NREL National Renewable Energy Laboratory
Innovation for Our Energy Future

Characterization and Development of Advanced Heat Transfer Technologies

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Overview

Timeline

- Project Start: FY 2008
- Project End: FY 2010
- Percent Complete: 66%

Budget

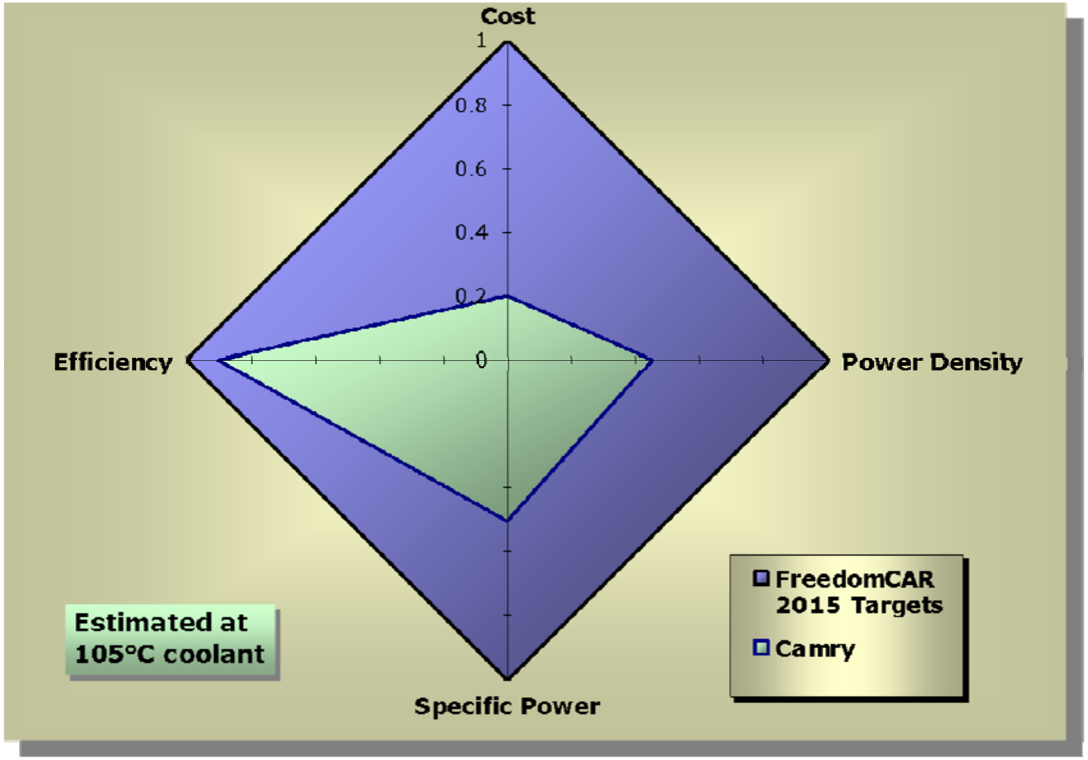
- Total Funding (FY07-FY10)
  - DOE: $**825**K
  - Contract: $0K
- Annual Funding
  - FY08: $375K
  - FY09: $450K

Partners/Collaboration

- Electrical and Electronics Technical Team (EETT)
- Semikron, Delphi
- Purdue University, University of Colorado, Wisconsin University
- NASA, ONR, IAPG

