Materials and Processes for High Temperature Packaging of Power Electronic Devices

G. Muralidharan, A. Kercher, M. L. Santella, R. Battiste
Materials Science and Technology Division
Oak Ridge National Laboratory, Oak Ridge, TN

L. Seiber, and Burak Ozpineci
Engineering Science and Technology Division
Oak Ridge National Laboratory

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Energy Storage and Power Electronics Peer Review
Power Electronics research needs are necessary at many levels

This project addresses these two levels
Purpose of Work

- Realization of the future electric grid depends on the availability of high efficiency, low cost, weight, and volume power electronic components and subsystems.

- Future power electronic systems need to operate:
  - At junction temperatures of 250°C or higher vs current 125°C in silicon devices due to higher power densities.
  - Reliably for an extended period of time.

- Increased operating temperatures require use of:
  - Alternate packaging materials to withstand higher temperatures.
  - Wide band-gap semiconductor devices.

- Need to understand effect of higher temperatures and alternate materials on device degradation.
A typical package consists of multiple materials with distinctly different properties.
Cross-section of an IGBT Module

1200V-100A IGBT

Section A-A

AlN

Si diode

Si IGBT

Pb•Sn•Sb Solder

Copper

Pb•Sn•Sb Solder

Copper

Copper

Courtesy A. Wereszczak
Significant Issues

- Most materials currently used for 125°C operation will be UNSUITABLE for 250°C operation
  - Polymers will degrade if exposed to high temperatures
  - Commonly used solders (example: eutectic Pb-Sn) will melt at the higher temperatures required for OE applications

- Higher temperature exposure and thermal cycling result in
  - Microstructural changes that degrade properties of solder joints (die attach materials) and wire bonds
  - Decrease lifetime and reliability

- Reliability of high temperature packages and testing protocols have NOT been established
Overall Research Plan: Evaluating and Improving Reliability of Die Attaches and Wire Bonds

- Evaluate High Temperature Performance of Selected Die Attach Materials and Wire Bonds
  - Evaluate Methods to Improve Performance of Die Attach Materials
    - Composite solder materials
    - Alternate high temperature solders
  - Evaluate Methods to Improve Performance of Wire/Ribbon Bonds
    - Alternate bonding techniques
    - Alternate wire materials for high temperature operation
Accomplishments: Initial Evaluation of the Effect of Thermal Cycling on a Commercial Package is on-going

- Commercially available 600V/100A diode modules rated for maximum junction temperature of 150°C were obtained from industrial partner

- Modules were thermally cycled between -65°C and +150°C as per JEDEC standards in an environmental chamber

- Electrical characteristics were measured at periodic intervals 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

• Need to understand mechanism responsible for degradation
X-ray Imaging Shows Some Differences in Thermally Cycled Device

Typical Commercial Device (Decapped)

Different Device After Thermal Cycling (Decapped)
Future Work: Reliability of High Temperature Joints Will be Evaluated

- High temperature packages for SiC are NOT available commercially
- Preliminary work has been completed on fabricating Au-Sn solder joints and die shear testing of joints (Milestone due September 30, 2008)
- Simple die attach joints will be fabricated with INACTIVE SiC dies obtained from industrial collaborator and materials suitable for 250°C operation using vacuum soldering system
- Effect of steady-state exposure to 250°C and the effect of thermal cycling on packages will be evaluated by thermally cycling from -65°C to or 250°C or higher
- Properties of solder joints and microstructure will be characterized

X-ray Tomography of Voids in Processed Au-Sn Joints
Vacuum Solder Reflow System for processing void-free joints
Improving Reliability of Die Attaches

Two major causes for failures of commercial power packages are wire bonds and die attaches.

Evaluate High Temperature Performance of Selected Die Attach Materials and Wire Bonds

Evaluate Methods to Improve Performance of Die Attach Materials
  • Composite solder materials
  • Alternate high temperature solders

Evaluate Methods to Improve Performance of Wire/Ribbon Bonds
  • Alternate bonding techniques
  • Alternate wire materials for high temperature operation
CTE Mismatch Occurs Across Die-Attach

- **SiC**: CTE: ~4.5 ppm
- **Eutectic Au-Sn**: CTE: ~17 ppm
- **Copper**: CTE: ~16 ppm

[Diagram showing layers and materials with CTE values indicated]
Composite Solder Joints Will Reduce Thermal Expansion Coefficient Mismatch
Ceramic Particulates Could Not Be Retained within Joint

- Ceramic particulates were rejected during solidification
- Better understanding and control of wettability of the particles with molten solder is needed
Future Work (Solder Joints)

- Surface modification techniques will be utilized to improve wettability of ceramic particles
- Solder processing techniques will be refined to retain ceramic particles within the joint
- Electrical properties of die attach will be measured as a function of particulate content to identify optimum volume fraction
- Effect of steady state exposure and thermal cycling will be evaluated to compare performance of composite solder joints with that of solder joints without SiC/AlN particles
Future Work (Ribbon Bonding)

- Ribbon bonds will be fabricated using prototype processing system and properties will be measured
- An alternate prototype system has been designed and several parts have been procured
  - System will allow a greater degree of control on descent of friction tool
  - Better control of time of contact and pressure will be facilitated in the new system
- Strength of bonding and electrical properties of ribbon bonds will be characterized and compared to that of ultrasonic bonding
- Effect of alternate processing on microstructure of joint will be evaluated
- Reliability of bonds will also be characterized using thermal cycling
Summary

• Significant applied materials research and process development work is needed to achieve the next generation high temperature-capable power electronic systems

• Advances have been made in several areas:
  – Reliability testing of a commercially available package has been initiated and degradation has been observed
  – Initial processing and testing of solder joints that are needed for high temperature packaging is underway
  – One scheme to reduce thermal expansion mismatch stresses in die attaches is being evaluated
  – Proof-of-concept research on alternate bonding technology that may result in more reliable ribbon bonds in high temperature packages has been initiated

• Future work will enable the identification of an initial suite of materials for high temperature packages