Lightweight, Low-Cost Heat Sink for High-Heat Flux Applications

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ULTRAMET

TFAWS Meeting

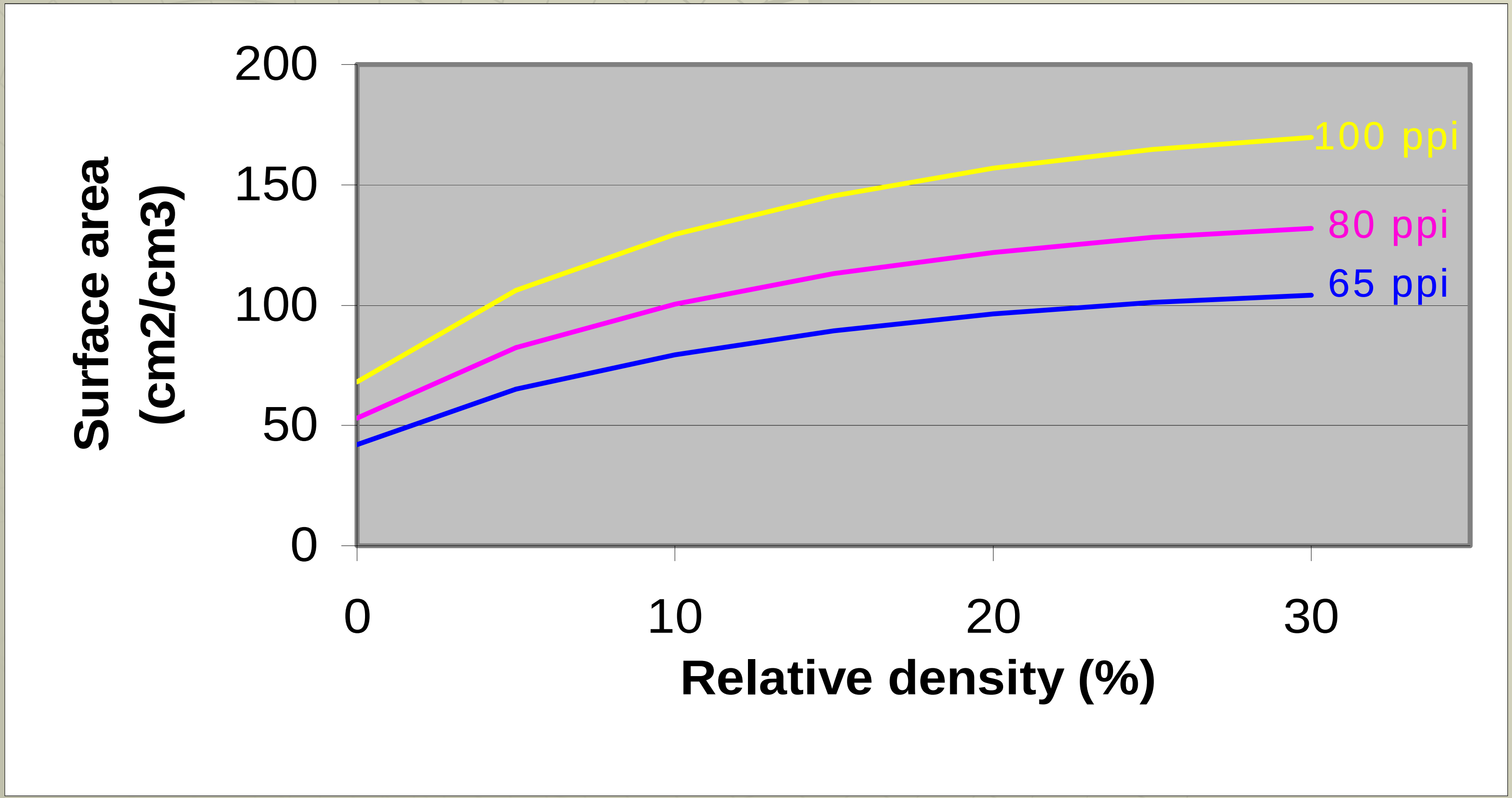
August 8, 2006

Basic Concept

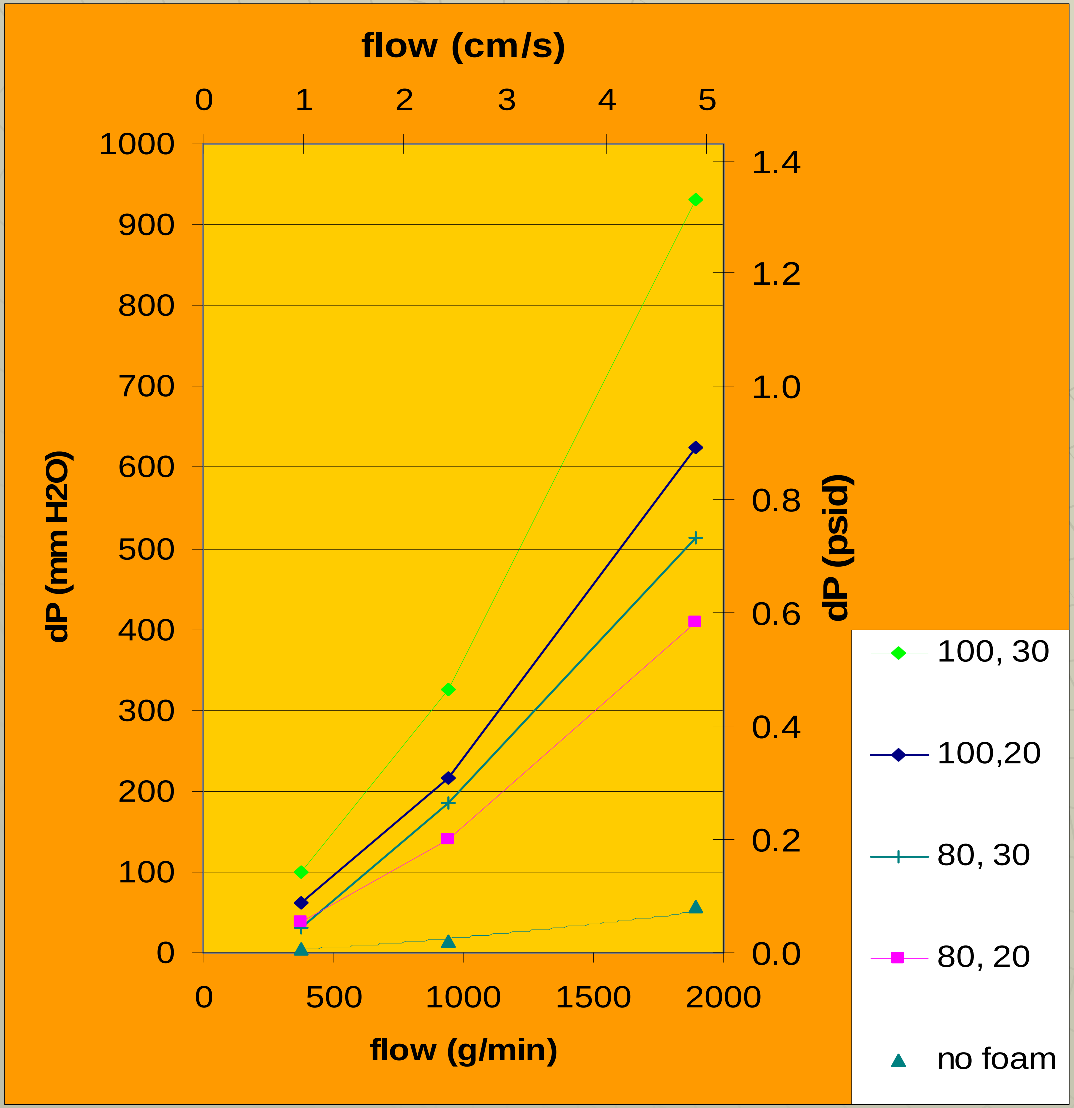
- Use open-cell SiC foam as an extended surface or cooling fin for SiC integrated circuits (ICs).
- Advantages
  - Perfect CTE match with SiC ICs
  - High thermal conductivity
  - High surface area
  - Low pressure drop
  - Immune to corrosion

