Performance and Reliability of Bonded Interfaces for High-Temperature Packaging

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Overview

Timeline

- Project start date: FY17
- Project end date: FY19
- Percent complete: 20%

Budget

- Total project funding
  - DOE Share: $492K
- Funding for FY 2017: $492K

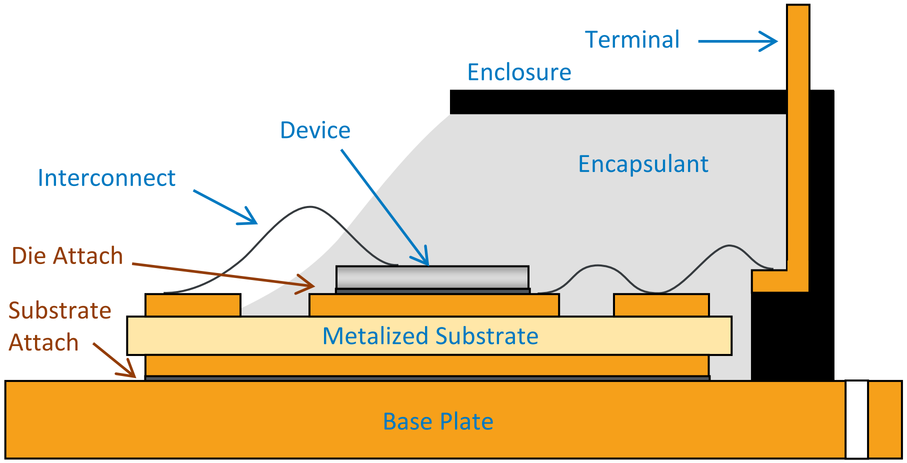
Barriers

- Cost
- Size and Weight
- Performance and Lifetime

Partners

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

Relevance



Traditional Power Electronics Package

Maximum operating temperature – 150 ° C

Cree Wide Bandgap Device Package

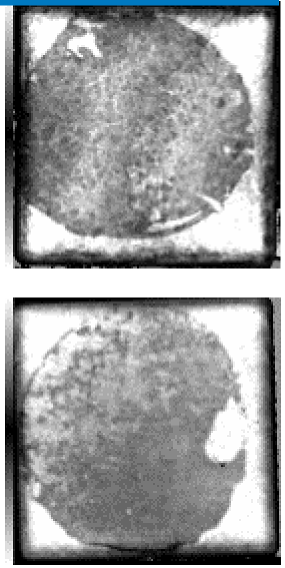
Crack Propagation in Sintered-Silver

Approach

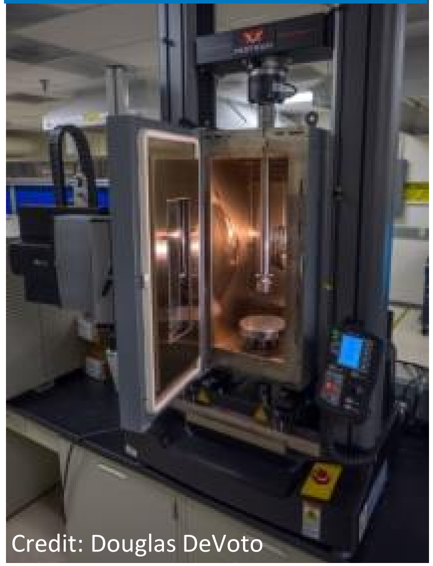
- Conduct a mechanical characterization study (stress versus strain relationship) of sintered-silver
- Evaluate reliability of sintered-silver under thermal cyclic loading conditions
- Develop finite element analysis (FEA) models that can capture the fatigue behavior of sintered-silver

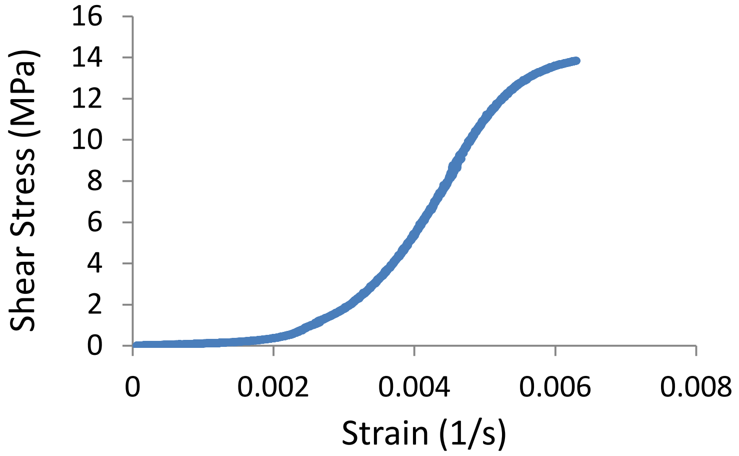
Approach – Mechanical Characterization

Double Lap Sample



Shear Testing



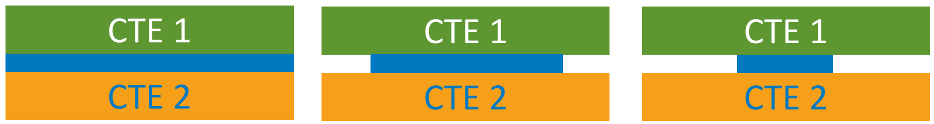


- Impact of synthesis pressure will be investigated
- Output is a constitutive model
  - Anand viscoplastic model
  - Ohno Wang – Armstrong-Frederick model
  - Abdel Karim – Ohno model