Barriers

- Cost ($/kW)
- Specific Power (kW/kg)
- Power Density (kW/L)
- Efficiency

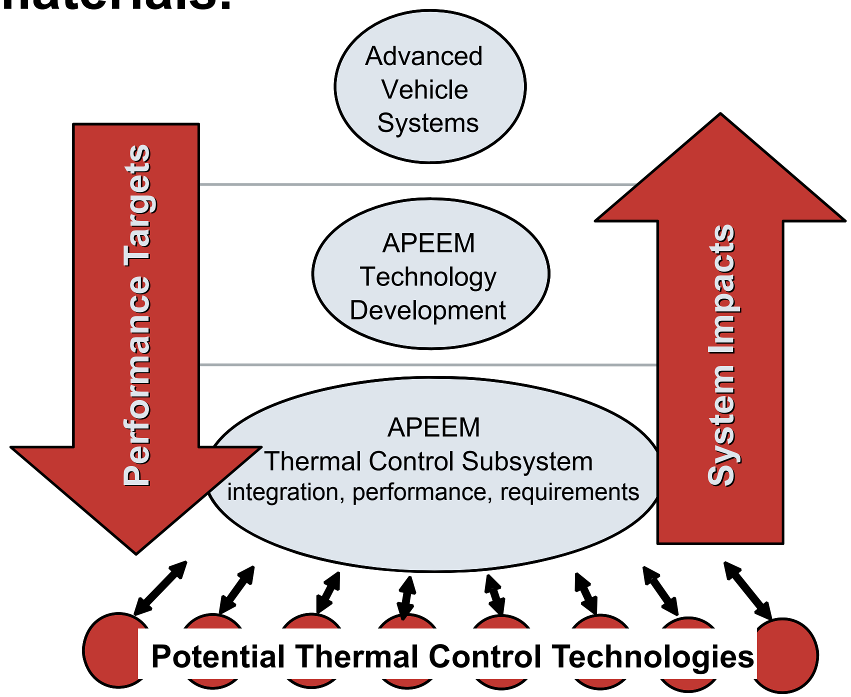


Problem Statement

- **Low-cost / high performance thermal solutions are critical to achieving program targets – increased power density, specific power, and lower cost.**
- **Many advanced heat transfer technologies focus on high performance but tend to add system complexity and cost.**
- **Automotive PE systems may be over-designed or de-rated to compensate for thermal limitations.**

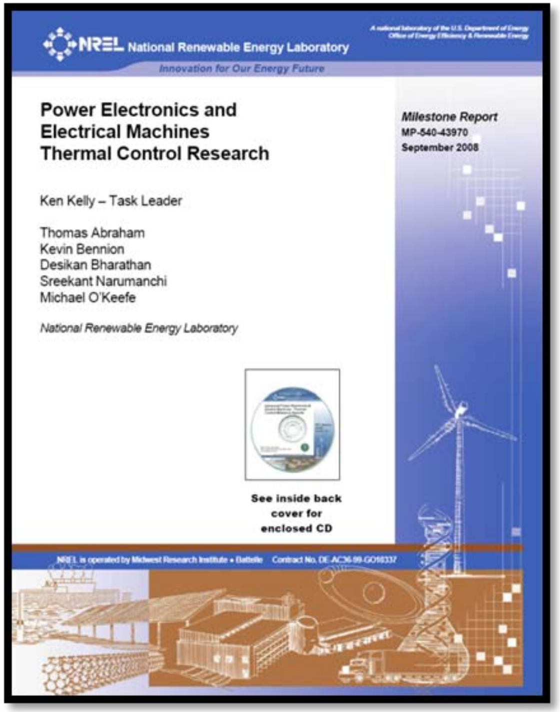
Objectives

- **Characterization and development of candidate heat transfer technologies which have the potential in enabling low-cost thermal solution for Automotive Power Electronics.**
- **Enable improved power density and system cost reductions through effective heat transfer performance in conjunction with lower cost materials.**



Characterize Performance
Develop Promising Technologies

Milestones (FY08 & FY09)



FY08

Report on status and results of the thermal control technology R&D (September 2008):

- Completed testing and evaluation of baseline elliptical pin-fin and low thermal resistance heat exchangers with Semikron inverter.
- Demonstrated Testing showed over 35% decrease in thermal resistance and improved temperature uniformity.
- Presented integrated modeling process to evaluate tradeoffs between thermal performance and low-cost material selection.

FY09

Evaluate potential for implementing low-cost materials with aggressive heat transfer (July 2009).

Report on status and results of the thermal control technology R&D (September 2009).

