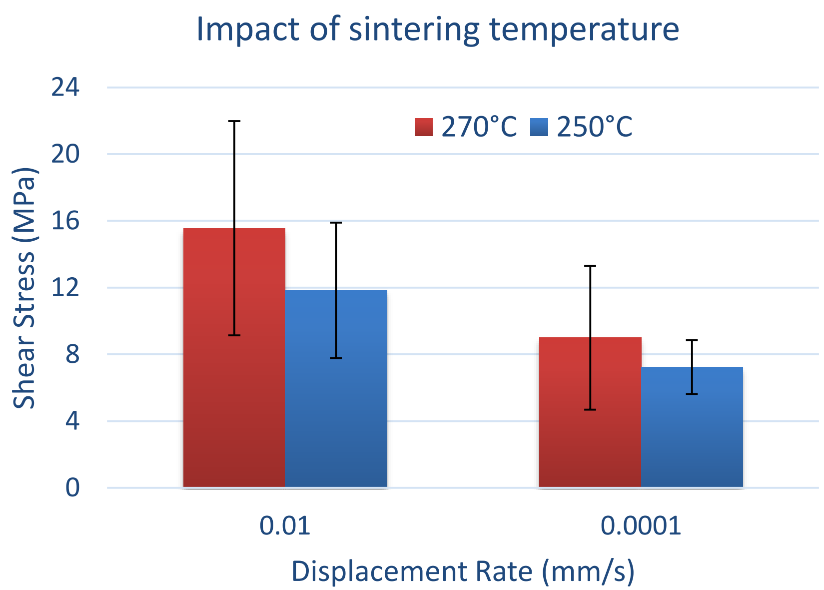
Cohesive fracture

- A few double-lap samples were cross-sectioned and subjected to shear test
- A digital microscope took images of the sintered silver interface
- Cohesive fracture mechanism was observed to be the failure mechanism

