Cooling for AIPM Using Carbon Foam

Dr. James Klett
Metals and Ceramics Division
P.O. Box 2008, Oak Ridge National Laboratory
Oak Ridge, Tennessee, 37831-6087
(865) 574-5220
klettjw@ornl.gov

www.ms.ornl.gov/sections/mpst/Cimtech/default.htm

Keywords: Graphite Foam, Thermal Conductivity,Thermal Management

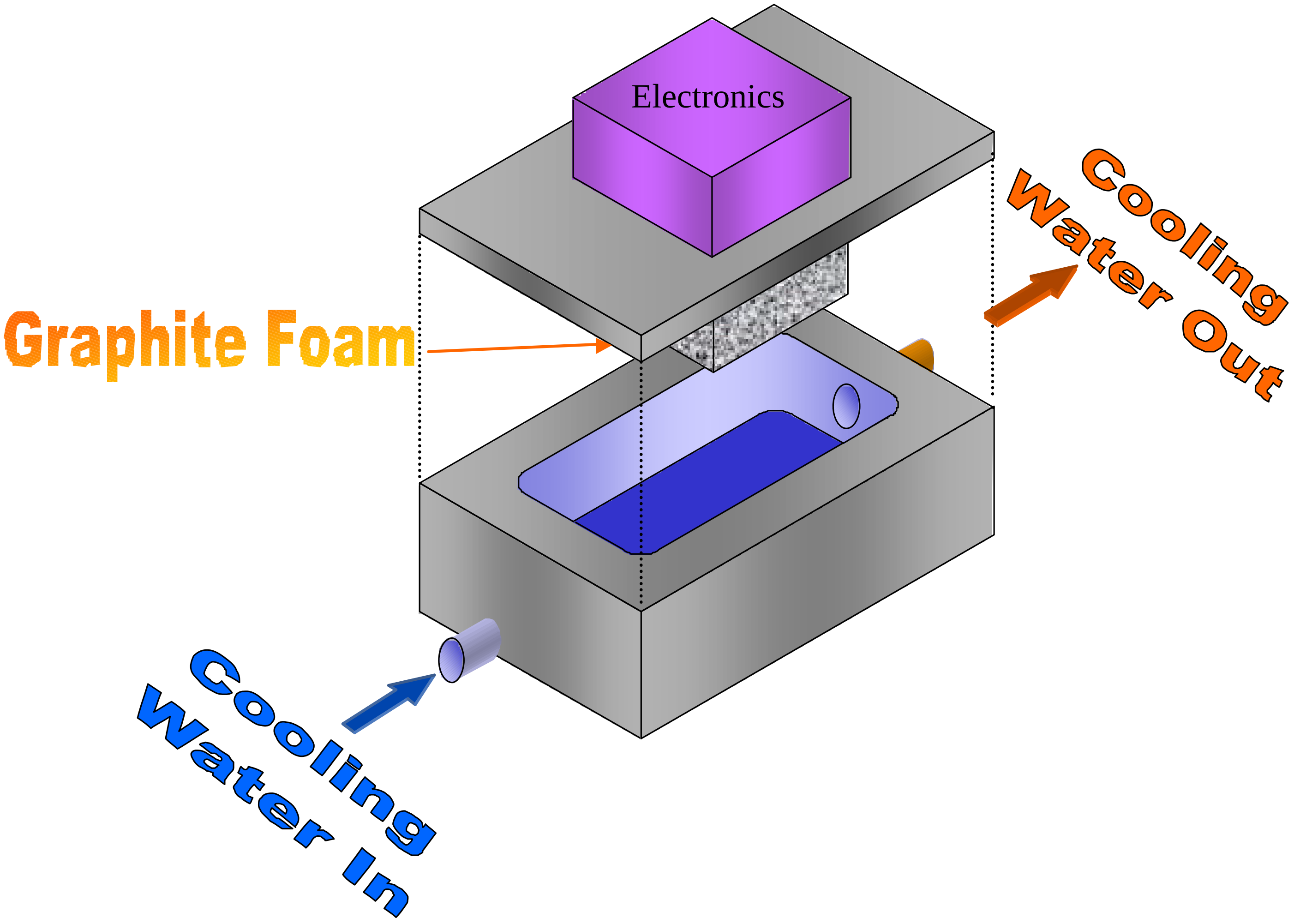
June 16, 2001

Power Electronics Cooling

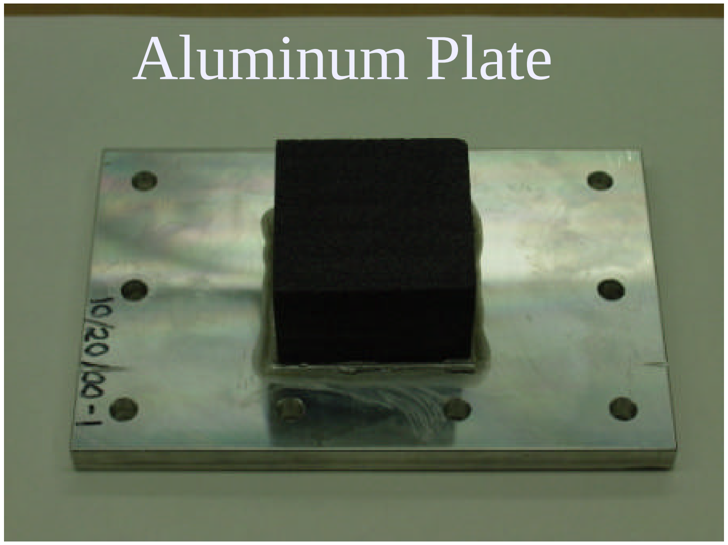
Power Electronics Cooling

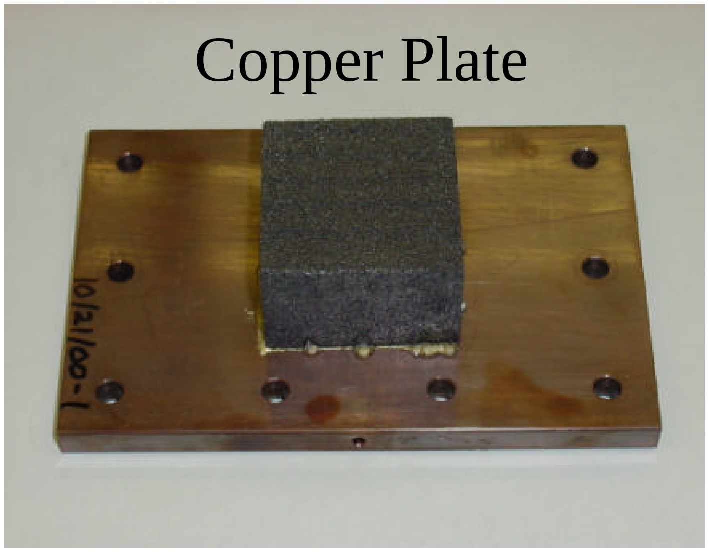
- Team effort with Materials Resources International (MRi) for development of braze/solder technology
- SBIR with BMDO (ORNL was subcontractor to MRi)
- MRi tested several fluxless brazing/soldering techniques (S-Bond^{TM})
  - Vacuum brazing
  - Manual brushing
- MRi evaluated thermal cycling effects on interface
- ORNL tested effects of thermal interface