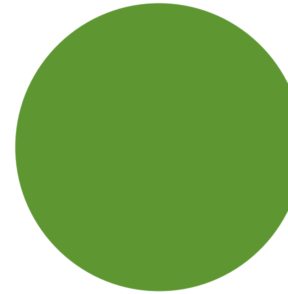
Approach – Reliability Evaluation

Copper – Invar Coupons

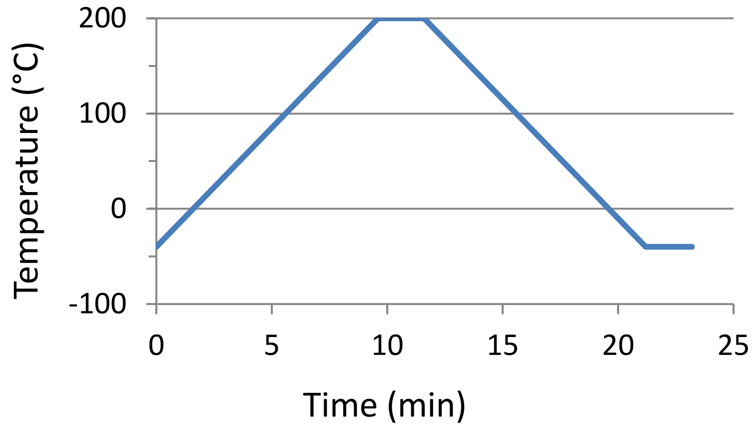
Side Views



Top View



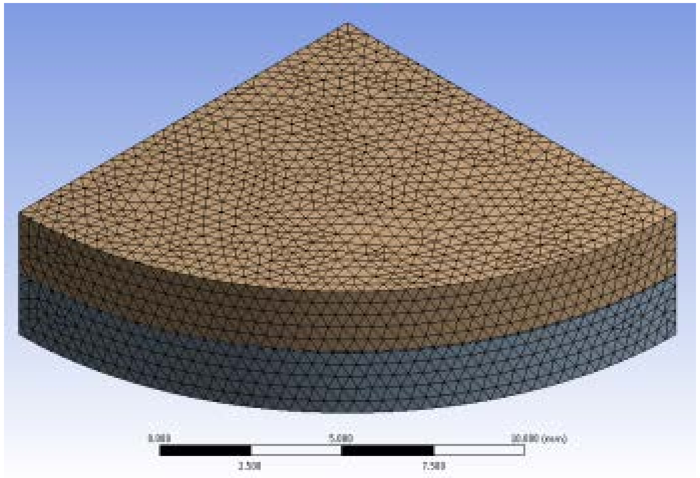
Φ 25.4 mm



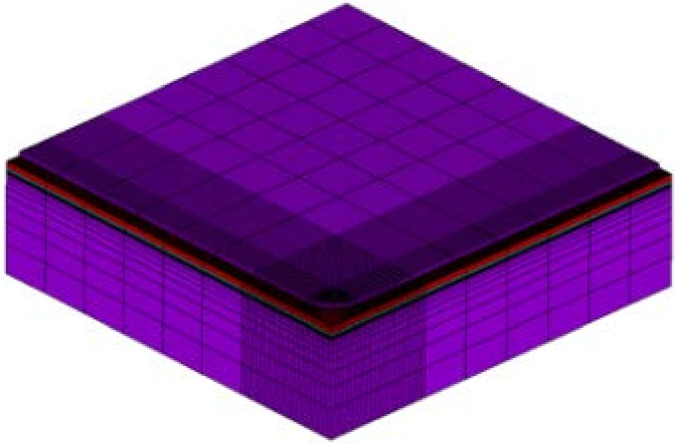
- Main output from accelerated testing would be cycles-to-failure

