# Solder Joints of Power Electronics

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# Overview

## Timeline

- Project start: June 2007
- Project end: September 2010
- Percent complete: 30%

## Budget

- Total project funding Received
  - DOE 100%
- Funding Received in FY08: $150k

  FY09: $68k

## Barriers

- Barriers Addressed
  - B. Performance (105$^{o}$C coolant)
  - C. Life (15 years)
  - D. Abuse tolerance, reliability, and ruggedness (high temperature exposure)
- Targets Addressed
  - Life target of 15 years for hybrid and 10 years for EVs

## Partners

- Lead: ORNL

Collaborators/Interactions

- Powerex – manufacturer of power modules
- SemiSouth-manufacturer of SiC devices

# Objectives

- **Develop an understanding of the effect of selected solder joint compositions and microstructures on**
  - Higher temperature steady state operation (200°C with SiC vs current 125°C), and
  - Thermal cycling reliability when subjected to higher temperatures

## FY08 Objectives

- Understand degradation in a typical commercial package and evaluate experimental methodology
- Process Au-Sn solder joints
- Evaluate effect of steady state exposure and thermal cycling on Au-Sn solder joints

# Milestones

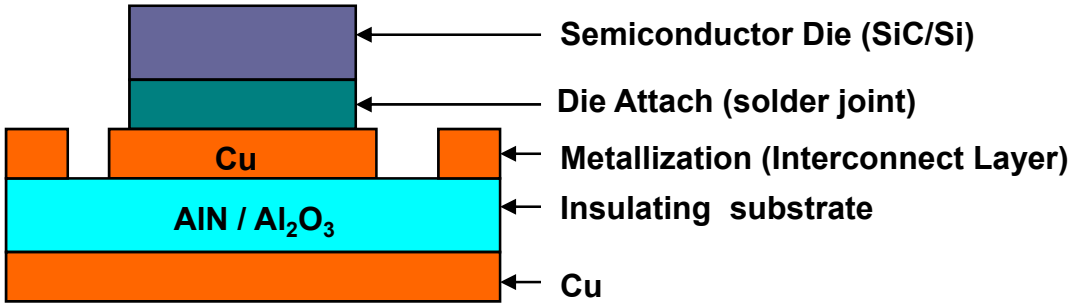
## FY2008

- **Evaluate microstructural evolution and causes related to the failure of one most commonly used solder in a selected high temperature package when subjected to stress testing conditions (9/08)**
  - Completed evaluating the degradation in behavior of a commercial package subjected to thermal cycling
  - Evaluated the failure of Au-Sn solder joints subjected to thermal cycling

## FY2009

- **Complete evaluating the effect of thermal cycling and long term aging at 200°C on Sn-3.5Ag solder (9/09)**

# 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
- Database 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

- Two solders were selected for initial study
  - 80Au-20Sn ($T_m$=280°C)
  - Sn-3.5Ag ($T_m$=221°C)
- Criteria for selection
  - Pb-free
  - Highest melting temperatures to allow 200°C operation and temperature excursion
- In collaboration with Powerex, joints were prepared between AlN DBC with Cu/Ni(P)/Au and Si resistor die with Ti/Ni/Au metallization

# Key Progress/Results

- A commercial package was subject to thermal cycling testing to understand degradation and to evaluate methodologies
- 80Au-20Sn and Sn-3.5Ag solder joints were processed
- Thermal cycling testing and steady state high temperature exposure at 200°C of 80Au-20Sn and Sn-3.5Ag solder joints have been performed and are continuing
- Several limitations have been identified in technologies that have been evaluated

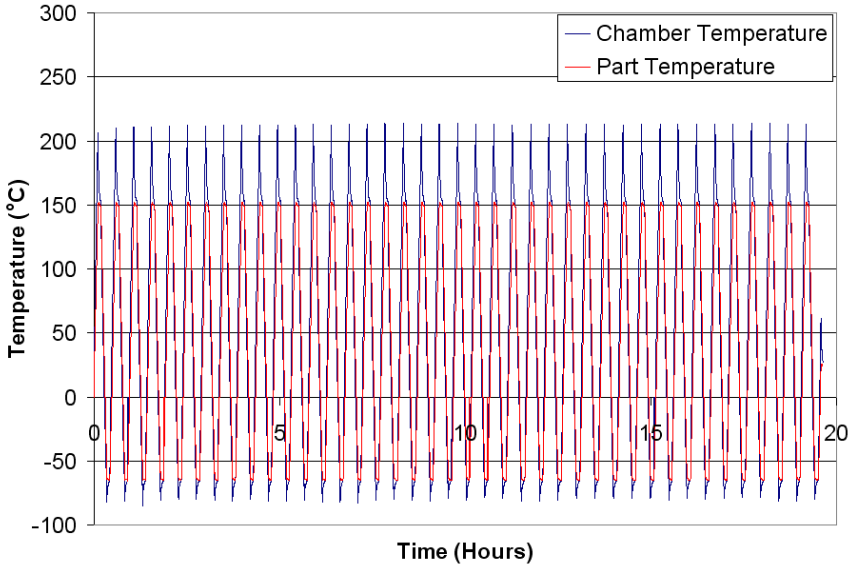
# Accomplishments: A Commercial Package Was Thermally Cycled To Examine Degradation

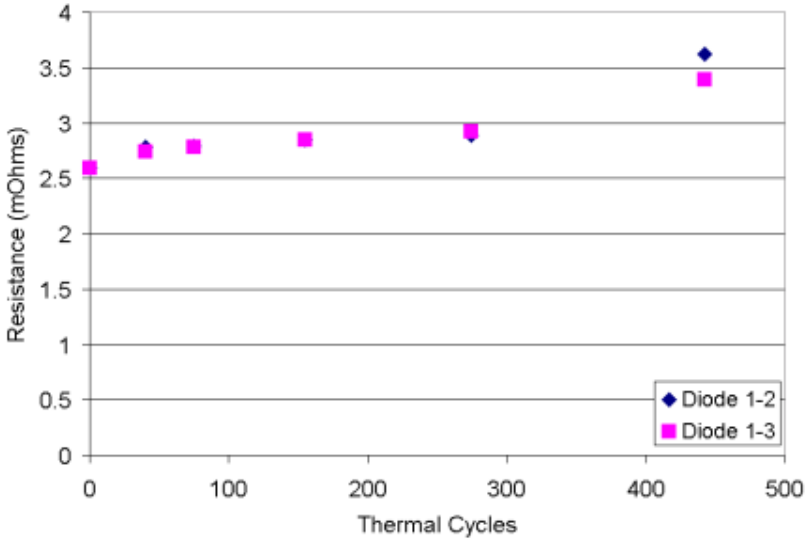
- Commercially available 600V/100A diode modules rated for maximum junction temperature of 150°C were procured
- Modules were thermally cycled between -65°C and +150°C as per JEDEC standards in single environmental chamber
- Electrical characteristics were measured at periodic intervals by removing module from the chamber to observe degradation, if any

