# Materials and Processes for High Temperature Packaging of Power Electronic Devices

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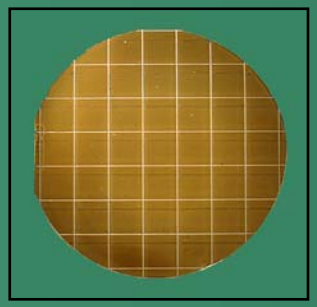
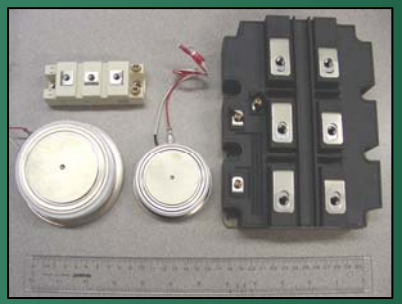
# Power Electronics research needs are necessary at many levels





**Applied Materials Research**

**Power Electronic Module Development**

**Next Generation Equipment**

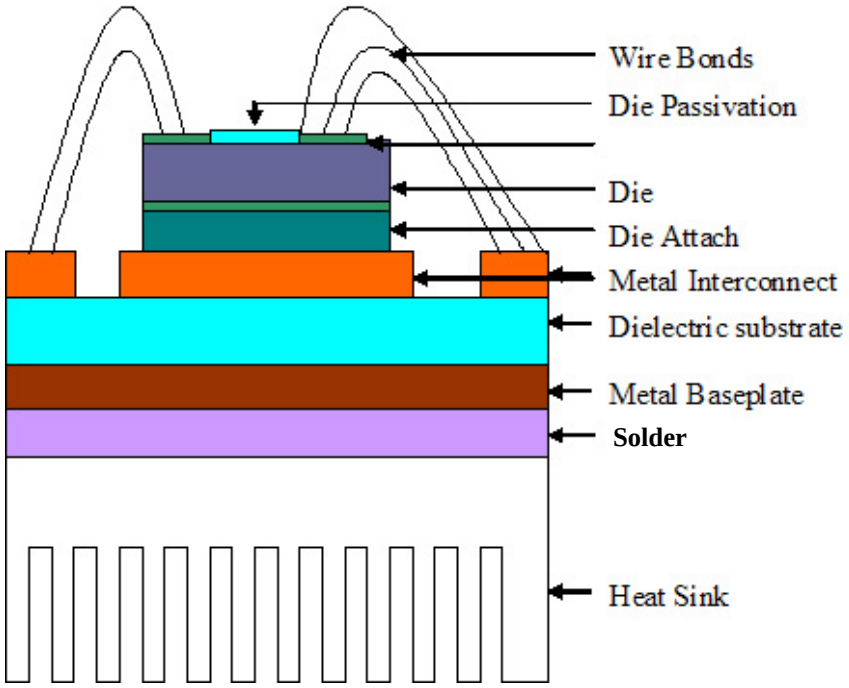
**System Reliability**

This project addresses these two levels

# Purpose of Work

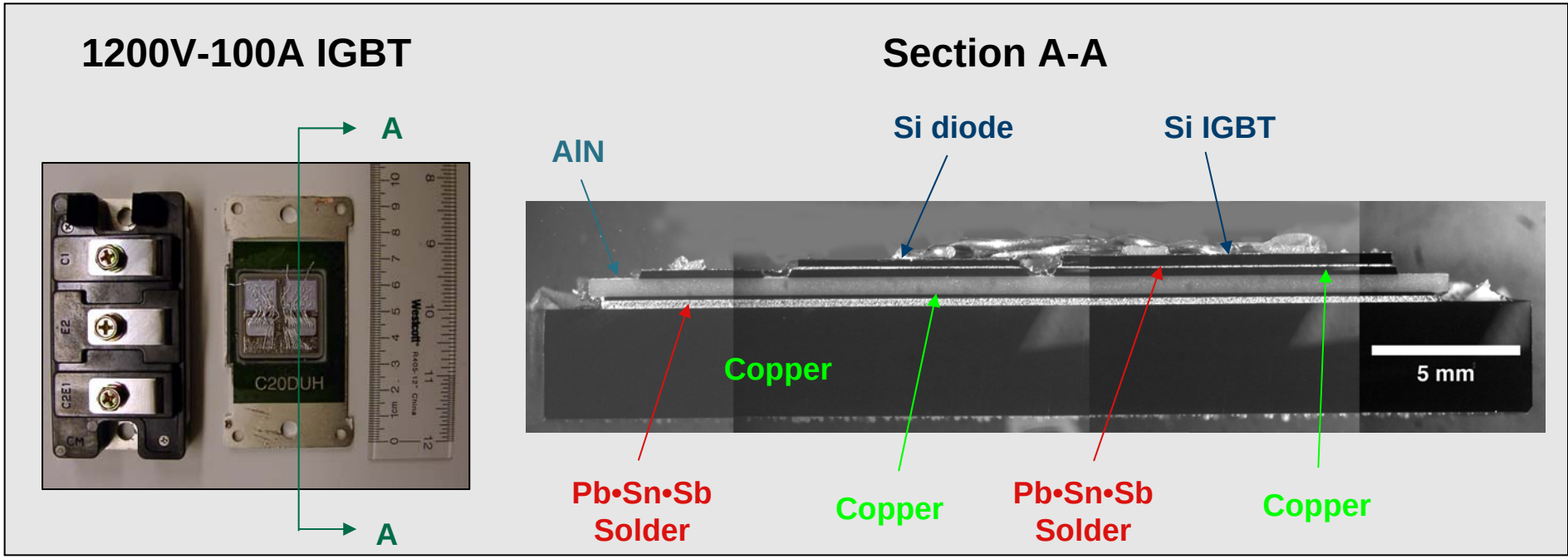
- Realization of the future electric grid depends on the availability of high efficiency, low cost, weight, and volume power electronic components and subsystems
- Future power electronic systems need to operate
  - At junction temperatures of 250$^{o}$C or higher vs current 125$^{o}$C in silicon devices 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 Packaging Scheme for High Temperature Operation




