# Solder Joints of Power Electronics

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**June 10, 2010**

Project ID # pm015

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U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

# Overview

## Timeline

- Project start: June 2007
- Project end: September 2010
- Percent complete: 70%

## Budget

- Total project funding Received
  - DOE 100%
- Funding Received in FY09: $150k
- Funding for FY10: $150k

## Barriers

- Barriers addressed include increasing the specific power, improving the volumetric power, extending reliability, and improving thermal management, while reducing cost of power electronics systems
  - Higher coolant temperatures (105$^{o}$C)
  - Lifetime
- Targets Addressed
  - Operational Lifetime of 15 years

## Partners

- Lead: ORNL

Collaborators/Interactions

- Powerex – manufacturer of power modules
- SemiSouth-manufacturer of SiC devices
- Ford Motor Company

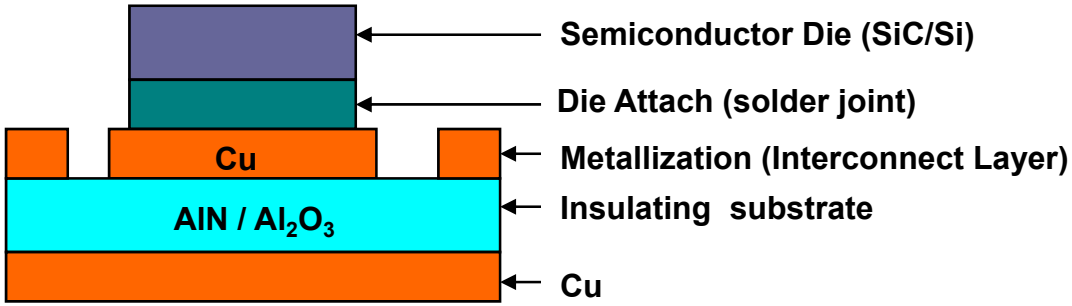
# Relevance

- Increase in coolant temperatures will increase junction temperatures
- Use of wide bandgap devices will increase specific power and volumetric power but needs tolerance of higher temperatures
- Solder die attaches should have the required electrical, thermal and mechanical properties over the lifetime of the product
- Increase in temperatures can accelerate degradation of solder joint properties
- Objectives: To develop an understanding of the following on die attach properties
  - Higher temperature steady state operation (200$^{o}$C with SiC vs current 125$^{o}$C), and
  - Thermal cycling reliability when subjected to 200$^{o}$C operation
- To understand the effect of solder joint composition and microstructure on the above properties

# Milestones

- Complete study of steady state exposure of Au-Sn joints and Sn-3.5Ag joints at 200°C for times up to 3000 hours and evaluate joint degradation
- Continue thermal cycling tests on Sn-3.5Ag joints to follow void growth and property degradation for up to 3000 cycles
- Study the effect of thermal cycling on SAC405 and follow void growth
- Evaluate effect of replacing Si die with SiC die on joints prepared with Au-Sn solder