Commercial Diode Module

Thermal Cycling Chamber

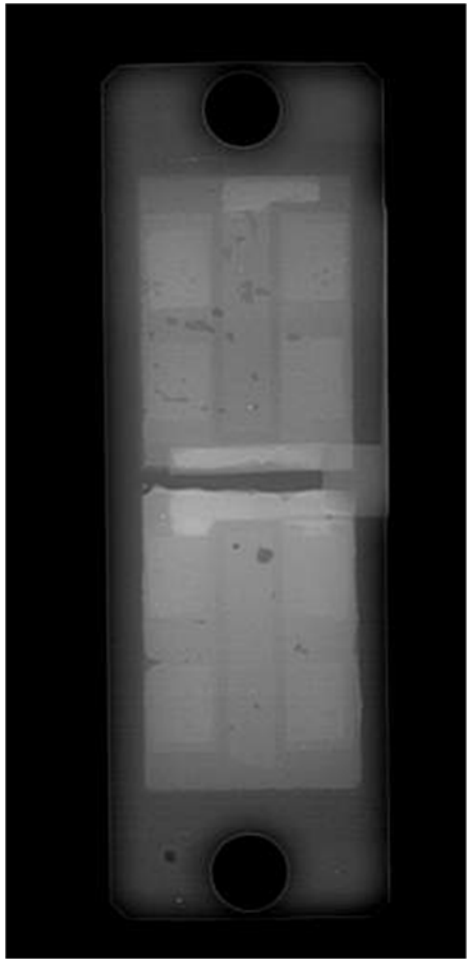
# Thermal Cycling Testing Results in Degradation of Electrical Properties



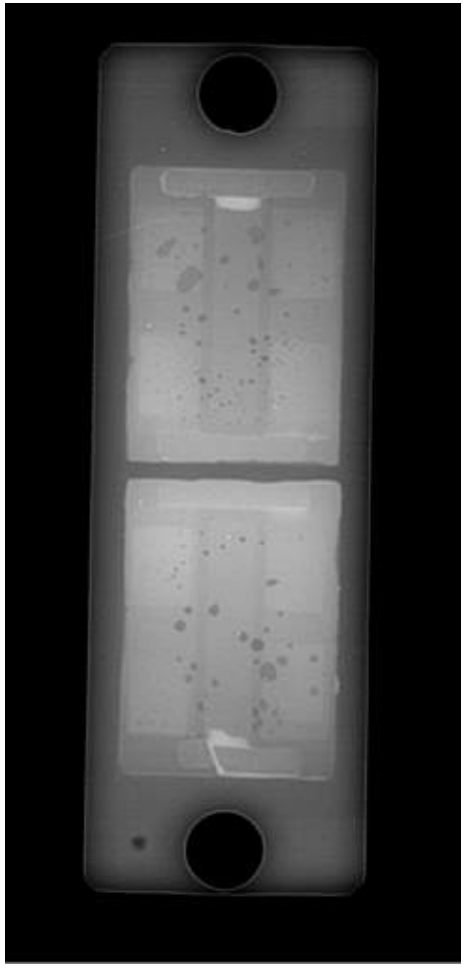




- Forward resistance increases after thermal cycles between 150°C and -65°C
- Diode characteristics were altered after thermal cycling