Silicon Carbide Foam

- High surface area
- Important for transferring heat to cooling medium

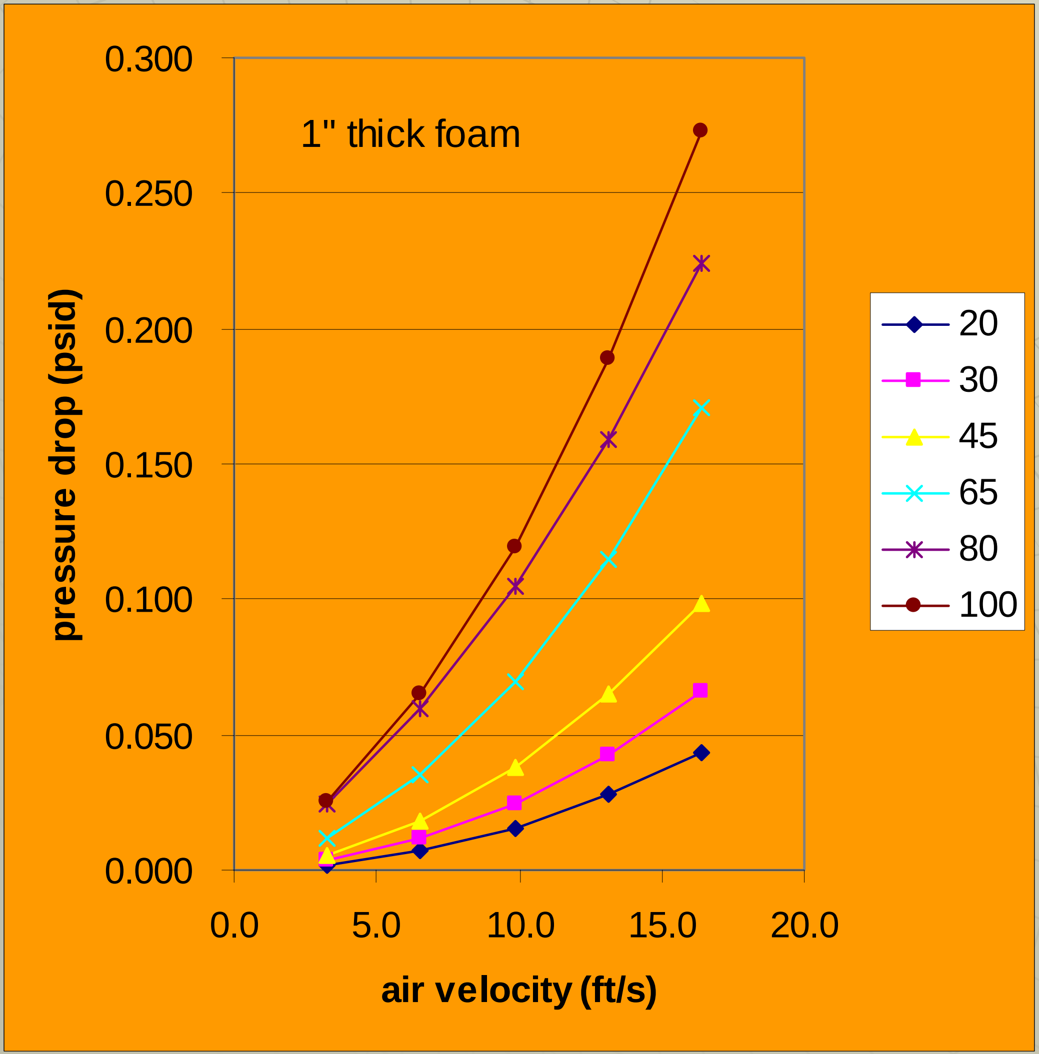


Pressure Drop



- Silicon carbide foam
  - 0.5 x 2 x 3” slab
  - Water flow parallel to long axis.
  - Important for flowing large quantities of coolant without pressure drop penalty.