# Approach

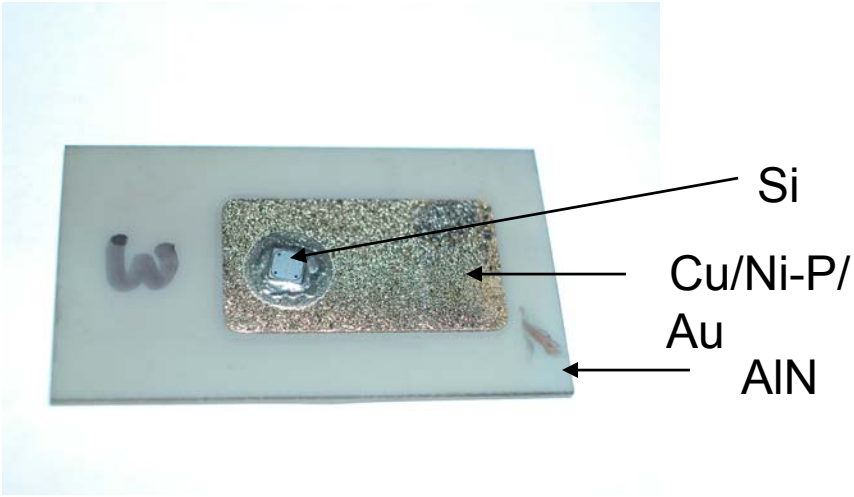


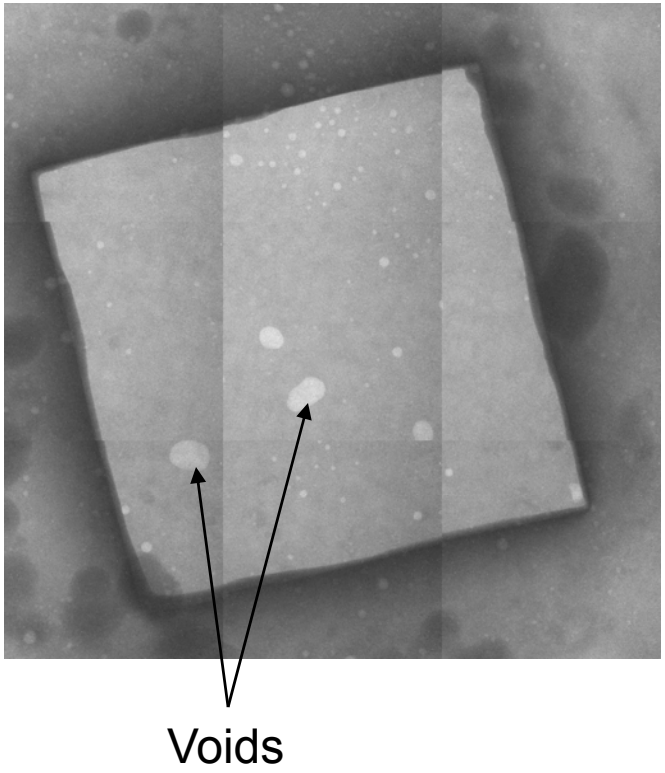

- Simple solder joints will be fabricated with selected solder compositions
- Effect of steady-state exposure to 200°C on microstructure, and strengths of solder joints will be measured as a function of time
- Effect of thermal cycling on degradation of joints will be evaluated using thermal cycling from -65°C to 200°C
- Joints will be fabricated with several solder candidates and tested to develop knowledge relating degradation to solder composition and microstructure
- Knowledge will be used to guide future design/selection of appropriate solder joint composition based on composition-property evaluations

# Technical Accomplishments/ Progress/Results: Solder Joint Design and Processing

- Three solder compositions have been studied
  - 80Au-20Sn ($T_m$=280°C)
  - Sn-3.5Ag ($T_m$=221°C)
  - Sn-4.0Ag-0.5Cu ($T_m$= 217°C)
- Criteria for selection
  - Pb-free
  - Highest melting temperatures to allow 200°C operation and temperature excursion
- In collaboration with Powerex,
  - Solder joints were prepared between AlN DBC with Cu/Ni(P)/Au and Si resistor die with Ti/Ni/Au metallization
  - Solder joints were also prepared between AlN DBC with Cu/Ni(P)/Au and SiC die

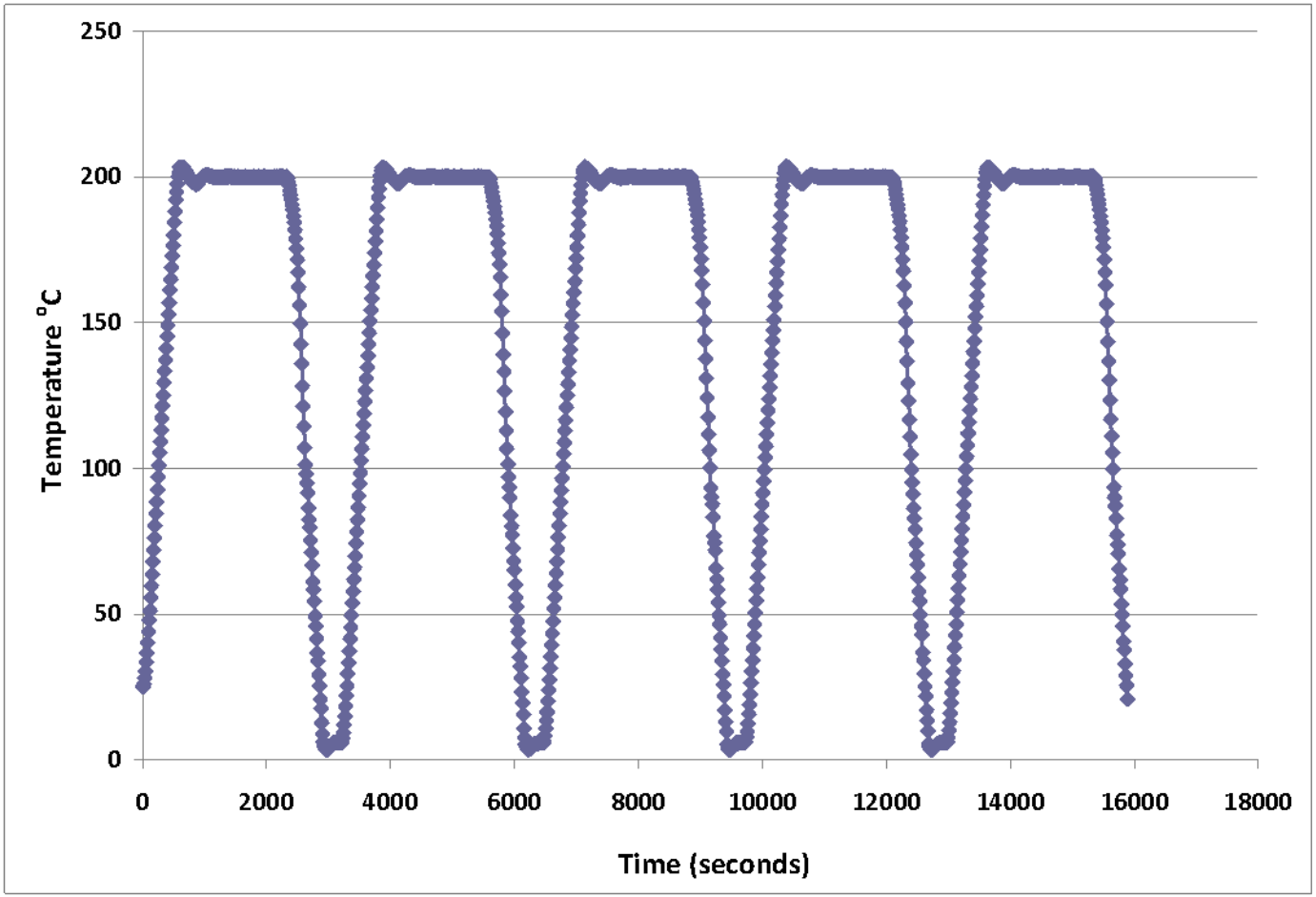
# Typical Image and High Resolution X-ray Radiograph of Processed Au-Sn Solder Joint



