



# Physics of Failure of Electrical Interconnects



*U.S. Department of Energy  
Vehicle Technologies Program  
Annual Merit Review*

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**Project ID: APE036**

This presentation does not contain any proprietary, confidential or otherwise restricted information

# Overview

## Timeline

- Project start date: FY11
- Project end date: FY13
- Percent complete: 10%

## Barriers Addressed

- Efficiency
- Performance and Lifetime

## Targets Addressed

- Efficiency
- Power Density

## Budget

- Total project funding
  - DOE share: \$300K
  - Contractor share: \$0
- FY11 Funding: \$300K

## Partners

- Interactions & Collaborations
  - Oak Ridge National Laboratory, Materion Technical Materials, Orthodyne Electronics
- Project lead: NREL

# Relevance (1/3)

- Automotive power electronic devices are moving toward higher power densities and more advanced thermal management techniques.
- Present electrical interconnect technology limits current carrying capabilities.
- Elevated temperatures ( $>150^{\circ}\text{C}$ ) and temperature cycling can degrade the performance and reliability of interconnects.
- The package size of power modules are being reduced and require more spatially efficient interconnects.

# Relevance (2/3)

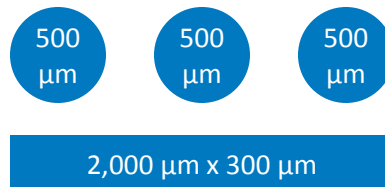
- Traditional interconnect technologies, such as wire bonds, do not sufficiently meet the needs of the latest power inverters, which function at high frequencies, high power densities, and elevated temperatures.
- Wire bond limitations:
  - Current-carrying density
  - Reliability from thermally induced stresses
  - Package size and geometry

# Relevance (3/3)

- A transition from round wire interconnects to ribbon interconnects provides many advantages.

Electrical Advantages	Mechanical Advantages
Higher current density	Higher shear and pull strength
Lower impedance and inductance	Lower profile and minimal sagging
Lower parasitics at high frequencies	Stacked bonding capability
	Ribbon width and thickness selected independently

For equivalent current density, three 500- $\mu\text{m}$  wires can be replaced by a single 2,000  $\mu\text{m}$  x 300  $\mu\text{m}$  ribbon.



# Objectives

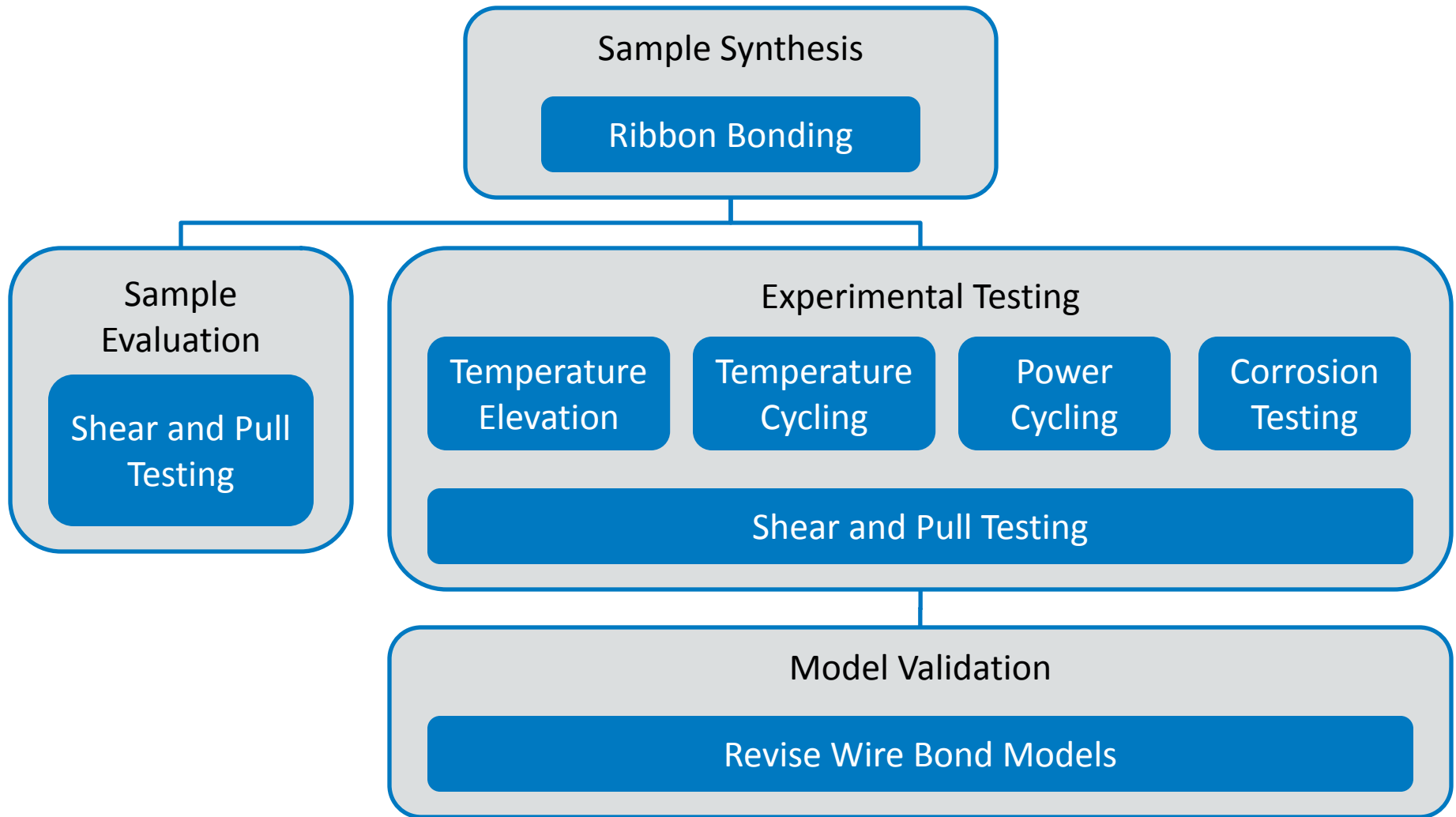
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- Test and model ribbon bonds to prove they exhibit equivalent or greater reliability than industry accepted wire bond technology.
- Demonstrate that ribbon bonds enable the required power density for high power inverters in automotive vehicles.
- Quantify ribbon bond advantages for design packaging of automotive power electronic devices.