**CTE – co-efficient of thermal expansion*

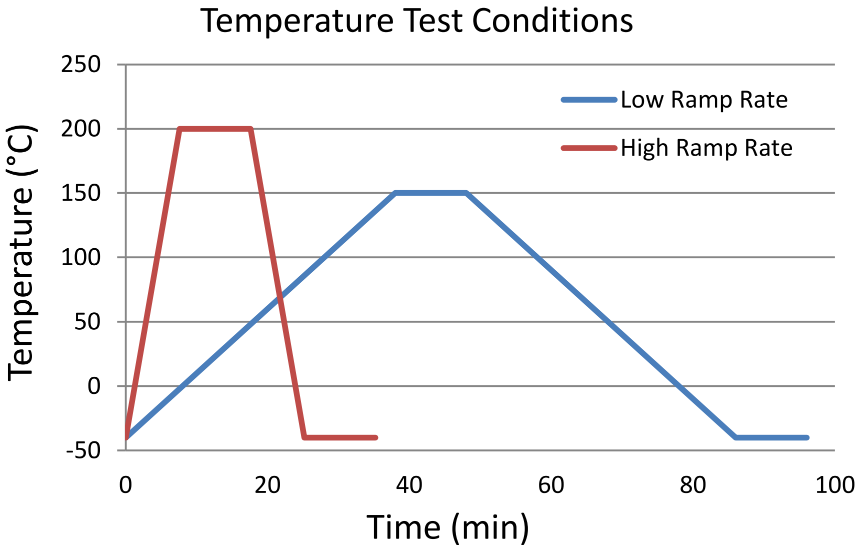
Approach – Thermomechanical Modeling



Φ 25.4-mm Sample



50 x 50-mm Sample

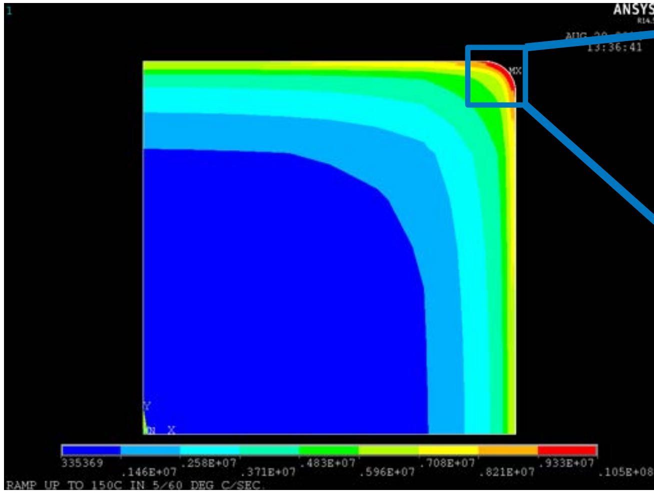


- Anand viscoplastic material model applied to sintered-silver layer
- Outputs
  - Strain energy density/cycle (MPa)
  - J-integral/cycle (J/m^2)

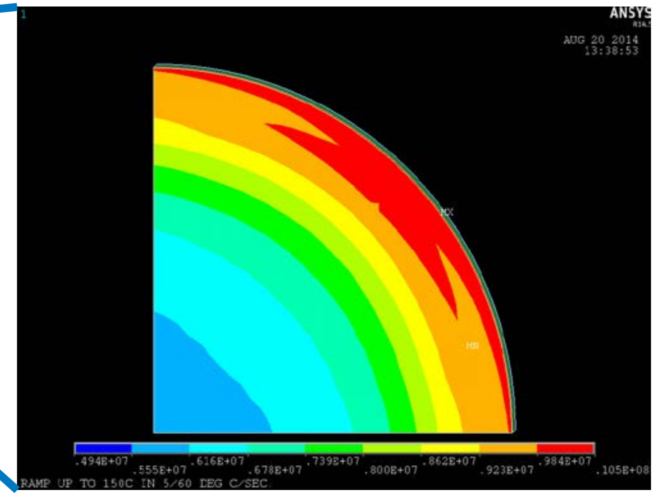
Milestones

Month / Year	Description of Milestone or Go/No-Go Decision	Status
December, 2016	Conduct thermomechanical modeling simulations to obtain strain energy density and J-integral values	Completed
May, 2017	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
September, 2017	Develop a preliminary crack propagation model of sintered-silver material with the appropriate constitutive model as input	Ongoing
December, 2018	Conduct accelerated thermal cycling tests on round coupons to obtain cycles-to-failure **(Go/No-Go)**	To be started
April, 2018	Formulate a lifetime predictive model correlating modeling outputs and experimental results	To be started
August, 2018	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

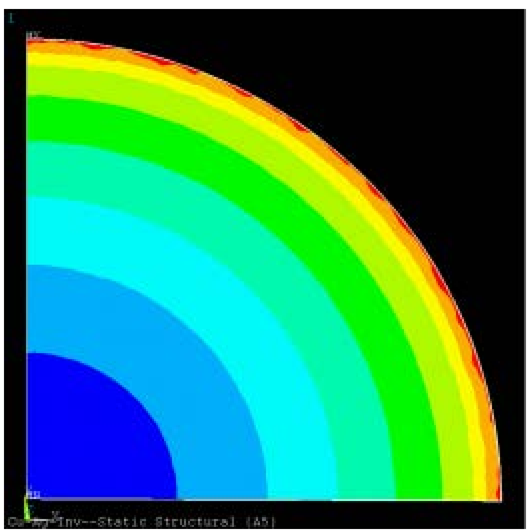
Approach – Strain Energy Density Calculation