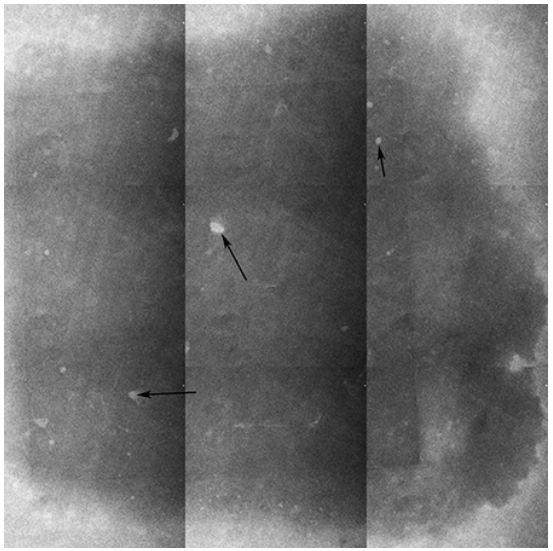

Chip size: 2.5 mm x 2.5mm, Bondline thickness ~ 75 μm

# Thermal Cycling Conditions Used in the Study

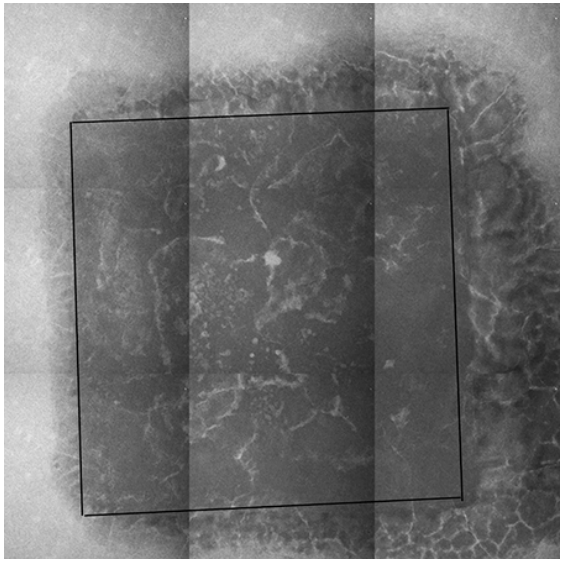



- Ramp 5°C to 200°C, 30 min hold at 200°C, 5 min hold at 5°C
- Simulates 30 minutes of uninterrupted operation

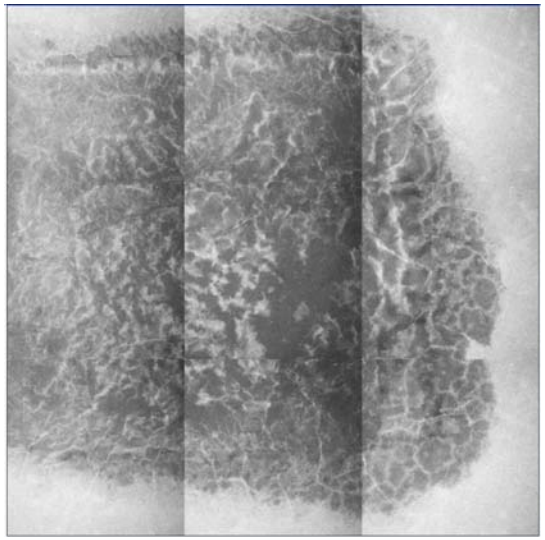
# Effect of Thermal Cycling on Damage Accumulation in Sn-3.5Ag Joints



