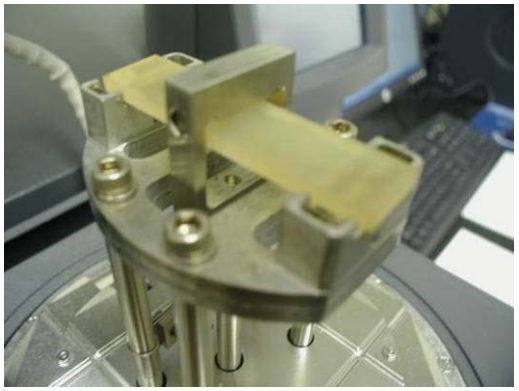

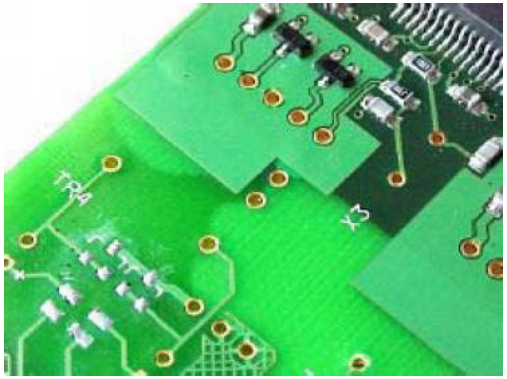

High-Temperature Circuit Boards for Use in Geothermal Well Monitoring Applications

May 19, 2010

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Composite Technology Development, Inc.

High-Temperature Tools and Sensors, Downhole Pumps and Drilling

Project Overview

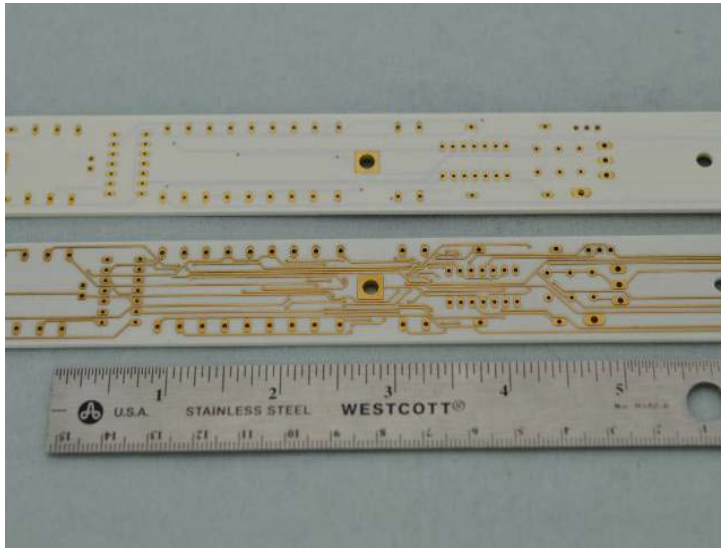
- Goal: Develop and demonstrate high-temperature, multilayer electronic circuits capable of sustained operation at 300˚C
- Timeline
  - Start date: Jan 2010
  - End date: Jan 2012
  - Total budget: $737,150
  - DOE share: $557,150, awardees share: $180,000
- Barriers: Barrier D, Site/Well Characterization
  - High-temperature logging tools
- Partners:
  - Calumet
  - A-Power
  - Sandia National Laboratory

Relevance/Impact of Research

- EGS wells can be up to 10 km beneath the surface and reach temperatures in excess of 300˚C
- Electronic packages are needed to enable the construction of data-logging tools for characterizing EGS wells
  - High-aspect-ratio circuits (e.g., 18” x 1”)
  - Measure temperature, pressure, etc.
  - Current materials and systems limited to 150˚C for long-term use, and 200-250˚C for short-term use

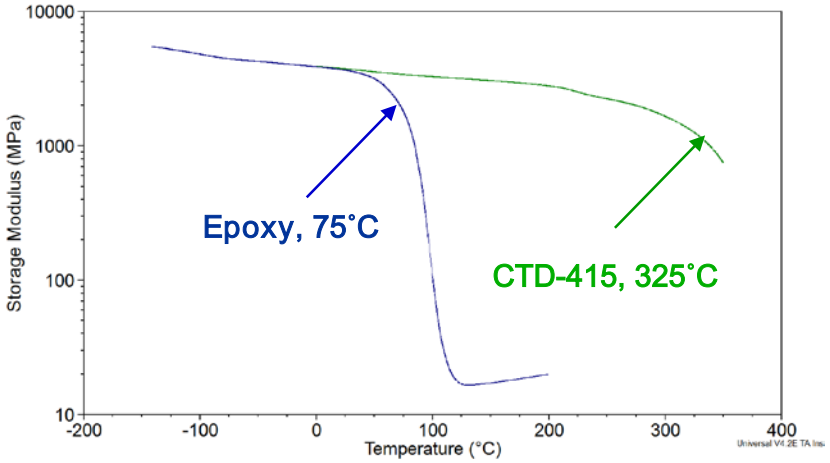
Scientific/Technical Approach

- Design and demonstrate multilayer circuit materials based on high-temperature inorganic and organic polymer materials
  - Thermal stability
  - Adhesion to copper (including after repeated thermal cycling)
  - Compatible with existing multilayer PC-board manufacturing processes
- Project tasks and milestones
  - Develop and characterize high-temperature multilayer systems (currently in progress)
  - Downselect best 2-5 systems (Month 6)
  - Fabricate and test 2-layer circuits
  - Downselect best 1-2 systems (Month 11)
  - Fabricate and test 6-layer circuits



