Materials Compatibility of Power Electronics

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Overview—Technical Work Has Been Ongoing For Approximately Two Years

Timeline

- Start – March 2008
- End – Sep 2010
- Percent complete – 70%

Budget

- Total project funding
  - DOE – $493K
- Funding in FY08 -- $200K
- Funding in FY09 -- $175K
- Funding for FY10 -- $118K

Barriers

- Barriers addressed
  - A. Cost of high temperature integrated power electronic (HTIPE) systems
  - D. Abuse tolerance and ruggedness of HTIPE systems
  - E. Weight, volume and thermal control of HTIPE systems

Objectives Addresses Needs Within the Propulsion Materials Program

- Develop and validate a laboratory methodology to evaluate the degradation of power electronics materials/components by evaporative cooling liquids
  - Direct cooling of components will allow for reduction of weight and volume of systems
  - Methodology will allow for expression of abuse tolerance and ruggedness of HTIPE

Milestones—Are Focused On Addressing Performance

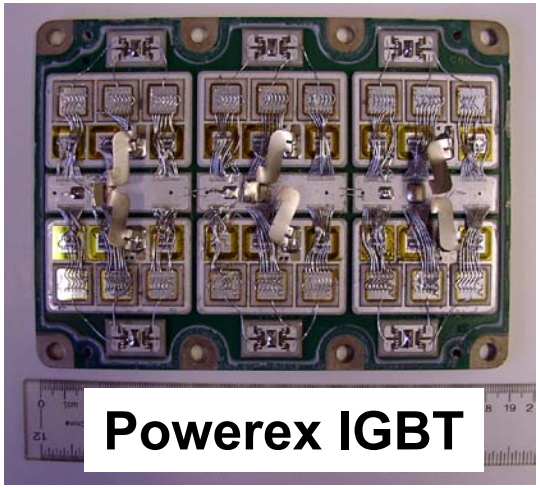
- **Develop methodology to evaluate the interaction of the power electronic components with the fluids used in the evaporative cooling systems. Initiate testing of methodology (09/08)** ***Achieved***
  - **Built test system and acquired commercially produced test specimens**
  - **Initiated testing**
- **Validate the proposed methodology for examining the interaction of the electrical components with evaporative coolant. (09/09)** ***Achieved***
  - **Collected and evaluated test data**
  - **Modified test parameter**
  - **Related data to material/component performance**
  - **Define "go/no-go" of failure as related to materials/component performance** ***Material Failure Demonstrated***

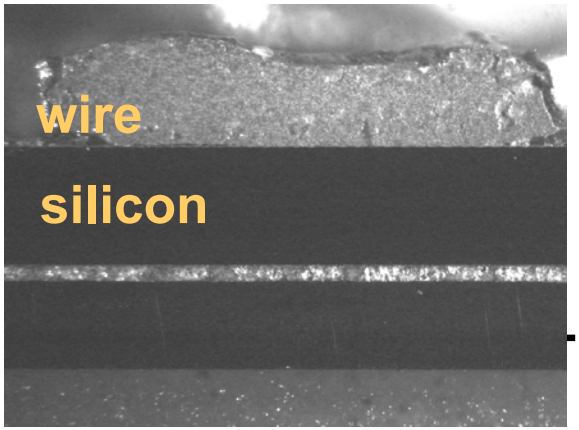
Milestones—Are Focused On Addressing Performance

- **Initiate mapping of materials compatibility space of power electronics with appropriate evaporative coolant. (09/10)** ***On track***
  - **One coolant**
    - **No consensus on what will replace R134a**
  - **Two configurations (circular and rectangular cross-sections) of wires**
    - **Does similar material failure mode occur**
  - **Refine "go/no-go" criteria of failure**
    - **Separate effects due to methodology from that due to coolant**
      - **Variables include coolant, current, cycle time**
  - **Confirm feasibility of cooling approach and develop minimum test data that allows for a meaningful dialogue with system designers**