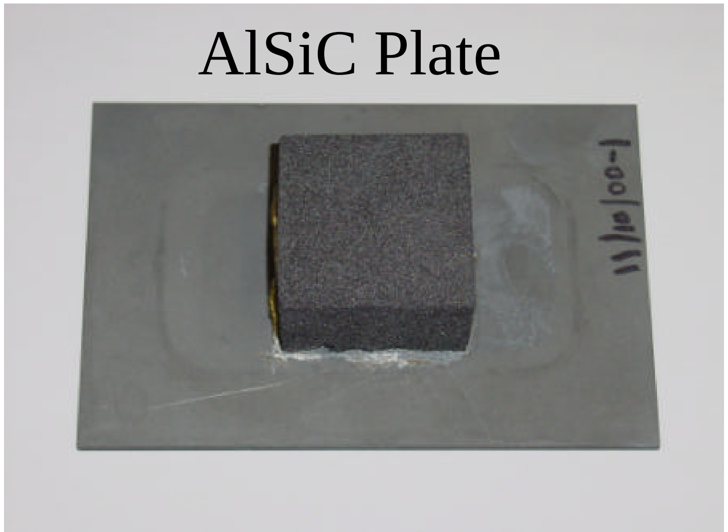
Model Heat Sink

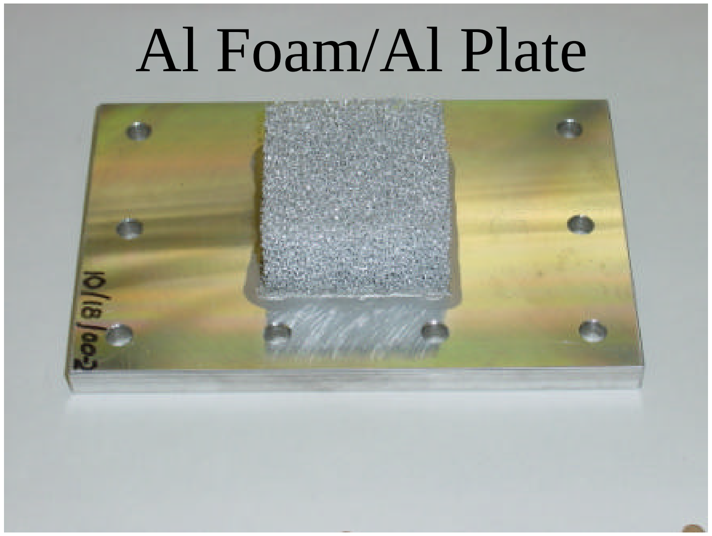


Test heat sinks bonded to different plates


Aluminum Plate

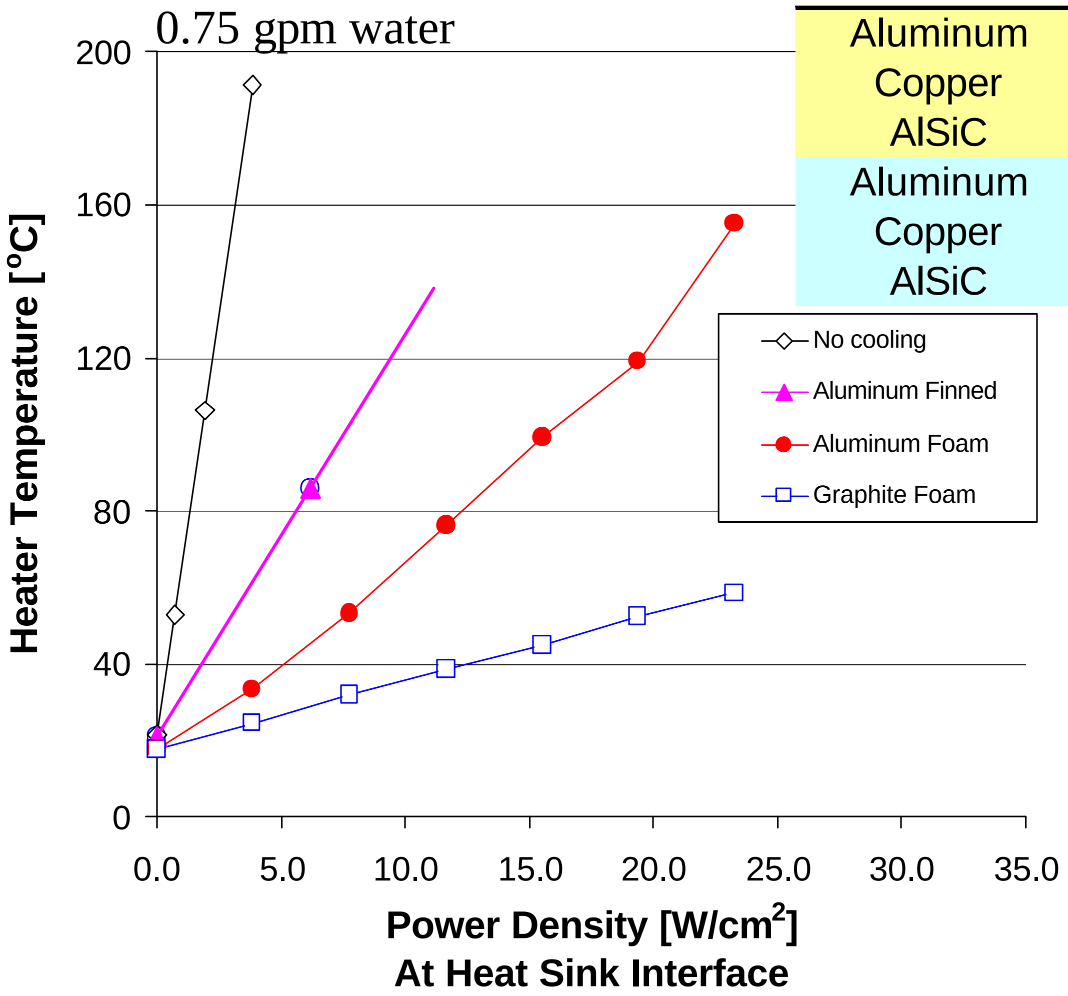

Copper Plate


AlSiC Plate


Al Foam/Al Plate

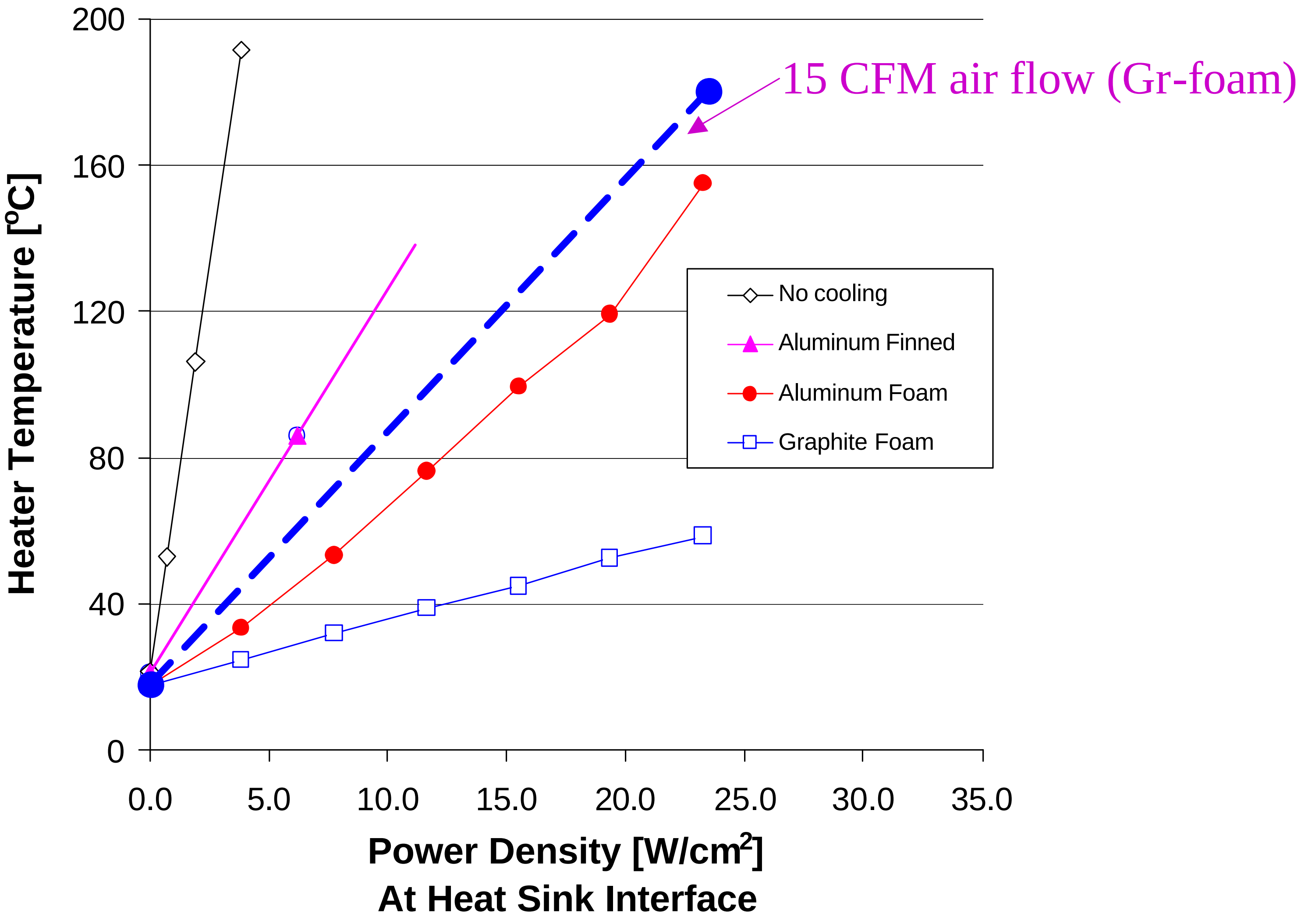
Electronic Temperatures vs. Power Density

Base Plate	Foam Type	Electronic Temp. @ 23 W/cm^2 [°C]
Aluminum	Aluminum	155.2
Copper	Aluminum	136.2
AlSiC	Aluminum	134.2
Aluminum	Graphite	59.8
Copper	Graphite	58.7
AlSiC	Graphite	59.3



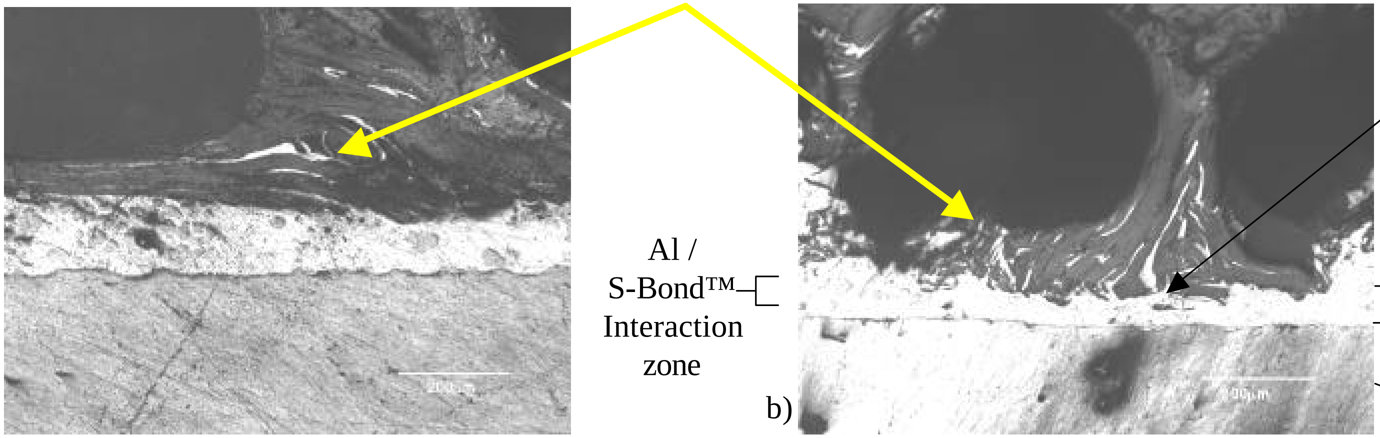
- After a change in conditions, the aluminum foam took more than **20 minutes** to reach apparent steady state.
- The carbon foam took about **1 minute**.

Air cooling with graphite foams versus water with other devices



Wetting Interface

- ➢ High conductivity interface compared to epoxies (45 W/m·K for solder)
- ➢ Good bonding and wetting results in excellent heat transfer



a)

b)

S-Bond™ wicked into mircocracks of foam

Sn_3Ti Intermetallic active phase

Al / S-Bond™ Interaction zone

S-Bond™ Alloy in joint

Aluminum base

Results

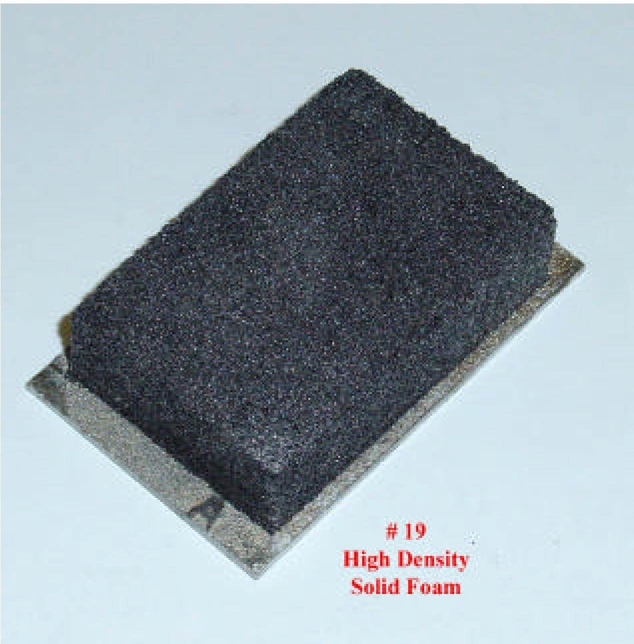
- Water cooling is most efficient
- Air cooling can perform very well (even better than water with some standard devices)
- High power densities (up to 23 W/cm^2) at temperatures less than 60°C have been achieved
- Some apparent corrosion was experienced with aluminum substrates
  - Galvanic reaction?

