NATIONAL RENEWABLE ENERGY LABORATORY

Two-Phase Cooling Technology for Power Electronics with Novel Coolants

2011 DOE Vehicle Technologies Program Review Presentation

PI: Gilbert Moreno

May 10, 2011

Project ID: APE037

Overview

Timeline

- Project Start: FY 2011
- Project End: FY 2013
- Percent Complete: 10%

Budget

- FY11: $550 K

Barriers

- Weight, Cost and Efficiency

Targets

- Specific Power, Power Density and Cost

Partners / Collaboration

- 3M
- DuPont
- General Electric (GE)
- Oak Ridge National Lab (ORNL)
- University of Colorado, Boulder
- EE Tech Team

Objective / Relevance

Project Objective

- Design and demonstrate a two-phase cooling solution which enables the 2015 DOE APEEM cost targets to be achieved by project's end (2013)

Relevance

- Potential application to increasing heat dissipation requirements in automotive power electronics
- Efficient heat transfer technologies can:
  - Reduce **cost** and increase **power density, specific power** and **efficiency**

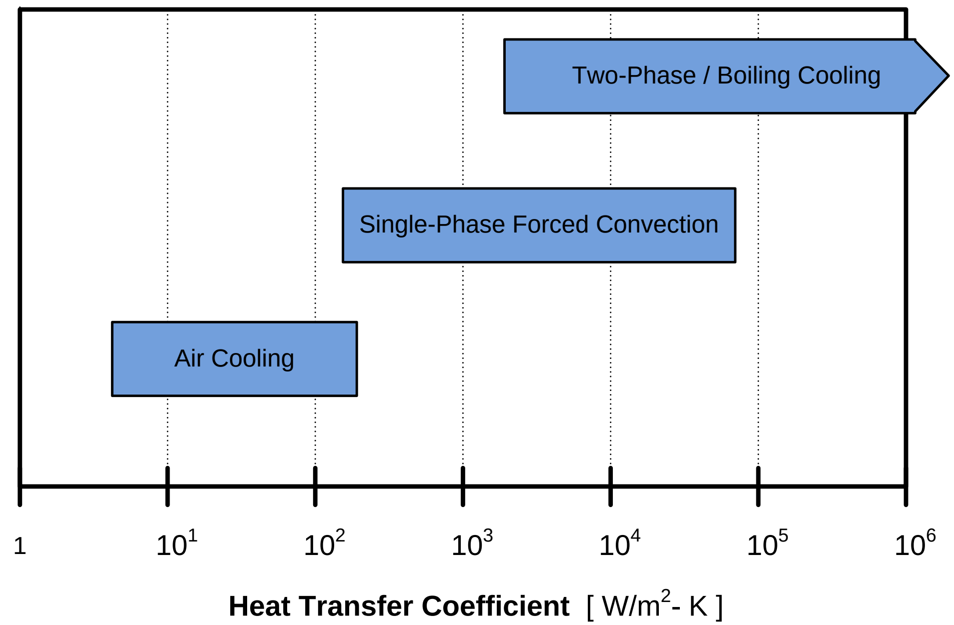
Milestones / Relevance

FY11

- Designed and fabricated high-pressure flow loop and immersion boiling vessel
- Completed HFO-1234yf and R134a immersion boiling tests with and without enhanced surfaces
- Conducting a mechanistic study investigating boiling on enhanced surfaces
- Initiate forced-convection two-phase experiments with high-pressure refrigerants

Approach / Strategy

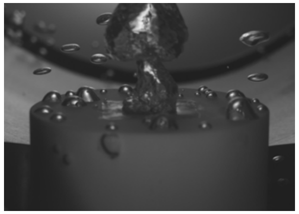
- Utilize high heat transfer coefficients of two-phase to improve power electronics cooling
- Investigate means of further enhancing two-phase heat transfer
  - Surface enhancements as well as other techniques
- Several novel refrigerants/coolants will be tested
  - DuPont HFO-1234yf: Potential next generation automotive A/C refrigerant
  - 3M Novec 649: Excellent dielectric and environmental (GWP=1) properties



Heat transfer coefficient values taken from Mudawar, I., 2001,

Approach / Strategy

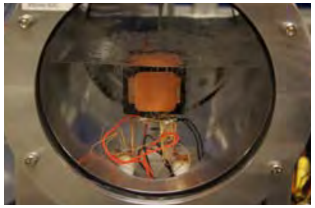
Fundamental Study



Small heaters
Uniform heat flux

- Enhancement techniques
- Mechanistic study
- Characterize performance of novel coolants

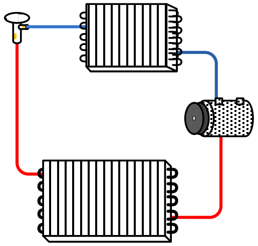
Package/Module-Level Study



Single and multiple power electronics modules

- System design
- Minimize coolant quantity
- Reliability

System Integration



Modeling Analysis

- A/C system integration
- Stand alone thermosyphon
- Pumped system

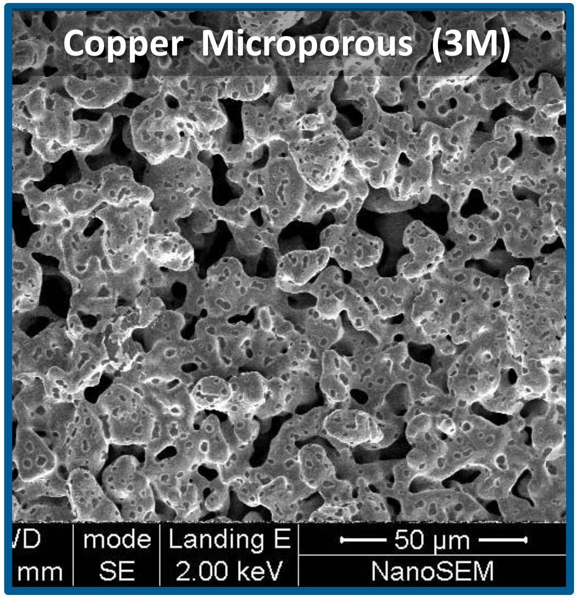
Credit: Gilbert Moreno, NREL (all images)