# Milestones

Month/ Year	Milestone or Go/ No-Go Decision Point
December 2010	<ul style="list-style-type: none"><li>• Contact relevant industry partners for collaboration.</li><li>• Seek new technologies that promise higher current-carrying ability and reliability.</li></ul>
March 2011	<ul style="list-style-type: none"><li>• Finalize test geometry of ribbon bonds.</li><li>• Begin mechanical testing to determine initial ribbon bond strength.</li><li>• Begin thermal, power and environmental testing.</li></ul>
September 2011	<ul style="list-style-type: none"><li>• Report on mechanical reliability of ribbon bonds under testing and make recommendations to industry partners.</li><li>• Update wire bond models to be applicable to ribbon bonds.</li></ul>

# Approach



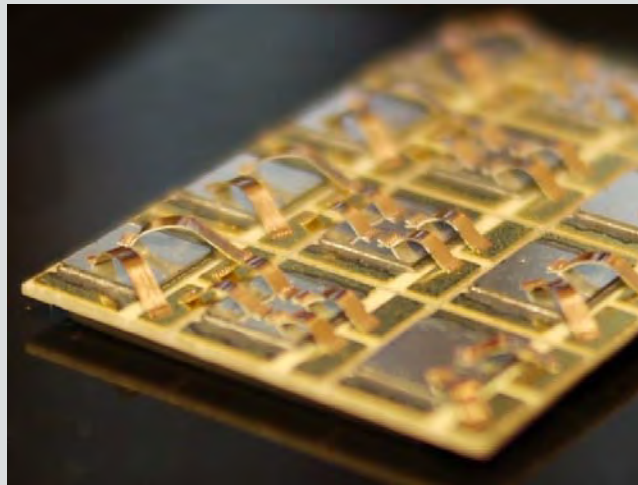
# Sample Synthesis

Ribbon Materials  
(Cu, Al, Cu/Al)

Ribbon Cross  
Section (2,000  $\mu\text{m}$  x  
200  $\mu\text{m}$ )