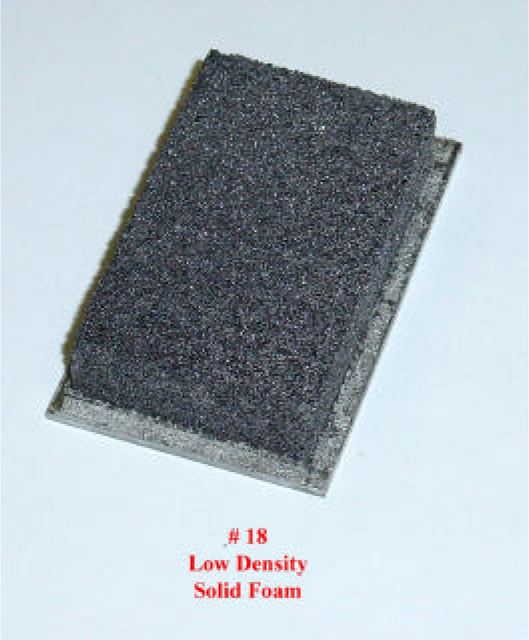
- Develop coating technique for carbon foams which insulate foams electrically without impeding thermal performance
  - Prevent electrical shorting
  - Prevent galvanic reaction with aluminum and copper in system
  - Liquid or CVI process for putting thin ceramic on all surfaces of foam