# X-ray Imaging Shows Differences Induced During a Typical Thermal Cycling

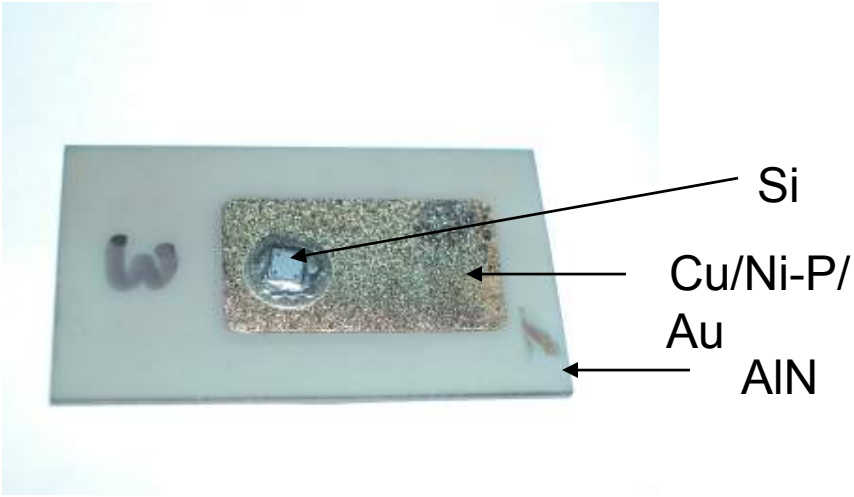


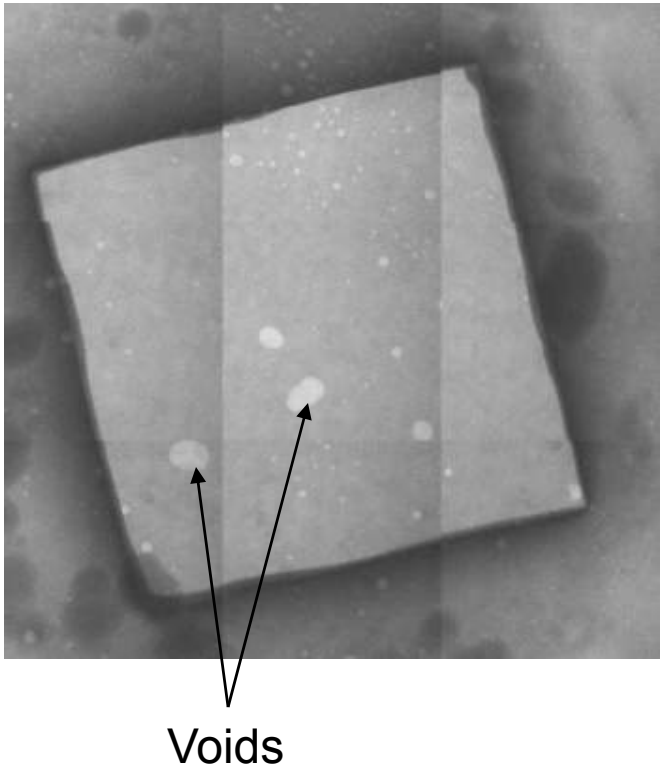
Typical Commercial Device
(Decapped)



Typical Device After Thermal Cycling
(Decapped)

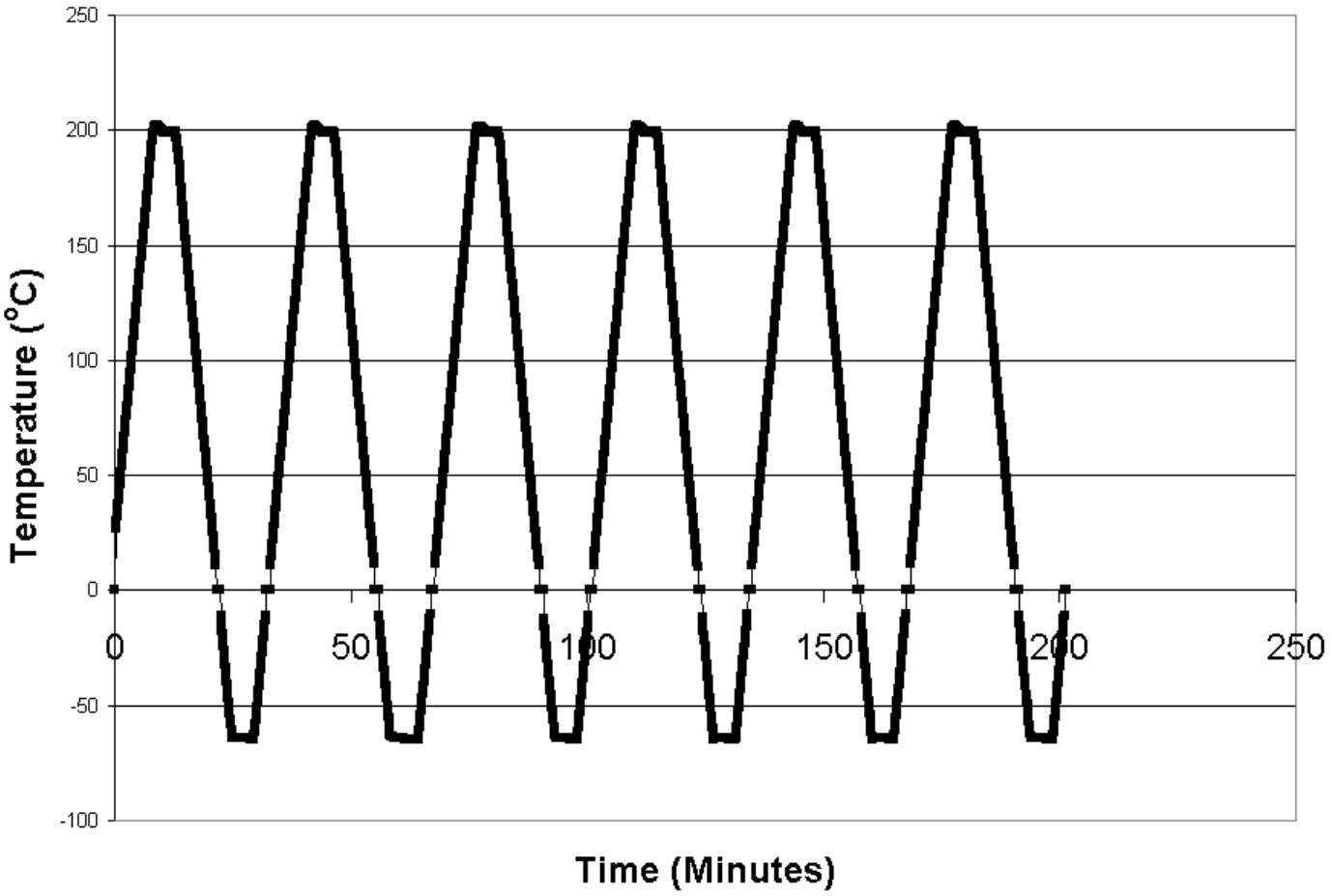
# Typical Image and High Resolution X-ray Radiograph of Processed Au-Sn Solder Joint



