Environmental Effects on Power Electronic Devices (Agreement 16307)

Andrew A. Wereszczak
Oak Ridge National Laboratory
Oak Ridge, TN 37831

25 February 2008

This presentation does not contain any proprietary or confidential information.

Outline

- Purpose of work
- Barriers
- Approach
- Performance measures and goals
- Technology transfer
- Plans for next fiscal year
- Summary

Purpose of Work

- By 2015 electric propulsion systems will need to deliver 55kW for short durations and 30kW continuously while using 105°C inlet coolant. The performance and capabilities of power electronic devices (PEDs) that comprise those systems are often limited by materials-related issues; this project works with the VTP's PEEM Program to study and resolve those issues.
- Characterize and interpret the complex relationship between environment (e.g., temperature, humidity, and vibration) and the performance of material constituents within PEDs.
- Model and interpret PED thermomechanical stress states.
- Optimize PED designs (i.e., seek to minimize stresses).
- Recommend alternative material constituents that will ultimately improve PED response, capability, and lifetime.

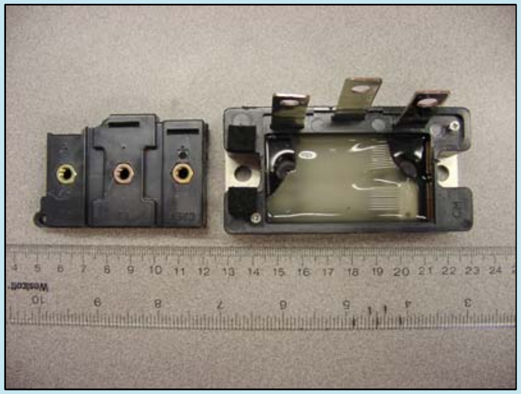
Barriers

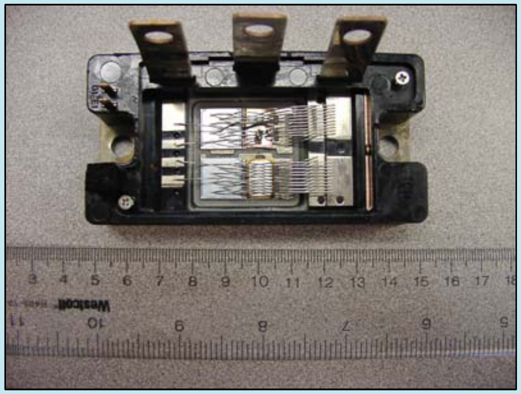
- Present PEDs only work up to ~ 125°C; they will need to operate to 200°C and eventually beyond.
- Anticipated higher temperature operation; need to reduce and dissipate heat more effectively.
- Present inverters too large; size (volume) reduction is needed.
- Multiple coolant loops occupy a lot of volume and there could be restrictions with the use of R134a refrigerant; need to utilize 105°C engine coolant and eliminate multiple coolant loops.

Approach

- Evaluate performance of PED constituents against temperature, humidity, and vibration, and understand failure mechanisms.
- Use finite element analysis (FEA) to evaluate thermal management effectiveness and seek means to improve it, its reliability, and its high temperature capability.
- Identify or develop alternative ceramic substrate materials that will improve PED performance.

Dissection of a Powerex 100A/1200V IGBT Module

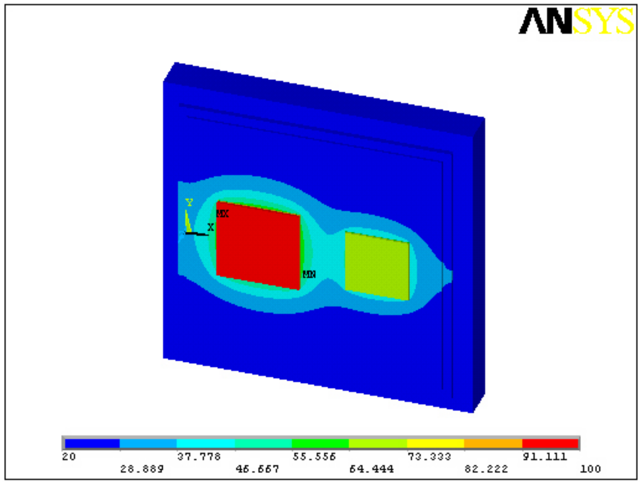




Performance Measures

- Recommend material substitutions or architectural changes in a PED that will sustain its ceramic substrate's mechanical reliability with a temperature increase to 200°C.
- Develop an alternative ceramic substrate material that has three times the thermal conductivity of Al_2O_3 but whose cost is less than 25% that of AlN.
- Assist in the development of an alternative PED cooling scheme that would decrease inverter volume by > 20%.