Ongoing Activities

- Identifying high-temperature polymers for use in multilayer fabrication
  - Cyanate ester-based systems (e.g., CTD-415)
  - Inorganic polymers
- Builds on CTD experience in high-performance electrical insulations
- Evaluating copper/composite adhesion
  - Short-beam-shear test specimen
  - Initial shear strength at metal/composite interface
  - Measure shear strength after thermal cycling to 300˚C

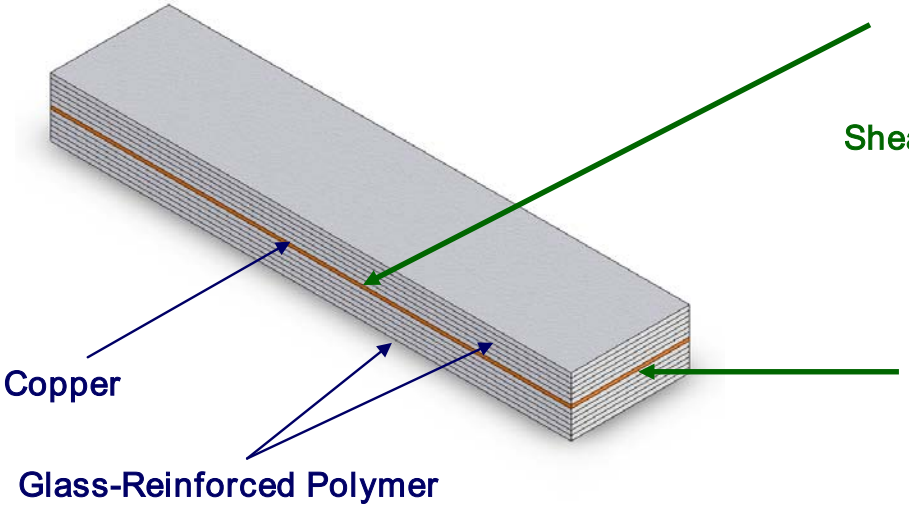


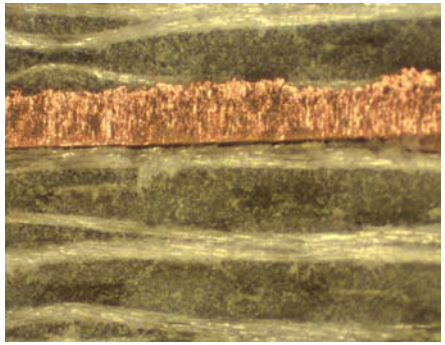
Inorganic composite insulation for cable applications

Copper/Composite Adhesion Test Specimen and Failure Modes

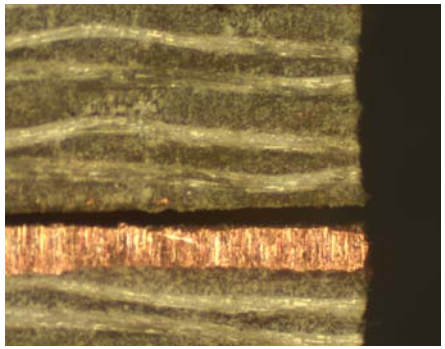
Short-beam-shear Test

- Destructive test to assess strength at interface
- Three-point mechanical loading
- Specimen design allows for thermal cycling and environmental testing





Shear failure along length of specimen



Shear failure at end of specimen

Project Management/Coordination

- Project management activities
  - Oversight of technical work
  - Establish priorities of technical staff
  - DOE reporting and documentation requirements
  - Budget management
- Coordination of work with collaborators
- Project integration
  - Leverages previous and ongoing work at Sandia on high-temperature electronics and downhole data logging
- Schedule
  - 24-month project, beginning Jan 2010

Future Directions

- Work planned for FY10
  - Complete evaluation of high-temperature materials
  - Fabricate 2-layer circuits (using a Sandia design)
  - Test performance of circuits to 300˚C
  - Downselect best multilayer systems for continued RD&D
- Work planned for FY11
  - Fabricate 6-layer circuits (using a Sandia design) based on FY10 results
  - Test performance of circuits to 300˚C to qualify materials for future use

Summary Slide

- High-temperature, multilayer circuit materials are being developed for use in EGS applications
- Project leverages ongoing commercial and DOE activities
  - High-performance, composite insulation development at CTD
  - Downhole data logging and test capabilities at Sandia
  - Compatible with conventional circuit manufacture
- Related markets and applications
  - Power electronics (including those for EGS and other downhole systems)
  - Automotive systems