Approach

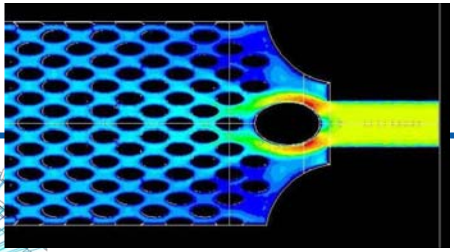
- Indentify potential heat transfer technologies through interactions with industry and research partners.
  - Literature search
  - Industry and research partner interactions

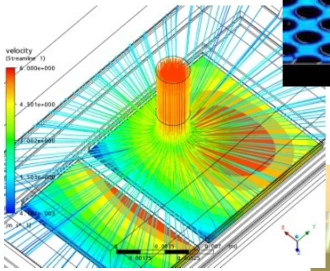
- Objective and consistent characterization of thermal performance of promising technologies relative to automotive requirements.
  - Move from fundamental to practical based solutions

- Development of most promising technologies based on automotive packaging and performance constraints with focus on enabling increase power density with lower system cost.
  - Design optimization with regard to industry partner requirements
  - Experimental characterization of final packaged prototype

- Transfer knowledge to industry partners.

Approach



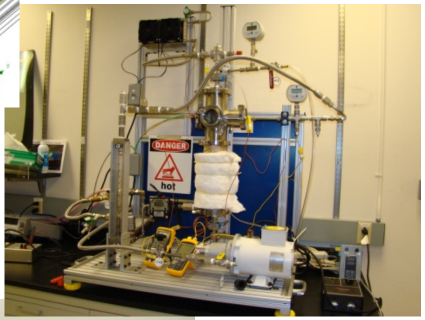


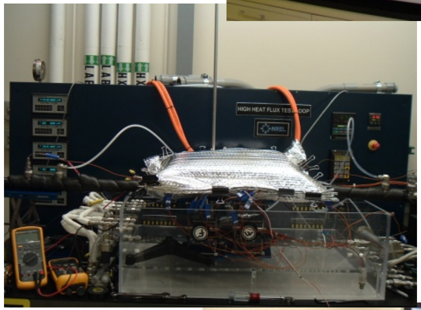
Improve PE device efficiency (ORNL)

Maximize base plate temperature
- PE materials selection
- Reduce thermal resistance

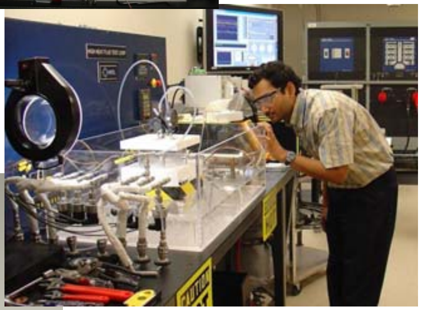
coolant temperature

$$Q = h\ A\ (T_B - T_C\ )$$

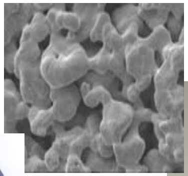


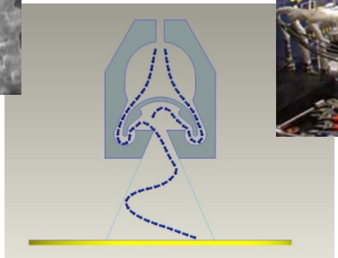


Increase surface area
-fin shape optimization
-double sided cooling
-surface enhancements
-thermal Spreading



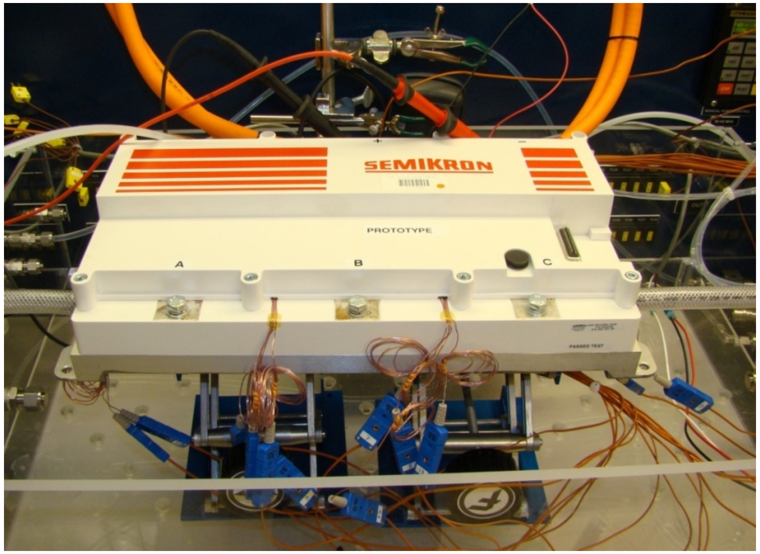
Enhance heat transfer coefficient
- jet / spray cooling
- self-oscillating jets
- phase change