As processed



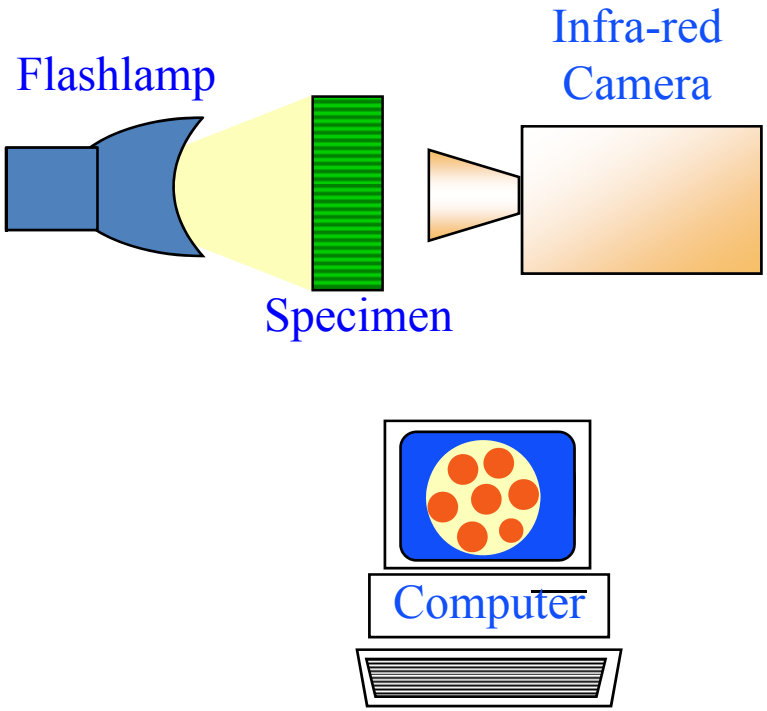
1102 Cycles

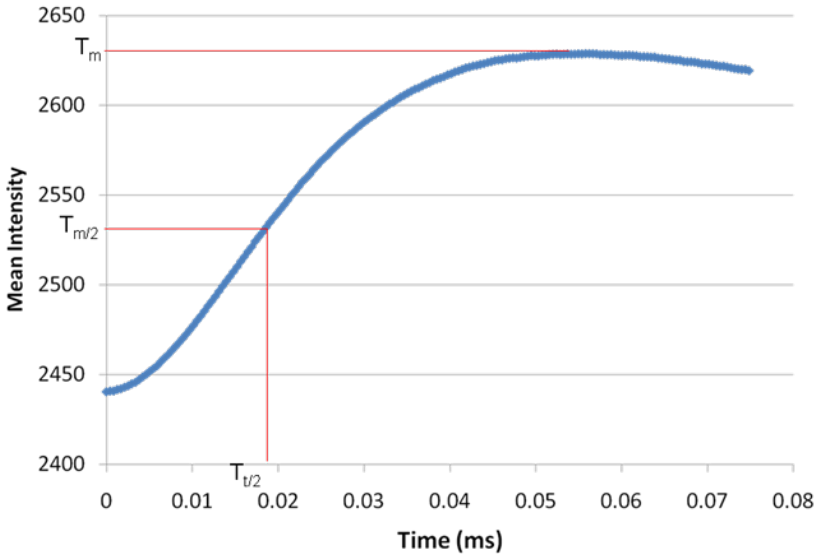


3000 Cycles

Thermal cycling of Sn-3.5Ag joints show significant damage accumulation in 3000 cycles

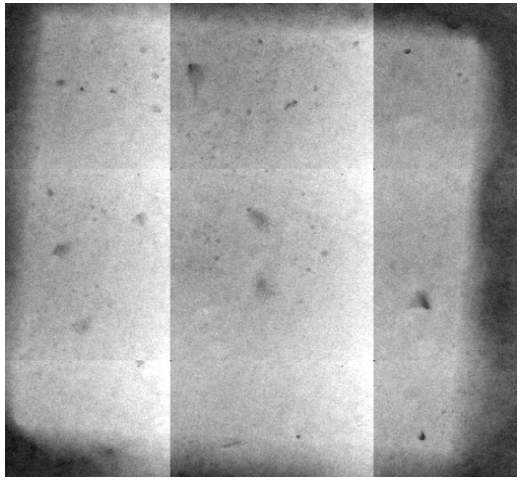
# Infrared Techniques were Used to Quantify Changes in Thermal Diffusivity