Compatibility Addresses Barriers/Design Criteria of Automotive Industry

- Barriers to deployment of power electronics (PEs) are:
  - Weight, size, reliability and cost
- Approach to decrease weight, size, and cost of PEs is to use:
  - Direct cooling of PEs by side-stream cooling from existing air-conditioner (A/C) systems using R134a refrigerant
    - Reduces weight of PEs
    - Eliminates secondary cooling system
- Direct side-stream cooling necessitates evaluation of PEs compatibility with and reliability in the coolant





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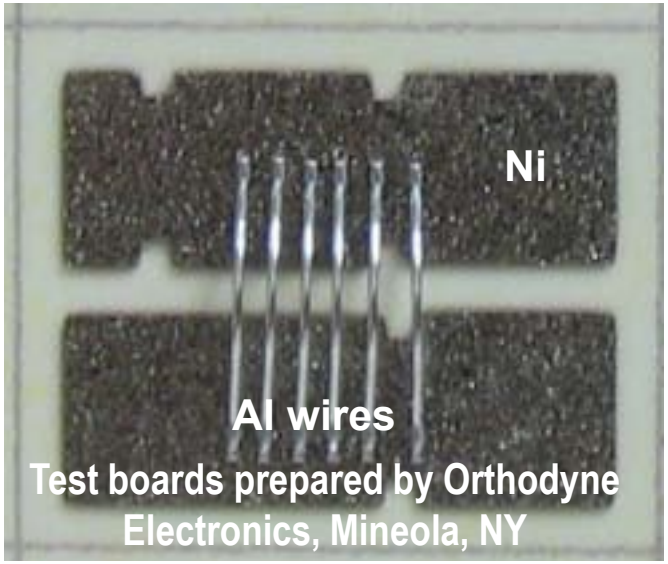
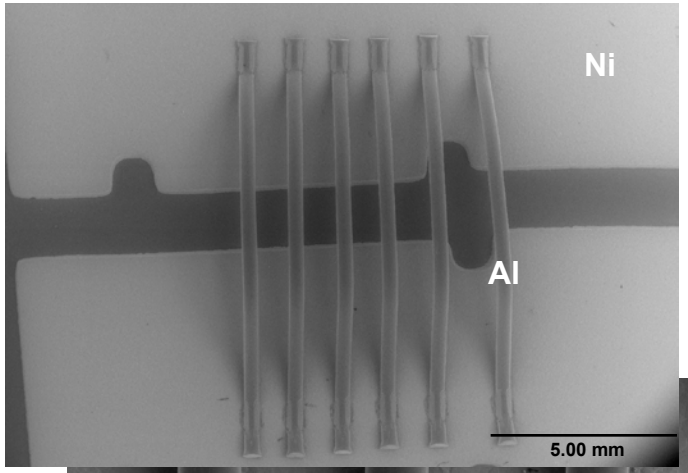
In Addition, Because of the Anticipated Low Reaction Rates in R134a, An Accelerated Test Was Sought

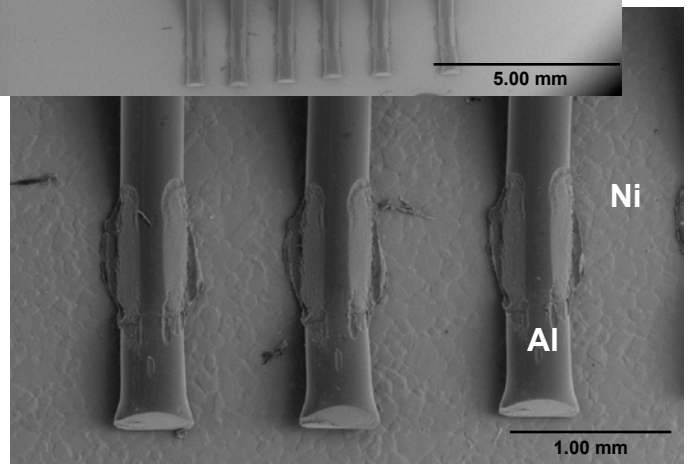
- Mimic in service use
- Exacerbate nucleate boiling effects
- Maximize effect of impurities
- Aggravate thermal mechanical stress
- But does not change the in-service failure mechanisms