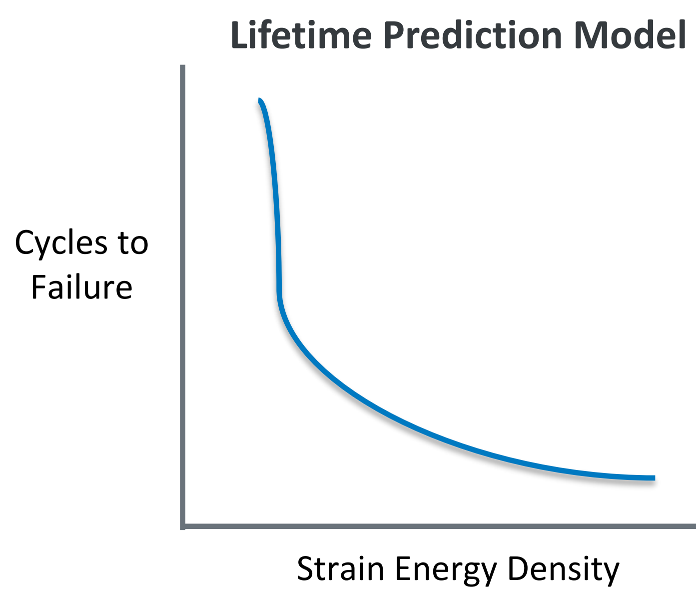
Strain Energy Density Contour Plot
– 50 x 50 mm



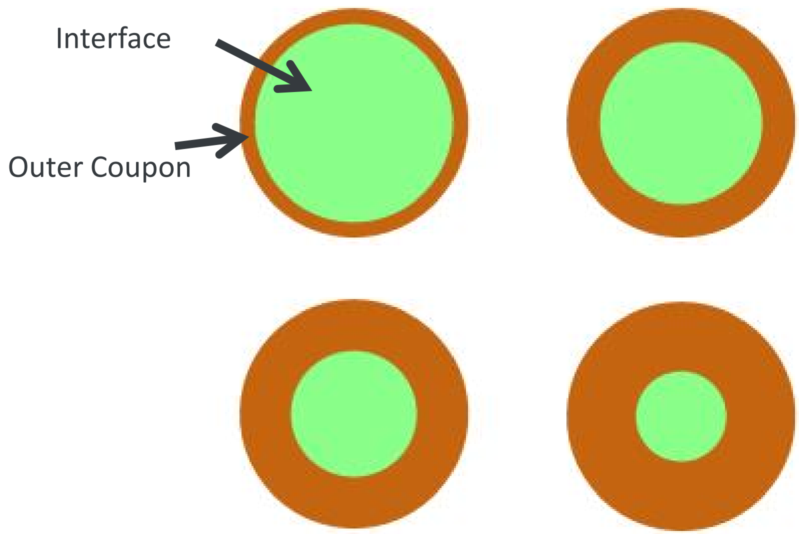
Corner Fillet Region



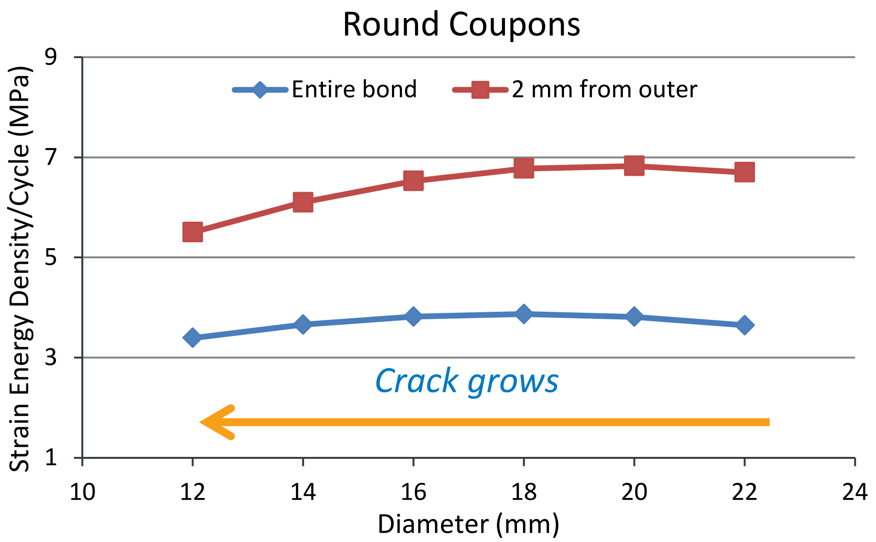
Strain Energy Density Contour Plot
- Round Coupons