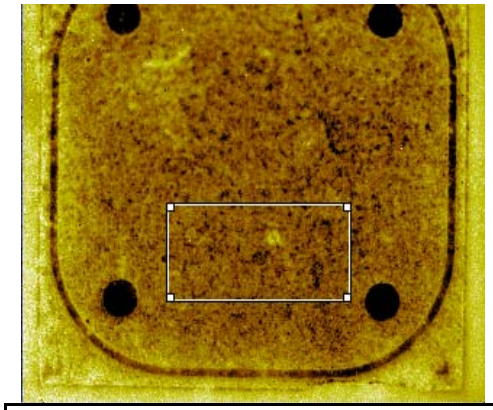


# Significant Reduction in Thermal Diffusivity is Observed in Sn-3.5Ag Joints

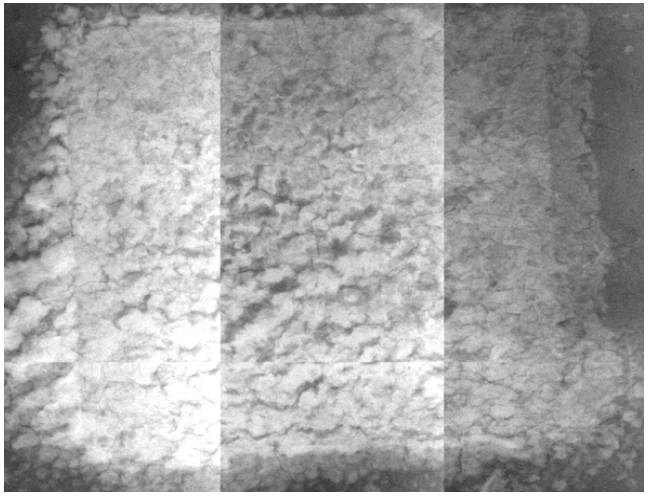
Sn-3.5 Ag Solder, 0 cycles

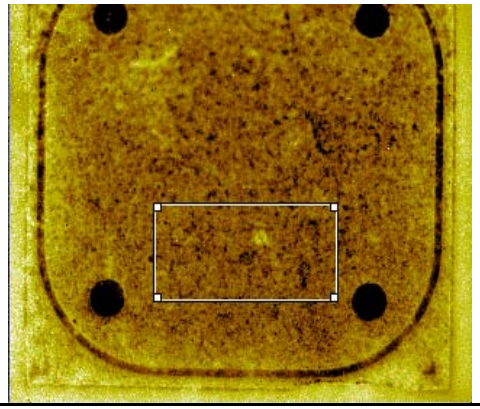




| Half Rise Time |
| --- |
| 0.009504 |

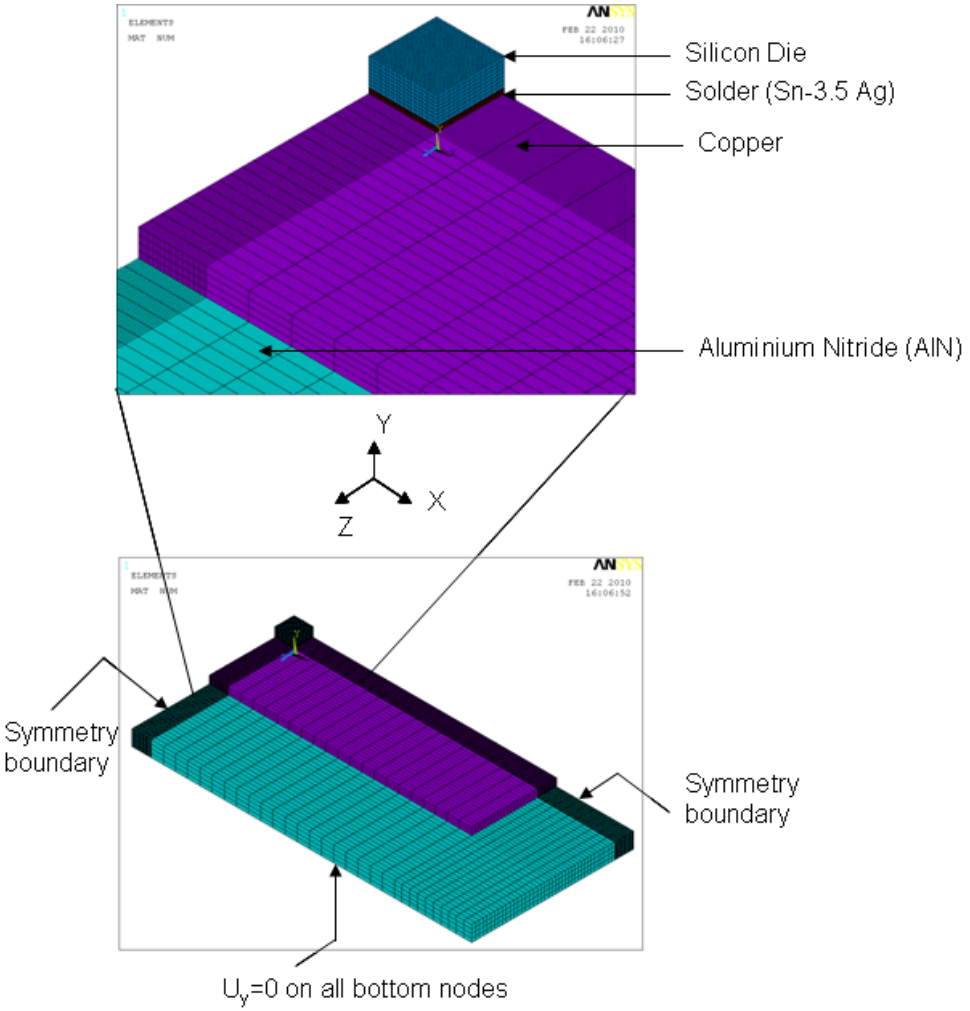
Sn-3.5 Ag Solder, 3000 cycles



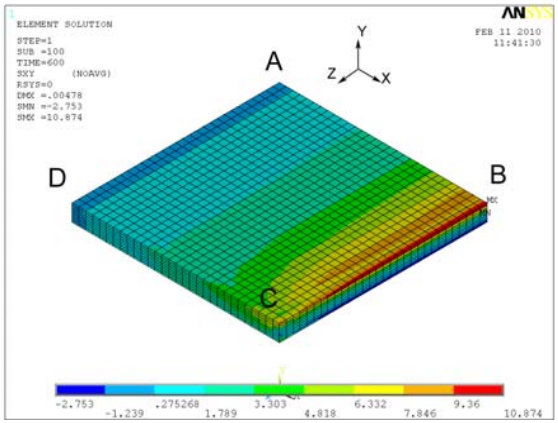