Technical Accomplishments

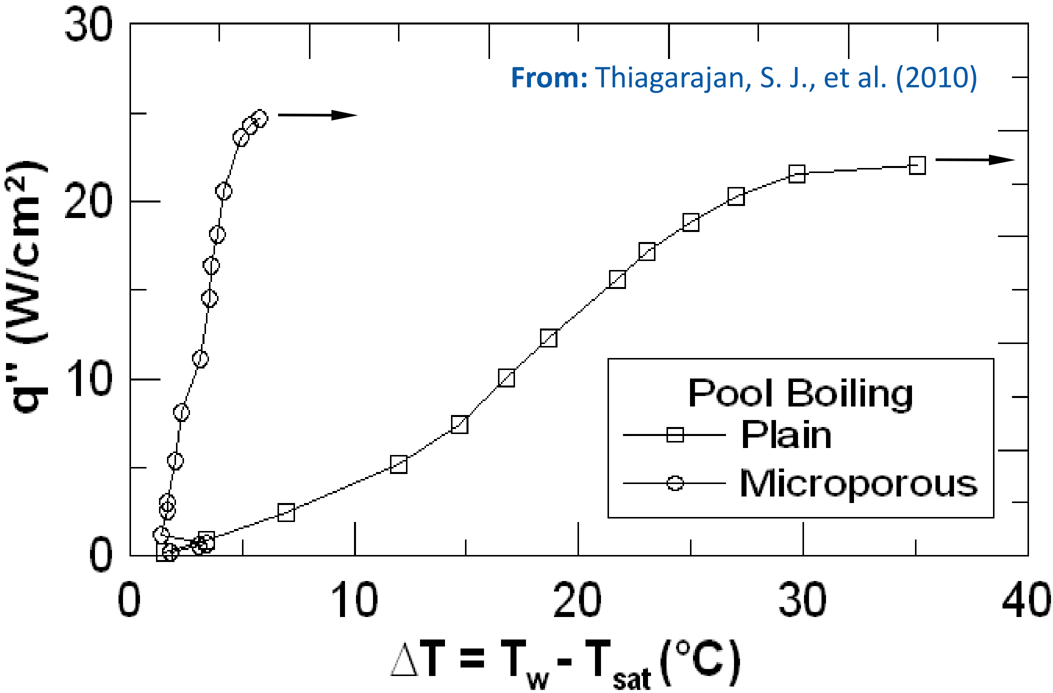
WORK PREVIOUSLY PRESENTED

Microporous coating:

- Enhances heat transfer up to 500%
- Decreases boiling incipience superheat (ΔT≈3 C)
- Increases critical heat flux by ~10%

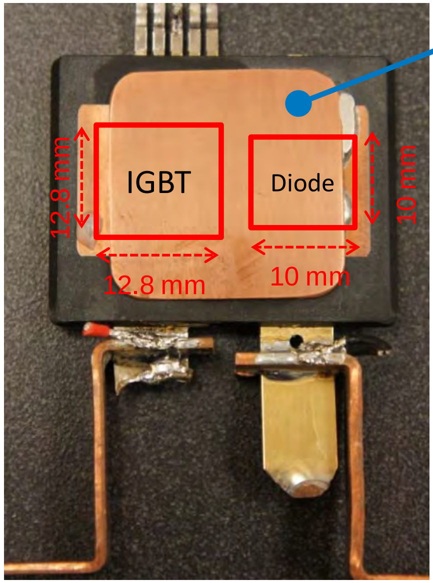


Credit: Bobby To, NREL



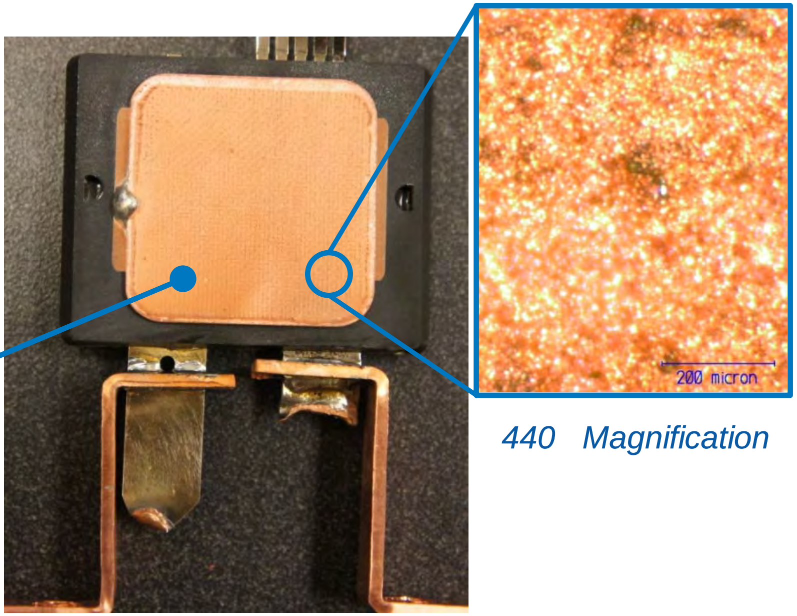
Technical Accomplishments

- Demonstrated effectiveness of immersion boiling with microporous (3M) coating to cool an automotive power electronics module
- Lexus modules supplied by ORNL and coated by 3M were used
- Plain (non-coated) and microporous coated modules tested