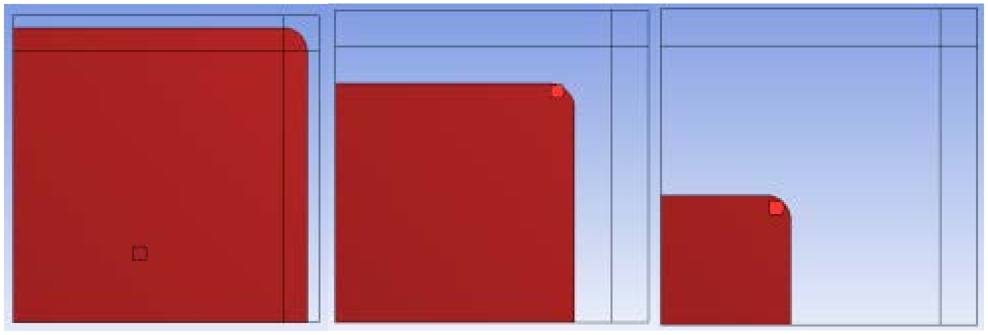


Accomplishments – Strain Energy Density Results

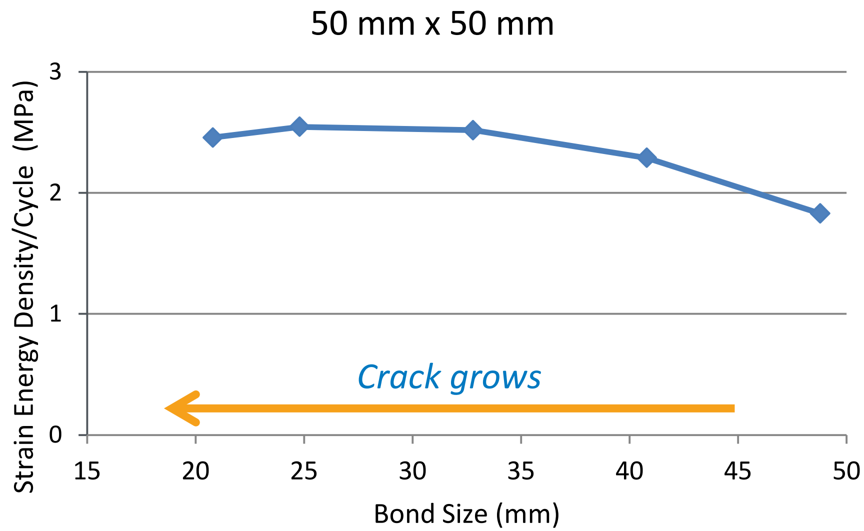


Copper- Invar Models

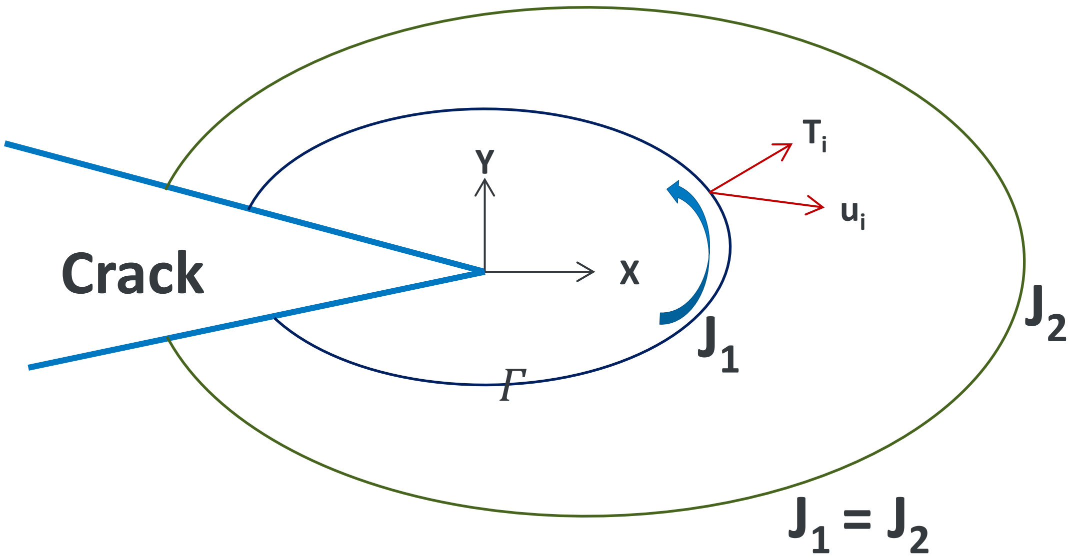




Sintered-Silver Interface Variation



Approach – J-Integral Calculation



$$J = \int_{\Gamma} W.\,dy - T_i.\left(\frac{\partial u_i}{\partial x}\right).\,ds$$