**A typical package consists of multiple materials with distinctly different properties**

# Cross-section of an IGBT Module

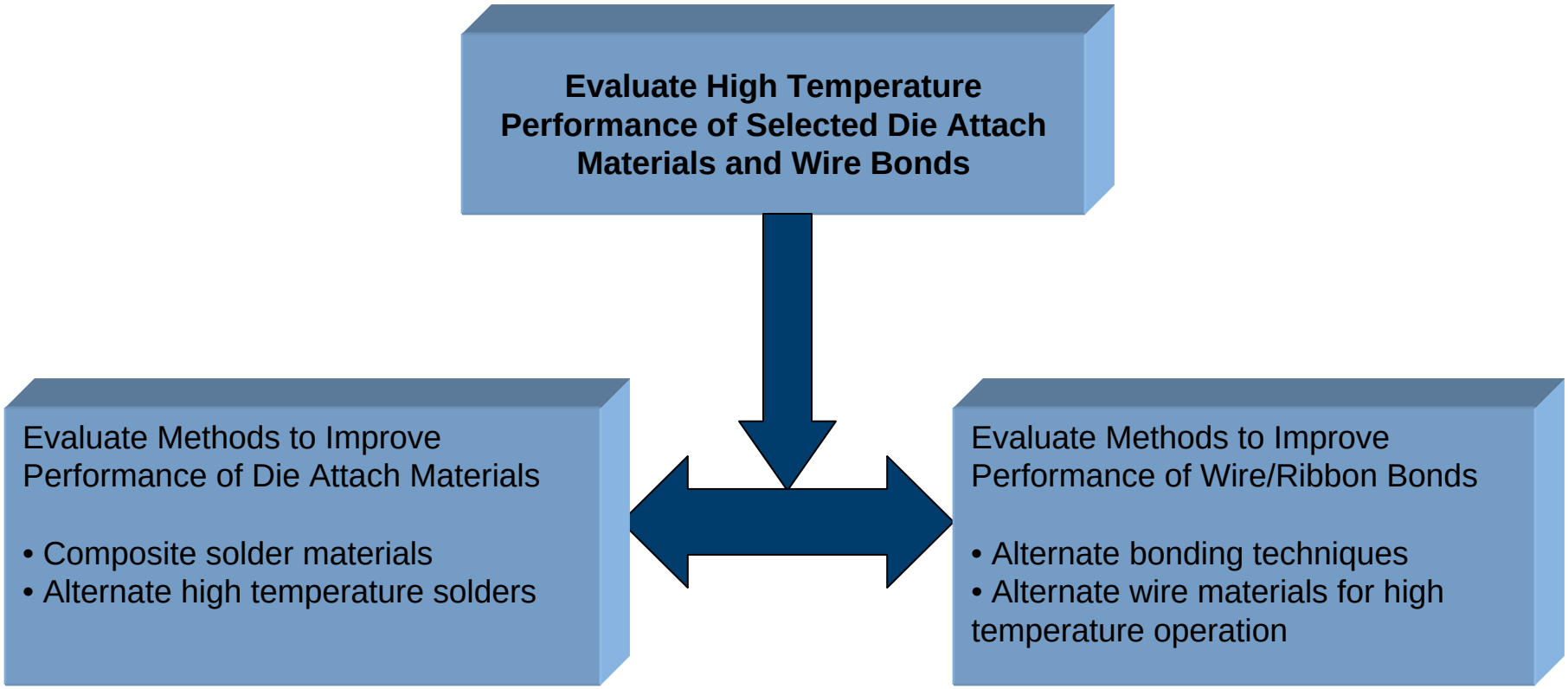



Courtesy A. Wereszczak

# Significant Issues

- Most materials currently used for 125$^{o}$C operation will be UNSUITABLE for 250$^{o}$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



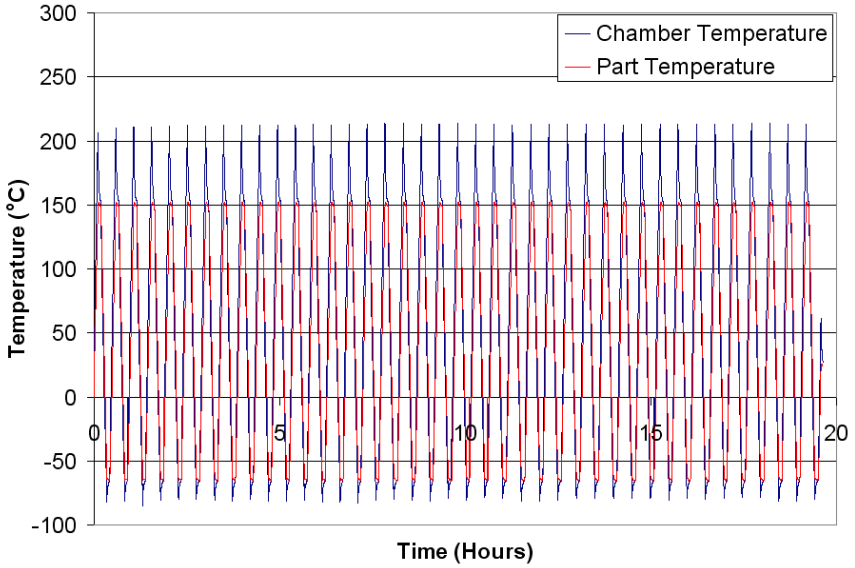
# Accomplishments: Initial Evaluation of the Effect of Thermal Cycling on a Commercial Package is on-going