Cu spreader plate baseline

Cu spreader plate with microporous (3M) coating



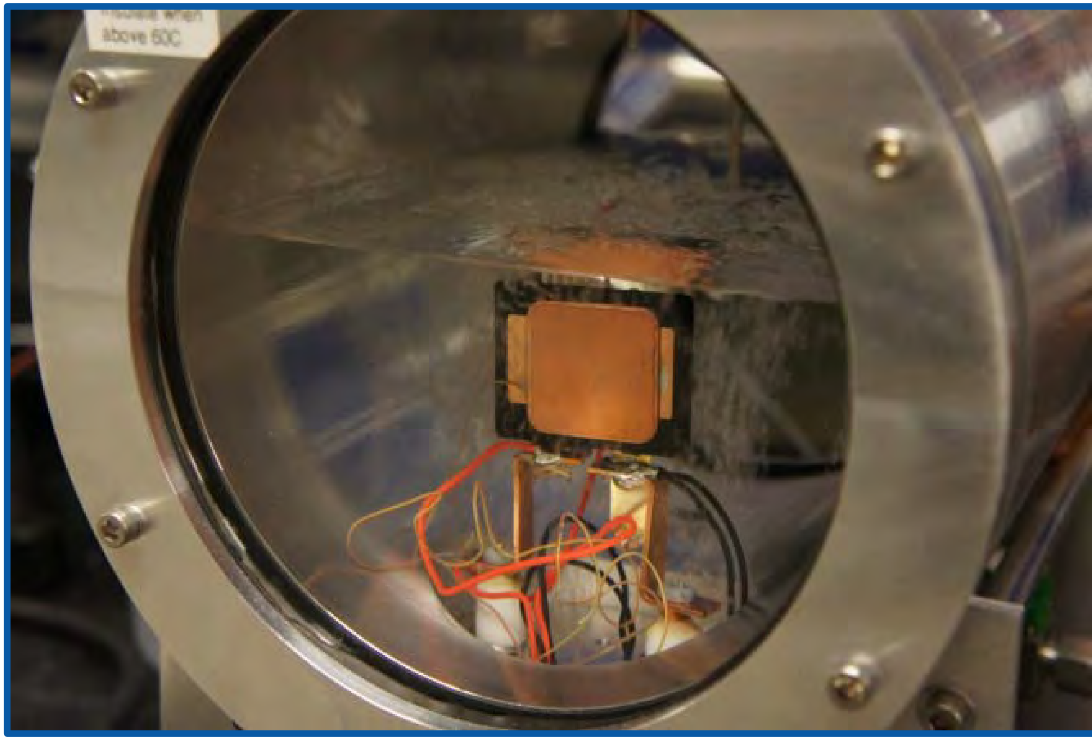
440 Magnification

Credit: Gilbert Moreno, NREL (all images)

Technical Accomplishments

Test Conditions:

- Saturated 3M HFE-7100 (dielectric) at atmospheric pressure 83 kPa (~12 psia)
- Modules powered using transient thermal tester
- Powered insulated gate bipolar transistors (IGBTs) (gated 10 volts). Sense current (100 mA) used to measure junction temperature