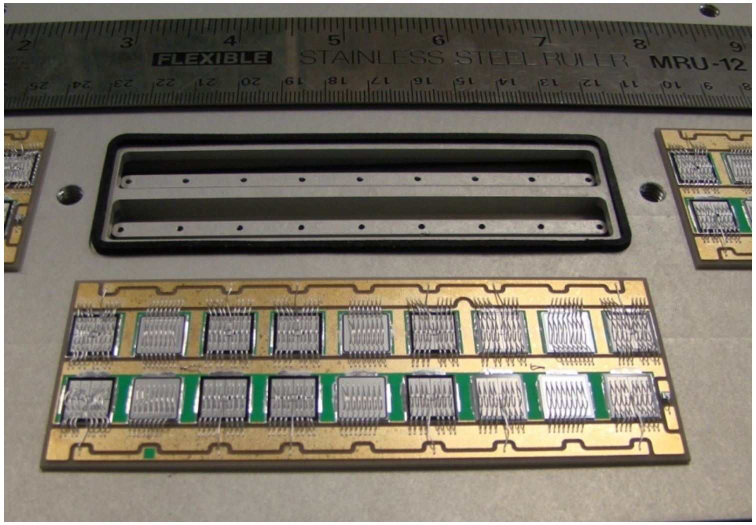




Technical Accomplishments

Low thermal-resistance structure for jet impingement cooling of power electronics





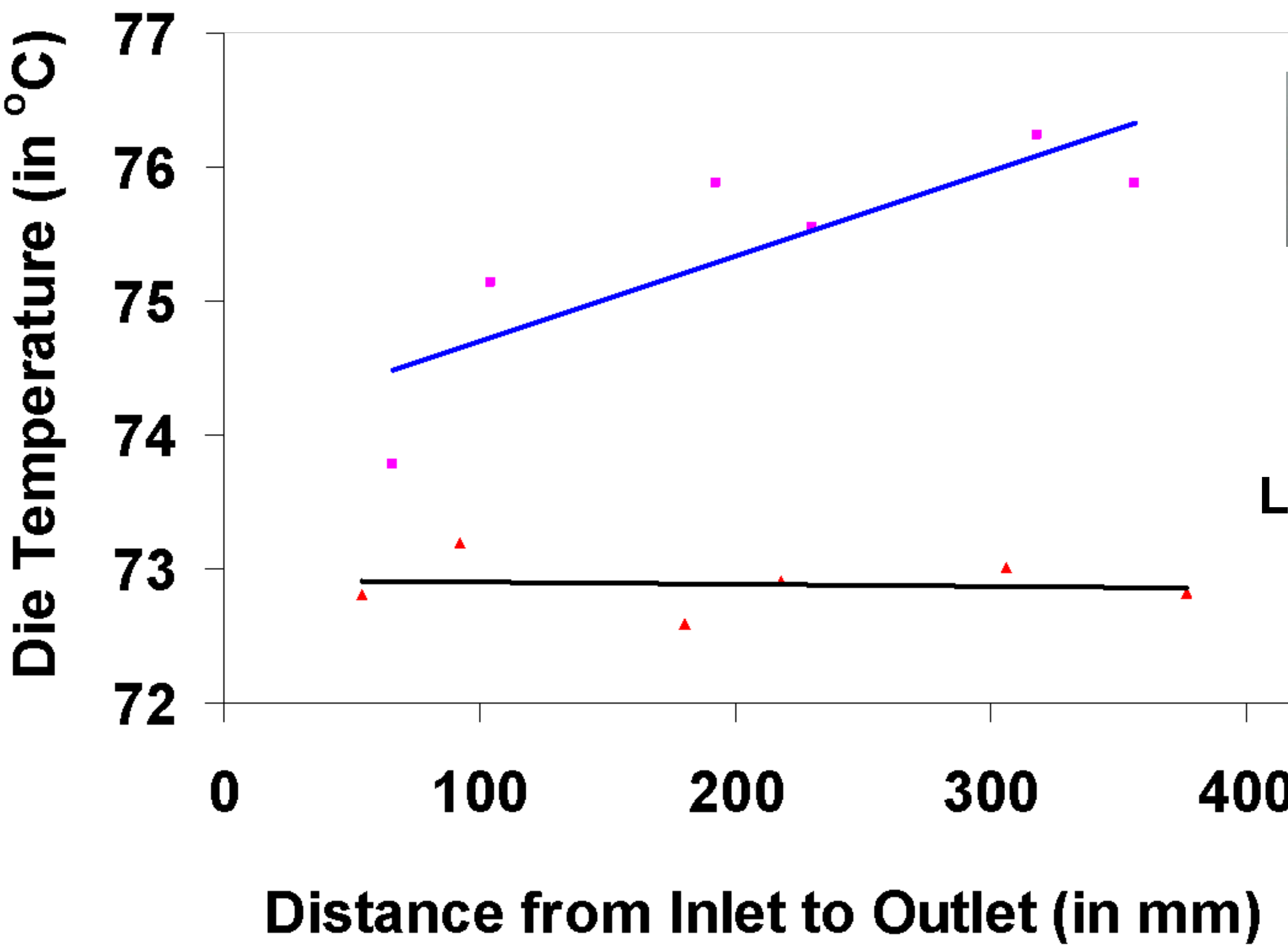
Completed testing of "Low Thermal-Resistance Power Module Assembly" demonstrated with Semikron inverter.