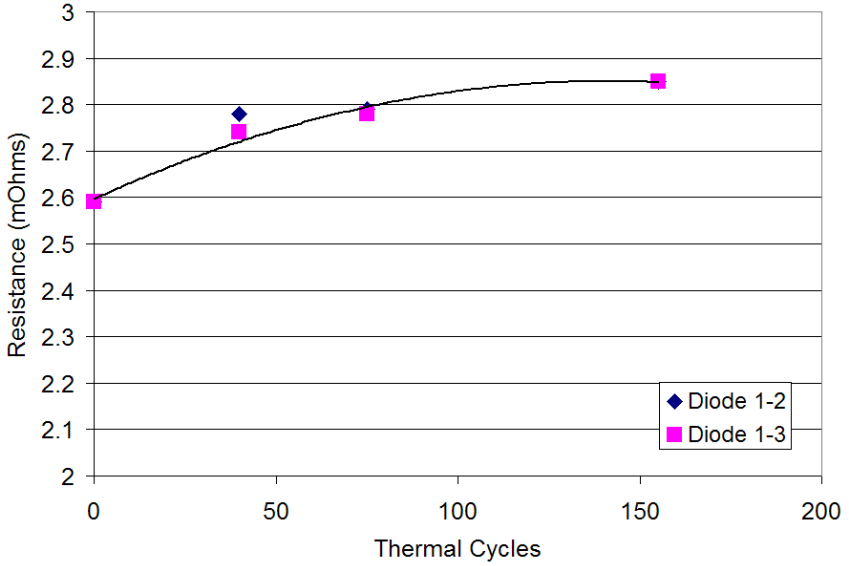
- **Commercially available 600V/100A diode modules rated for maximum junction temperature of 150°C were obtained from industrial partner**
- **Modules were thermally cycled between -65°C and +150°C as per JEDEC standards in an environmental chamber**
- **Electrical characteristics were measured at periodic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

**Commercial Diode Module**

**Thermal Cycling Chamber**

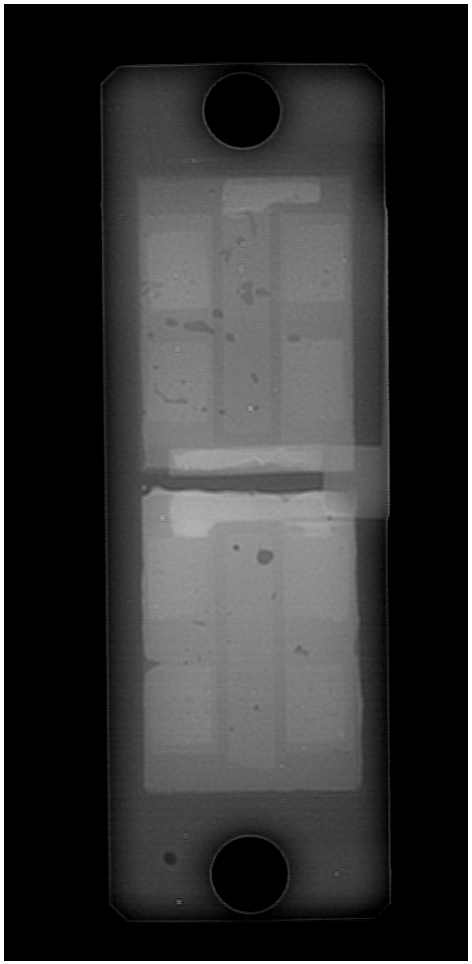
# Thermal Cycling Testing Results in Degradation of Electrical Properties