An Integrated Approach to Compatibility Issues Has Been Developed

- Effect of coolant on the PEs materials
  - Aluminum, nickel (general corrosion)
  - Bonds of aluminum and nickel (galvanic corrosion)
  - Polymeric materials
- Effect of nucleate boiling on the surface of the metals
- Effect of impurities in the coolant
  - Off-the-shelf or a result of interaction with containment materials
- Effect of thermal stress on the PEs materials
- Evaluation of synergistic effects

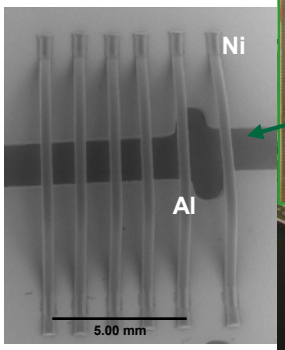




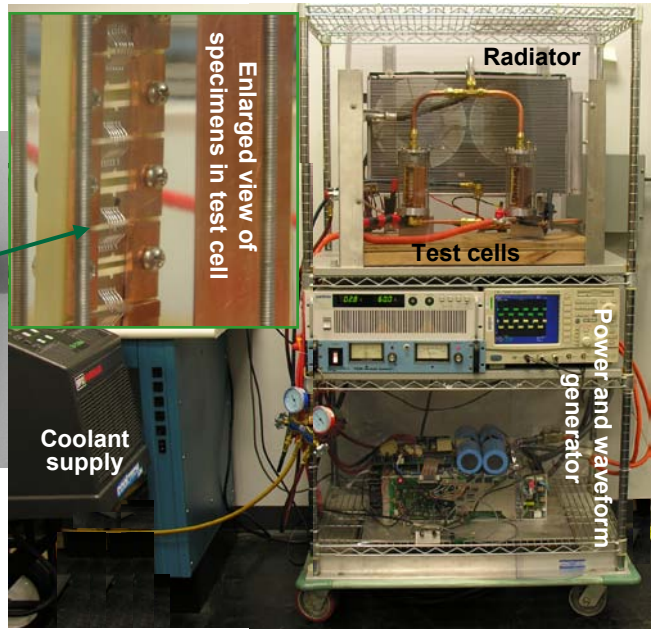
- Bonds all show uniform contact area and deformation associated with the bonding process

A Test System Was Designed and Built for Accelerated Evaluations

- Allows for high current flow and shaping of the current wave form
  - A square wave of one second on and one second off is driving 10 amperes through each 0.4 mm (400 microns) diameter aluminum wire
- Data recording
- Visual observation of the boards
- Post exposure evaluation of effects of resulting nucleate boiling on the aluminum bonds