Technical Accomplishments and Progress

Shear Stress Results – Nano-silver



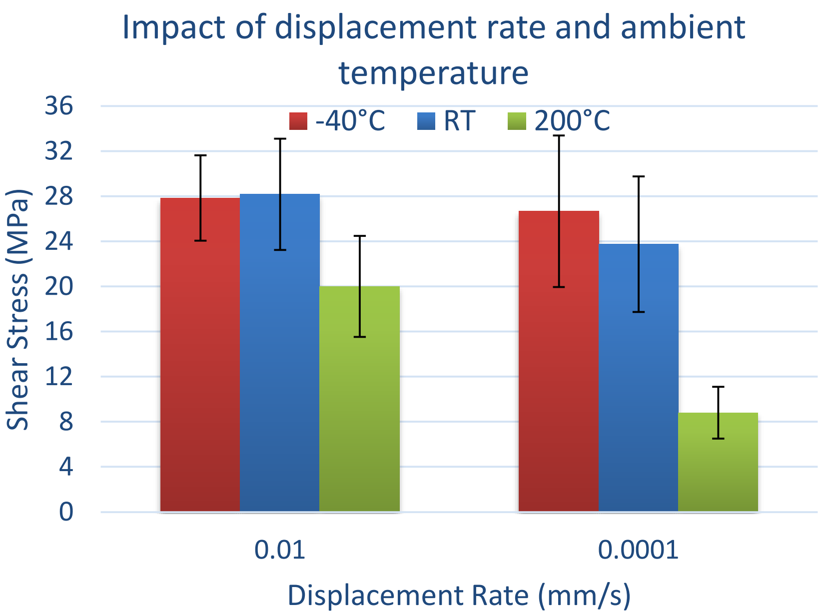


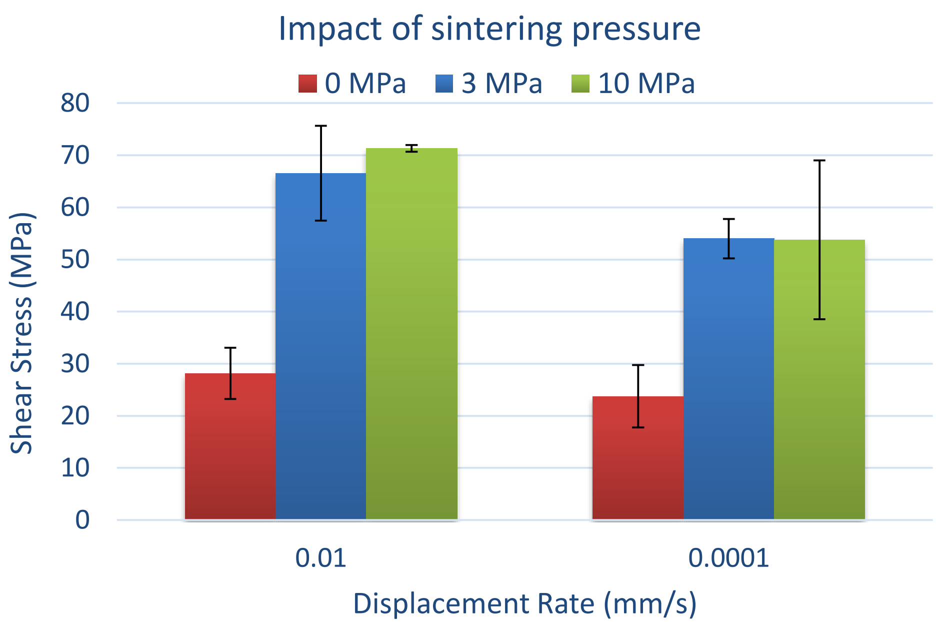
- Shear stress values drop with rise in ambient temperature, possibly due to creep strain
- Lower displacement rates allow more time, causing the defects to grow thereby weakening the sintered silver microstructure
- A rise in sintering temperature from 250°C to 270°C resulted in slight improvement in shear stress values

RT – room temperature

Technical Accomplishments and Progress

Shear Stress Results – Hybrid-silver



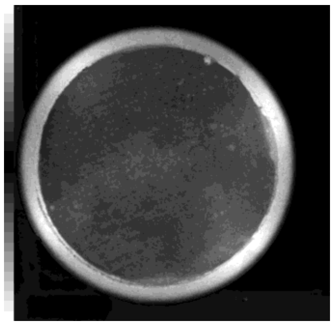


- No significant difference in the shear stress results between -40°C and room temperature
- Rate dependence is strong at elevated temperatures (200°C)
- Pressure-assisted sintering results in a denser bond with low porosity; results in high shear strength
- Between 3 MPa and 10 MPa of sintering pressure, shear stress variation was relatively insignificant