- Tests showed 35% reduction in overall thermal resistance (junction to coolant)
- Enables high temperature coolants
  - 200 W/cm^2 heat dissipation
  - 105 ^{o}C inlet coolant, Tmax = 150 ^{o}C
- Achieved thermal performance without increased pressure drop / parasitic power
- Improved temperature uniformity
- Elimination of TIM layer
- Potential for reduced cost, weight, and volume

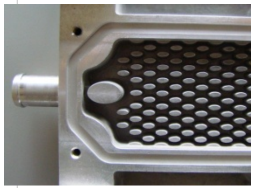
The technology is adaptable to other package configurations.

Technical Accomplishments

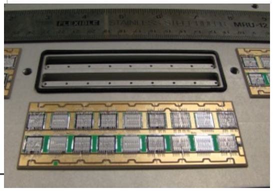
IGBT Test, 1000 W, 10 lpm, 35 W/cm^2



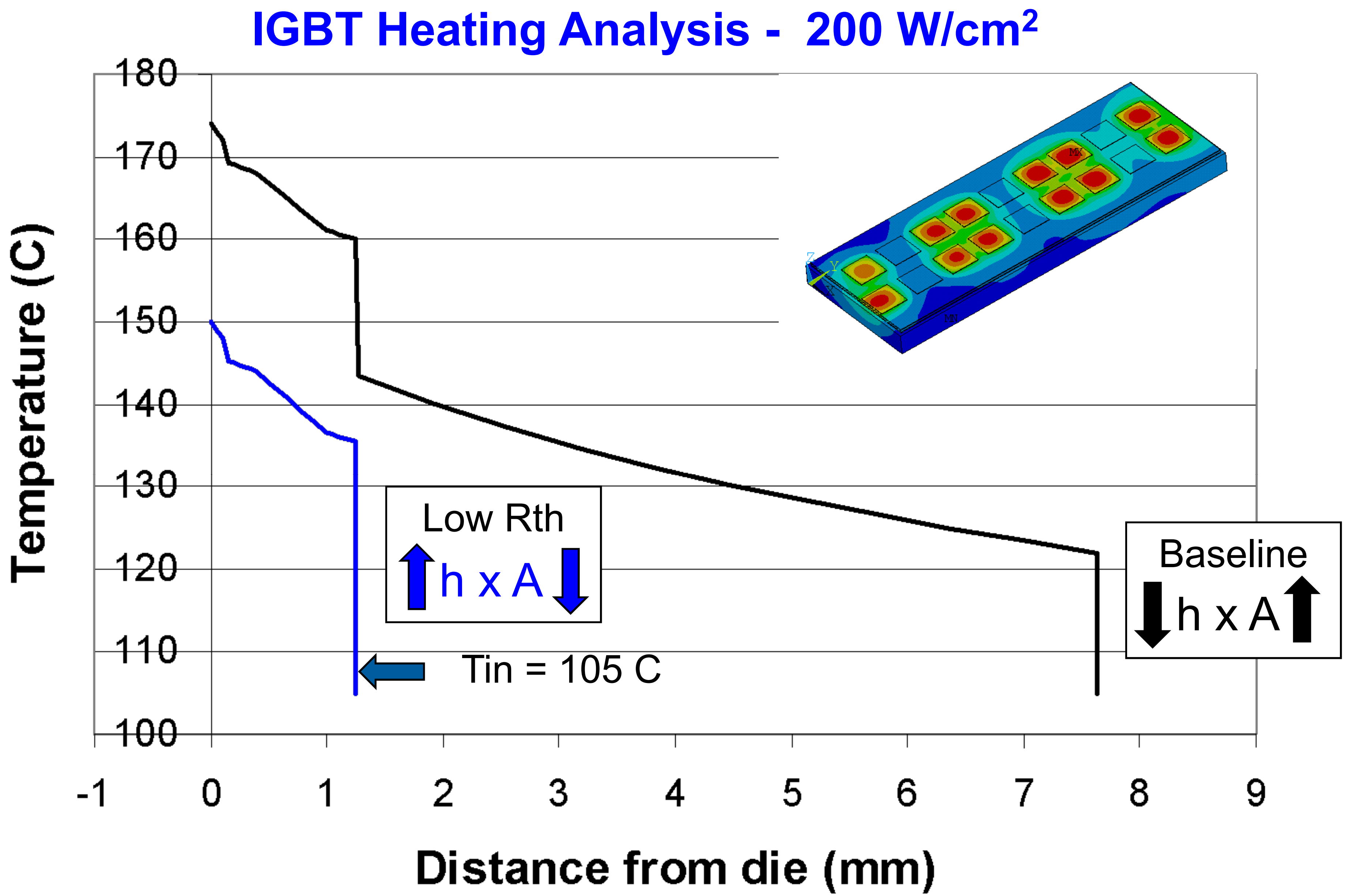
Baseline



Low R_{th} Design



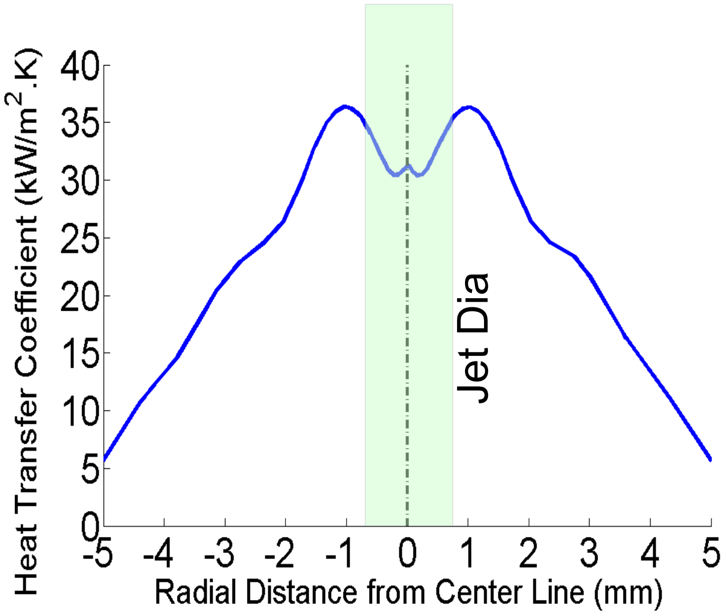
Technical Accomplishments

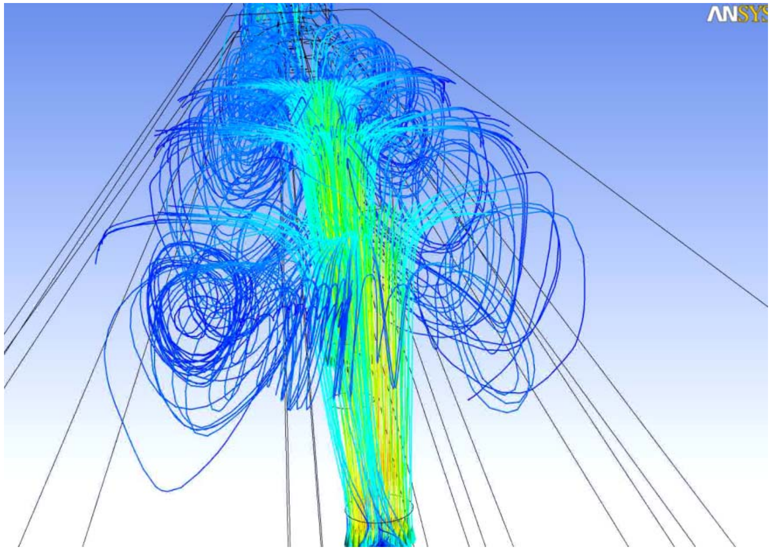


Technical Accomplishments

Parametric Jet Simulation Studies