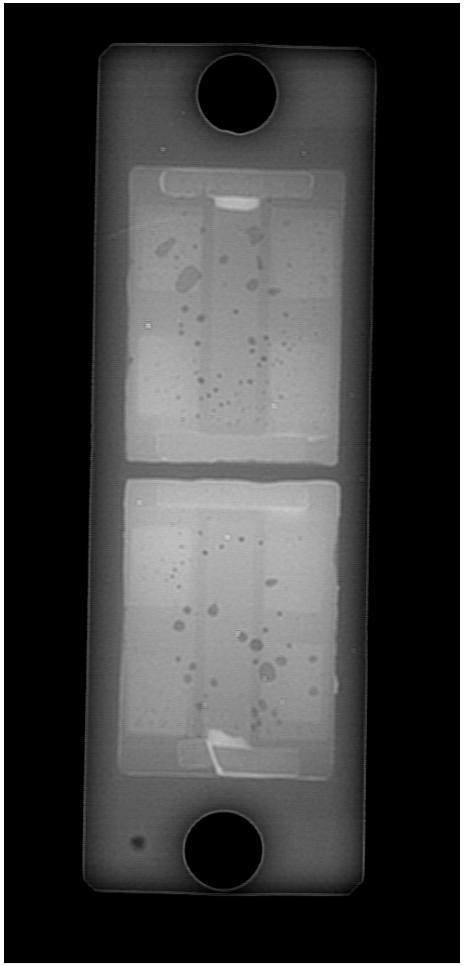




- **Forward resistance increases after thermal cycles between 150°C and -65°C**
- **Need to understand mechanism responsible for degradation**

# X-ray Imaging Shows Some Differences in Thermally Cycled Device



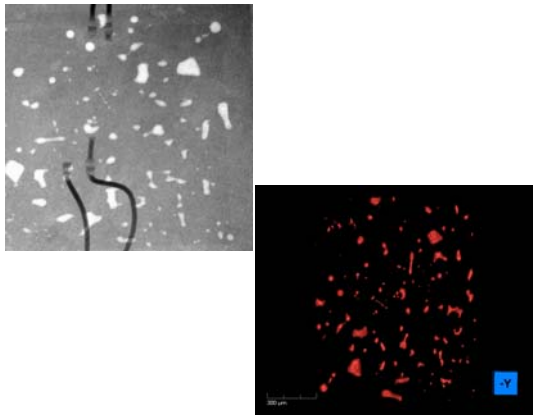
Typical Commercial Device (Decapped)



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$^{o}$C operation using vacuum soldering system
- Effect of steady-state exposure to 250$^{o}$C and the effect of thermal cycling on packages will be evaluated by thermally cycling from -65$^{o}$C to or 250$^{o}$C or higher
- Properties of solder joints and microstructure will be characterized