Pressure Drop



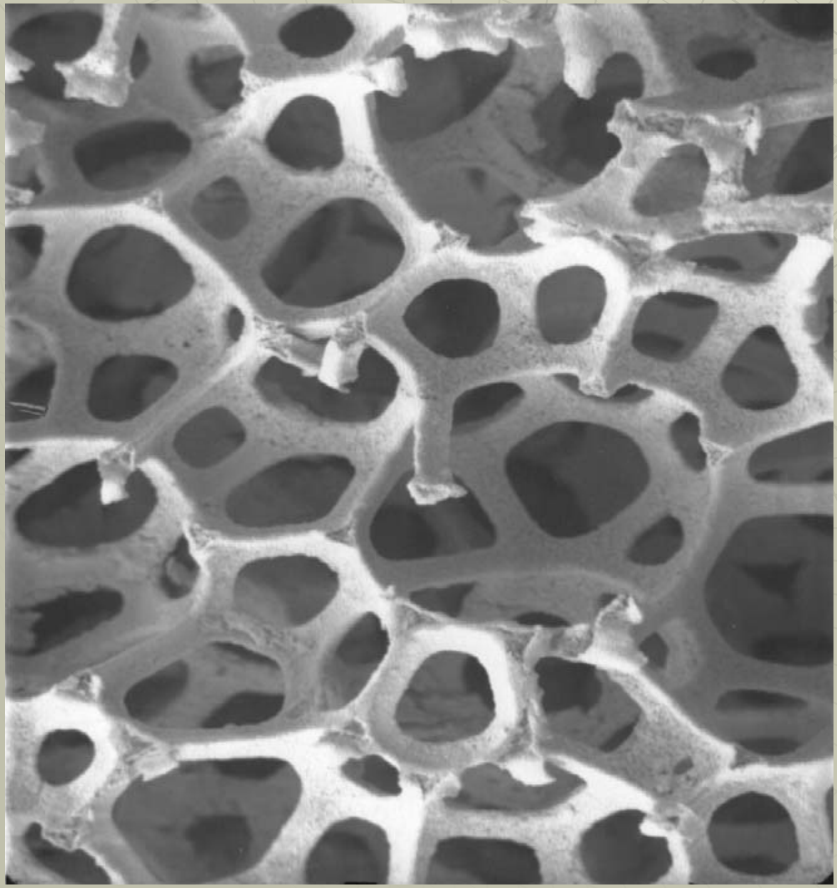
- Carbon foam
  - 1” thick slab
  - Air flow perpendicular to thickness
  - Very low pressure drop

Ultrafoams

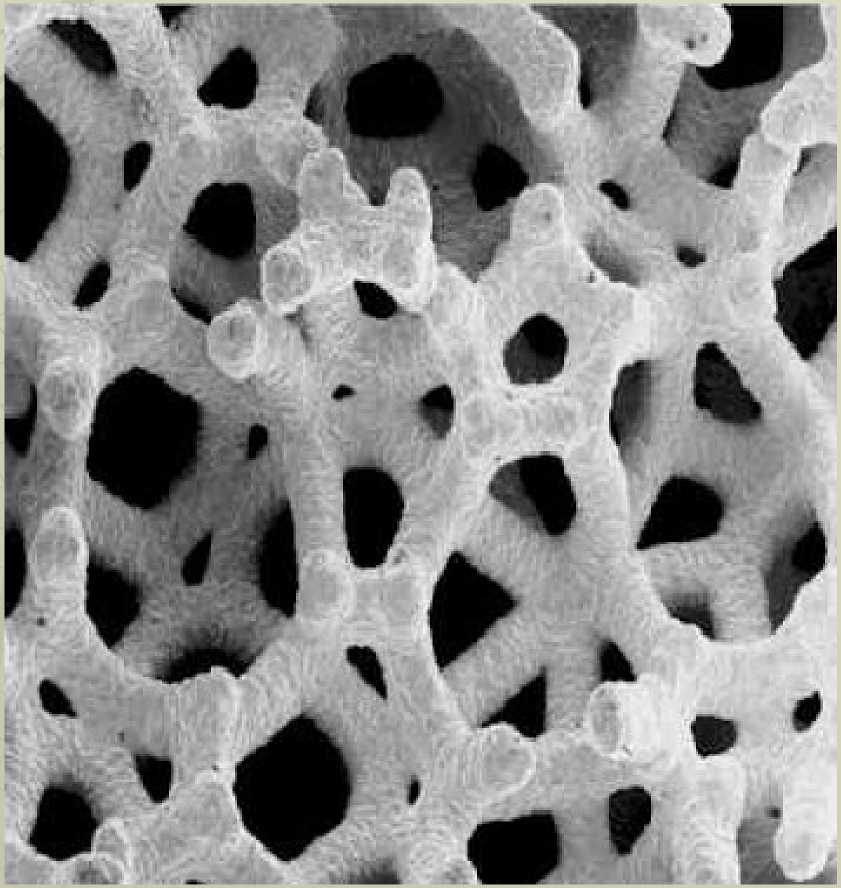
- Begin with polyurethane
- Impregnate with resin
- Pyrolyze to form glassy carbon
  - 3-1000 pores per inch (ppi)
- CVI with SiC
  - 5-30% relative density
  - Other materials: Si, Gr, pyC, Si(C), refractory metals, etc