- Conducted initial parametric investigations of packaging effects.
- Excellent correlation with experimental results.
- Peak heat transfer coefficient **(h)** confined to small target area.



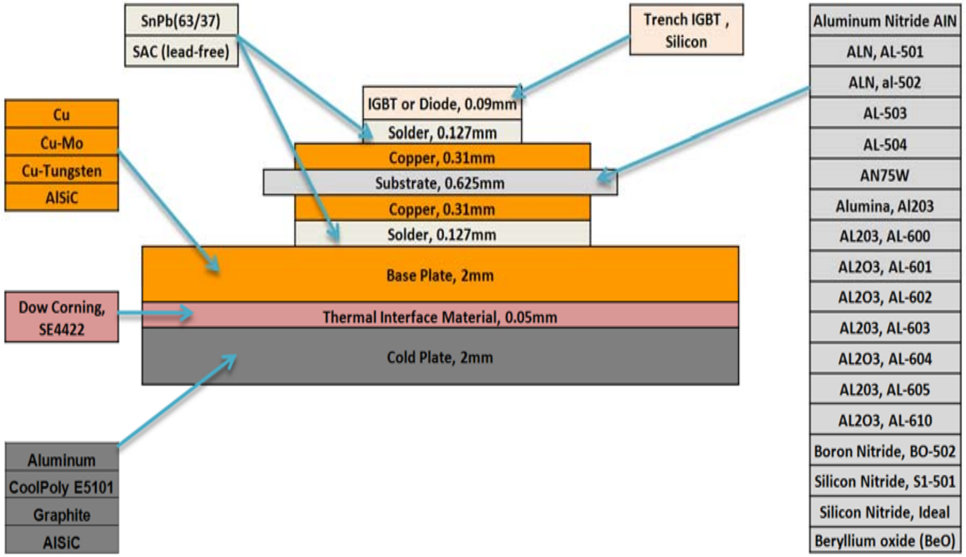


Conclusions

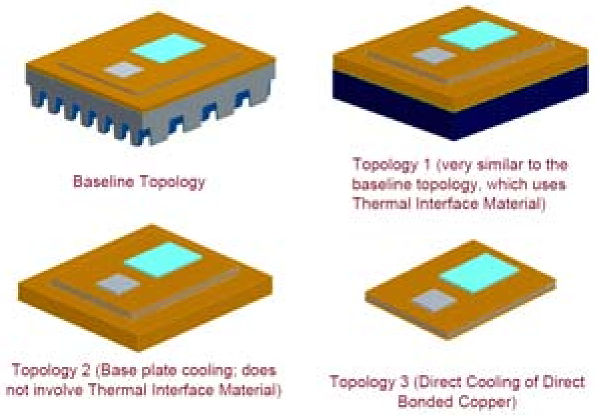
- Jet cooling system must be optimized for a specific package.
- Combining jet impingement with surface enhancement **(h x A)** to maximize overall performance.