Independent Prototype Testing

Foam brazed/soldered to Alumina substrate

- Brazed with MRi technique –S-bond™

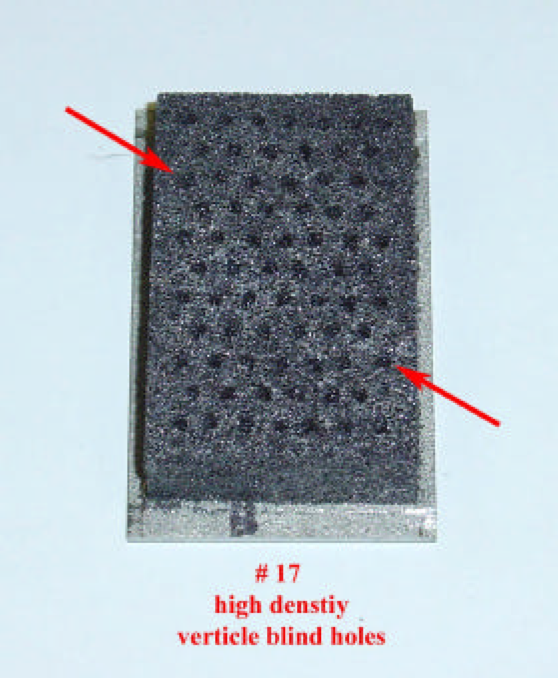




Design Engineering

- Study different foam geometries to reduce pressure drop

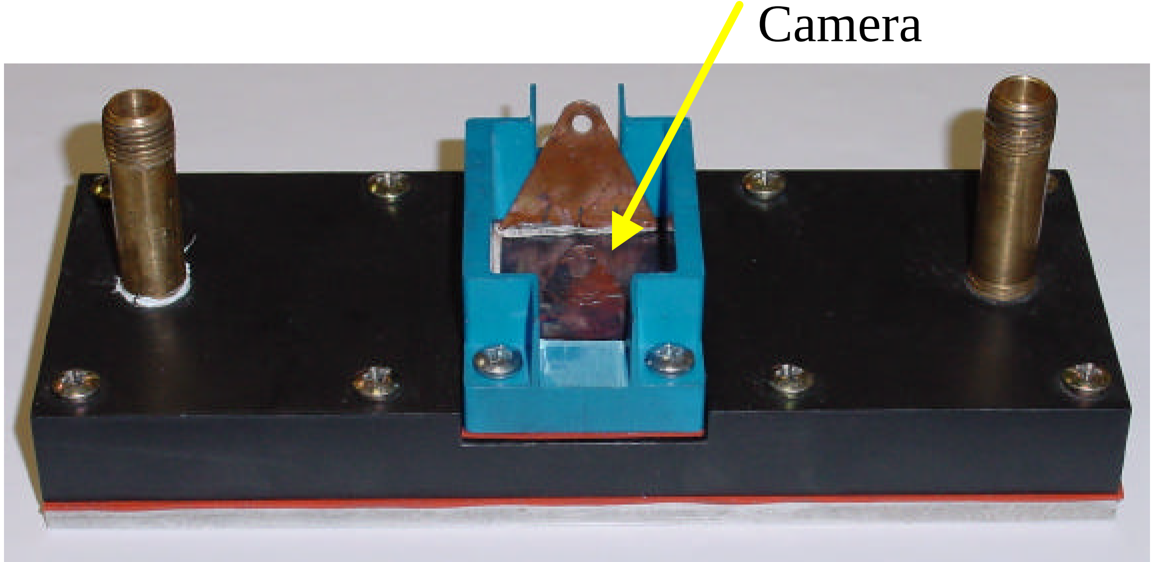
20
High Density
Horizontal Blind Holes



17
high denstiy
verticle blind holes

Heat Sink Testing

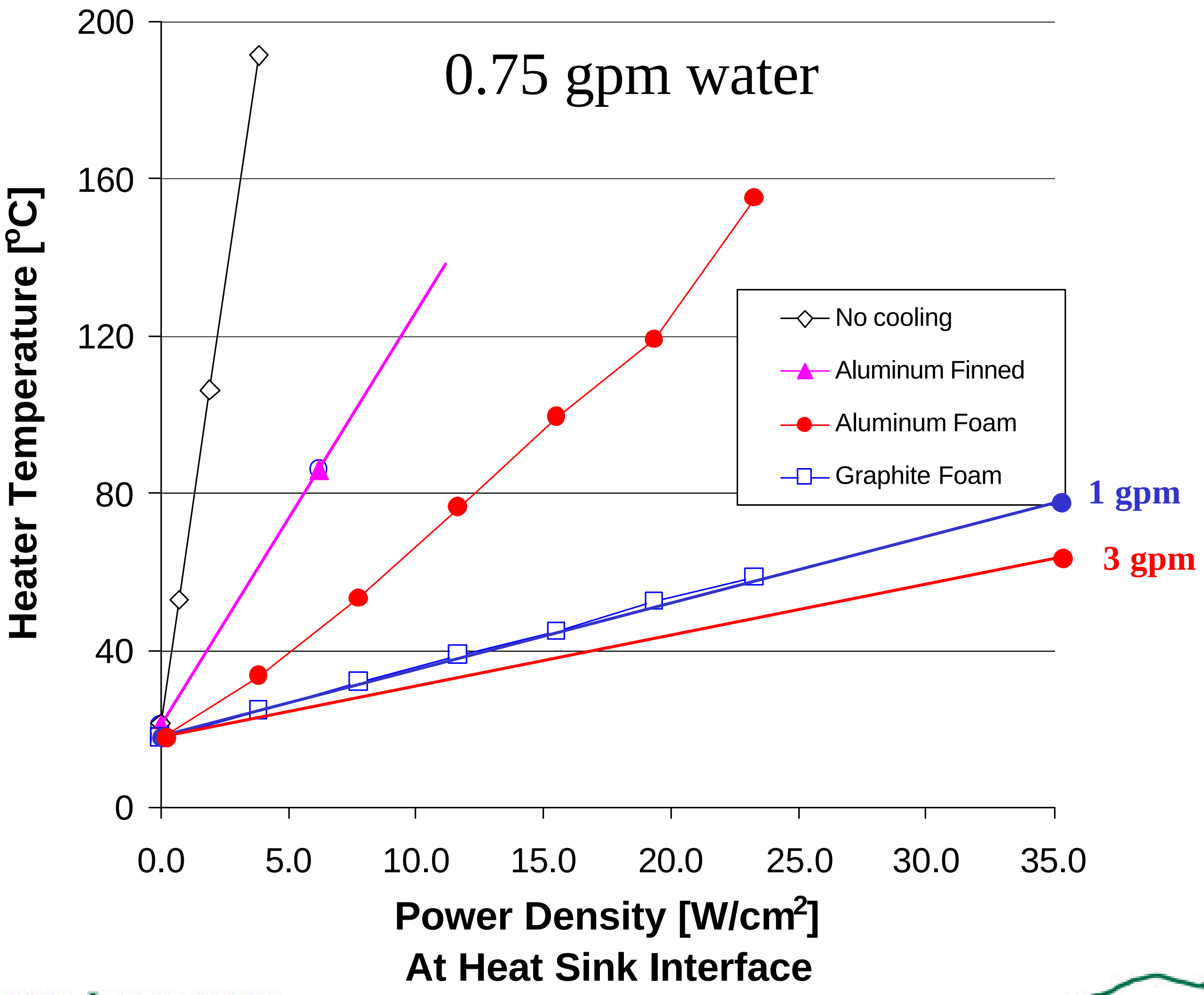
- ➢ Utilize their proprietary heat sink



Thin printed resistor allows viewing with IR Camera

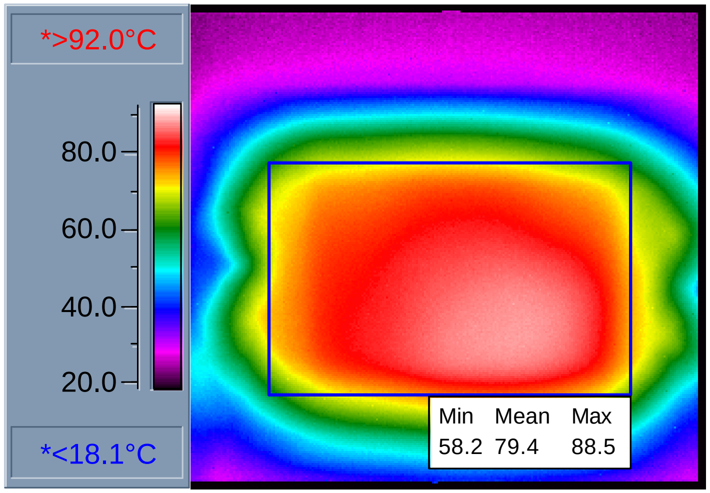
