Direct Cooled Power Electronics Substrate

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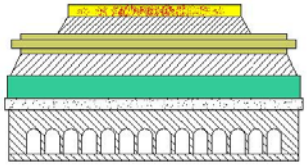
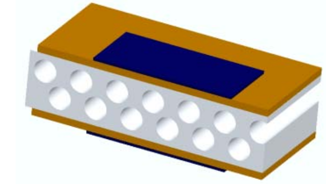
Project ID #
apep_09_wiles



Overview



Timeline

- Project start – Oct. 2007
- Project end – Sept. 2010
- Percent complete – 55%

Budget

- Total project funding
  - DOE 100%
- FY08 - $349K
- FY09 - $428K
- FY10 - $600K

Barriers

- Barriers
  - Sealing of substrates – Protection of electronics from water/ethylene glycol (WEG) coolant
  - Thermal growth – Stress levels inside substrate under thermal load
  - Strength degradation – Strength of ceramic substrate when in contact with flowing WEG
- Vehicle Technology Program Targets
  - DOE 2015 targets: 105°C Coolant
  - DOE 2015 target: 12 kW/l

Partners

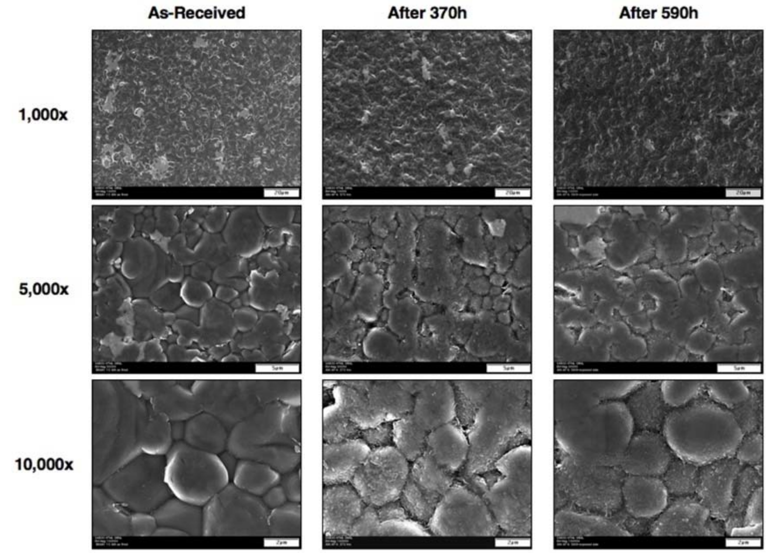
- CoorsTek – Ceramic Fabrication
- Aegis, Inc. – Substrate Plating
- Orthodyne Electronics – Ribbon Bonds
- NBE Tech., LLC. – Chip Soldering/Sintering

Objectives

- **High Temperature Coolant** - Develop a direct-bonded copper (DBC) substrate design to enable the use of silicon devices with 105°C water/ethylene glycol (WEG) coolant
- **Volume Reduction** – Unique substrate design allows for the maximum surface area to be utilized within the smallest geometrical volume.
- **Weight Savings** – A weight reduction of approximately 3 kg can be achieved by the removal of the traditional base plate and heat sink.
- **Power Densities:**
  - ~8 kW/l when using lower thermal conductivity ceramic substrates, and with a significant cost savings
  - ~14 kW/l when using high thermal conductivity ceramic substrates, but at a compromised cost

Milestones

- **FY08**
  - **Candidate materials and processing methods for the substrate design were identified; ceramic materials for optimum heat transfer were determined**
  - **Design parameters for computer models were established:**
    - Determined appropriate thermal load for 3-D simulations.
    - Justified the number of chips to use for specific designs.
    - Created the metrics needed for a successful design.
  - **Thermal finite element analysis (FEA) results were obtained on 5 designs**
    - Structural FEA results were completed on the preferred designs – Go / No-Go decision was favorable based on both structural and thermal results.
  - **Preliminary results of the compatibility of ceramic substrates with WEG shows**
    - Aluminum nitride (AlN) material not feasible.
    - Aluminum oxide (Al_2O_3) material is inert to WEG (high purity).
    - Silicon carbide (SiC) and silicon nitride (Si_3N_4) material is inert to WEG.



WEG impingement on AlN Surface Shows Evidence of Chemical Reaction. Such a Reaction Can Enable Erosion.