Technical Accomplishments

Materials exploration studies: Trade-off between Cost and Performance



Thermal Packaging Topologies

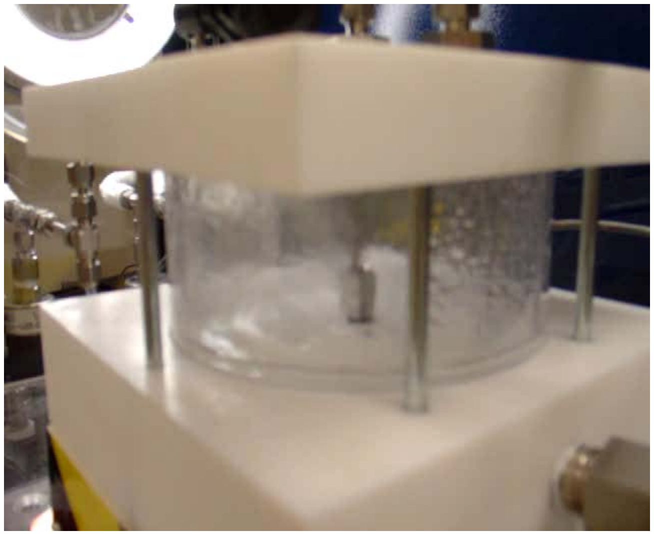


Developed basic framework for rapid assessment of interactions between thermal packaging topologies, materials, and thermal performance

Low-cost alternate materials are enabled by advanced thermal control (advanced cooling technologies in conjunction with novel thermal packaging topologies).

Technical Accomplishments

Initiated Surface Enhancement Study –
Objective: Low-Cost, High Performance Area Enhancement

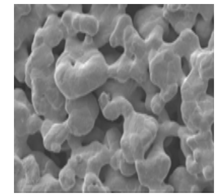


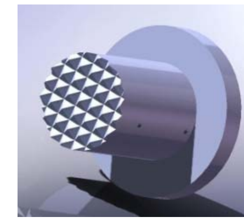
Surface coatings

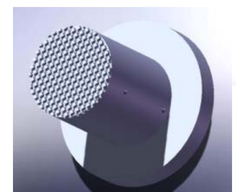
Protrusions

Etching

Roughing







- Identified candidate surface enhancement geometries through literature search
- Initiated testing with NREL's jet impingement test fixture
- Completed testing of several candidate geometries

Key Accomplishments during prior FYs

- Optimized pin-fin design transferred to Semikron
- Awarded patent for “Low Thermal Resistance Power Module Assembly”.
- Published detailed experimental characterization of self-oscillating jet technology.
- Published experimental and modeling characterization of two-phase with R134A for both jets and spray cooling.

Future Work: FY2009 & FY2010

- Complete experimental evaluation of surface enhancement structures.
- Transfer most promising surface enhancement approaches that combine high performance with low cost manufacturing.
- Evaluate thermal performance of future refrigerant fluid(s) for two-phase cooling of electronics (HFO1234xy).
- Evaluate the potential of electrically activated heat transfer enhancements.

Summary

DOE Mission Support

- Characterization and development of candidate heat transfer technologies which have the potential in enabling low-cost thermal solution for Automotive Power Electronics.
- Enable improved power density and system cost reductions through effective heat transfer performance in conjunction with lower cost materials.

Approach

- Indentify potential heat transfer technologies
- Objective and consistent characterization relative to automotive requirements.
- Development of most promising technologies
- Transfer knowledge to industry partners.

Summary

Technical Accomplishments

- Completed testing of “Low Thermal-Resistance Power Module Assembly” integrated with Semikron inverter.
- Testing showed over 35% decrease in thermal resistance and improved temperature uniformity.
- Parametric investigation of package-specific jet impingement design parameters.
- Integrated modeling approach to evaluate tradeoffs between thermal performance and material selection.

Collaborations

- Semikron – collaborative development and demonstration of jet impingement in Semikron inverter.
- Delphi – performance data fed into parametric technology investigation.
- Universities – migration of fundamental research to practical solutions / correlation of test results.
- NASA / ONR / IAPG – two-way sharing of program information, concepts and results.