Electronic Temperatures vs. Power Density

- Compare independent results to that previously reported



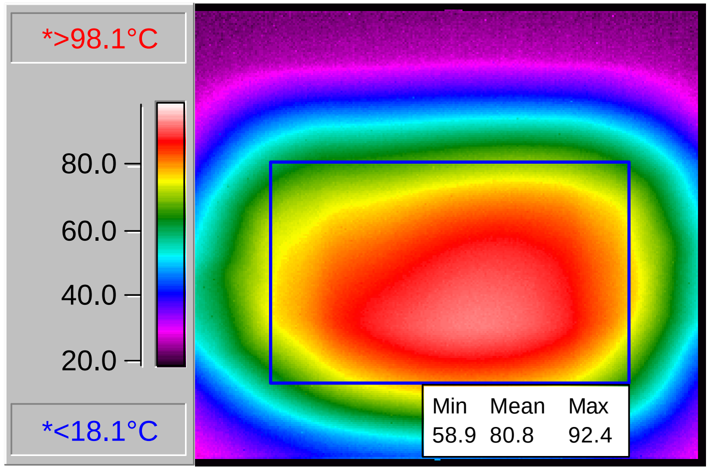
IR imaging of experiments in-situ

High Density – Vertical Blind Holes



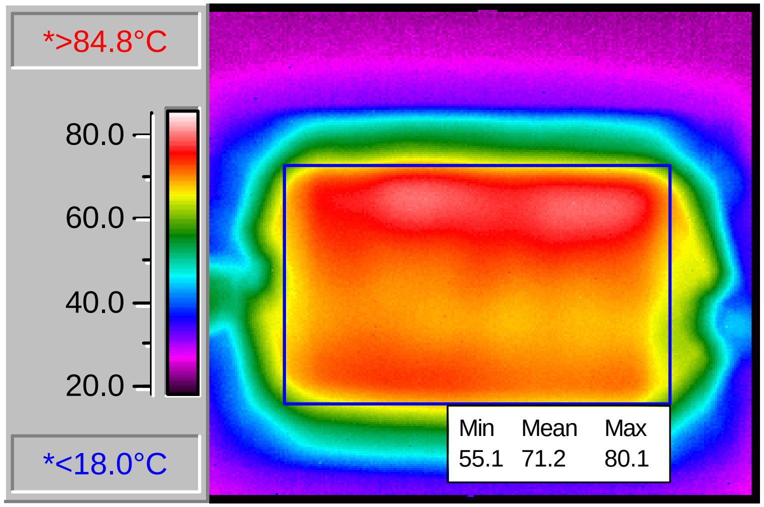
Min	Mean	Max
58.2	79.4	88.5

Low Density



Min	Mean	Max
58.9	80.8	92.4

High Density – Horizontal Blind Holes

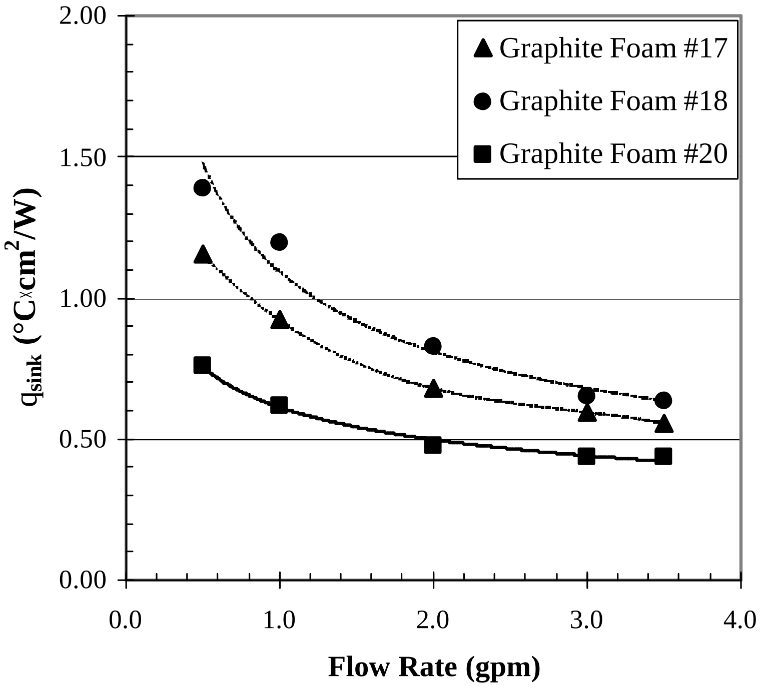


Min	Mean	Max
55.1	71.2	80.1

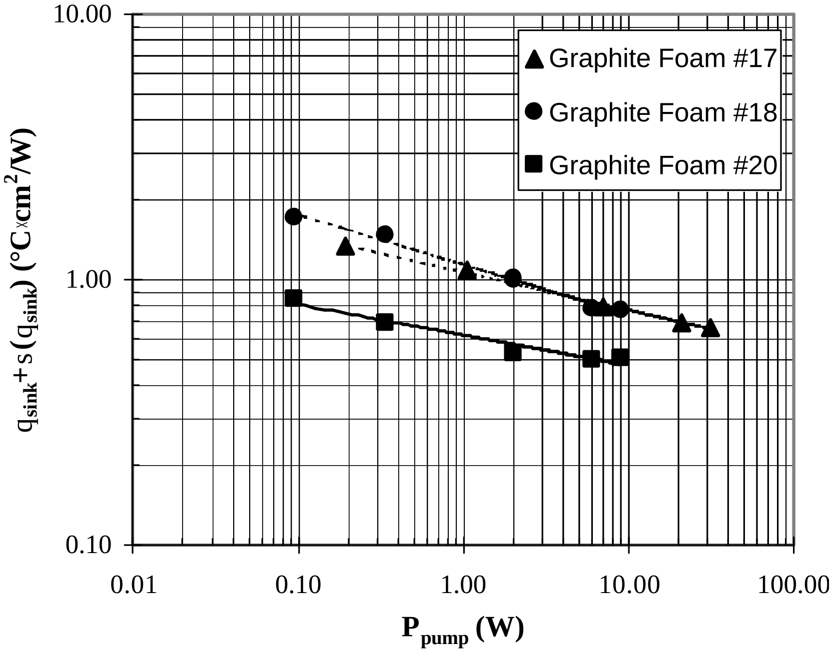
All tests at 45 W/cm^2 power density and 3 gpm water cooling