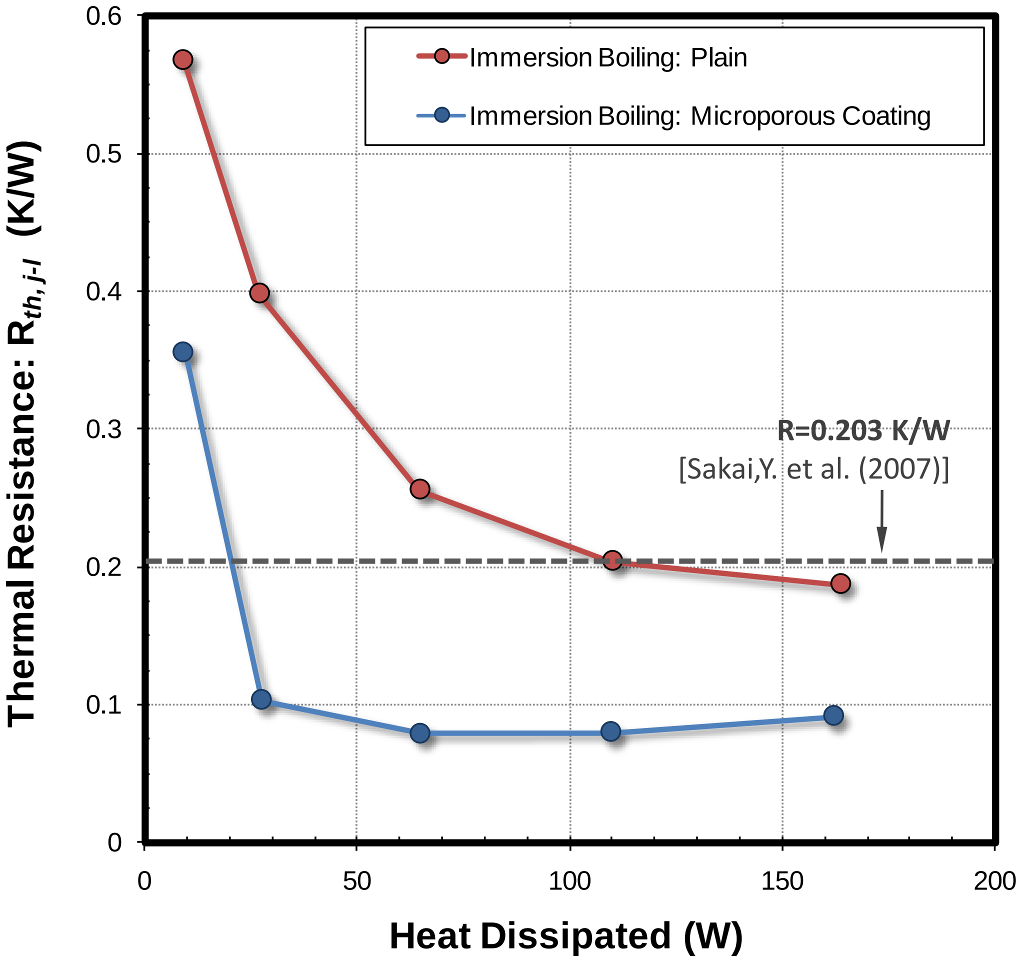


Credit: Gilbert Moreno, NREL

Technical Accomplishments

Immersion Boiling with Enhanced Surfaces

- Reduced thermal resistance by over 50% as compared with existing dual-sided cooling
- Achieved better performance with no pump required