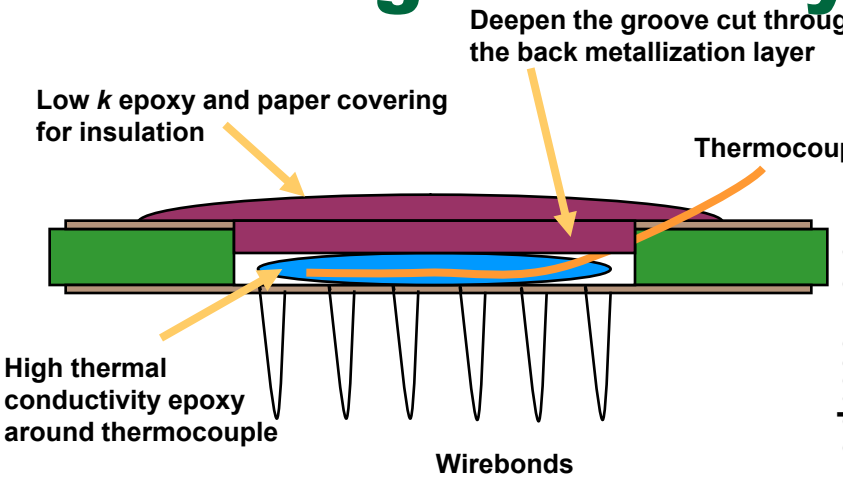


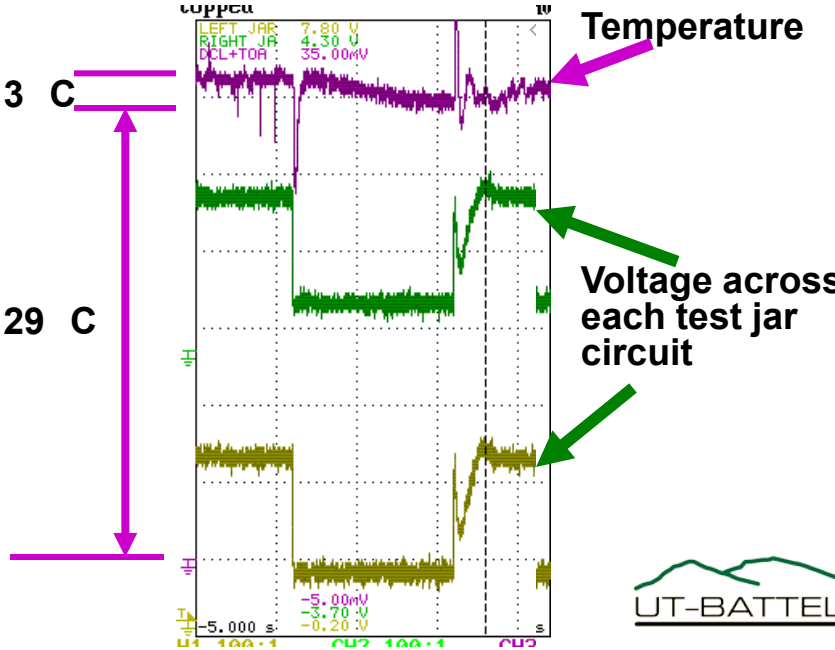
Wirebonds



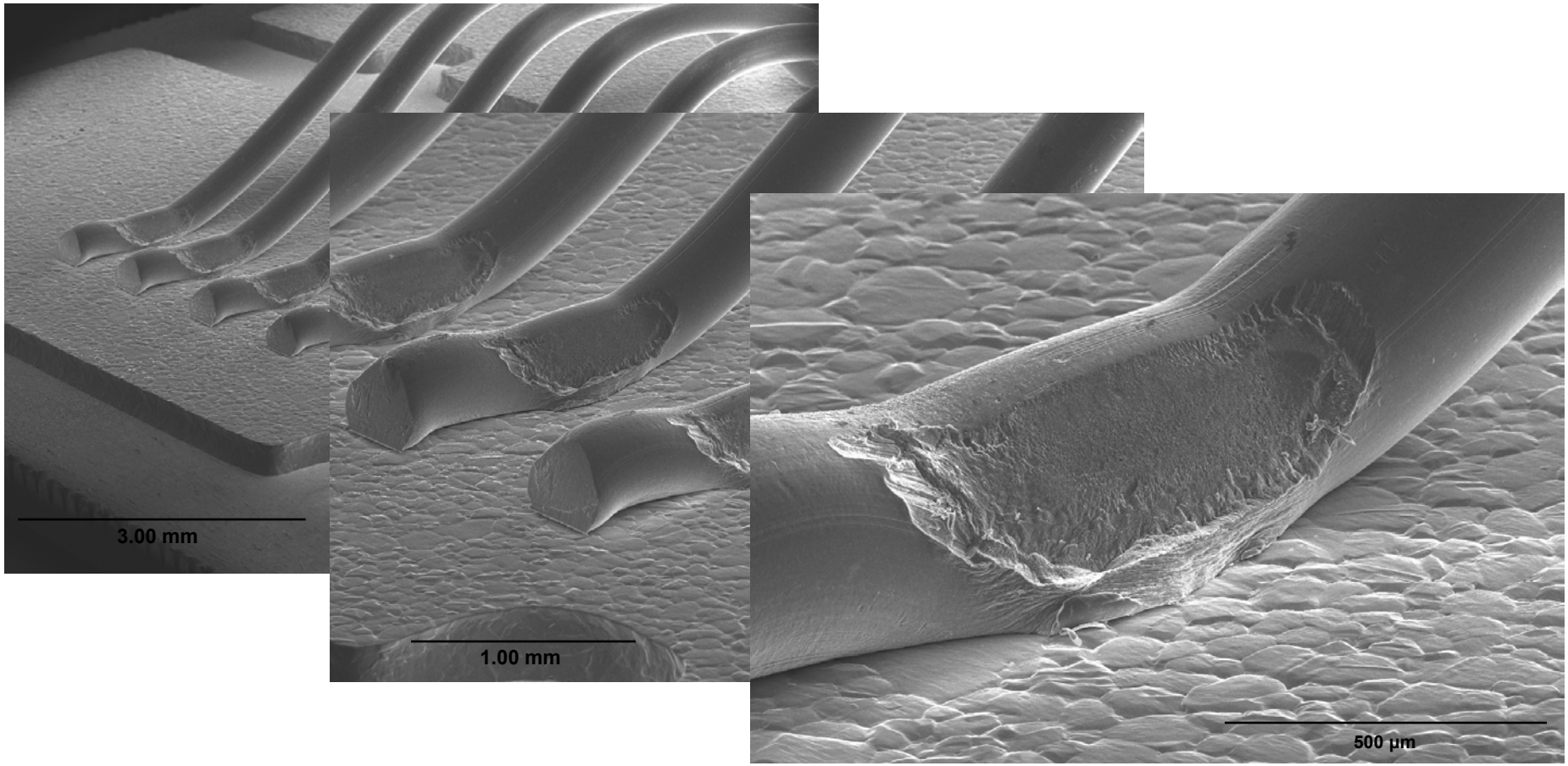
Temperature Measurements Allow For Correlating Current Changes To Temperature Swings And Testing Flexibility

- Measure temperature change
  - Actual temperature measurements in evaporative cooling is inherently difficult
- Increase test current
  - Testing at 50% greater peak current per wire reported for available hybrid auto inverter
- Increase current on time of waveform
  - A square wave of two second on and two second off is driving 30 amperes through each 0.4 mm (400 microns) diameter Al wire



