# *Carbon Foam Thermal Management Materials for Electronic Packaging*

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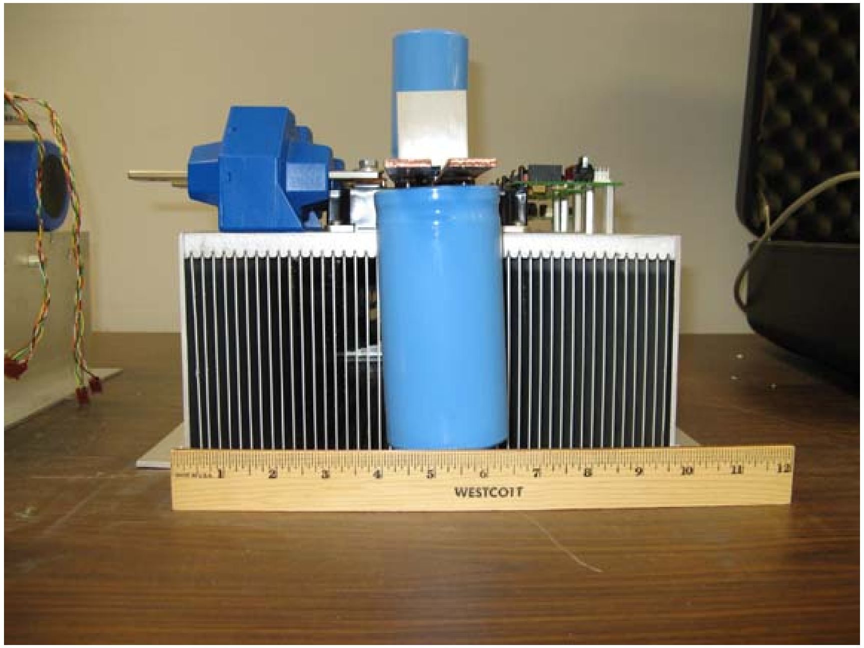
**This presentation does not contain any proprietary or confidential information.**

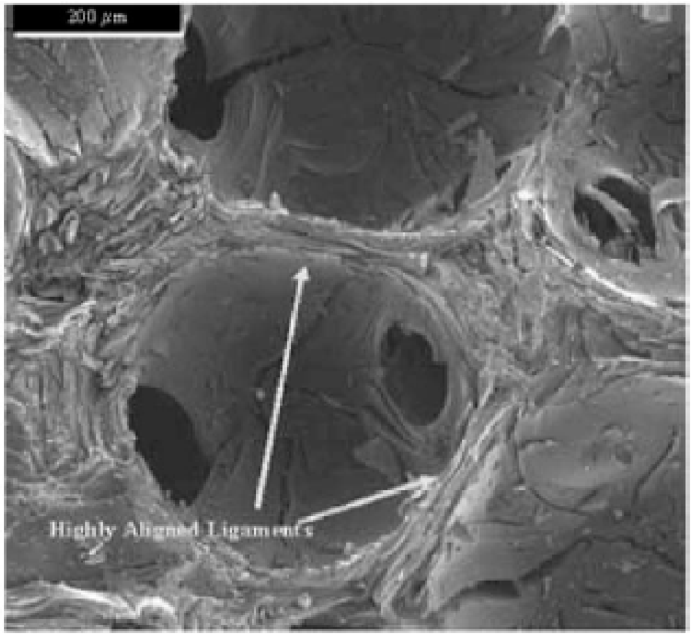
# Purpose of Work

- Collaborate with industry partners to develop and demonstrate an optimized heat exchanger/heat sink design that best utilizes the excellent heat transfer properties of high conductivity graphite foam to ***significantly reduce the size and weight*** of the thermal management system.