Ultrafoam

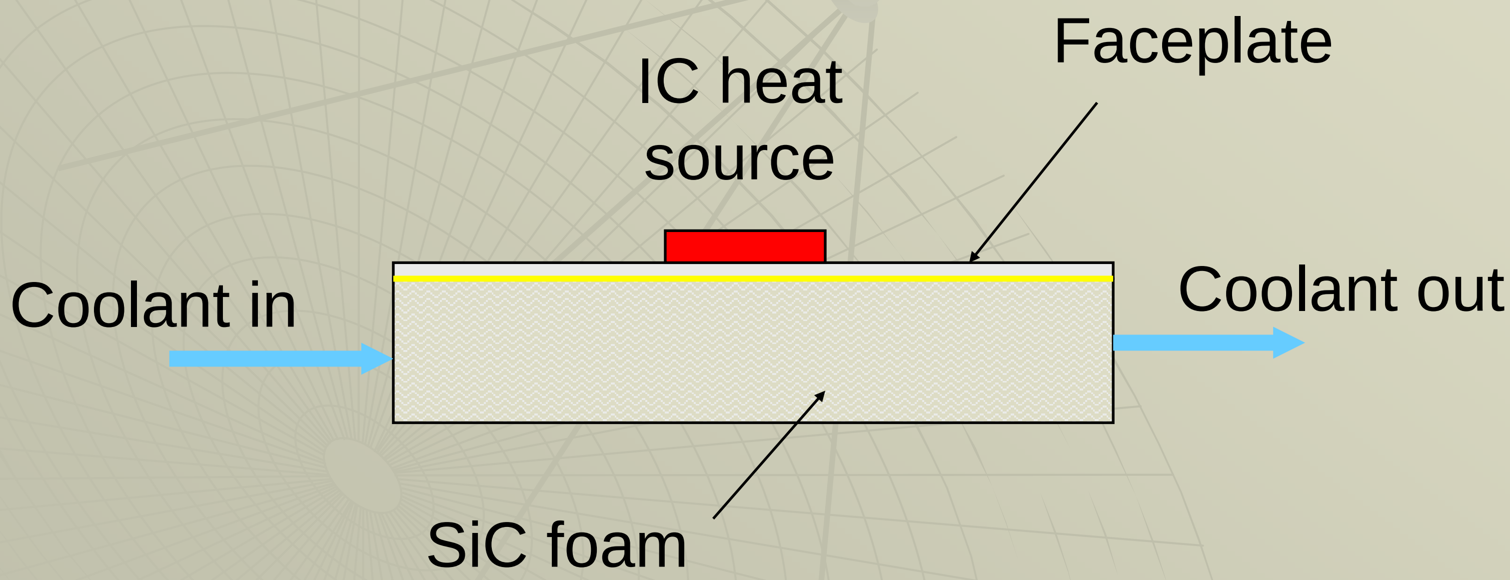
Vitreous carbon



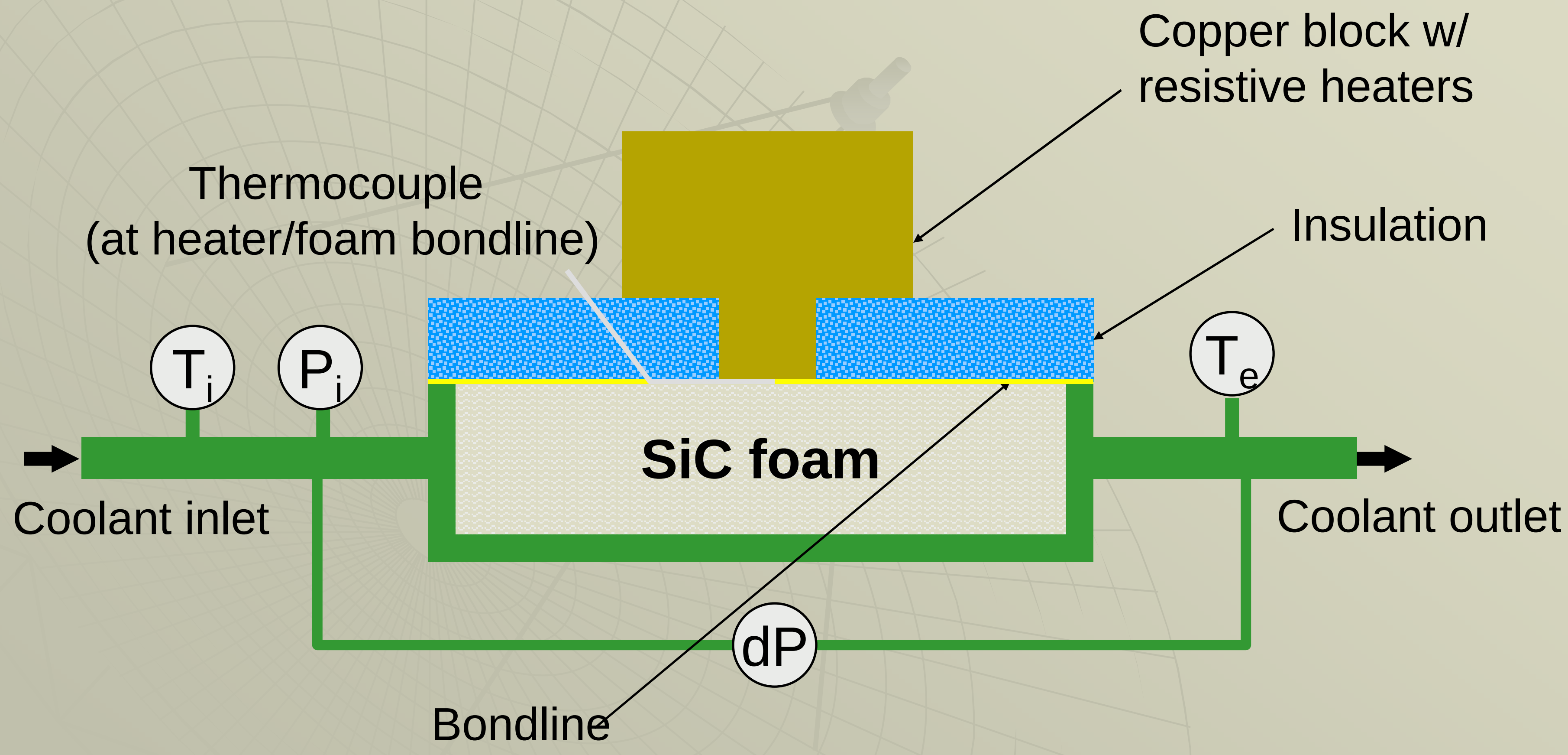