Ribbon Span and  
Loop Height

Test Sample



Credit: Douglas DeVoto, NREL

Pad Length and  
Number of Stitches

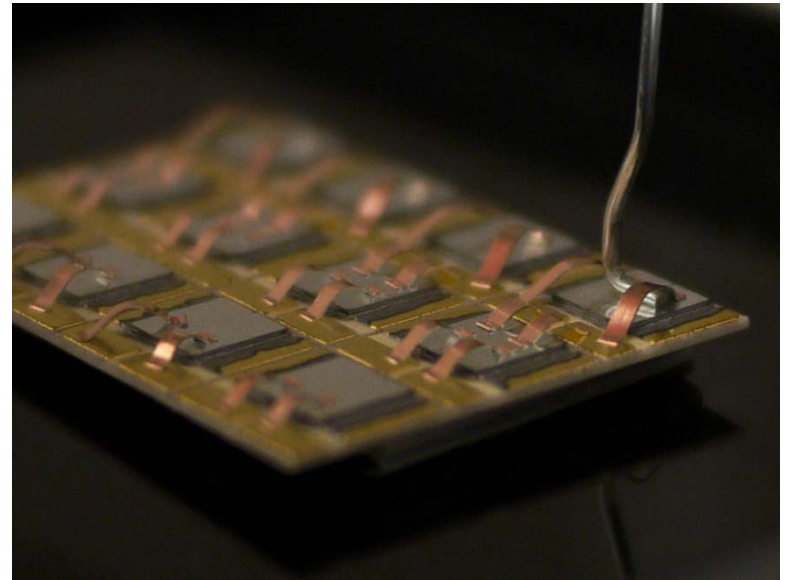
Stacked Pads

Forced Angle

# Sample Evaluation

- Initial sample evaluation with shear and pull testing provides knowledge of the bond strength.
- Ribbon pad shear testing evaluates the adhesion strength between the ribbon and substrate.
- Ribbon pull testing also indicates the strength of the ribbon bond. A strong bond will cause the ribbon to fail at its heel. A poor bond will cause the ribbon to lift off the pad.

Ribbon Pull Test



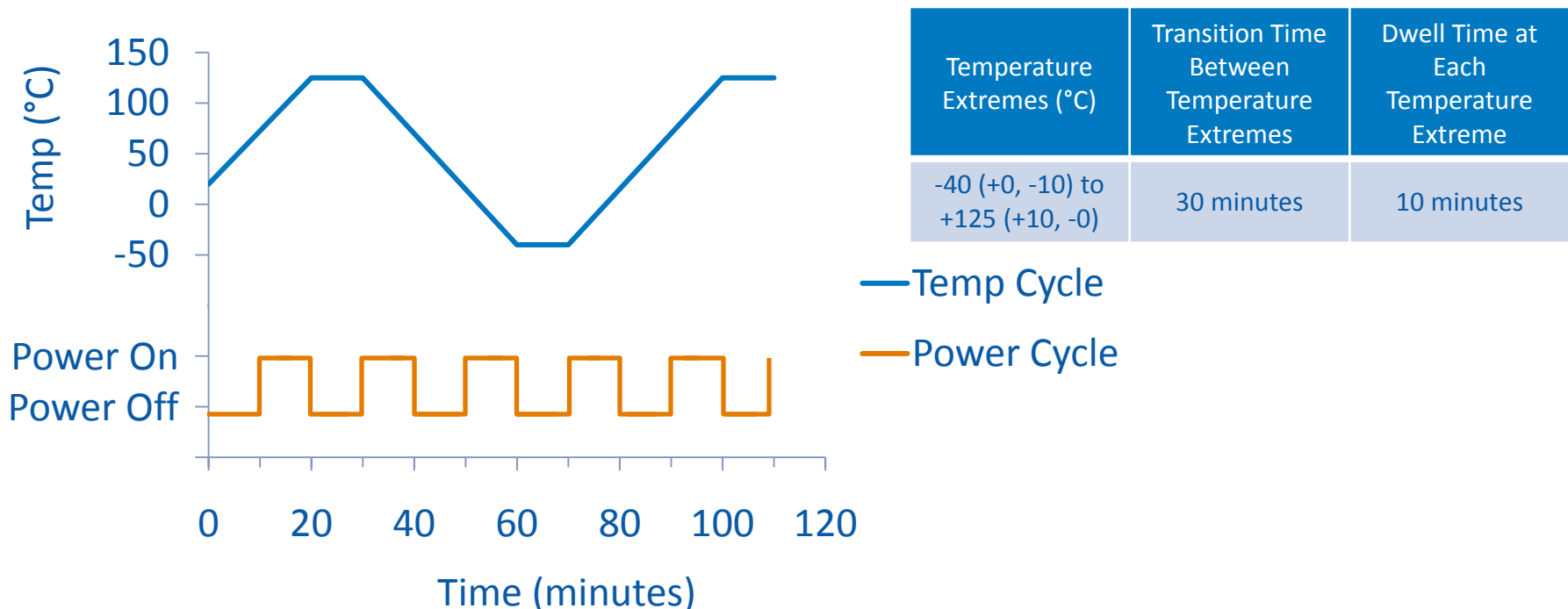
Credit: Douglas DeVoto, NREL

# Experimental Testing

- Temperature Elevation
  - Samples subjected to high temperature storage testing highlight thermally activated failure mechanisms.
  - Samples will be stored under two test conditions, at 150°C for 1,000 hours and 200°C for 96 hours.
  - Shear and pull testing will monitor changes to bond strength, and cross sectioning will monitor the development of intermetallic compounds.
- Temperature Cycling
  - Alternating temperature extremes will evaluate the ability for interconnects to withstand thermally induced mechanical stresses.
  - Samples will be cycled from -40°C to 150°C for 2,000 cycles, with ramp rates of 10°C/minute and dwell/soak times of 10 minutes.