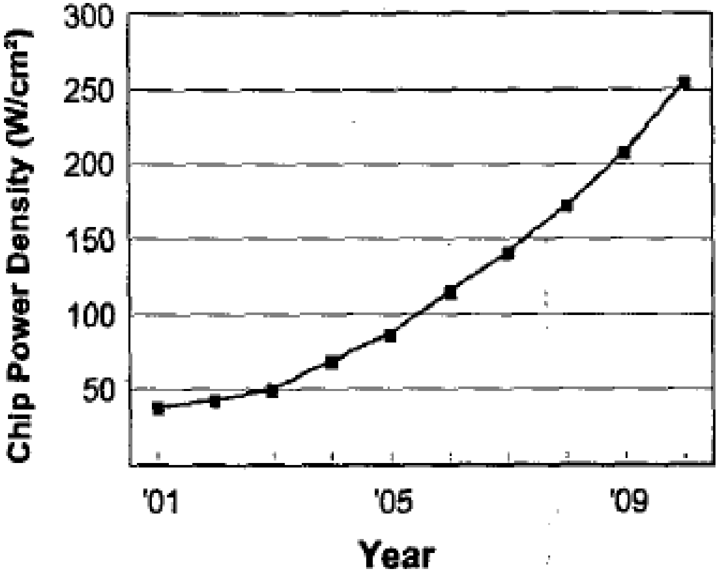
# Benefits of High-Thermal Conductivity Graphite Foam

- ***High thermal conductivity***
  - 4X more conductive than copper and 6X more conductive than aluminum
  - Heat spreads out over a larger surface area
  - Surfaces are hotter and heat transfer is more efficient
- ***Light weight***
  - 20% of the weight of aluminum or copper
- ***Large surface area***
  - Internal surface area up to 50,000 $m^2 / m^3$
- ***Low thermal storage***
  - Stores 65% less heat per unit weight than copper
  - In combination with its high thermal conductivity, this means that graphite foam can transport heat away from hot spots about 15X faster than copper (ideal heat spreader material)



# Need for Better Thermal Management Systems for Vehicle Power Electronics

- Electric hybrid and fuel cell vehicles use power electronics to control electric motor.
- Requirements for power are increasing rapidly while materials operating temperatures remains fairly constant.
- Current cooling methods are reaching their limit: air- and liquid-based systems can only cool up to 40-W/cm$^2$.




Processor chip power density trend[1]

[1]Ellsworth, M.J., “Chip Power Density and Module Cooling Technology Projections for the Current Decade,” Inter Society Conference on Thermal Phenomena, 2004, pp. 707-708