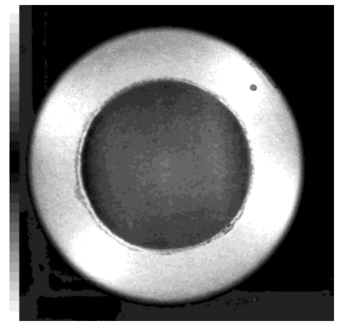
Technical Accomplishments and Progress

Reliability Evaluation – Hybrid-silver

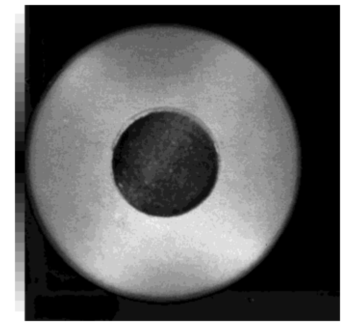
3 MPa sintering pressure



22 mm

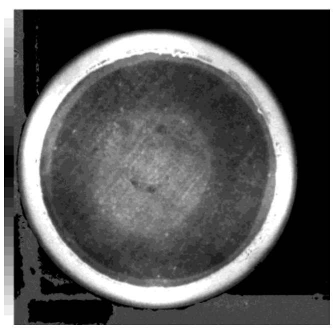


16 mm

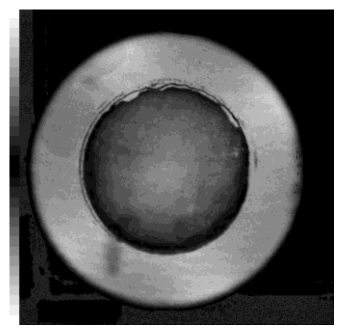


10 mm

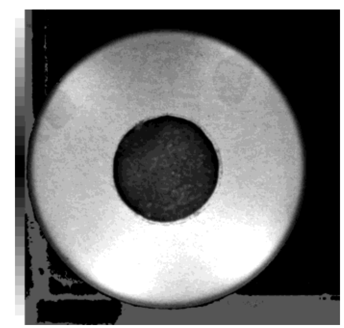
10 MPa sintering pressure



22 mm



16 mm

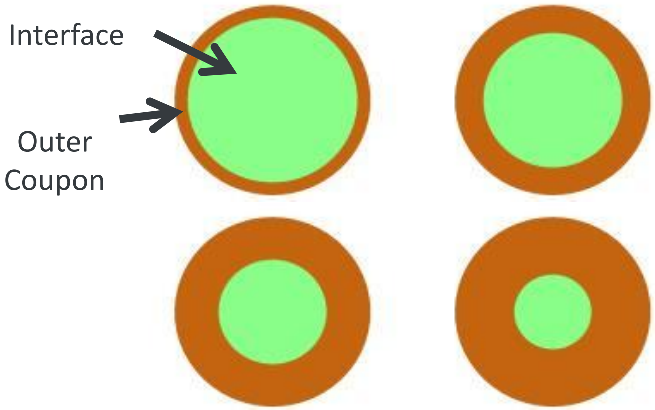


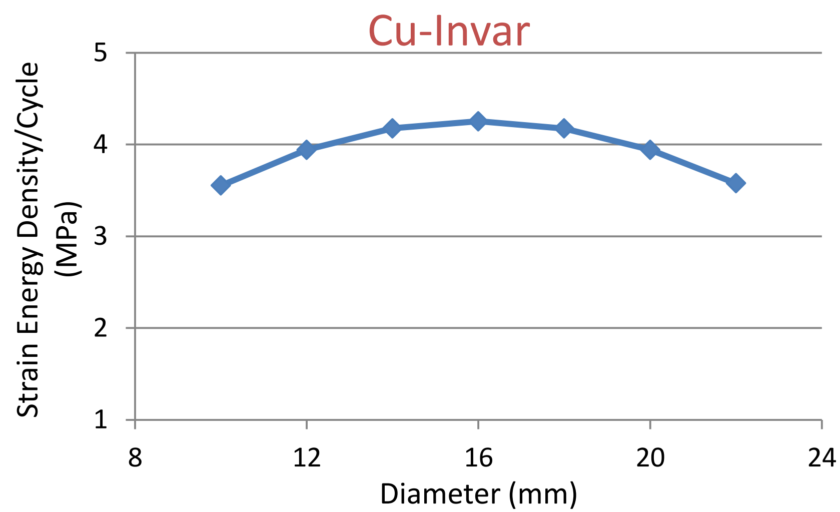
10 mm

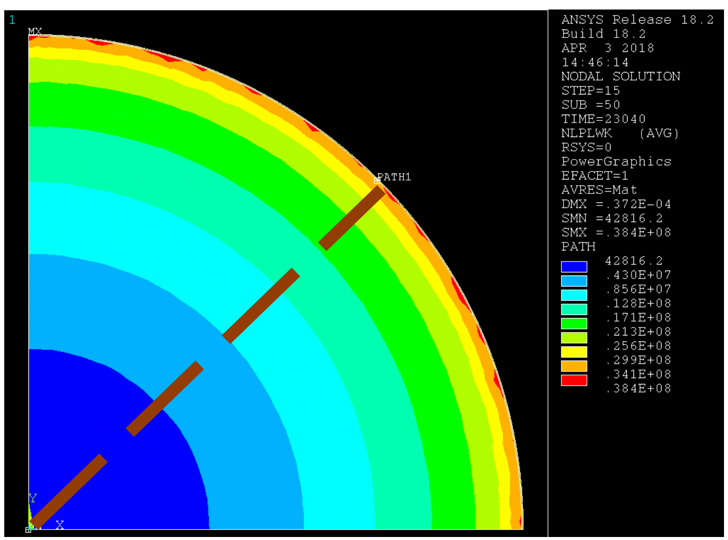
C-SAM images of pressure-assisted hybrid-sintered silver samples at zero cycles