W – strain energy density

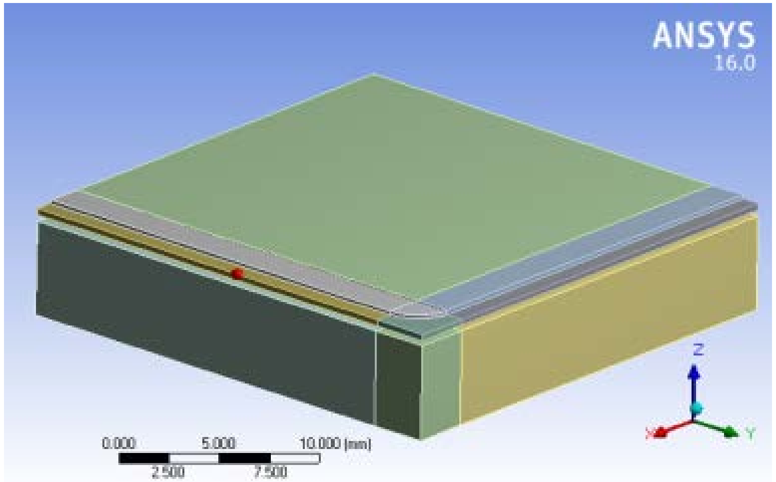
T_i – traction vector

u_i – displacement vector

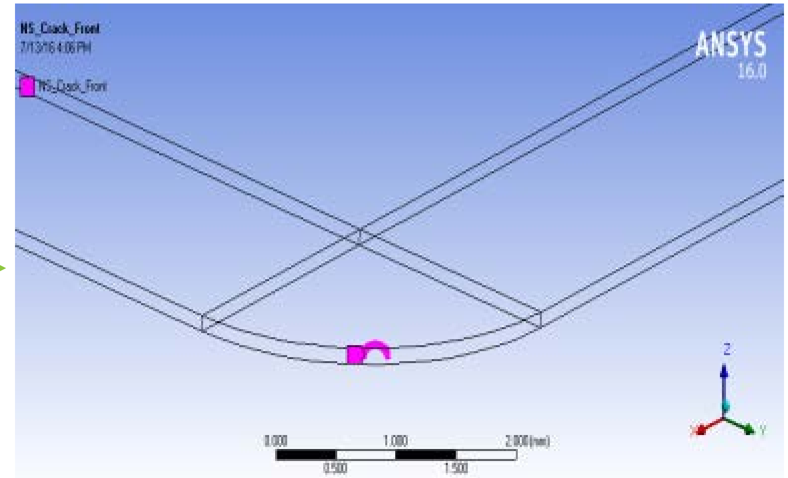
Characteristics of J-integral

- Represents the energy release rate for a unit crack growth
- Path-independent around the crack tip (2-D) or crack front (3-D)

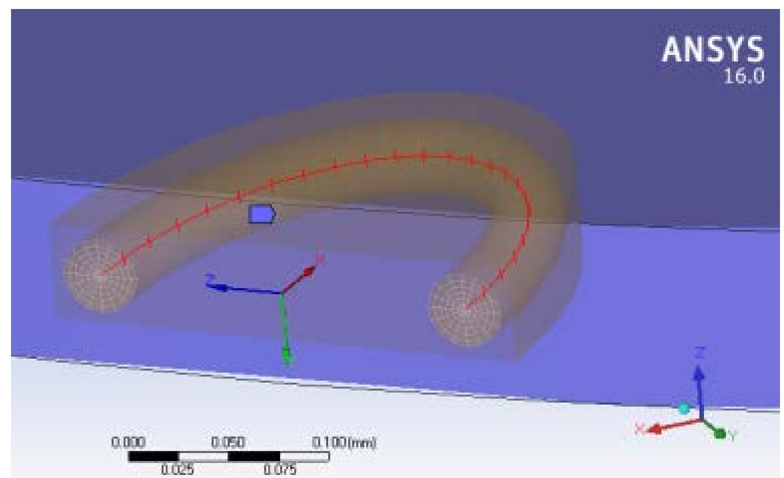
Accomplishments – J-Integral Modeling Methodology