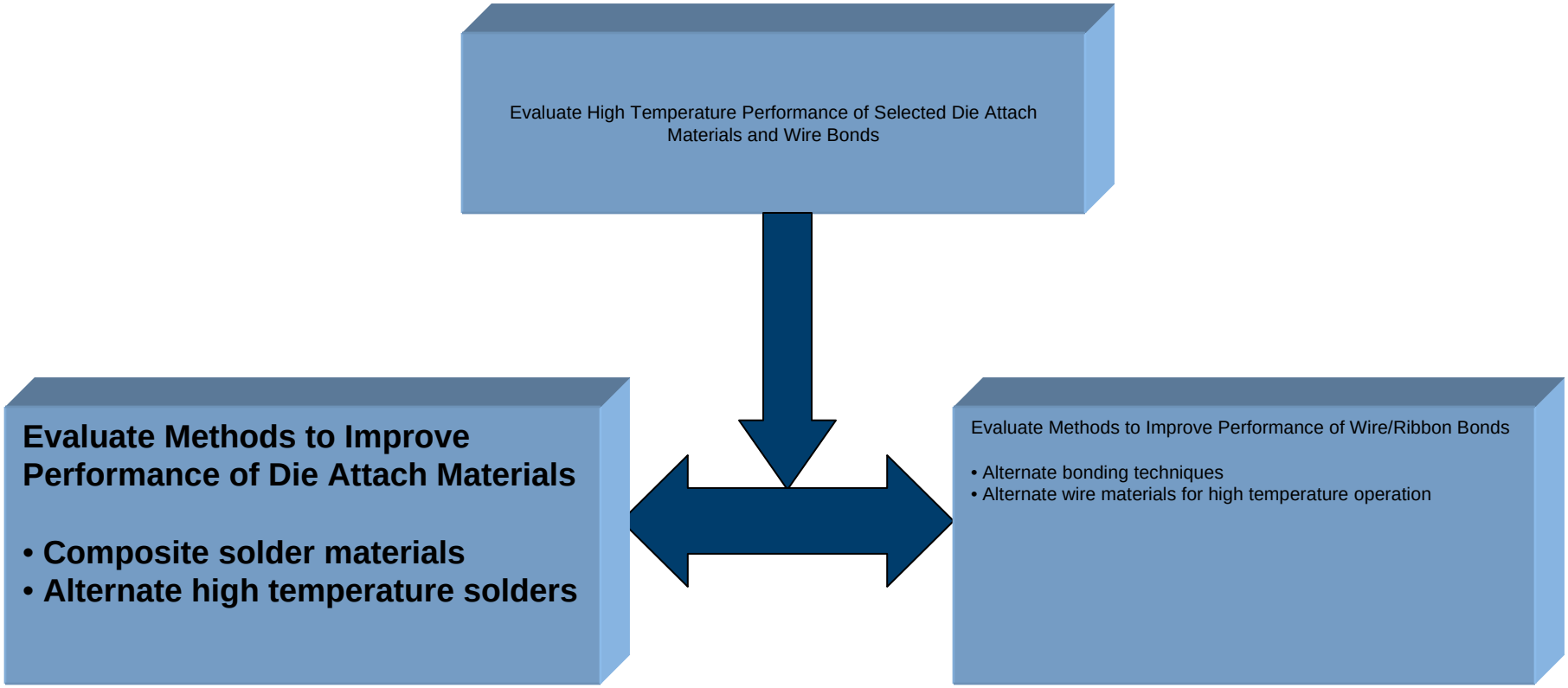


**X-ray Tomography of Voids in Processed Au-Sn Joints**