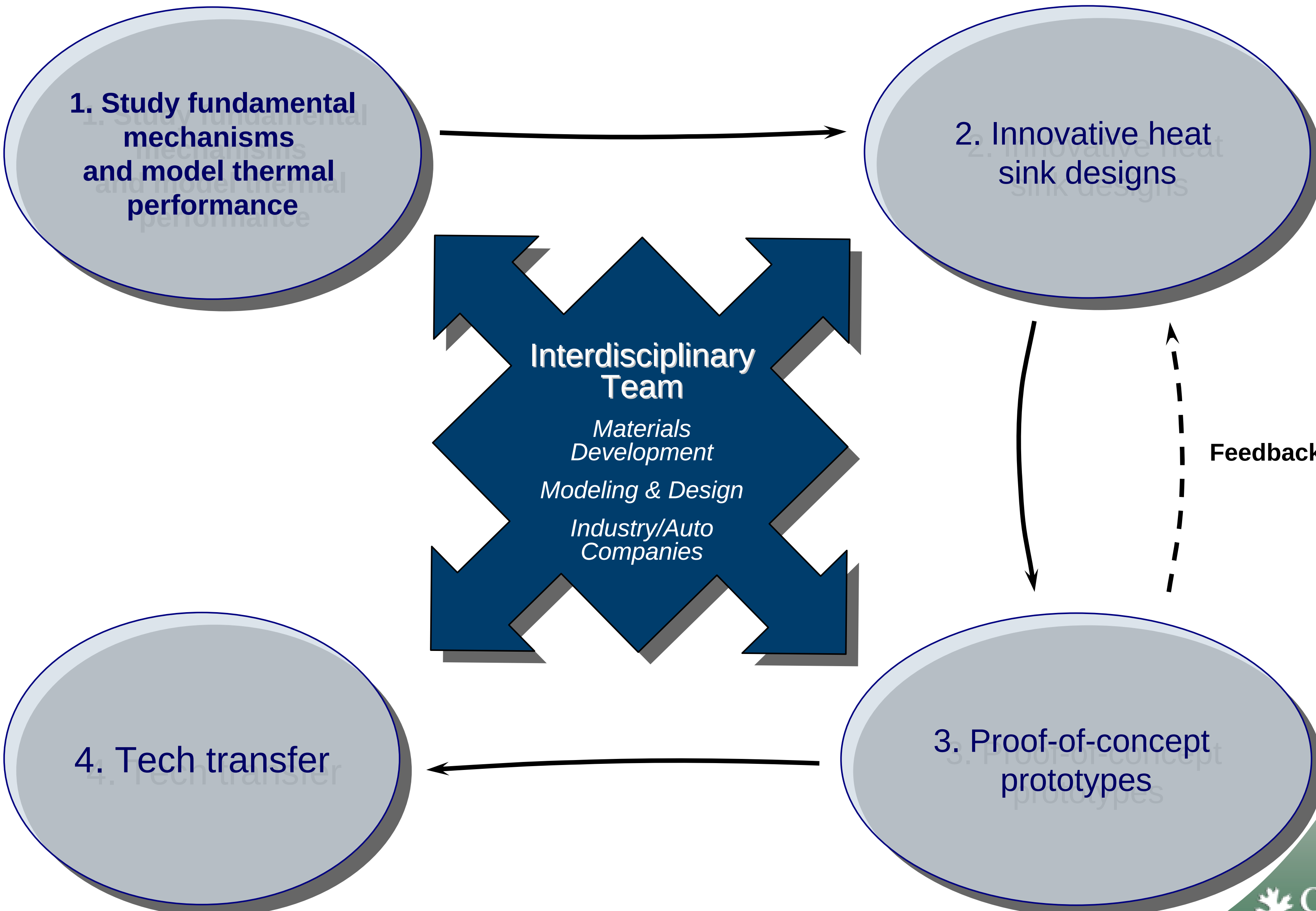
# Response to Previous Year Reviewers' Comments

- Project was presented at previous reviews of the Advanced Power Electronics and Electrical Machines Program, however, it was not formally reviewed .
- Our participation at these reviews meetings has guided our research activities and has helped us focus and narrow down the applications.

# Barriers / Challenges

- Determine the best cooling method in which the properties of graphite foam can be fully exploited
- Obtain optimum foam permeability for the given cooling method
- Determine durability and reliability of foam as heat sink material
- Reduce the cost of carbon foam

# Approach


1. Study fundamental mechanisms and model thermal performance
2. Innovative heat sink designs
Interdisciplinary Team
Materials Development
Modeling & Design
Industry/Auto Companies
Feedback
3. Proof-of-concept prototypes
4. Tech transfer

# Technical Accomplishments

## Power electronics cooling methods studied:

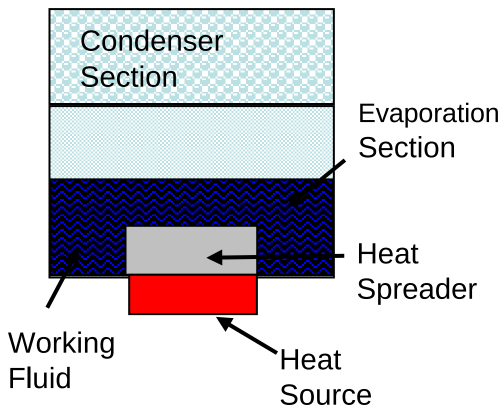
- ***Forced fluid convection:*** Using air can cool up to 25 $W/cm^2$; this can be increased by using liquid such as water or glycol. Erosion of foam is a major issue.

- ***Spray cooling:*** This is typically an open looped process that sprays de-ionized water or fluoroinerts onto the heat source and removes heat through the fluid's latent heat of vaporization. Localized erosion of foam is a major issue.