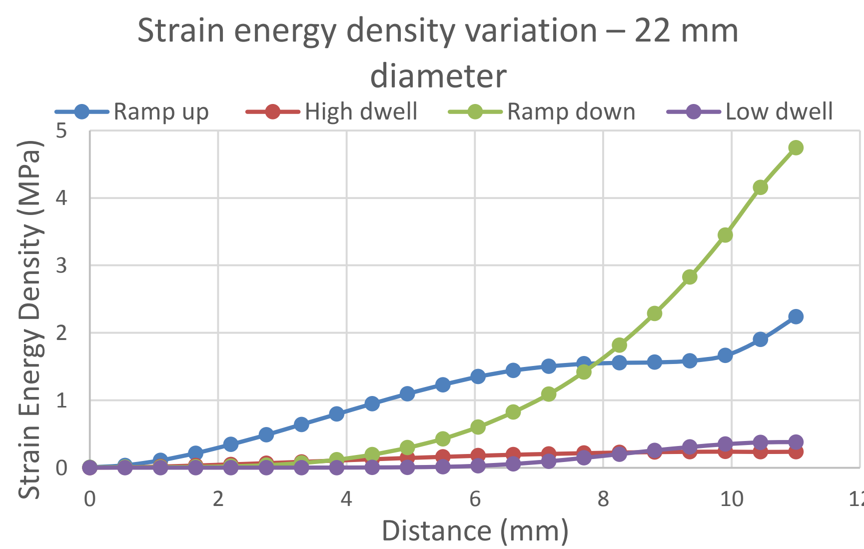
Technical Accomplishments and Progress

Strain Energy Density Results









Responses to Previous Year Reviewers' Comments

The reviewer commented that Anand viscoplastic and other material models were used in the study to simulate sintered silver layer

Simulation results to date are based on the Anand viscoplastic model only. Mechanical characterization results will be used to develop other material model parameters

The reviewer pointed to correlating the reliability aspects of the sintered silver joint with its porosity

Sintered silver samples manufactured using 3 MPa and 10 MPa of sintering pressure will be subjected to thermal cycling. Investigating the reliability of samples made using different sintering pressures will provide insights into the effects of porosity on thermomechanical fatigue

Collaboration and Coordination with Other Institutions

- Virginia Tech: technical partner on the synthesis of sintered-silver samples

- ORNL : technical guidance

- Private industries in power electronics

Remaining Challenges and Barriers

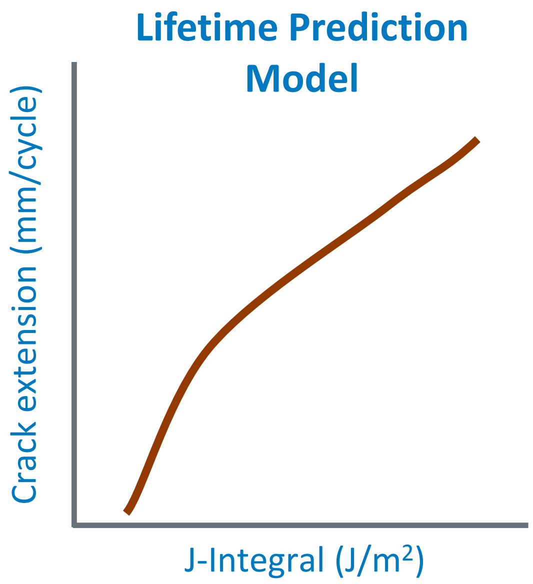
- Existence of a correlation between shear strength and reliability of sintered silver may be uncertain
- Developing void-free round large-area bonded coupons for reliability evaluation with pressure-less sintering process is not trivial
- The suitability of modeling parameters such as strain energy density and J-integral for accurately predicting the lifetime of sintered silver joints needs to be validated

Proposed Future Research – FY18

- Complete accelerated thermal cycling test on sintered silver until failure

- Develop a lifetime prediction model correlating modeling outputs with experimental results

- Validate the thermomechanical model with experimental results; make changes to the model to improve its accuracy



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

Proposed Future Research – FY19

- Submit a journal paper capturing the various findings of the project, including both modeling results and experimental data

- Investigate the reliability of other high-temperature bonded interface materials
  - Cu – Al , Cu – Sn alloys

- Initiate a multiscale modeling approach to predict failure due to fatigue in high-temperature bonded interface materials

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

Summary

- DOE Mission Support
  - Sintered silver is a promising material 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
  - Conducted mechanical characterization tests and studied the impact of microstructure, ambient temperature, displacement rate, sintering temperature, and sintering pressure on the shear strength of sintered silver
  - Conducted thermomechanical simulations, and obtained strain energy density/cycle and J-integral/cycle results
  - Synthesized round CTE-mismatched coupons for reliability evaluation of sintered silver
- Collaborations
  - Virginia Tech
  - ORNL
  - Power electronics industry partners

Acknowledgments

Susan Rogers, U.S. Department of Energy

EDT Task Leader

Sreekant Narumanchi
Sreekant.Narumanchi@nrel.gov

Phone: (303)-275-4062

Team Members

Douglas DeVoto (NREL)
Joshua Major (NREL)

For more information, contact

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

Thank You

www.nrel.gov