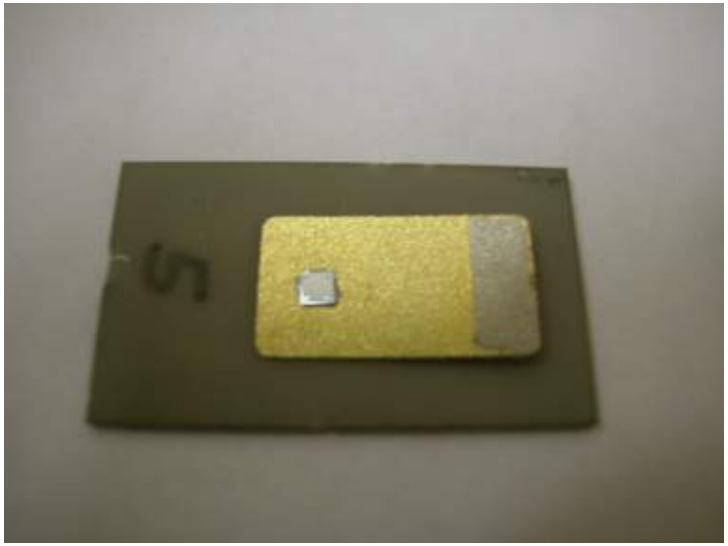

Chip size: 2.5 mm x 2.5mm, Bondline thickness ~ 75 μm

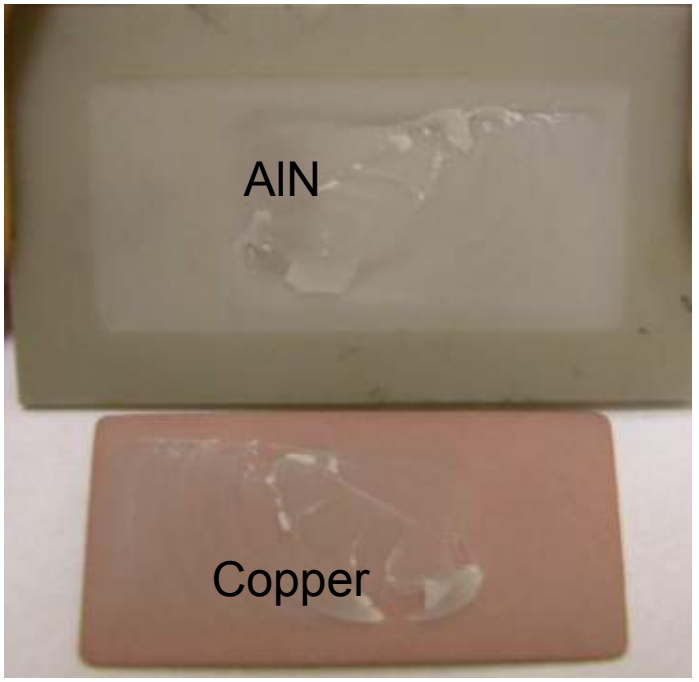
# Thermal Cycling: Type 1




**-65°C to 200°C, Dwell time 5 min at each temperature**

# Delamination of Copper Layer From AlN in the DBC Was Observed

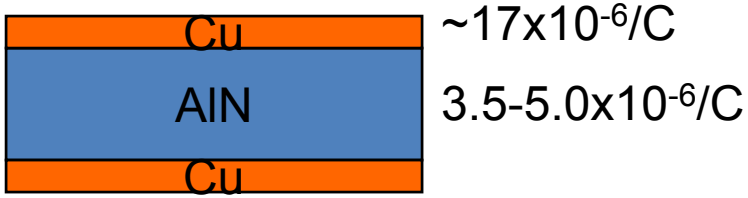



Bending of the Cu was observed with delamination progressing from an edge

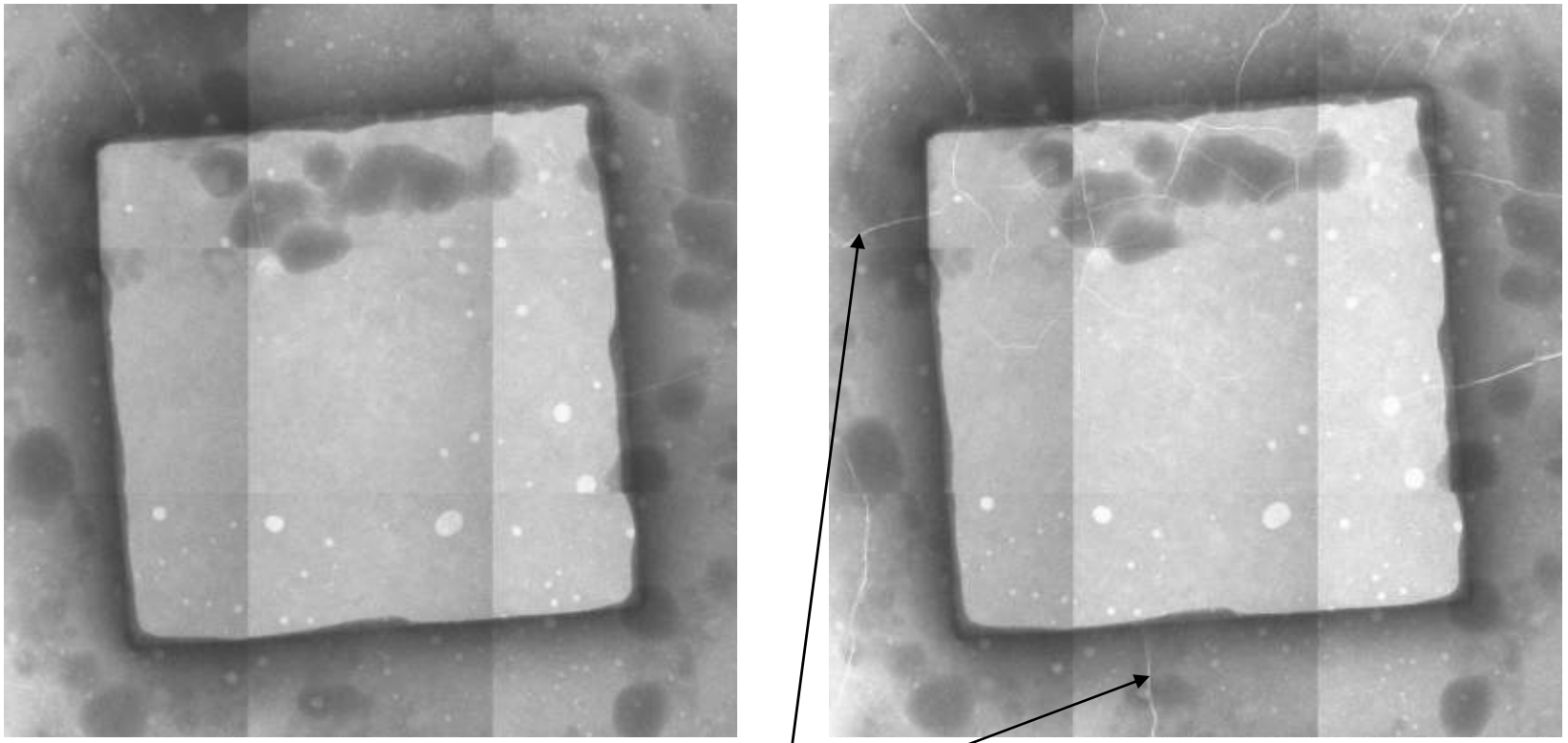