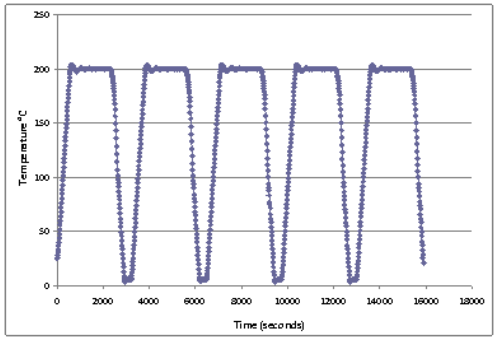
| Half Rise Time |
| --- |
| 0.01605ms |

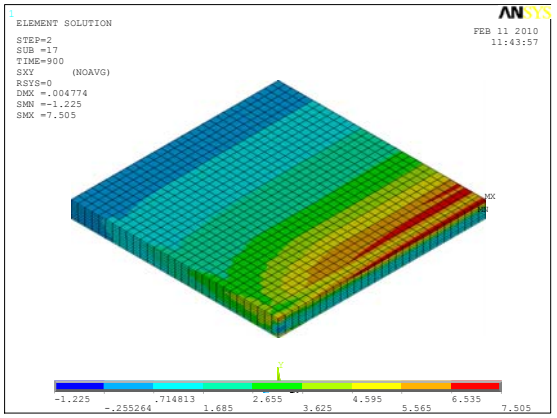
# 3-D Elasto-Plastic Finite Element Modeling Has Been Initiated to Understand Damage Evolution

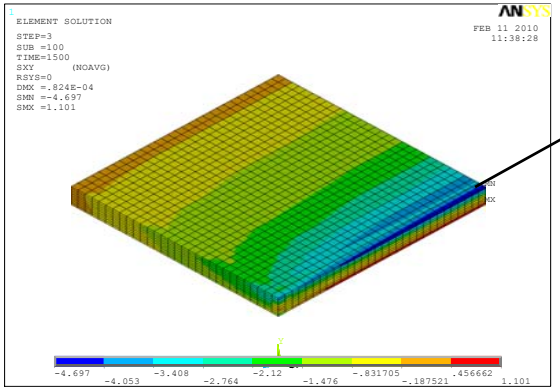


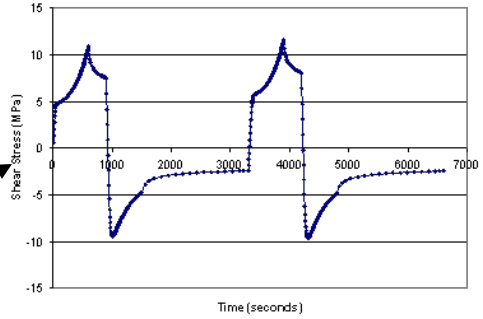
# Variation in Stresses within the Solder Joint as a Function of Thermal Cycle Has been Calculated for Sn-3.5Ag Solder