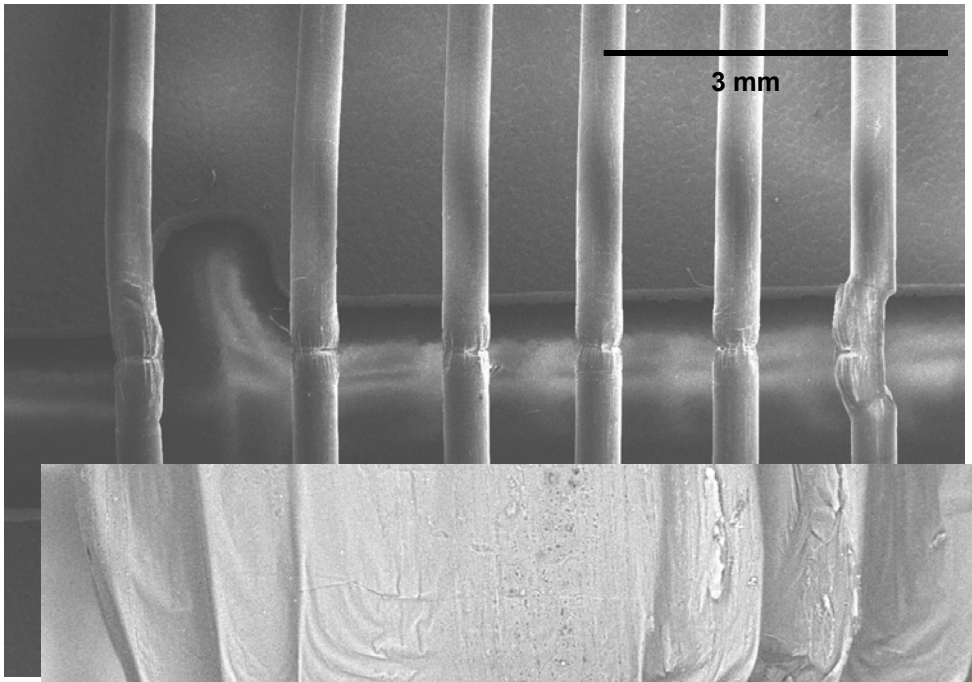


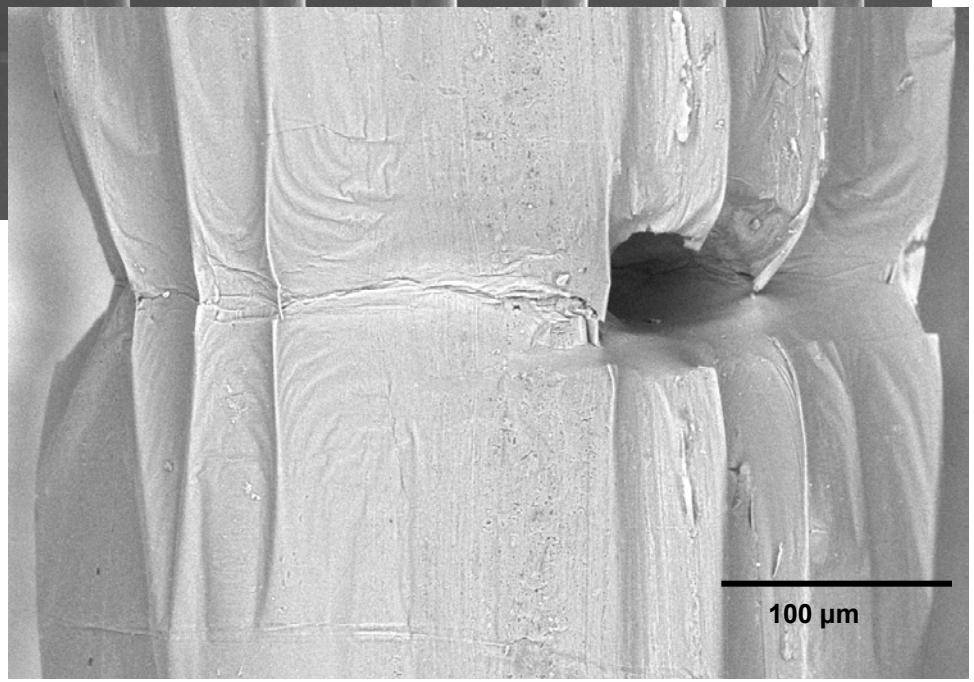
There Were No Observable Environmental Effects On Wires Or Board After 690,570 Test Cycles Of One Second On (10 Amperes) And One Second Off