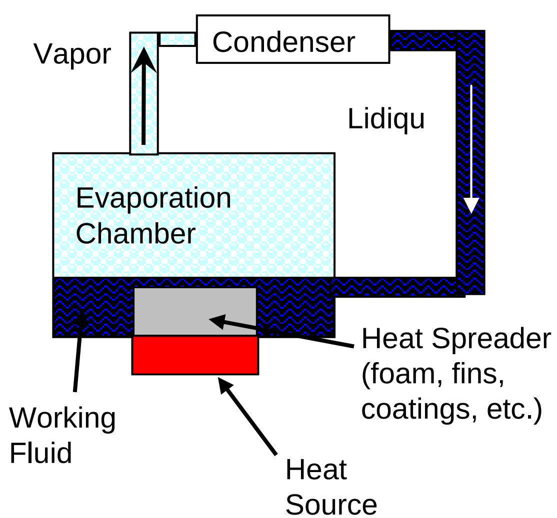
- ***Thermosyphons:*** This is a system similar to the heat pipe; however, a thermosyphon relies on gravity to return the condensate not the capillary action. Foam is not exposed to forced flowing fluids and therefore erosion of foam is drastically minimized.

**Graphite foam properties are better exploited in thermal siphon systems**

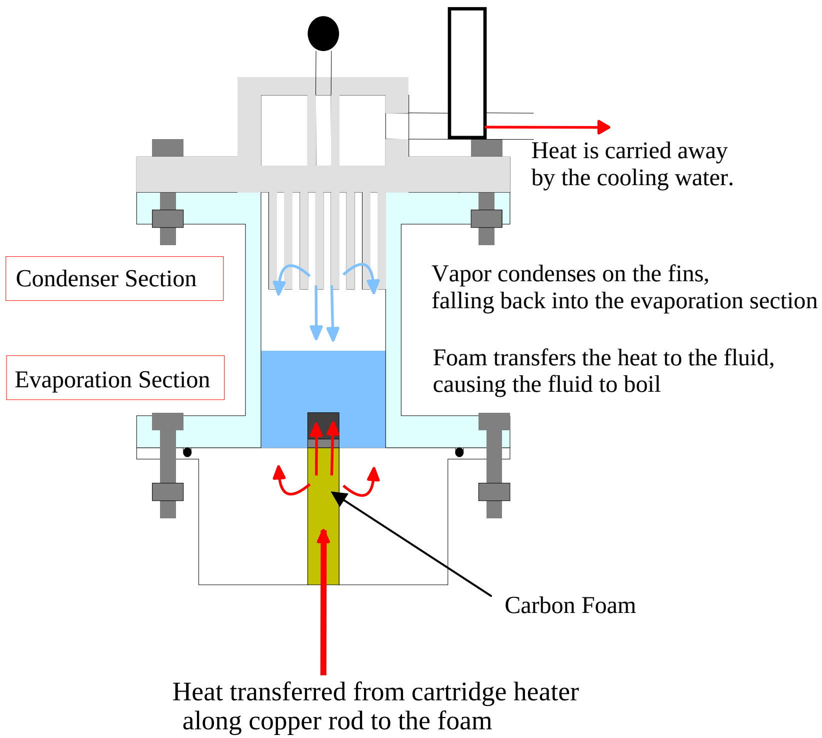
# Thermal siphon systems




Single chamber closed thermal siphon