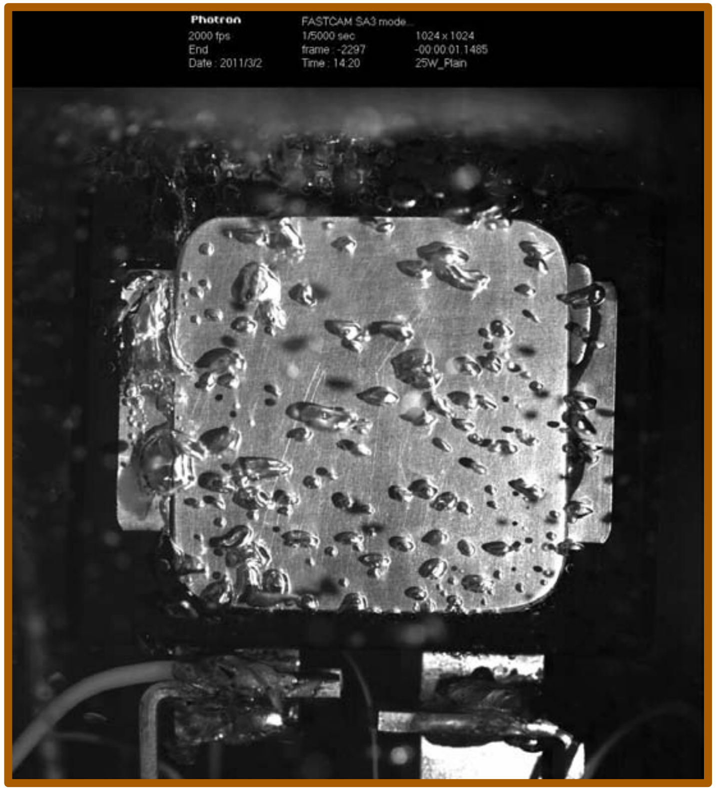


Technical Accomplishments

Power dissipated: 28W

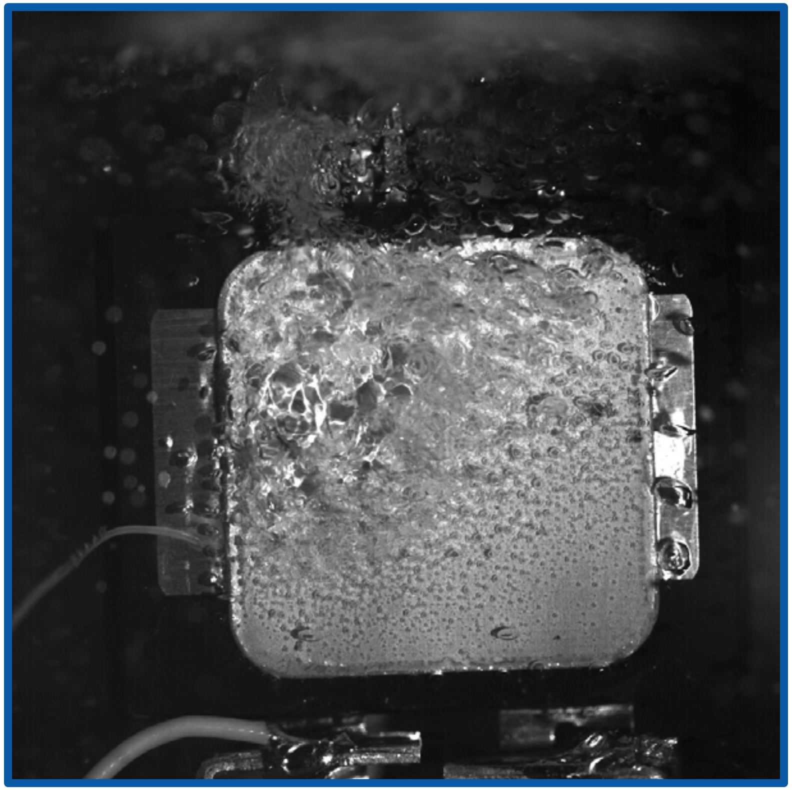
IGBT heat flux: ~17 W/cm^2

Non-coated



$R_{th\ (j\text{-}l)}$: 0.39 K/W

Microporous



$R_{th\ (j\text{-}l)}$: 0.1 K/W

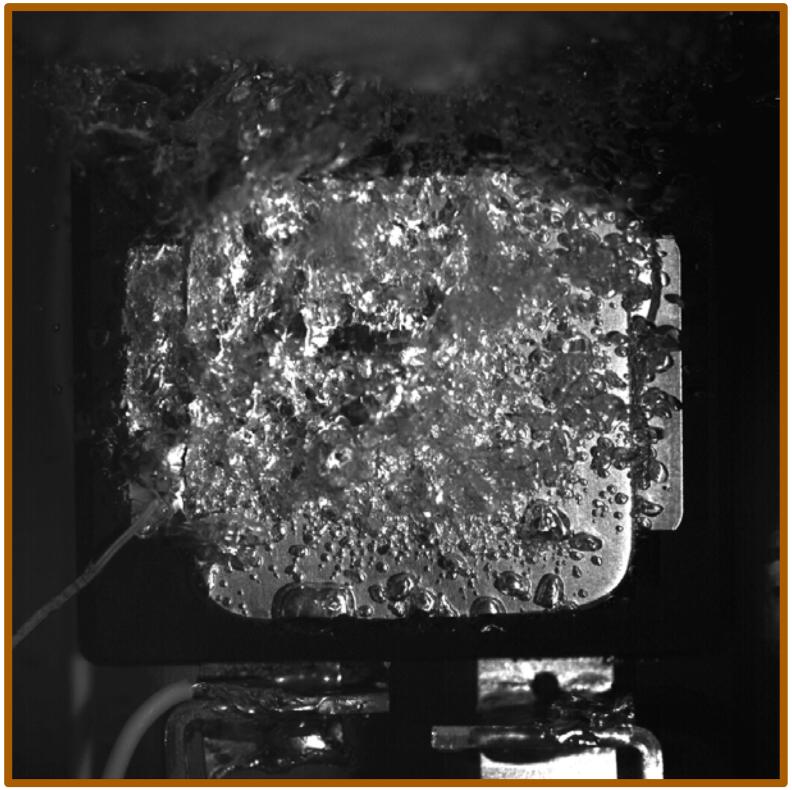
Credit: Gilbert Moreno, NREL (all images)