Example of a temperature profile about a silicon IGBT and diode



Accomplishments/Progress/Results

- Dissected several PEDs (IGBTs) to study their internal architecture and enable their thermomechanical FEA.
- Used FEA to contrast effects of mechanical properties and temperature gradients on thermomechanical stress states.
- Develop test matrix to mechanically evaluate Al_2O_3, BN, AlN, and Si_3N_4 substrates and acquired those materials.
- Developed test system that enables strength testing of ceramic substrates in WEG.
- Working with an established manufacturer to develop an alternative ceramic substrate material having high voltage breakdown, high resistivity, high thermal conductivity, low CTE, and relatively low cost.
- Collaborated with ORNL’s NTRC (Wiles, Ayers, and Lowe) to develop a concept for a direct cooled ceramic substrate.

Technology Transfer

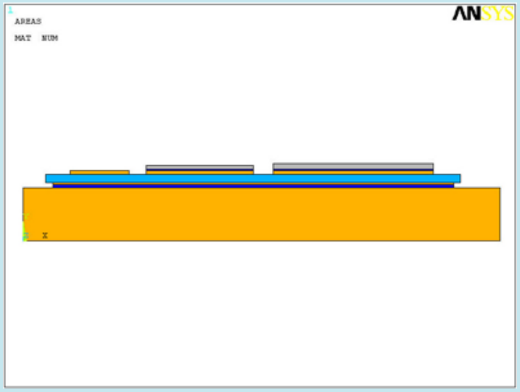
- Direct cooled ceramic substrate developed with ORNL's NTRC will enable more efficient PED cooling and with smaller volume. Invention disclosure submitted and its licensing is anticipated.

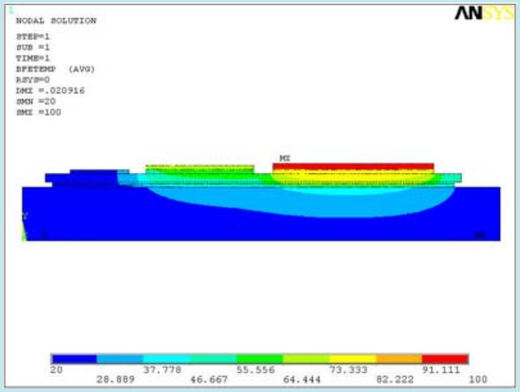
- An established ceramic manufacturer has been contacted about fabricating the alternative electronic ceramic that is under consideration and development in this project.

Activities for Next Fiscal Year

- Test competing PEDs under environmental test conditions and contrast their response.
- Predict reliability of silicon and ceramic subcomponents and contrast the reliability of different ceramic candidates.
- Refine ceramic designs of direct cooled ceramic substrate using FEA to minimize tensile stresses.
- Work with ceramic manufacturer(s) to further develop alternative electronic ceramic material for PED substrates.

IGBT Cross-section and Representative Temperature Profile





Summary

- Improved PEDs & their enabling technologies will ultimately lessen vehicle weight and increase mpg.
- PED constituents characterized.
- Choices of materials and architectures of PED constituents scrutinized for stress minimization.
- Direct cooled ceramic substrates & alternative ceramic substrate material to be available.
- Next year's planned efforts:
  - Comparison of environmental responses and reliability prediction of competing PEDs and their constituents.
  - Continued development of alterative electronic ceramic.
  - Design refinement of direct cooled ceramic substrate.

Publications, Presentations, Patents

- Invention disclosure: *Direct Cooled Power Electronics Substrate*, R. H. Wiles, C. W. Ayers, A. A. Wereszczak, and K. T. Lowe, ORNL/UTB, January 2008.