Results of Testing

Thermal Impedance vs. Water Flow Rate



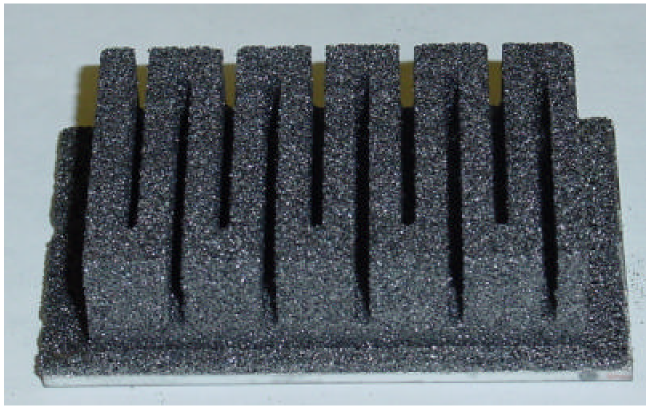
Thermal Impedance vs. Pumping Power



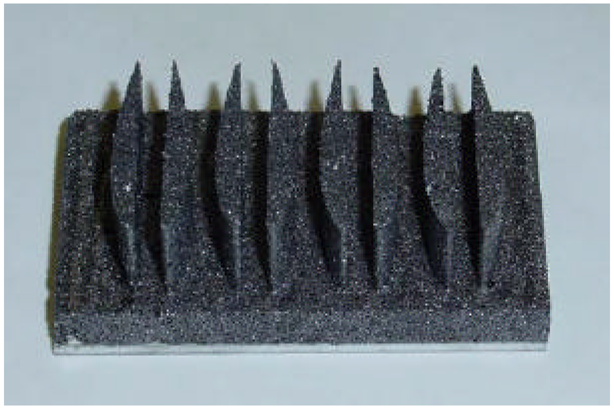
Horizontal blind holes are more efficient in maintaining high heat transfer at the lowest pumping power required.

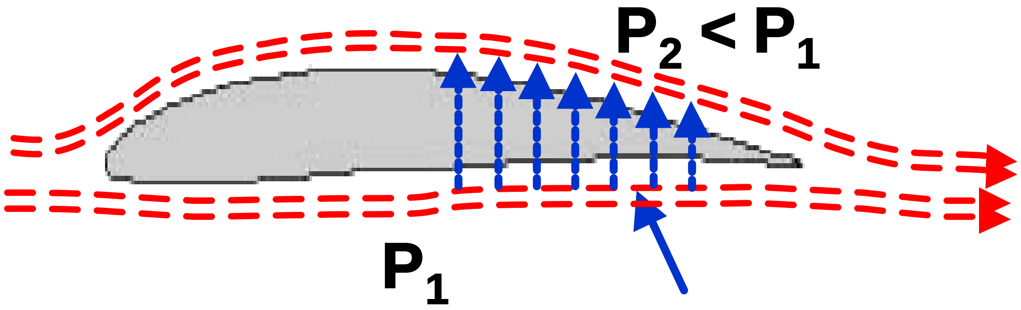
Optimized Designs?

Corrugation
-decreased pressure drop
- continued flow through foam



Air Foil Fins
-Aerodynamics forces fluid to flow through porous fin
- Reduced drag compared to pin fins yet porous flow attained



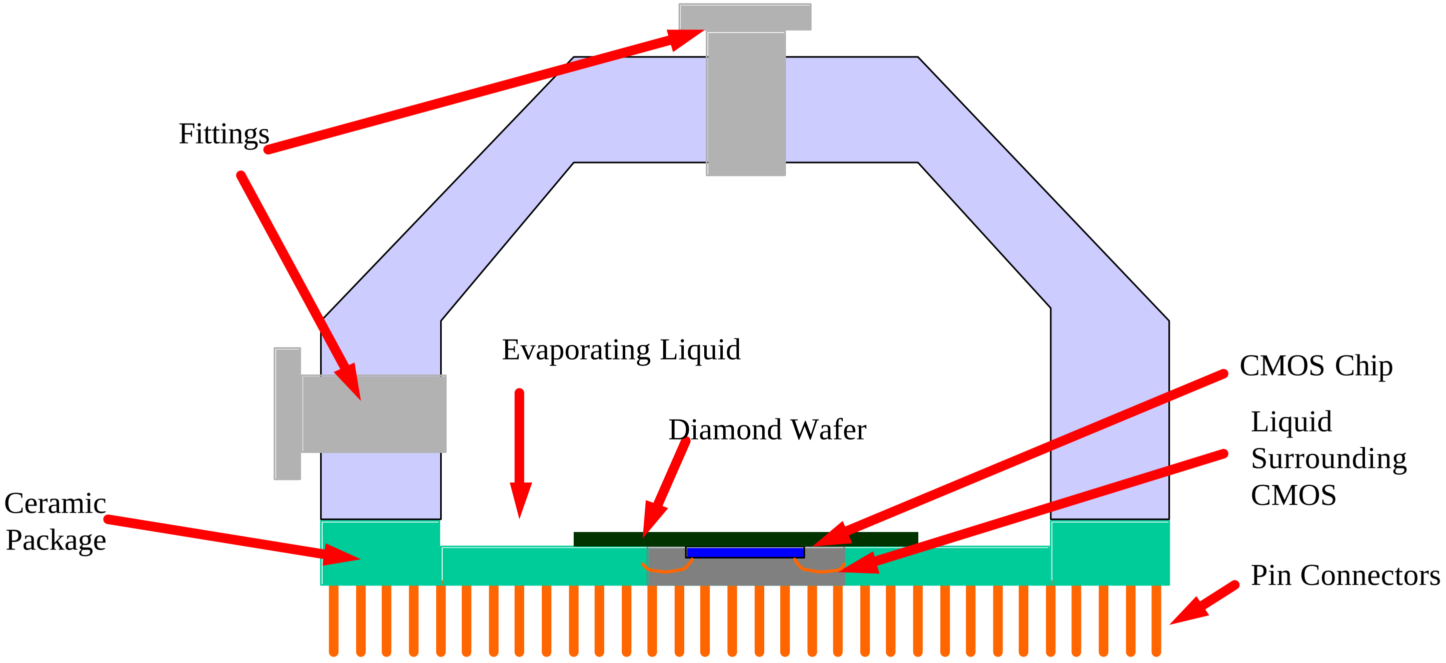


Fluid flow induced by aerodynamics

Evaporative Cooling Developed By National Security Agency (NSA) in Collaboration with ORNL