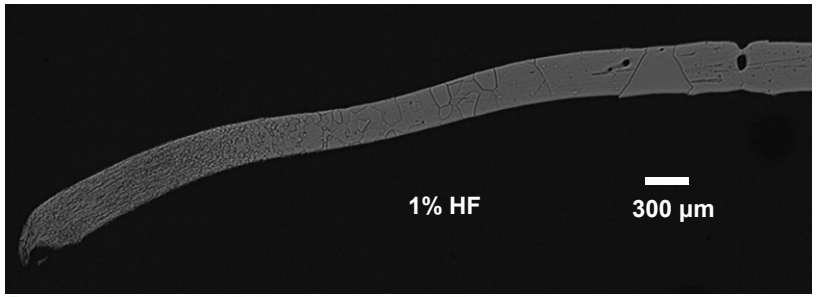


However, Changes Were Observed After 932,770 Cycles Of 2 Seconds On (40 Amperes) And 2 Seconds Off

- Deformation of wires
  - Especially at crown
  - Possible pore formation
- Recrystallization and grain growth
  - Few grains across diameter of Al wire at the crown







Recently, Testing Up To 933,400 Cycles Of 2 Seconds On (39 Amperes) And 2 Seconds Off Have Been Completed

- Evaluate significance of current value
  - Initial optical evaluation did not reveal the massive deformation seen at 40 amperes
  - Detailed microstructural evaluation will be performed
- Modifications for testing of rectangular cross-section wires is being pursued
  - Current density limitations

The Evolving Methodology Allowed For Expression Of Failure & Accelerated Testing

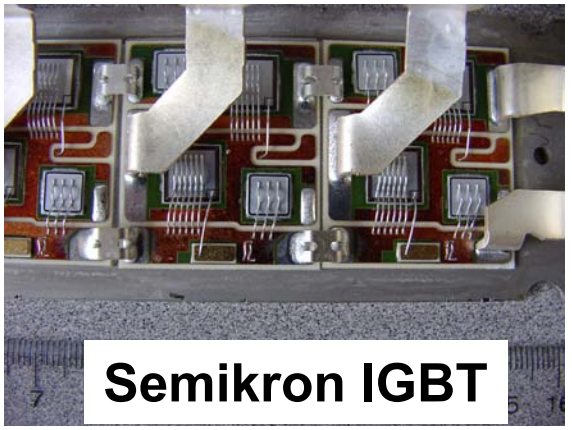
- Work continues to determine the relationships between the morphological changes
  - Changes in grain size and structure, and the failure at the crown of the wires
- Final failure occurs as a result of the wires achieving a critical heat flux (CHF) at the crown
  - Under CHF conditions, the vapor filled bubbles cannot transport themselves away fast enough to allow for cooling in the region
  - Insulation provided by the vapor reduces the cooling at this site and the crown melts
- Basis of "Go/no go" criteria is changes in microstructure which then leads to the critical heat flux situation

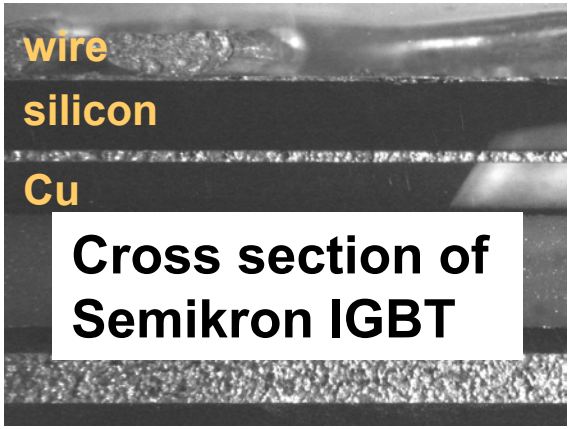
Future Work—Continue As Needed Enhancements

- Use more prototypic boards
  - Refine “go/no-go” criteria of failure
- Develop minimum test data that allows for a meaningful dialogue with system designers

Successful Demonstration of Compatibility of Direct Side-Stream A/C Cooling With Power Electronics Allows For:

- PEs concepts that reduce the component count and integrate functionality to decrease size, weight, and cost





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