# Potential Causes for Delamination

- Coefficient of Thermal Expansion (CTE) mismatch present in DBC

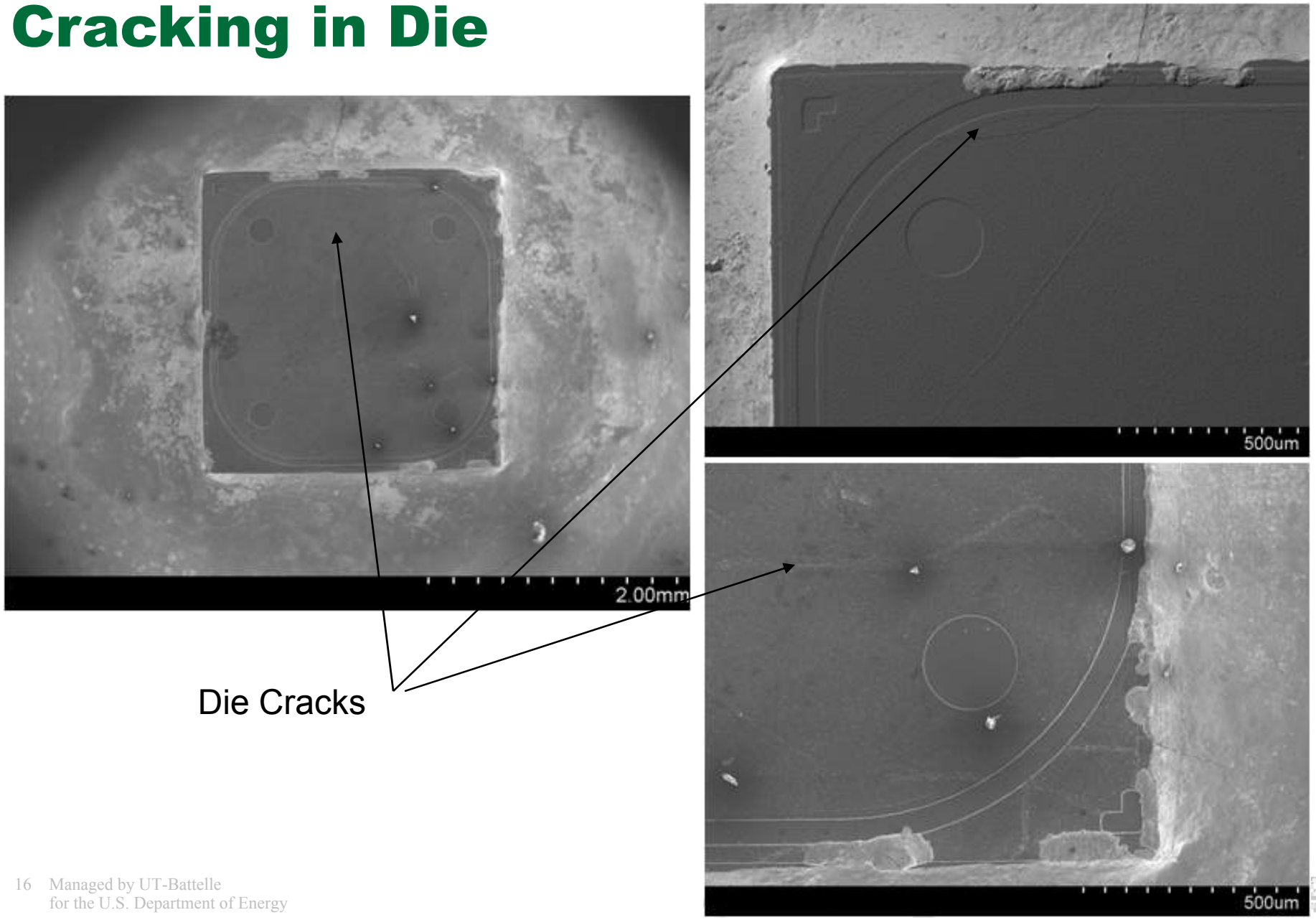



- Environment may affect the performance of AlN DBC
  - Further work is required to understand the delamination and its control

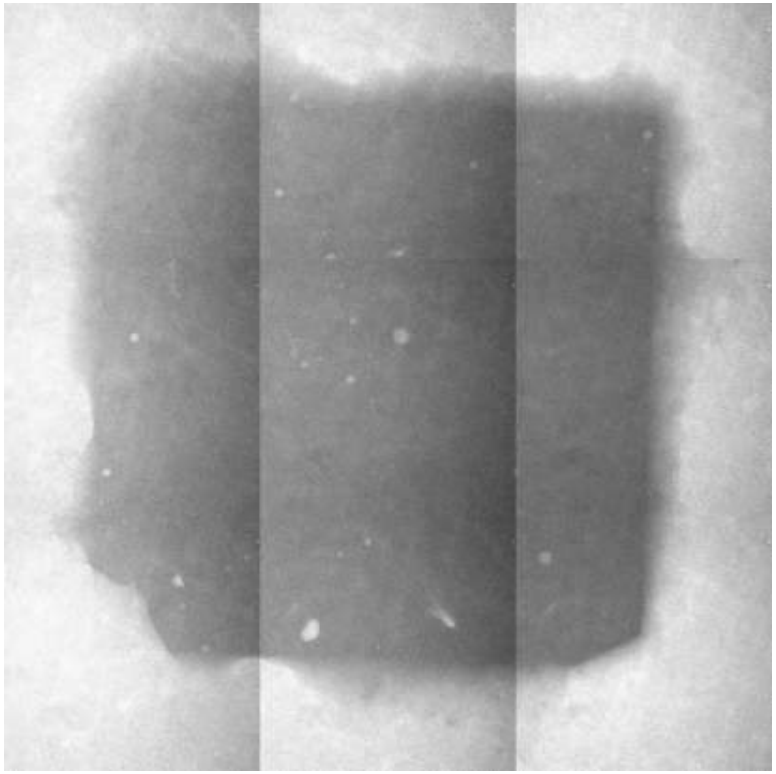
# High Resolution X-ray Radiography Shows Cracking in Au-Sn solder After Thermal Cycling of Type 1