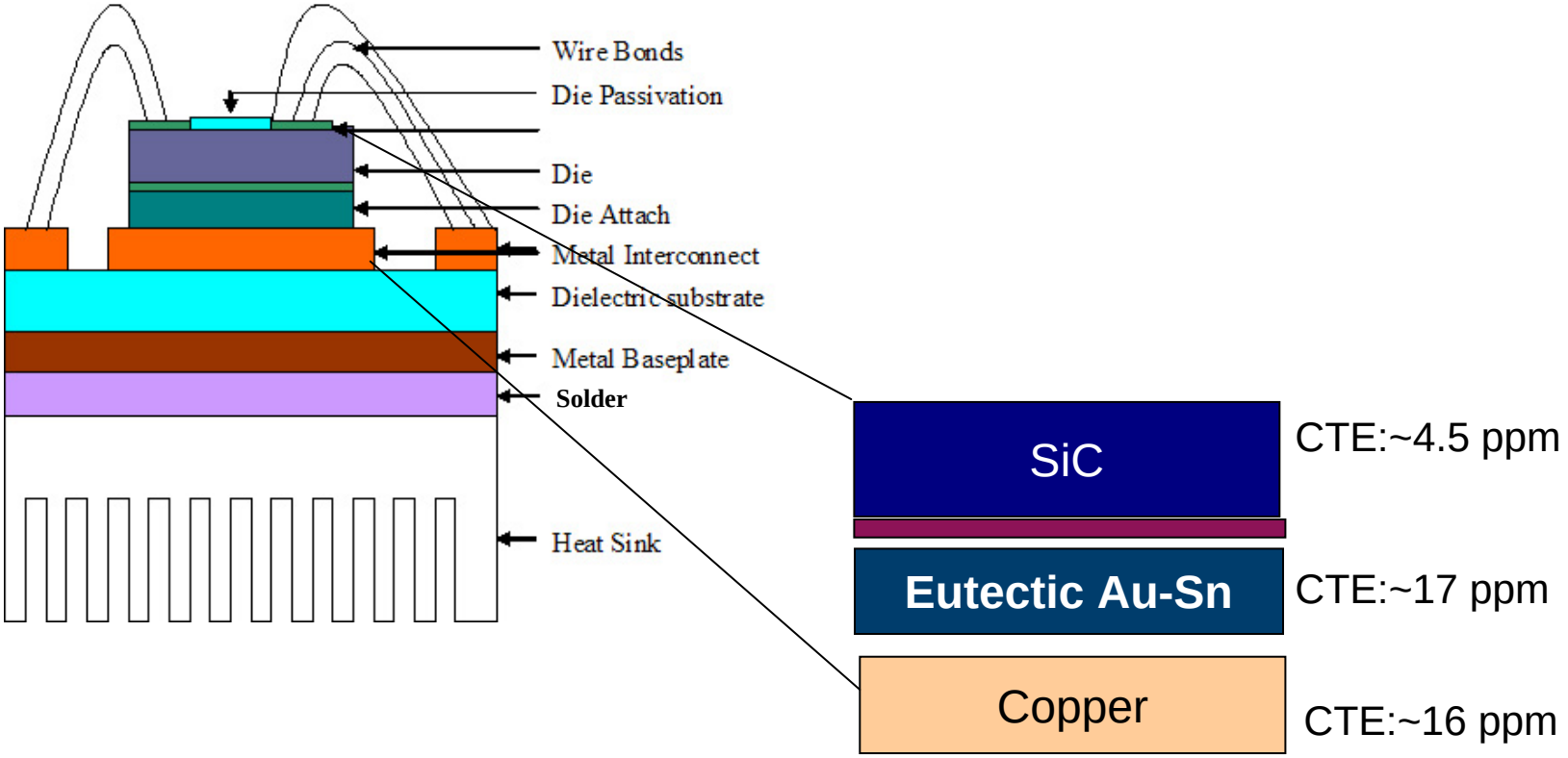
**Vacuum Solder Reflow System for processing void-free joints**