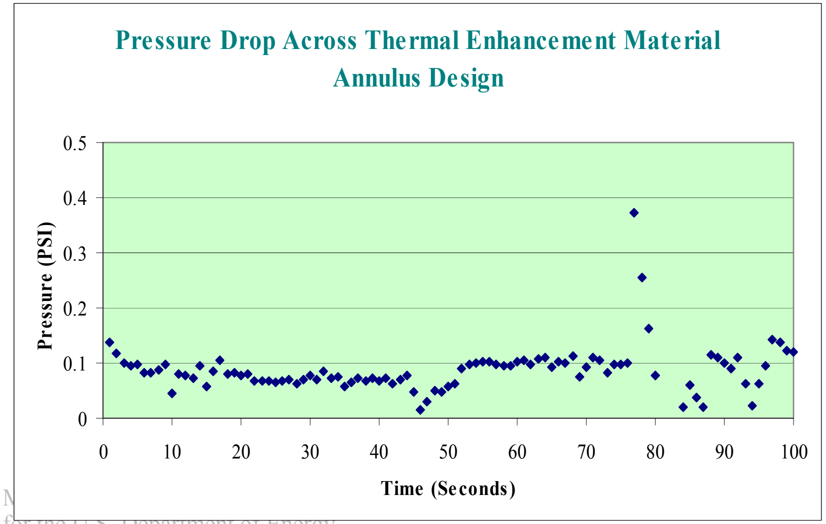
- **FY09**
  - **Ceramic substrates have been fabricated, metalized and chips have been soldered into place**
  - **Pressure drops in the coolant channels containing the thermal enhancement material were evaluated**
  - **Single module testing completed August 09 – Go / No-Go decision will be favorable if testing results are comparable to FEA results**

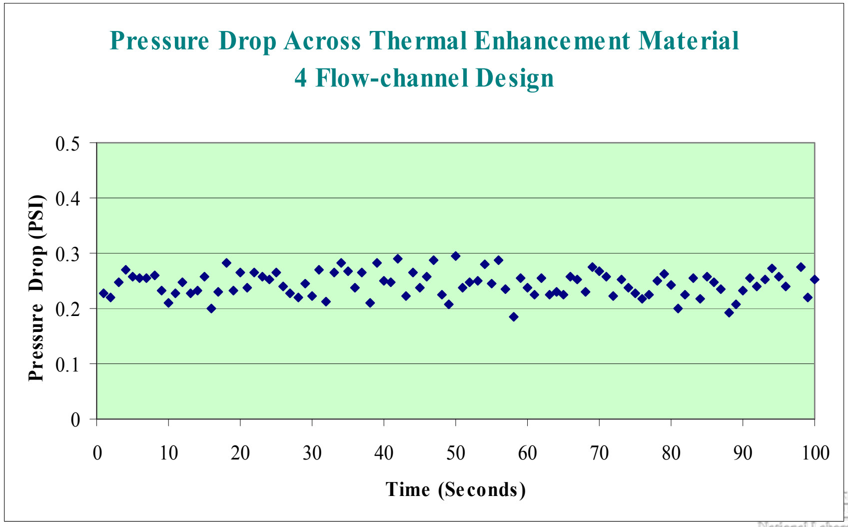
Technical Approach

- **Finalize design requirements for a single leg module:**
  - Perform final thermal finite element simulations on two substrate designs.
  - Compare FY09 test results with the final thermal finite element projections.
- **Assemble the single leg module:**
  - Work with manufacturer to produce ceramic substrates.
  - Finalize substrate assembly (including copper cladding, chip sintering, wire bonding, etc.).
- **Test assembled module:**
  - Install assembled module in test apparatus.
  - Test assembled module using 105°C WEG coolant.
  - Assess test results.
- **Prepare final design and testing report:**
  - Include proposed inverter design and module test results in the Vehicle Technologies Annual Report.

Technical Accomplishments

- FY09 testing incorporated the fabrication and assembly of designs 4 and 5. These substrate designs were metalized with copper, chips are soldered into position and ribbon bonds will be applied.
- Collaborative efforts include:
  - Aegis Technology is performing the brazing/metallization of the substrates and Ni/Au plating.
  - Chips were obtained from Infineon and Semikron.
  - Soldering/sintering of the chips will be a collaborative effort between NBE Tech., LLC. and ORNL.
  - Ribbon bonds will be applied by Orthodyne Electronics.





Future Work

- Finalize design requirements for a complete inverter:
  - Complete buss design and fabricate components for the inverter assembly.
- Assemble the complete inverter:
  - Fabricate the gate card and associated hardware for inverter testing.
  - Fabricate coolant flow headers.
  - Finalize substrate assembly (including copper cladding, plating copper substrate, chip sintering, wire bonding, etc.).
- Test assembled inverter:
  - Install assembled inverter in test apparatus.
  - Test assembled inverter using 105°C WEG coolant.
  - Assess test results.

Summary

- Candidate materials and processing methods for the substrate design were identified; ceramic materials for optimum heat transfer were determined.
- Design parameters for computer models were established.
- Thermal finite element analysis (FEA) results were obtained on 5 designs.
- Preliminary results of the compatibility of ceramic substrates with WEG shows Aluminum Nitride was not feasible. High purity Aluminum Oxide, Silicon Carbide and Silicon Nitride are all inert to Water/Ethylene Glycol.
- Ceramic substrates have been fabricated, metalized and chips have been soldered into place.
- Pressure drops in the coolant channels containing the thermal enhancement material were evaluated.
- Single module testing completed August 09 – Go / No-Go decision will be favorable if testing results are comparable to FEA results.
- Fabrication and assembly of a prototype single leg design is complete.
- Test prototype using 105°C Water/Ethylene Glycol coolant June 09.
- Review testing results, complete a preliminary inverter design, and evaluate the design based on the Vehicle Technology Program targets.
- Vehicle Technology Program targets addressed:
    - DOE 2015 target: 105°C Coolant
    - DOE 2015 target: 12 kW/l