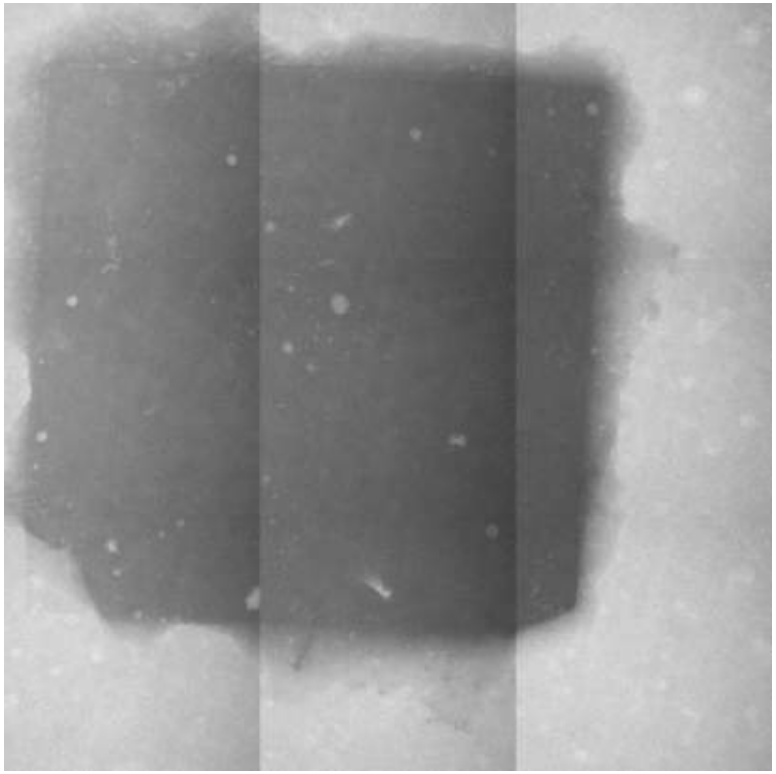
# Scanning Electron Microscopy Shows Cracking in Die