# Improving Reliability of Die Attaches

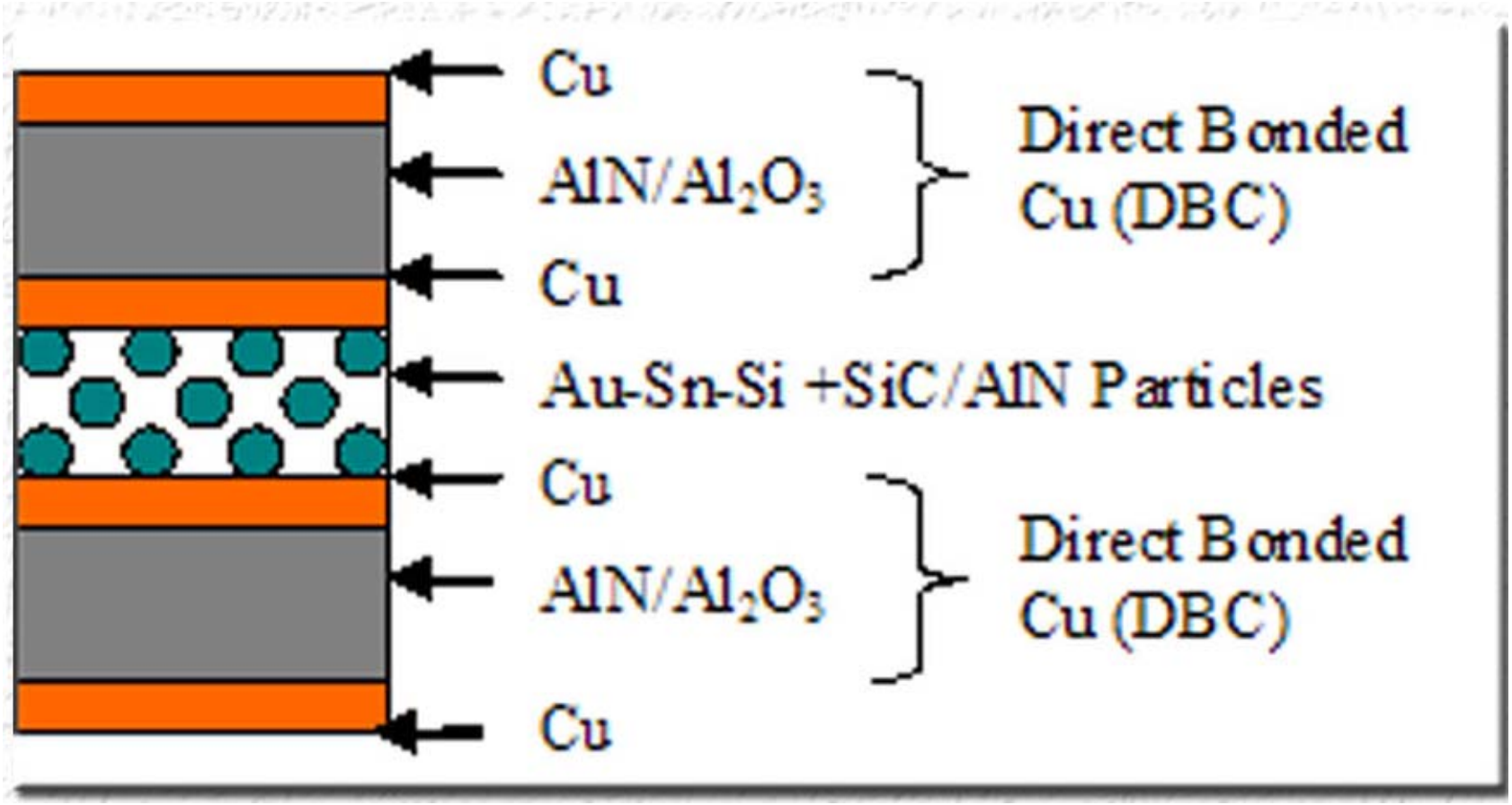
**Two major causes for failures of commercial power packages are wire bonds and die attaches**