Technical Accomplishments

Power dissipated: 165 W

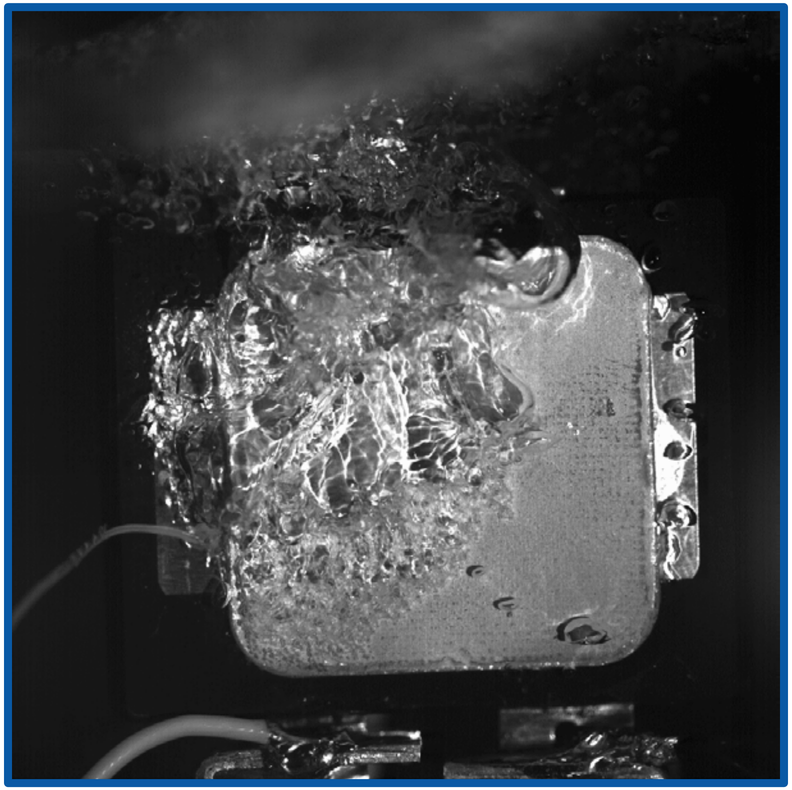
IGBT heat flux: ~100 W/cm^2

Non-coated



$R_{th\ (j\text{-}l)}$: **0.19 K/W**

Microporous



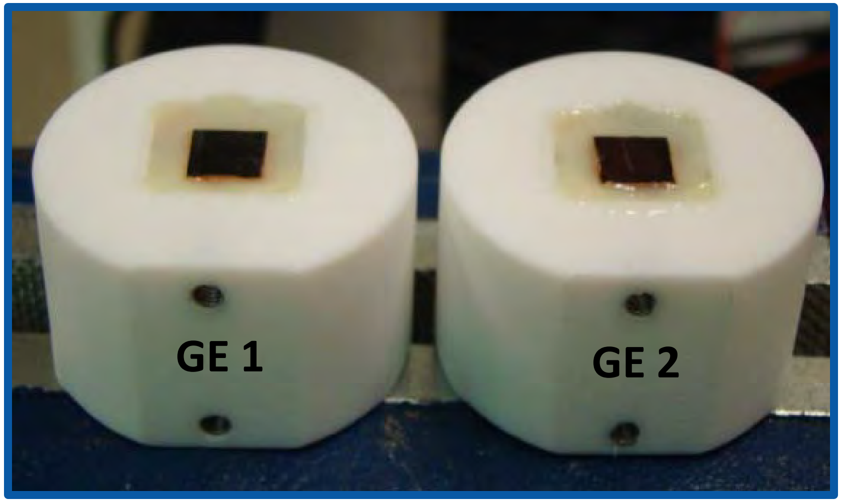
$R_{th\ (j\text{-}l)}$: **0.09 K/W**

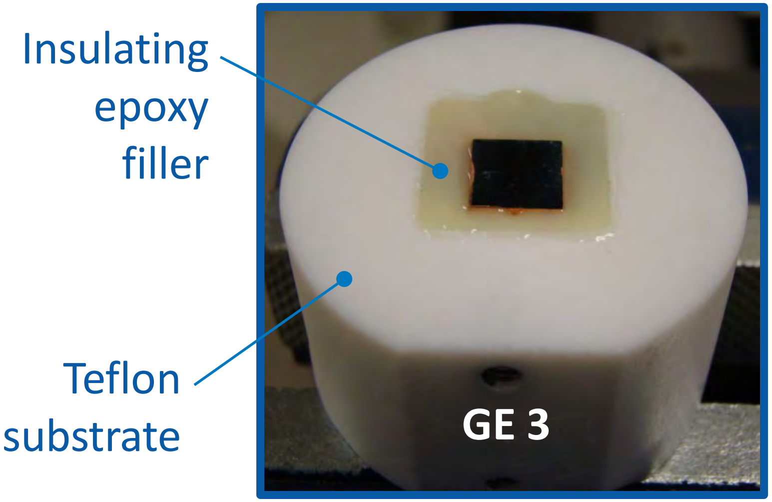
Credit: Gilbert Moreno, NREL (all images)

Technical Accomplishments

General Electric (GE) Nanostructured Surfaces

- Collaborative project with GE
- Optimize nanostructures to enhance two-phase heat transfer



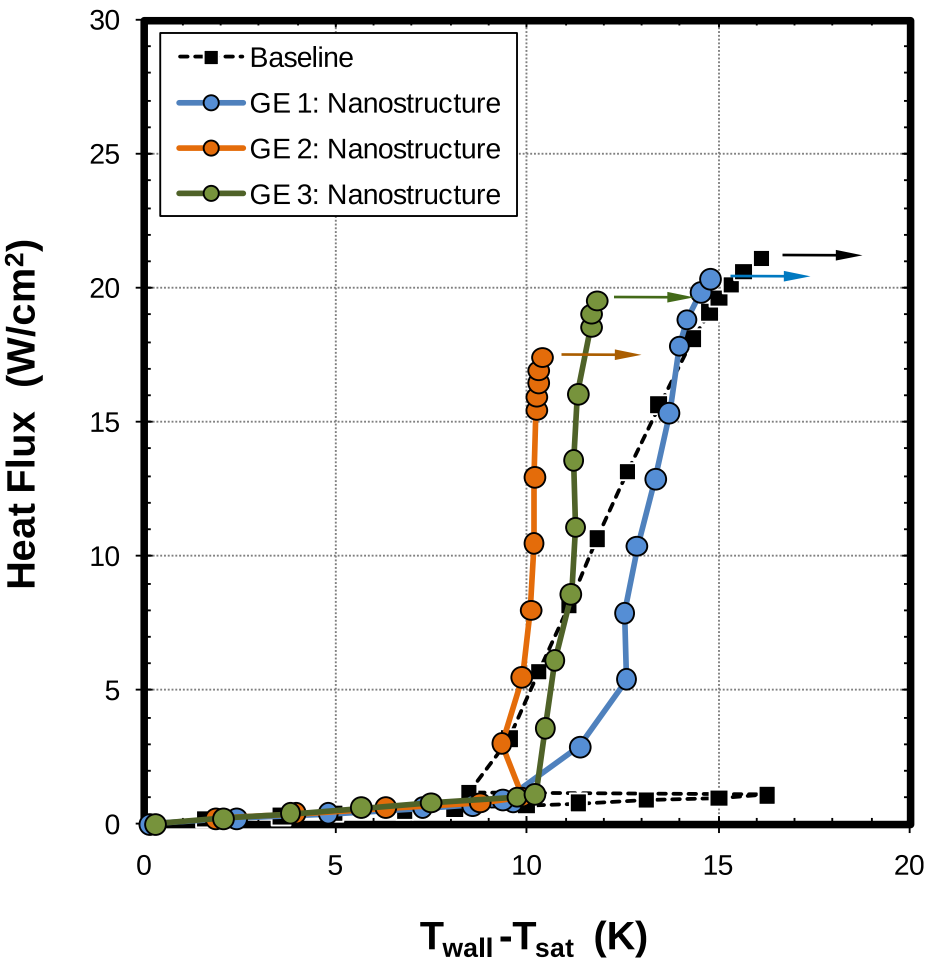


Credit: Gilbert Moreno, NREL (all images)