# Effect of Thermal Cycling on DBC with Si Die attached using Sn-3.5Ag



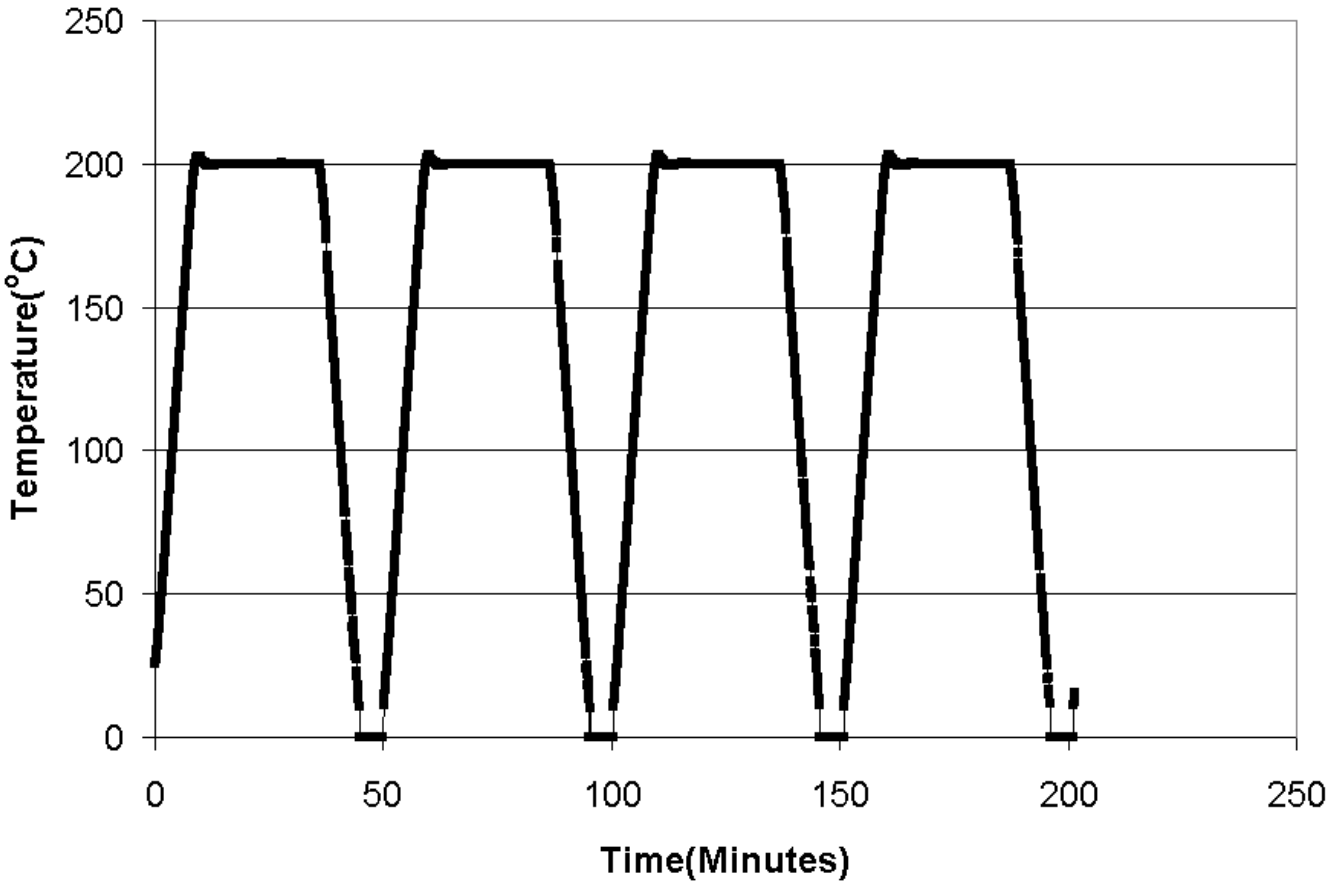
0 Cycles



Thermally cycled

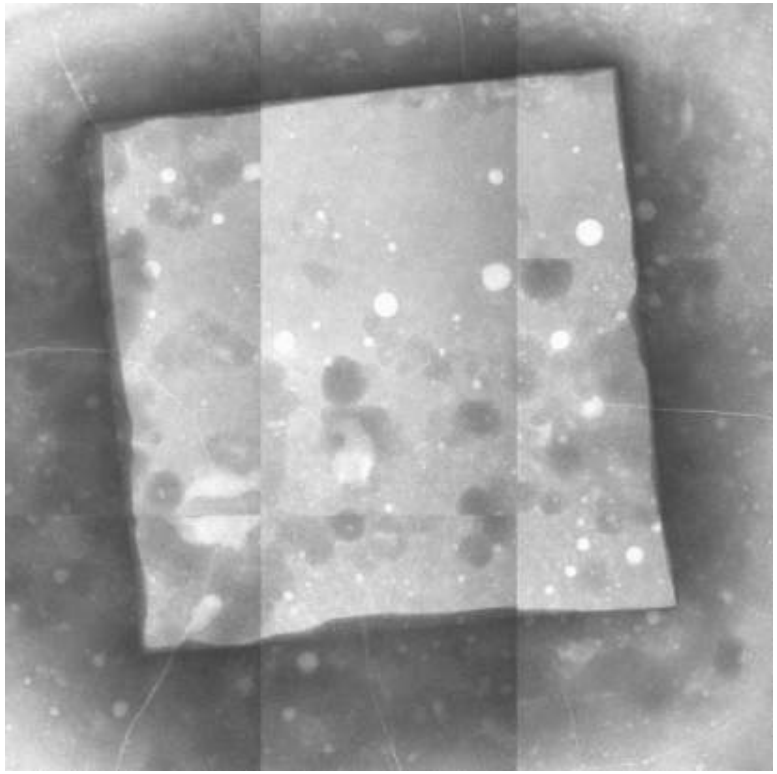
No cracking is observed after thermal cycling Sn-Ag solder joints for comparable cycles

# Thermal Cycling: Type 2

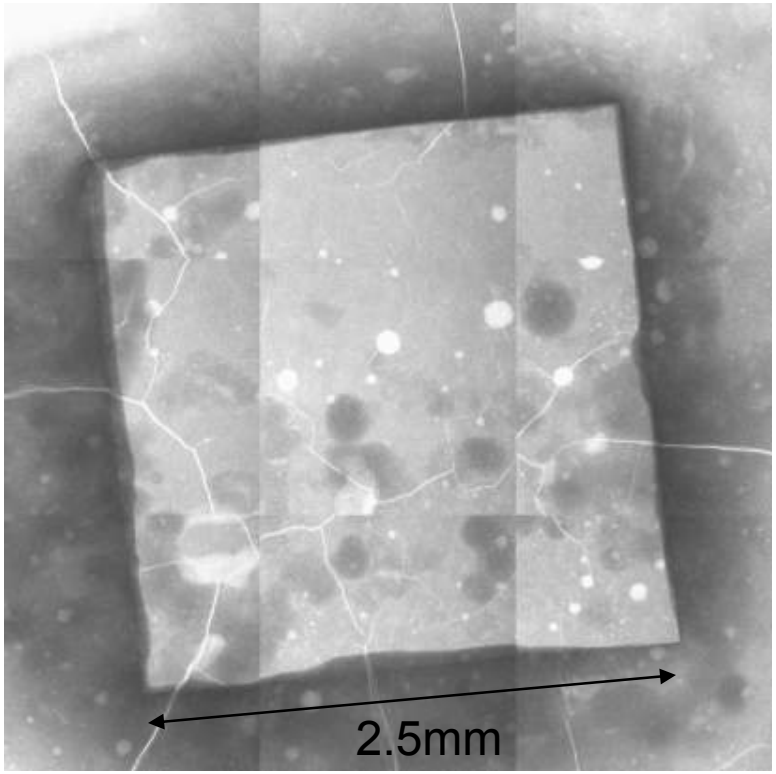



- 5°C to 200°C, 30 min hold at 200°C, 5 min hold at 5°C
- Simulates 30 minutes of uninterrupted operation