# CTE Mismatch Occurs Across Die-Attach

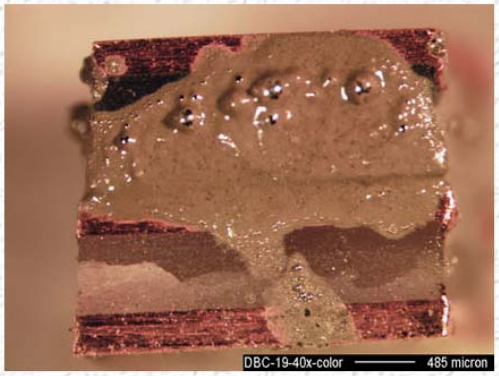


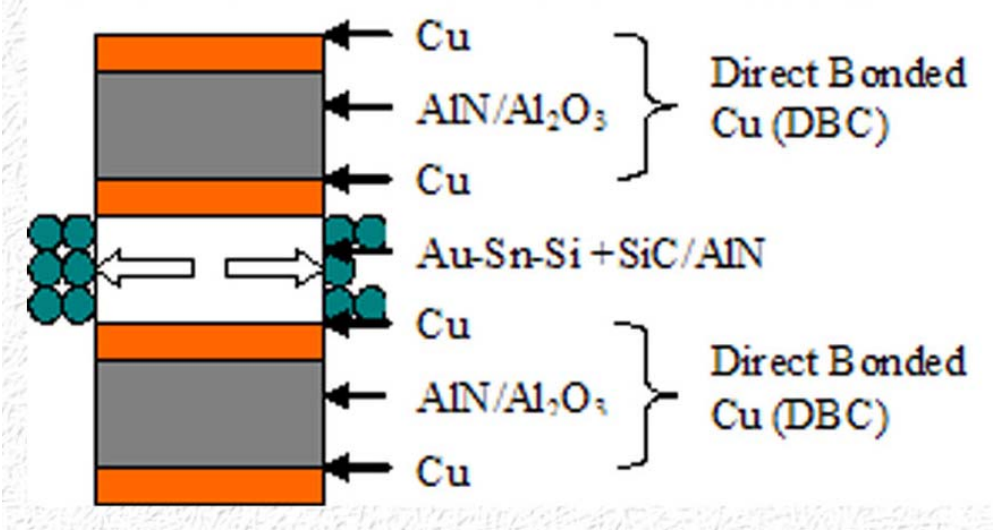
# Composite Solder Joints Will Reduce Thermal Expansion Coefficient Mismatch



# 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**