Technical Accomplishments

Pool Boiling: ~83 kPa (12 psia), degassed HFE-7100

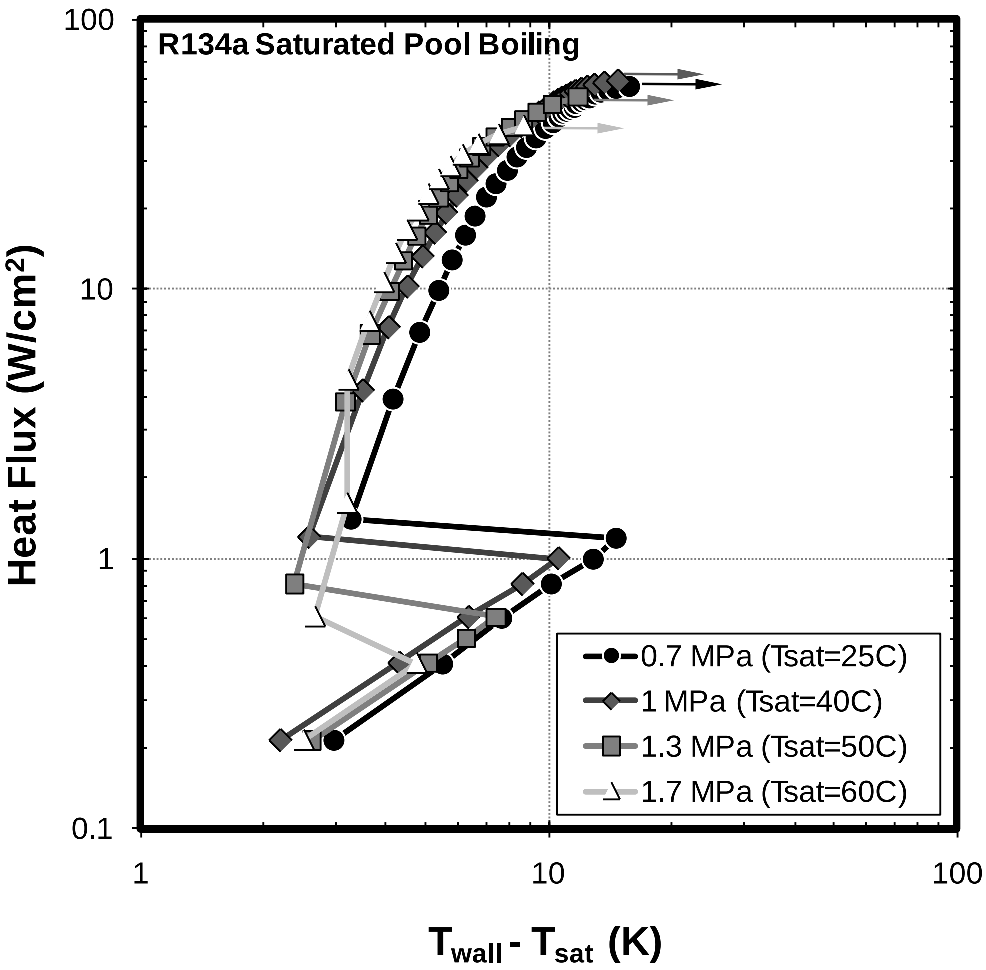
- All GE surfaces decrease boiling incipience superheat
- Some heat transfer coefficient enhancement with GE 2 and GE 3 nanostructured surfaces
- Collaborating with GE to optimize nanostructures



Technical Accomplishments

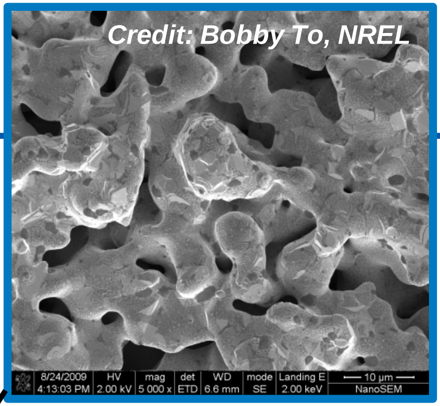
Pool Boiling: R-134a Automotive A/C Refrigerant

- Pressure range is typical A/C condenser pressures
- Higher pressures increase heat transfer, decrease boiling incipience superheat