Closed-loop natural circulation thermal siphon



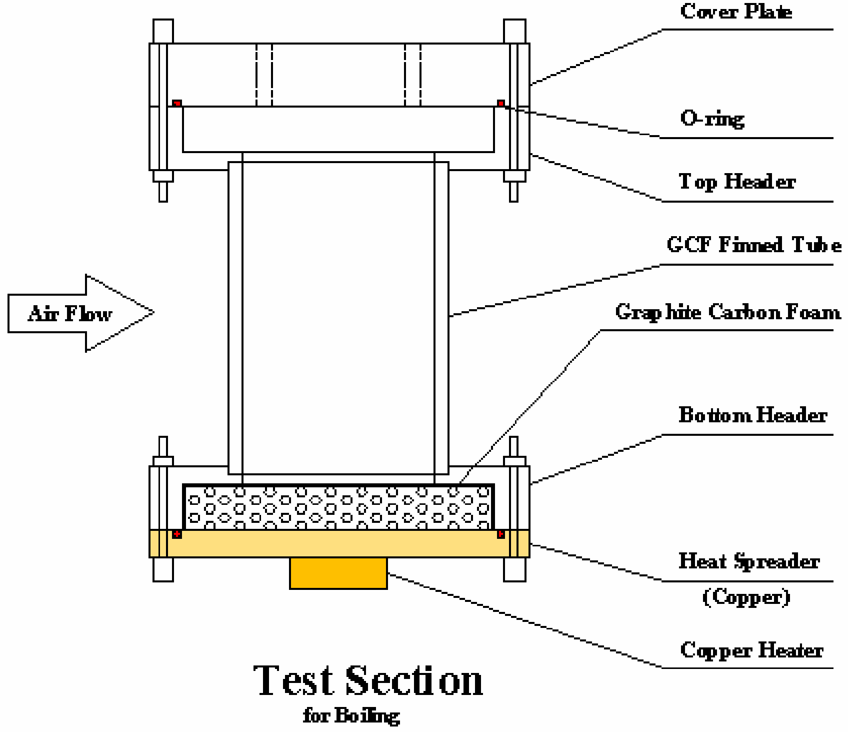

Graphite foam-based thermal siphon

# Technical Accomplishments

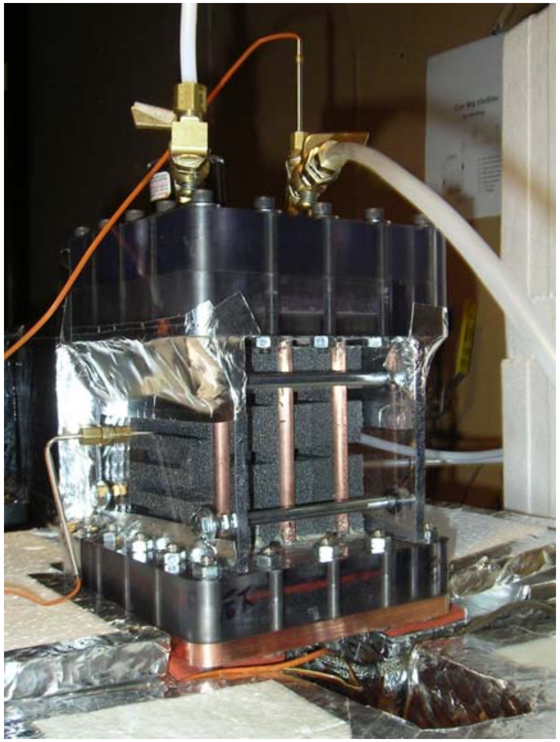
- Designed and built proof of concept thermal siphon utilizing high thermal conductivity graphite foam
- Demonstrated that the cooling rates from a proof-of-concept thermal siphon that utilizes graphite foam elements are improved by about 20% over conventional thermal siphon