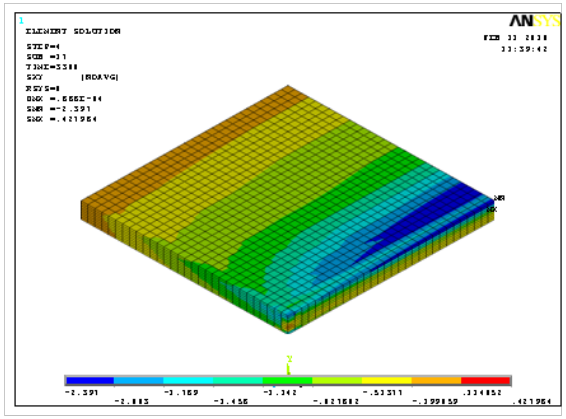


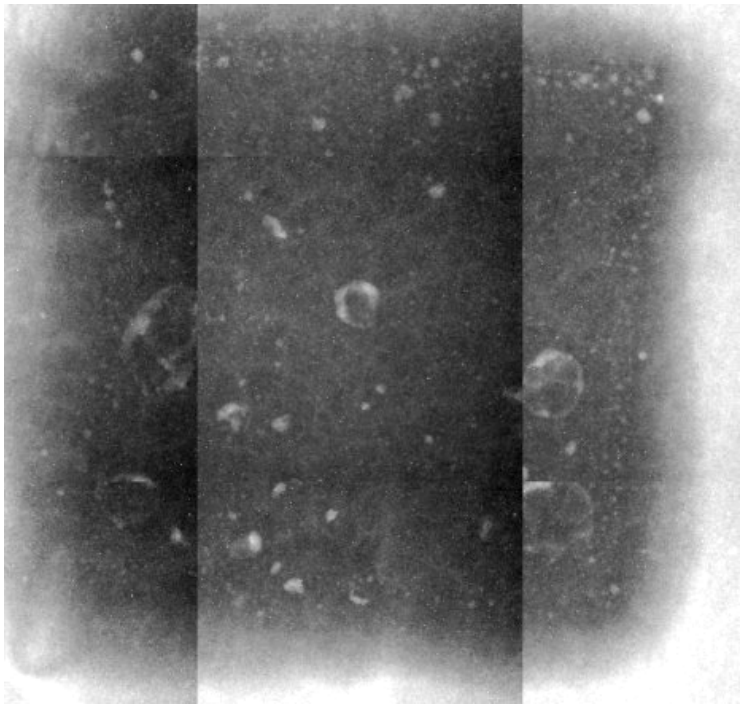



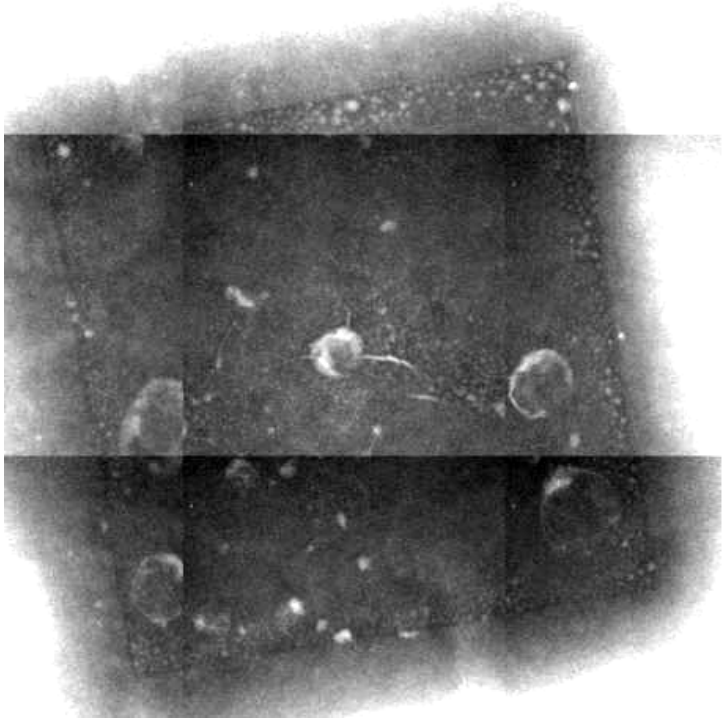




Correlating stresses with mechanisms of damage accumulation is on-going

# No Cracking is Observed in SiC Dies in Joints Prepared with Au-Sn Solder



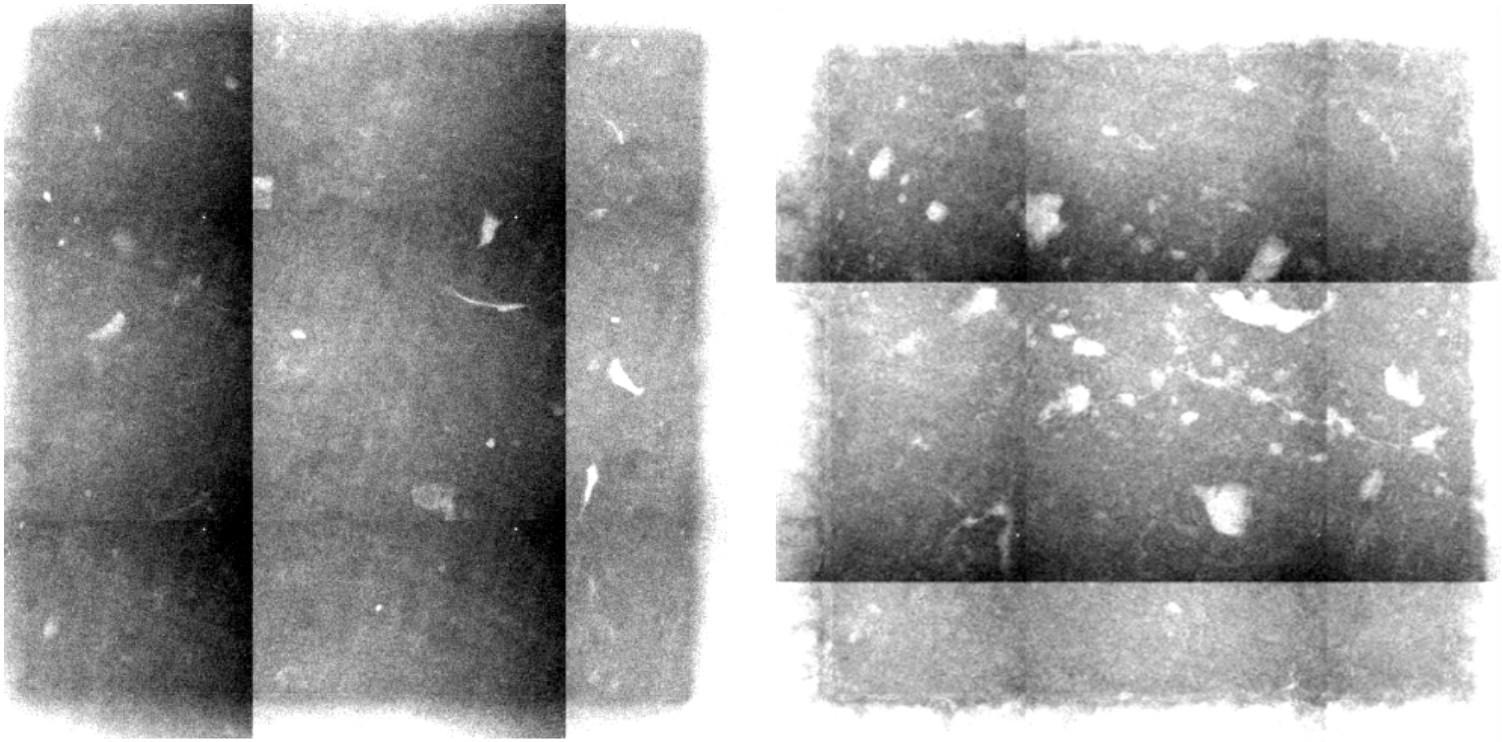
0 Cycles



1500 Cycles

Although silicon dies cracked, SiC dies were able to withstand atleast 1500 thermal cycles

# Thermal Cycling is On-going on SAC405 Joints

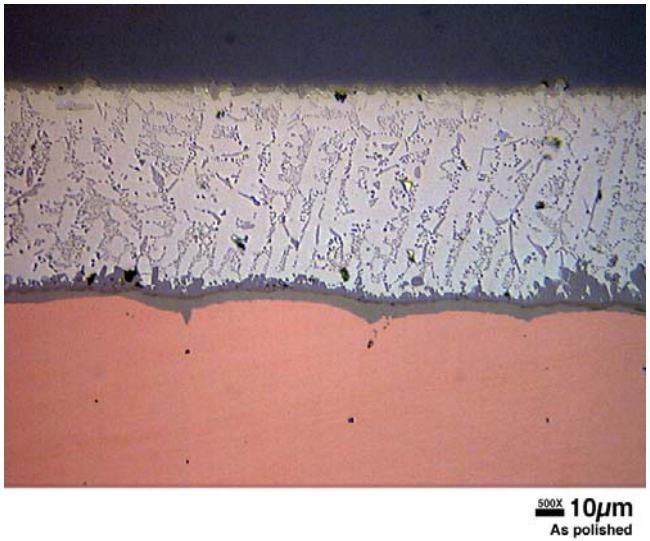


0 Cycles

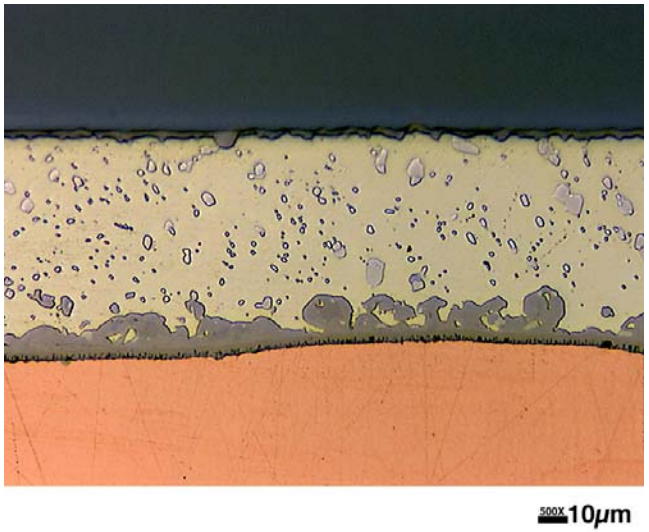
1500 Cycles

Damage is clearly observed after 1500 thermal cycles in SAC joints and is more extensive than in Au-Sn joints

# Optical Microscopy Shows Microstructural Coarsening in Sn-3.5Ag Joints




As Processed




3000 Hours at 200°C

# Collaborations/Interactions

- Active collaborations are on-going with Powerex
  - A joint paper has been submitted
- Interactions are also on-going with Ford Motor Company to understand the various areas of reliability that are of importance
  - Results of previous work have been shared with Ford
- Discussions have been carried out with NREL on reliability testing and modeling

# Future Work

FY10

- Thermal diffusivity measurements will be completed in thermally cycled joints to evaluate effect of damage accumulation on thermal diffusivity in Au-Sn Solder Joints, and SAC joints
- 3000 thermal cycles will be completed on all three joints and effect on thermal diffusivity will be evaluated
- Die shear measurements will be completed in thermally aged joints to quantify mechanical property degradation
- Sintered silver joints will be prepared and performance will be compared with Au-Sn solder joints

# Summary

- Advanced Power Electronics components and systems in hybrid and electric vehicles have to operate at higher junction temperatures (200°C vs. 125°C) with a lifetime of 15 years
- Long term reliability of die attaches/solder joints are critical to achieve operating temperature and desired lifetime
- Thermal cycling work between 200°C and -65°C/5°C has been completed to 1500 – 3000 cycles in 3 solder joints
- Different levels of damage have been observed in the three solder joints subject to thermal cycling
- Steady state aging up to 3000 hours has been completed in two solders joints
- Sintered silver joints currently being evaluated for their high temperature operation capability