Silicon carbide



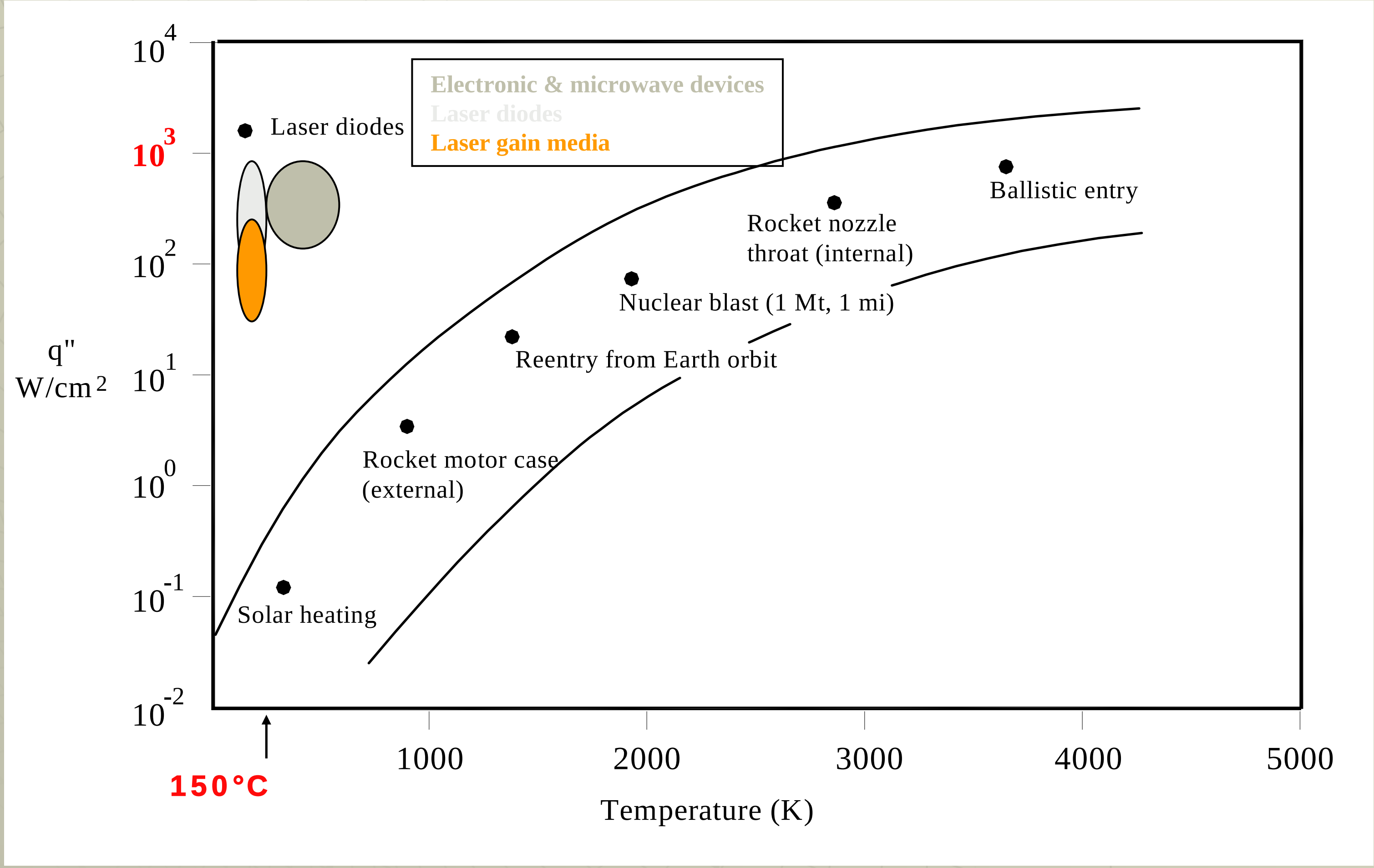
Basic Concept



Experimental



Unique Thermal Control Challenges
(High Heat Flux, High Power, Low Temperature)



