Solder Joints of Power Electronics

G. Muralidharan, Andrew Kercher
Materials Science and Technology Division

Burak Ozpineci
Engineering Science and Technology Division

Oak Ridge National Laboratory
Oak Ridge, TN
May 21, 2009

Project ID # pmp_06_govindarajan

This presentation does not contain any proprietary, confidential, or otherwise restricted information
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°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 ($T_m=280^\circ C$)
  - Sn-3.5Ag ($T_m=221^\circ C$)

- Criteria for selection
  - Pb-free
  - Highest melting temperatures to allow 200$^\circ C$ 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.
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

Si
Cu/Ni-P/Au
AlN
Voids
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

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

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

0 cycles

After Thermal Cycling

2.5mm
Scanning Electron Microscopy of Cycled Au-Sn Joints Shows Presence of Multiple Die Cracks

Solder Cracks

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.