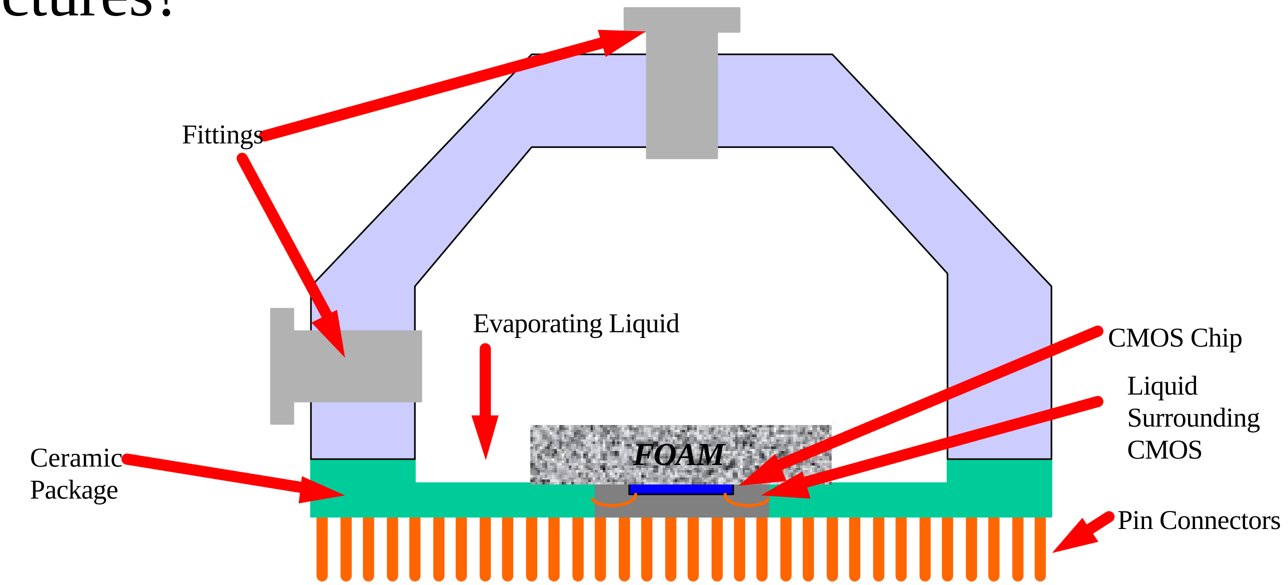
Modified Thermosyphon developed at NSA

- Utilize evaporative cooling on back of silicon wafer chip to enhance cooling

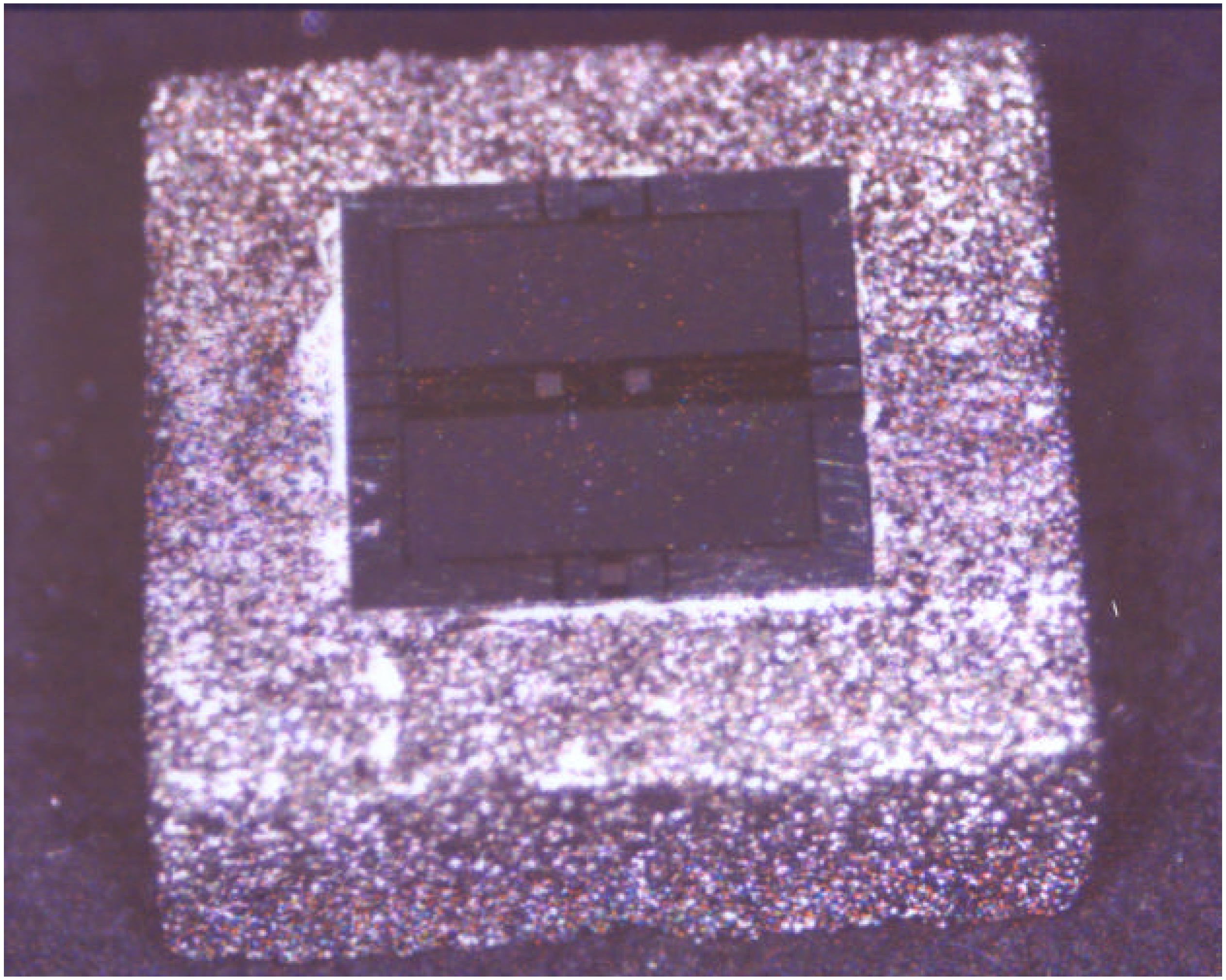


Typical Performance

- Foams will be utilized to replace **copper** and **diamond** evaporators and condensers in thermosyphon
- Typical **diamond** evaporators yield ~ **28W/cm^2** maximum cooling power at 100°C max temperature
- Modify design to utilize graphite foam instead of diamond structures?