# Technical Accomplishments

## *Proof-of-concept thermal siphon*



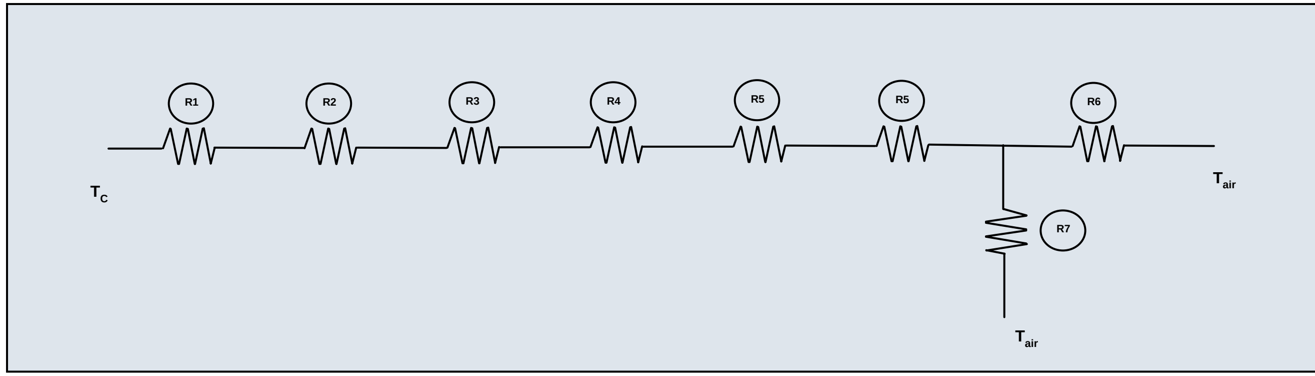

Schematic of test section

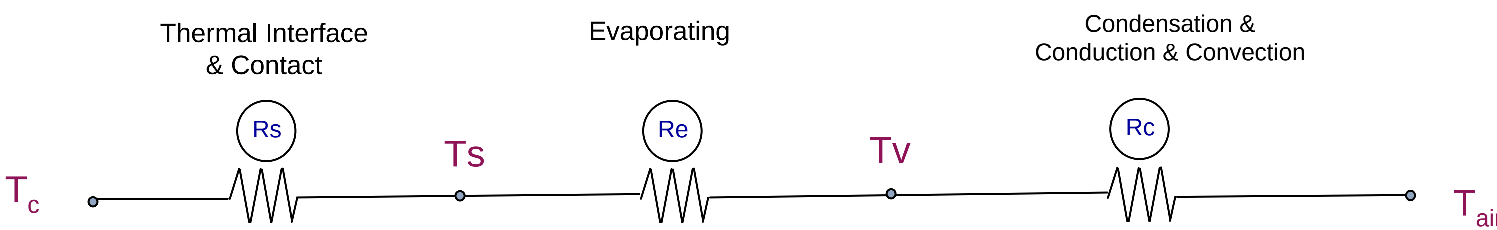


**Instrumented thermal siphon with airside heat exchanger and boiling enhancements both made from high thermal conductivity graphite foam.**