Credit: Gilbert Moreno, NREL

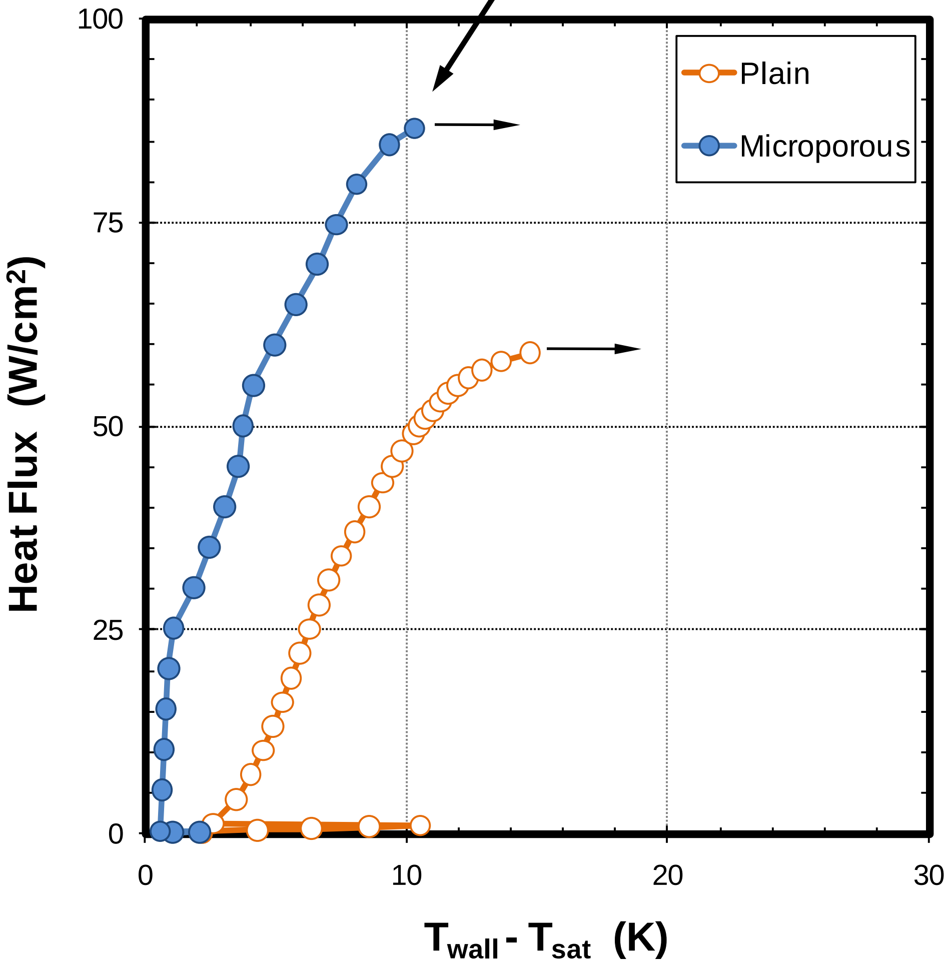
Technical Accomplishments



Pool Boiling: R-134a (T_{sat}= 40 C, P_{sat}=1 MPa)

Microporous Coating *(Preliminary results)*

- 400% heat transfer coefficient increase (>200,000 W/m^2-K)
- 32% critical heat flux increase
- ΔT=2 C boiling incipience superheat



Collaborations

UNIVERSITY PARTNERS

- University of Colorado, Boulder

INDUSTRY / NATIONAL LAB PARTNERS

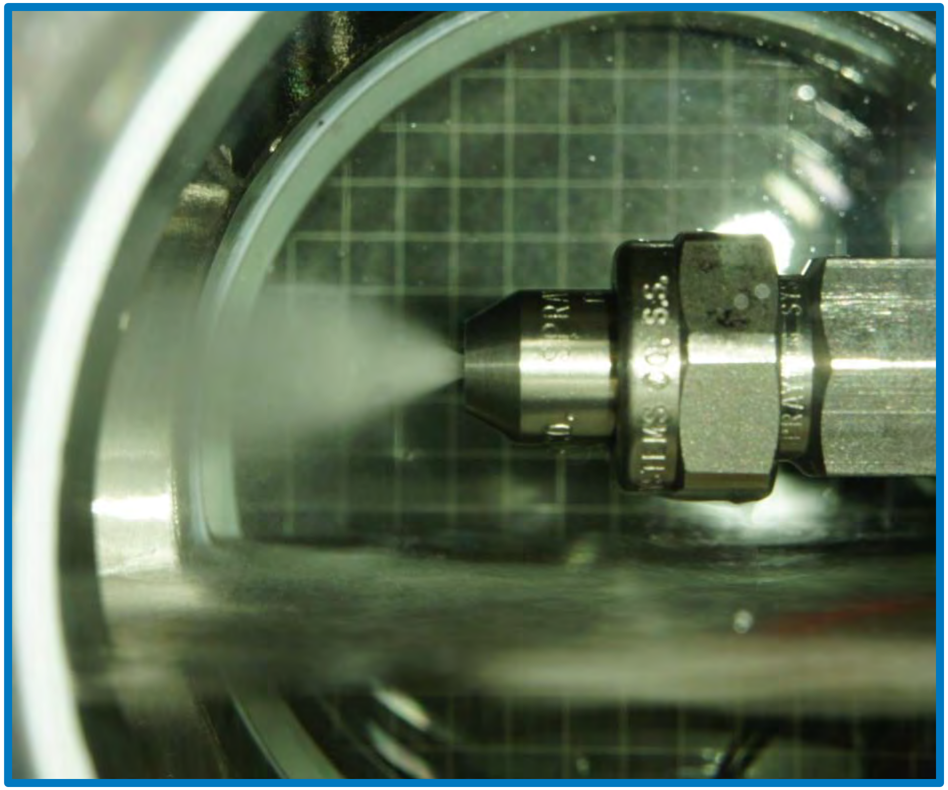
- 3M Electronics Markets Materials Division
- DuPont
- General Electric (GE)
- Oak Ridge National Lab (ORNL)
- EE Tech Team

Proposed Future Work

<u>FY11</u>

- Characterize pool boiling performance of HFO-1234yf with and without enhanced surface coatings
- Initiate forced-convection, two-phase heat transfer experiments
  - Flow boiling, jet impingement and spray cooling
- Conduct mechanistic study investigating boiling on enhanced surfaces

R-134a spray



Credit: Gilbert Moreno & Charlie King, NREL

Proposed Future Work

FY12

- Evaluate feasibility of heat pipes/vapor chambers for power electronics cooling
- Explore new techniques to delay critical heat flux limits and increase heat transfer
- Investigate potential integration into cabin cooling/heating systems
  - Multi-system modeling

FY13

- Develop prototype two-phase power electronics cooling system
- Address two-phase cooling concerns
  - Contamination, seals, cost

Summary

Objective / Relevance

- Design and demonstrate a two-phase cooling solution which enables the 2015 DOE APEEM cost targets to be achieved by project's end (2013)

Approach

- Conduct fundamental and system-level experiments
- Investigate means of further enhancing two-phase (boiling) heat transfer
- Characterize thermal performance of novel refrigerants/coolants

Summary

Technical Accomplishments

- Designed and fabricated two new two-phase heat transfer facilities
- Reduced package thermal resistance by over 50% through immersion boiling with microporous coating, no pumping requirements
- Demonstrated significant R-134a two-phase (boiling) heat transfer enhancement with microporous coating
  - 400% increase in heat transfer coefficient
  - 32% increase in the critical heat flux
- Collaborating with industry (3M, GE, DuPont) to obtain enhanced surfaces and novel coolants

NATIONAL RENEWABLE ENERGY LABORATORY

Acknowledgements:

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