Silicon Chip Soldered to Graphite Foam

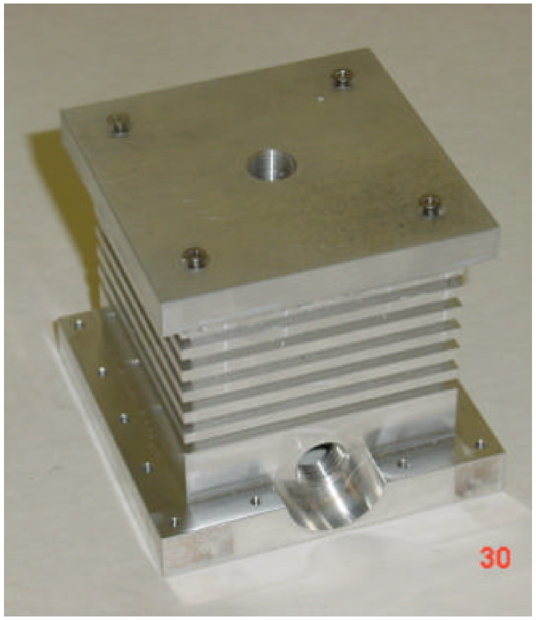


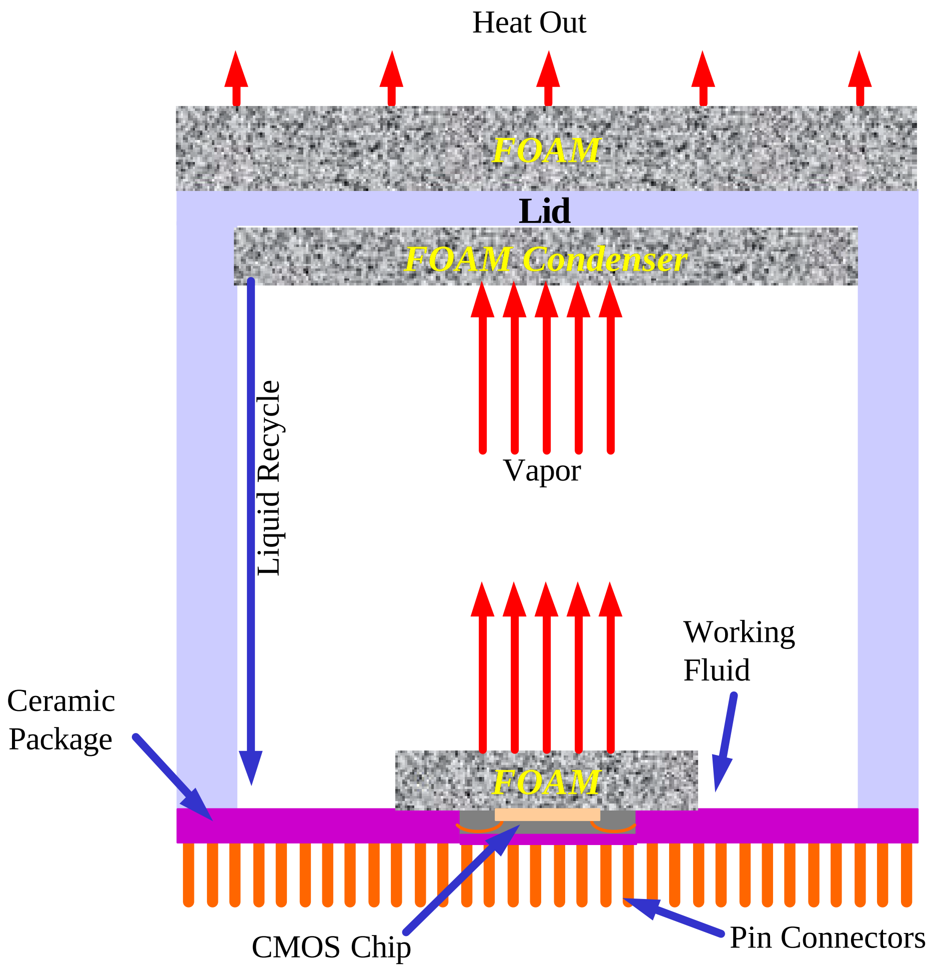
Improvements with Graphite Foam Evaporator

- First test of MRi soldered solid foam (density ~0.5 g/cc) to silicon die yielded 43W/cm^2 at same chip temperatures.
- **53%** improvement in power density over current optimized design
- Realized that pressure in system was exceeding design specs (thermodynamically preventing more evaporation)
- Modified system to accommodate pressure which resulted in a power dissipation of **100 W/cm^2** (357 % improvement)

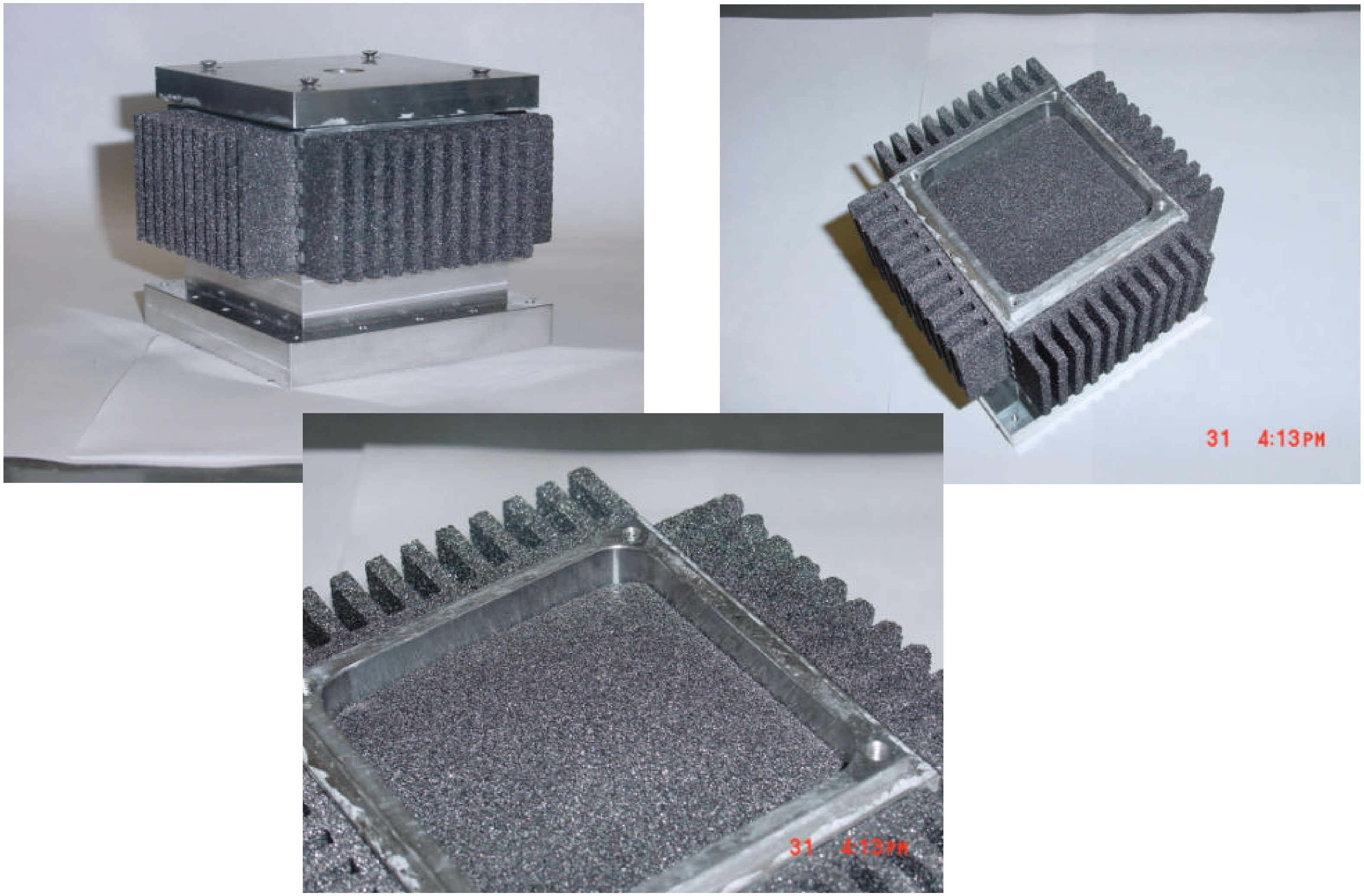
New Designs to Improve Performance

- Improve heat removal with carbon foam condenser
- Attach carbon foam to outside to improve heat removal





Improved Thermosyphon



Conclusions

- Carbon foams have been demonstrated to be more efficient than typical heat sink materials
  - Power densities up to 100 W/cm^2 have been demonstrated at temperatures less than 100°C
- Reliable joining techniques have been developed
- Engineering designs can be optimized to minimize pressure drop (pumping power) while maintaining high heat transfer.
- Corrosion protection has been identified as area for future work