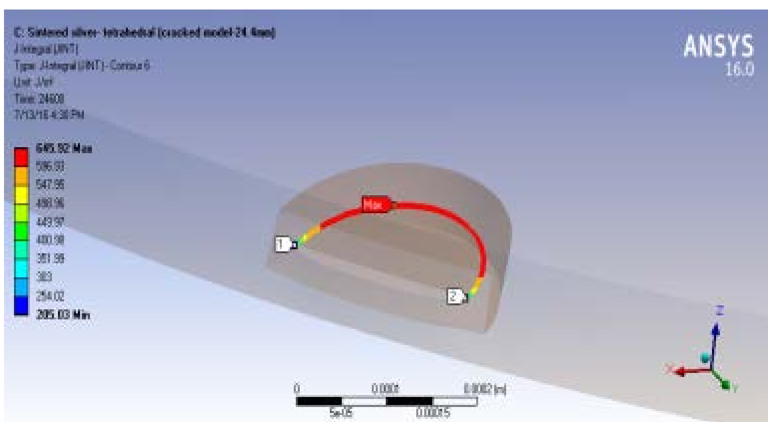
50 x 50-mm Model



Insertion of Crack Front

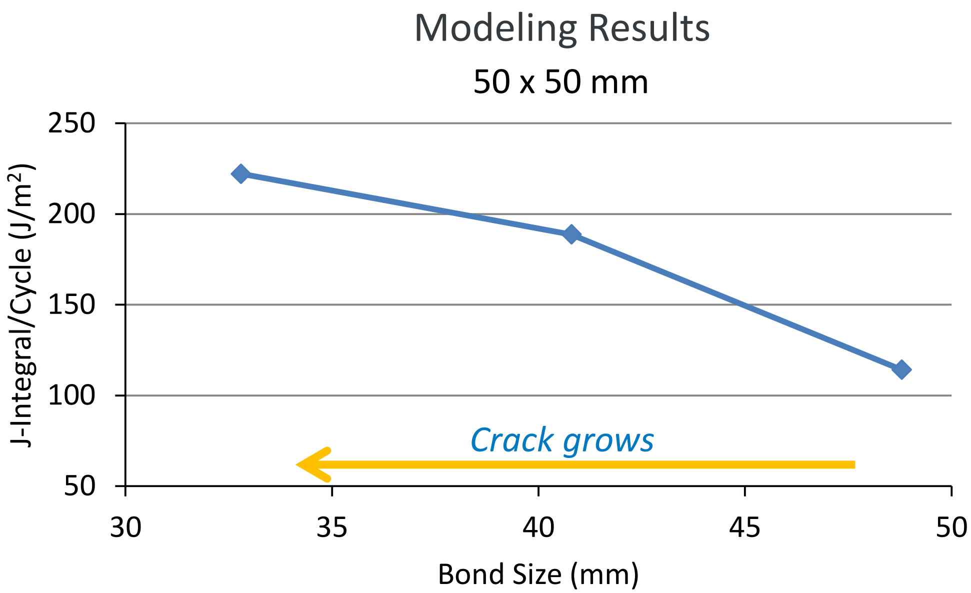


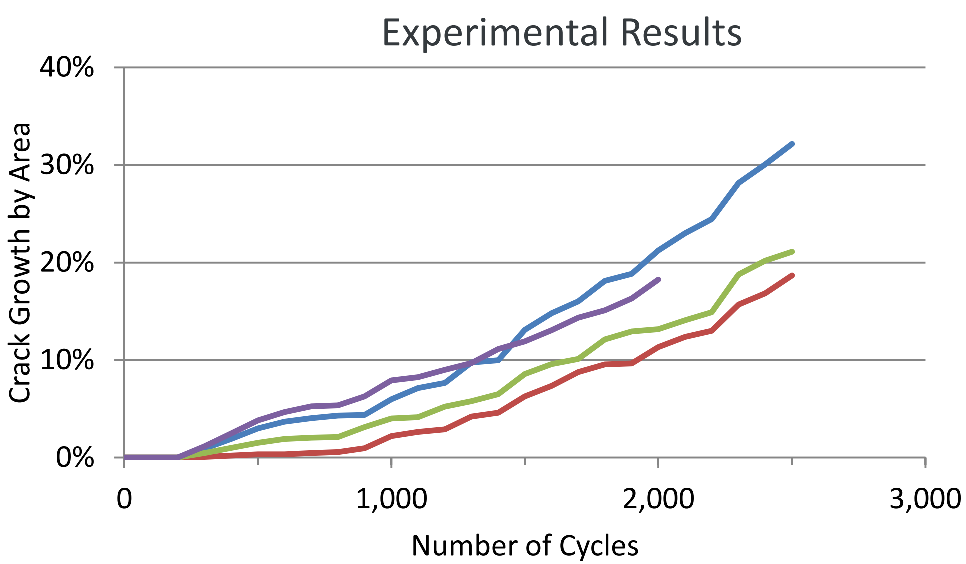
Crack Front Discretization

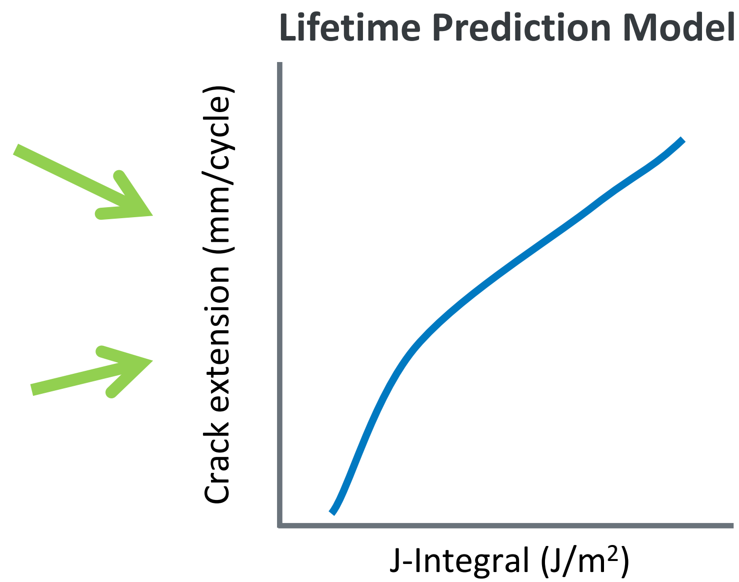


J-Integral Plot

Accomplishments – J-Integral Results







Response to Previous Year Reviewers' Comments

"This project is new for FY 2017, but relevant reviewer comments are provided below for the prior project"