# Technical Accomplishments

Thermal circuit for heat path



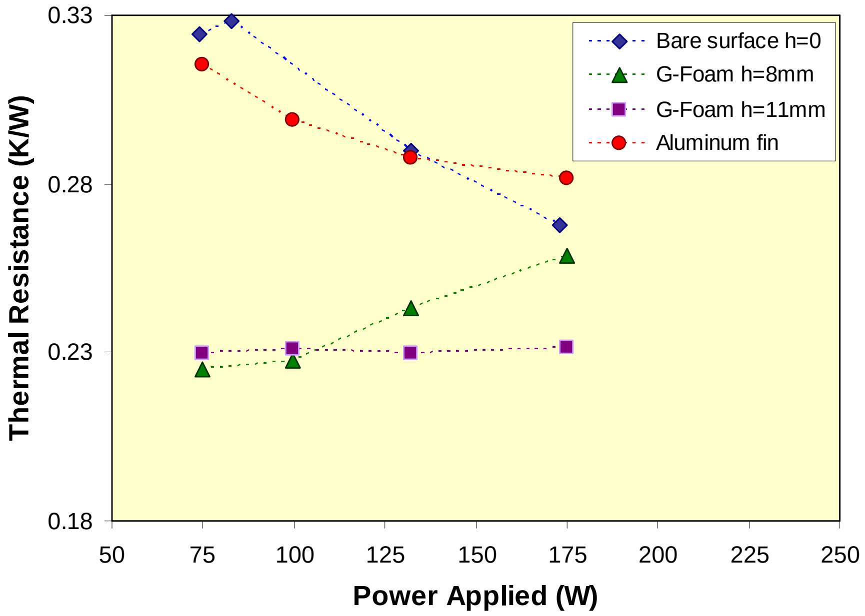

$R_s = R_1 + R_2$

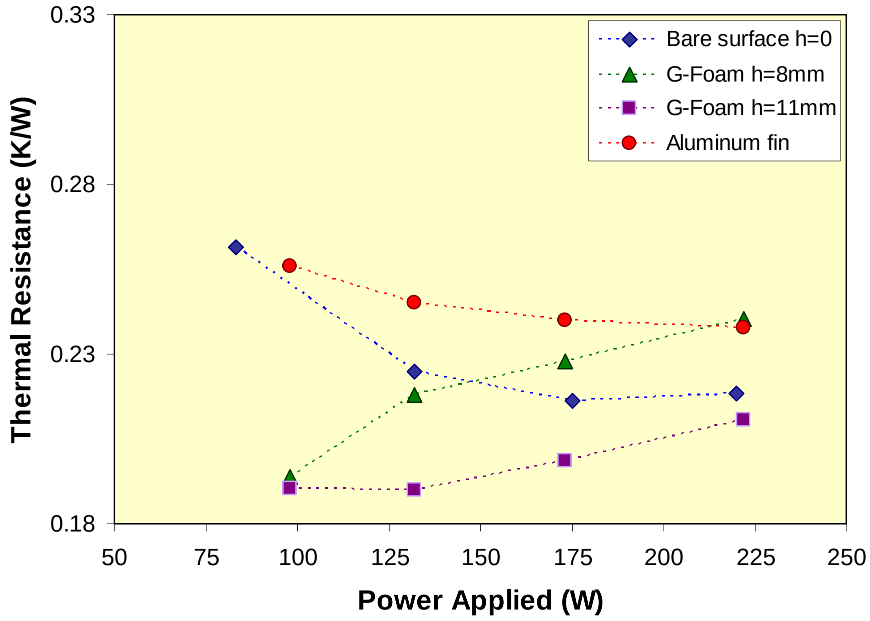
$R_e = R_3$

$R_c = R_4 + R_5 + (R_6 + R_7)^{-1}$

$$R_t = R_s + R_e + R_c$$

# Technical Accomplishments



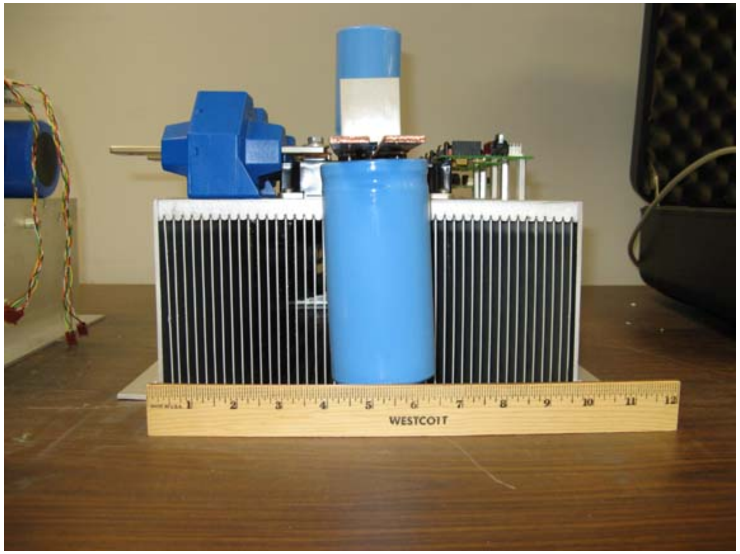

Conditions:
Forced Convection, 10 ACFM air flow rate

Conditions:
Forced Convection, 17 ACFM air flow rate

Cooling rates from a proof-of-concept thermal siphon that utilizes graphite foam elements are improved by about 20% over conventional thermal siphon

# Conclusion

- Project will be completed this year with the fabrication and testing of a thermal siphon with graphite foam components.
- Technology on graphite foam heat exchangers has been transferred to ThermalCentric. They have formed a joint venture with Koppers (manufacturer of foam) to commercialize graphite foam heat exchangers.
- Koppers developed less expensive graphite foams (~5X to 10X) from lower cost precursor materials.



# Publications

- Straatman AG, Gallego NC, Yu Q, Thompson BE, “Characterization of porous carbon foam as a material for compact recuperators”, Journal of Engineering for Gas Turbines and Power-Transactions of the ASME 129 (2): 326-330, 2007 .

- Straatman AG, Gallego NC, Thompson BE, Hangan H “Thermal characterization of porous carbon foam - convection in parallel flow”, International Journal of Heat and Mass Transfer 49 (11-12): 1991-1998, 2006.