# Experimental Testing

- Power Cycling
  - Interconnects will be subjected to a periodically applied operating bias while they experience high and low temperature extremes.
  - This test simulates worst case temperature conditions and will be conducted for 1,500 temperature cycles.



# Experimental Testing

- Corrosion Testing
  - A high humidity environment will determine the corrosion resistance of the ribbons and bonds.
  - Temperature humidity bias – Interconnects will be placed in an 85°C, 85% relative humidity environment for 1,000 hours. A DC bias will be applied.
  - Unbiased accelerated moisture resistance – Samples will be subjected to 121°C, 100% relative humidity environment for 96 hours. This is considered a destructive test.

# Model Validation

- Physics-of-failure (PoF) models identify the root cause of a failure, then provide a reliability estimation based on material properties, geometry, and environmental conditions.
- PoF assessment of wire bonds has led to the development of reliability models.
  - Bonding of dissimilar metals between the wire and pad causes intermetallic formation and Kirkendall voiding.
  - Wires subjected to thermal cycling undergo flexure due to thermal expansion mismatches between the wire, chip, and substrate. Models have been developed to predict the strains in the heel of the wire bond.
- Wire bond models will be adjusted for the new geometry of ribbon bonds.

Intermetallic formation between Au wire and Al bond pad.



Courtesy of Patrick McCluskey, UMCP

# Accomplishments

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- Industry partners have been selected for collaboration on ribbon bonding interconnect technology.
- Ribbon material and geometry have been selected for testing.
- Test samples have been synthesized and reliability testing has been initiated.

# Collaboration and Coordination

- Electrical & Electronics Tech Team (Industry)
  - Input on research and test plans
- Oak Ridge National Laboratory (National Laboratory)
  - Input on research and test plans
- Materion Technical Materials (Industry)
  - Industry partner for ribbon technology
- Orthodyne Electronics (Industry)
  - Industry partner for sample synthesis

# Future Work (1/2)

- Remainder for FY11
  - Determine ribbon bond strength through pull and shear tests
  - Complete thermal, power and environmental testing on ribbon bonds
  - Report on mechanical reliability of ribbon bonds under testing and make recommendations to industry partners
  - Update 2D wire bond models to be applicable for ribbon bonds

# Future Work (2/2)

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- FY12
  - Perform reliability testing and develop PoF models for additional interconnect technologies, such as planar interconnects
  - Apply PoF models to an actual application

# Summary (1/2)

- DOE Mission Support
  - Transitioning from wire bonding to ribbon bonding manufacturing will advance power electronics technology for compact, reliable packaging with higher current capabilities.
- Approach
  - Synthesis of ribbon bonds with varying material (Cu, Al, Cu/Al) and geometry (cross section, span and loop height, pad length, number of stitches, stacked pads, and forced angles) parameters.
  - Comprehensive reliability testing, including temperature elevation, temperature cycling, power cycling and corrosion testing.
  - Revision of wire bond models to be applicable to ribbon bonding.
- Accomplishments
  - Industry partners have been selected for collaboration on ribbon bonding interconnect technology.
  - Ribbon material and geometry have been selected for testing.
  - Test samples have been synthesized, and reliability testing has been initiated.

# Summary (2/2)

- Future Work
  - For ribbon bonding interconnects
    - Determine ribbon bond strength through pull and shear tests.
    - Complete thermal, power and environmental testing on ribbon bonds.
    - Report on mechanical reliability of ribbon bonds under testing and make recommendations to industry partners.
    - Update wire bond models to be applicable for ribbon bonds.
  - Investigate reliability of additional interconnect technologies.
- Collaborations
  - Electrical & Electronics Technical Team
  - Oak Ridge National Laboratory
  - Materion Technical Materials
  - Orthodyne Electronics

# Contacts and Acknowledgments

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# Photo Credit

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Slide 14:

McCluskey, P. University of Maryland and National Renewable Energy Laboratory