This reviewer acknowledged the methods are good but do not appear to be covering the characterization at the 200°C goal. The 175°C data point is also useful, but does not reach the 200°C or greater goals

Thermal cycling profile has been modified to include the 200°C data point

The reviewer requested that the team evaluate if Anand's model is sufficient for the conditions being investigated and if not to refer to literature to determine other models that are more relevant

Mechanical characterization tests are being conducted and, in addition to Anand's model, other constitutive models will be investigated

Collaboration and Coordination with Other Institutions

- Virginia Tech: technical partner on the synthesis of sintered-silver samples
- Kyocera: material and technical guidance
- ORNL : technical guidance

Remaining Challenges and Barriers

- Not all sintered-silver samples for testing may meet the minimum shear strength requirements; optimal synthesis profiles and processing conditions must be strictly followed across the entire sample set

- 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

- Developing crack propagation models with appropriate constitutive models as input is not trivial

Proposed Future Research – FY17

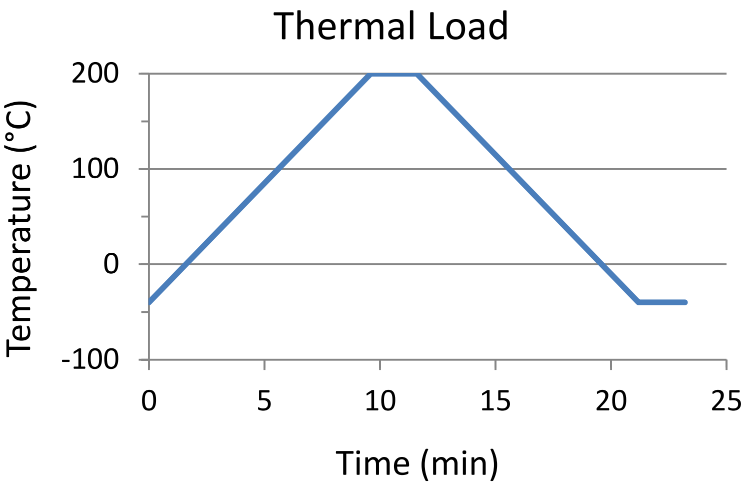
- Synthesize additional samples for mechanical characterization of sintered-silver
  - Develop appropriate constitutive model parameters for sintered-silver

- Complete synthesis of sintered-silver round samples for accelerated testing.
  - -40°C to 200°C, thermal cycle

- Develop a preliminary crack propagation model using X-FEM (Extended Finite Element Method) to simulate crack growth behavior in sintered-silver

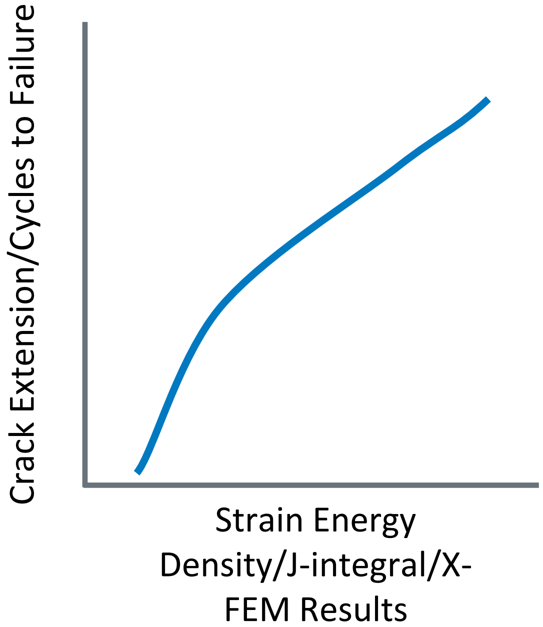
"Any proposed future work is subject to change based on funding levels"

Shear Test Fixture and Sample



Proposed Future Research – FY18

- Complete thermal cycling test on sintered-silver until failure
  - Develop a lifetime prediction model correlating modeling outputs with experimental results
- Validate the crack propagation model with experimental results; make changes to the model to improve its accuracy
- Submit a journal paper 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"

Summary

- DOE Mission Support:
  - Sintered-silver is a promising material for enabling low-cost, lightweight, and reliable power electronics package that can operate at high temperatures
- Approach:
  - Synthesis of sintered-silver bonds, mechanical characterization, reliability evaluation, thermomechanical modeling, and lifetime prediction models
- Accomplishments:
  - Conducted thermomechanical simulations, and obtained strain energy density/cycle and J-integral/cycle results
- Collaborations:
  - Virginia Tech
  - Kyocera
  - ORNL

NATIONAL RENEWABLE ENERGY LABORATORY

Acknowledgments

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