# Thermal Cycling of Au-Sn Bonds Using Type 2 Show Cracking As in Cycling Using Type 1



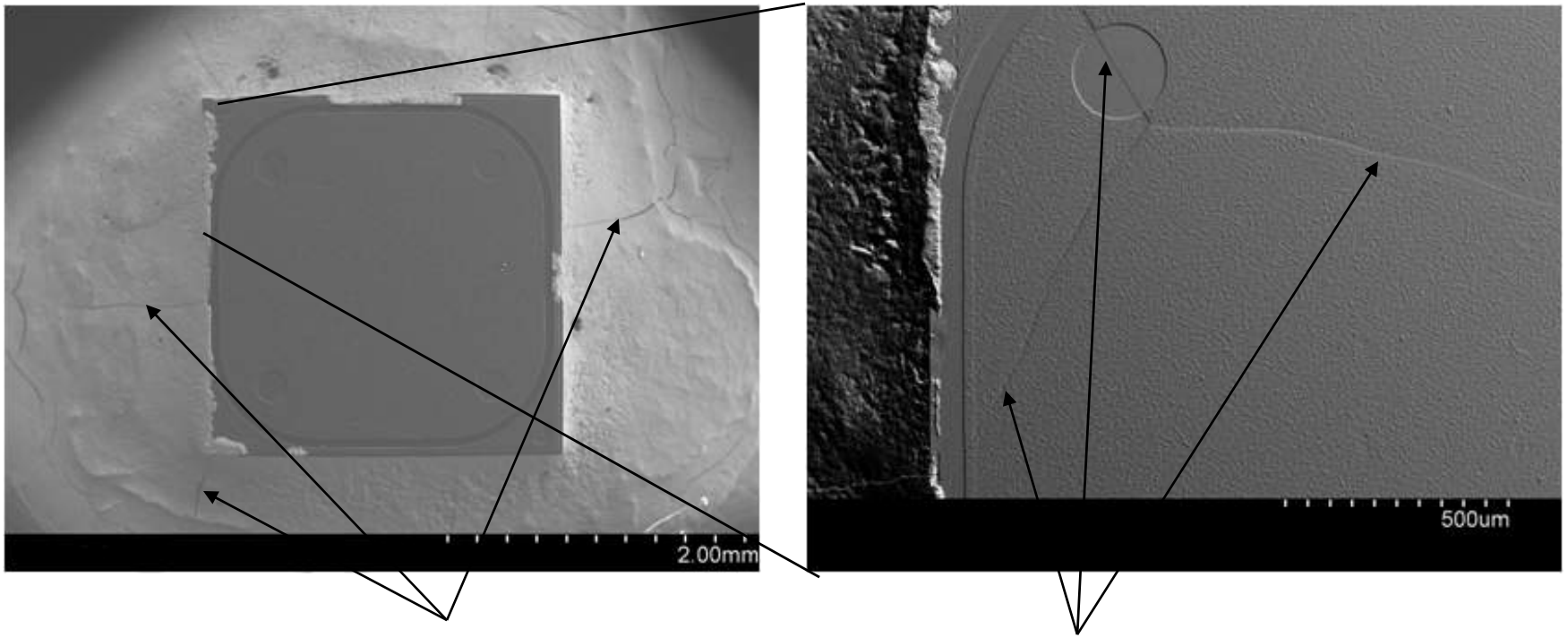
0 cycles



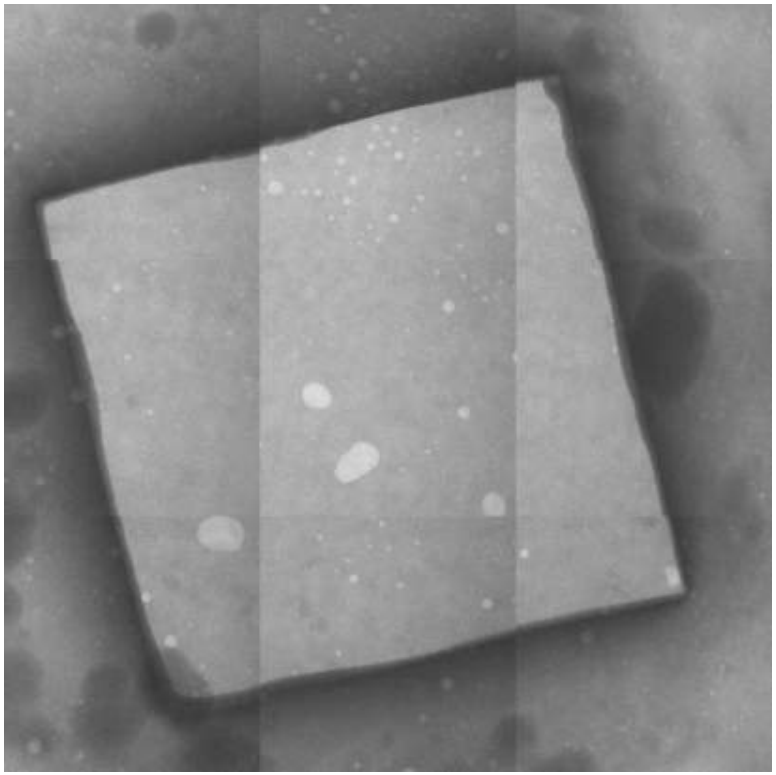

After Thermal Cycling

Voids seem to link some cracking seen in the die area (underneath die)

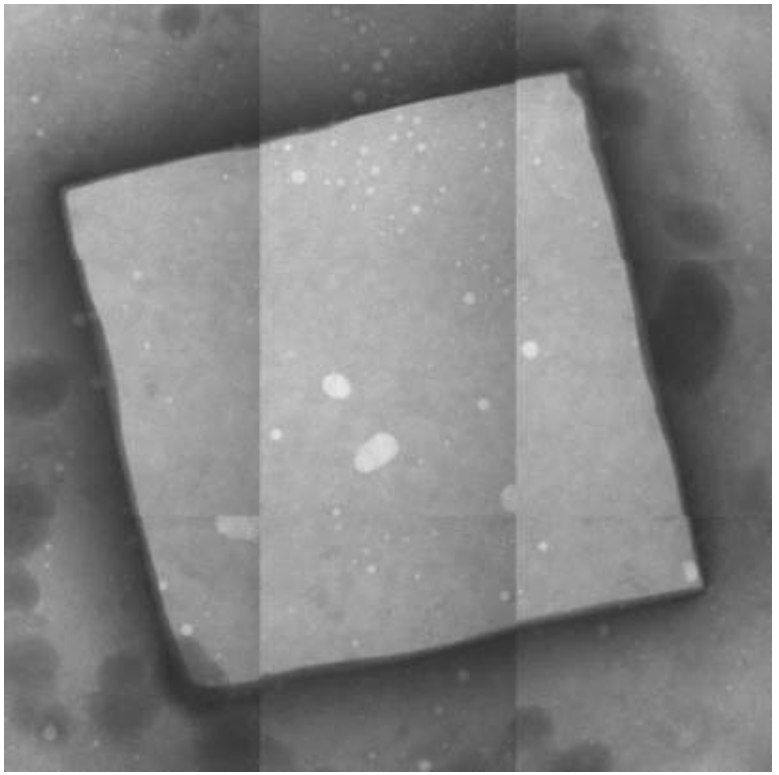
# Scanning Electron Microscopy of Cycled Au-Sn Joints Shows Presence of Multiple Die Cracks



# Accomplishments: Steady State Exposure at 200°C of Au-Sn Solder Shows Minor Void Evolution



As Processed



200 hours at 200°C

# Future Work

FY09

- Steady state exposure of Au-Sn joints and Sn-3.5Ag joints will be completed at 200°C for times up to 3000 hours and joint degradation will be evaluated using die-shear tests
- Thermal cycling tests will be continued on Sn-3.5Ag joints to follow void growth and property degradation for up to 3000 cycles
- Effect of replacing Si die with SiC die will be evaluated

FY10

- Based on results from FY09, one additional promising high temperature solder or solder joint technology (including transient bonding) will be studied for effect of thermal cycling and steady state aging
- Based upon reviewers' recommendations, one alternate high temperature die bond material (non-solder) will be evaluated

# 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 shows
  - One candidate high temperature solder, 80Au-20Sn solder may cause cracking of the die due to thermal expansion mismatch stresses
  - Copper delamination may occur in AlN DBC
- Other solders are currently being evaluated for their high temperature operation capability
- Collaborations are on-going with Powerex and initial contact has been made with Ford Motor Company