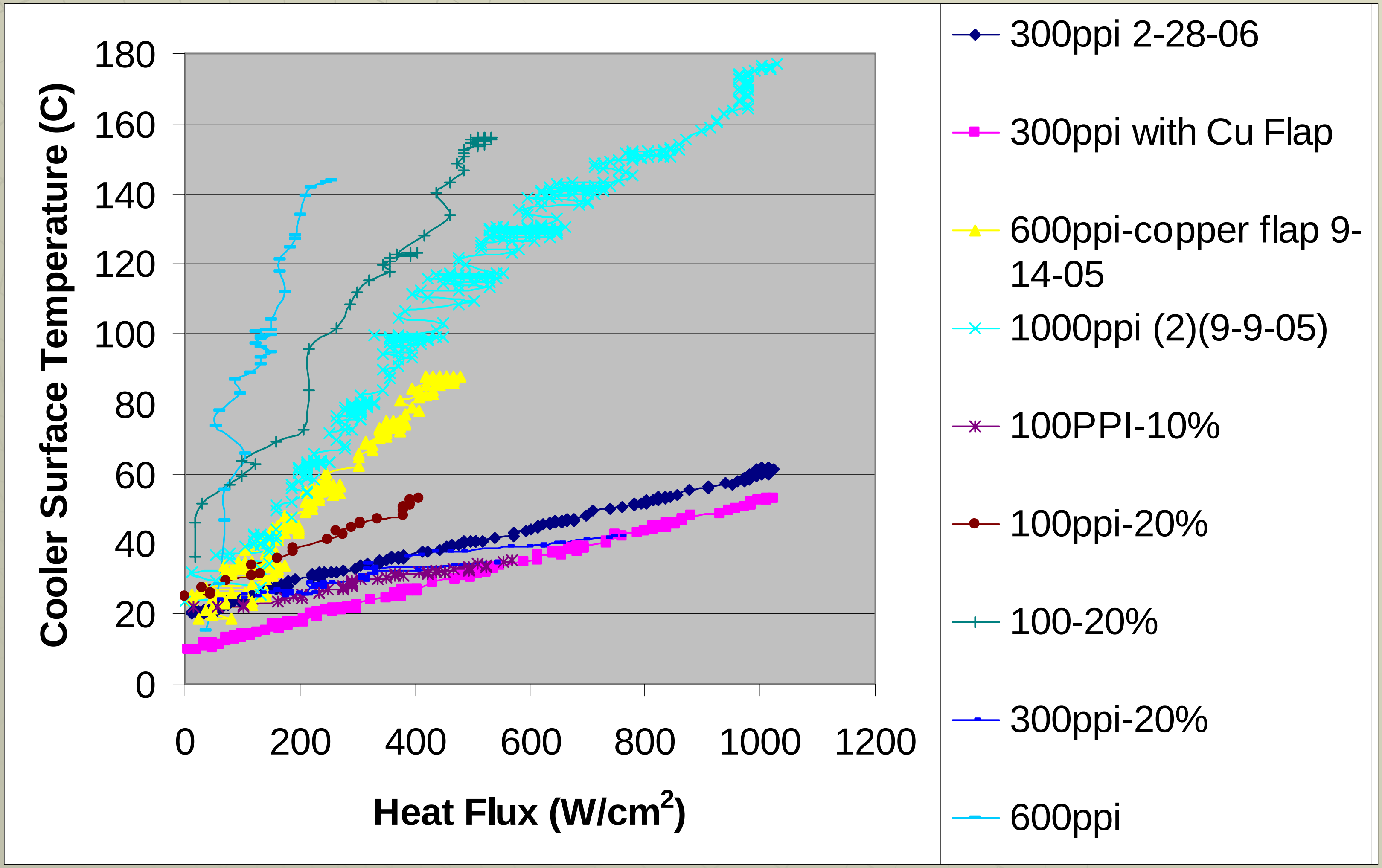
•Phase II goal was to reach 1000 W/cm² with temperature below 150°C

Experimental Results

Foam PPI / density	Heat Flux	Flow Rate	Heat Flux / Flow Rate	Cooler Surface Temperature
	(W/cm^2)	(GPM)	(W min /cm^2 G)	(°C)
100ppi/ 9.8%	711	0.5	1422	113
1000ppi / 12%	**867**	0.5	1734	**122**
100ppi/ 10%	**612**	0.5	1224	**47.8**
1000ppi/ 5%	**1006**	0.64	1572	**165**
300ppi/ 20%	**1011**	**0.5**	**2022**	**53**
100ppi/ 20%	**1000**	1.0	1000	**135**
300ppi/ 20%	**758**	**0.3**	**2527**	**42.4**

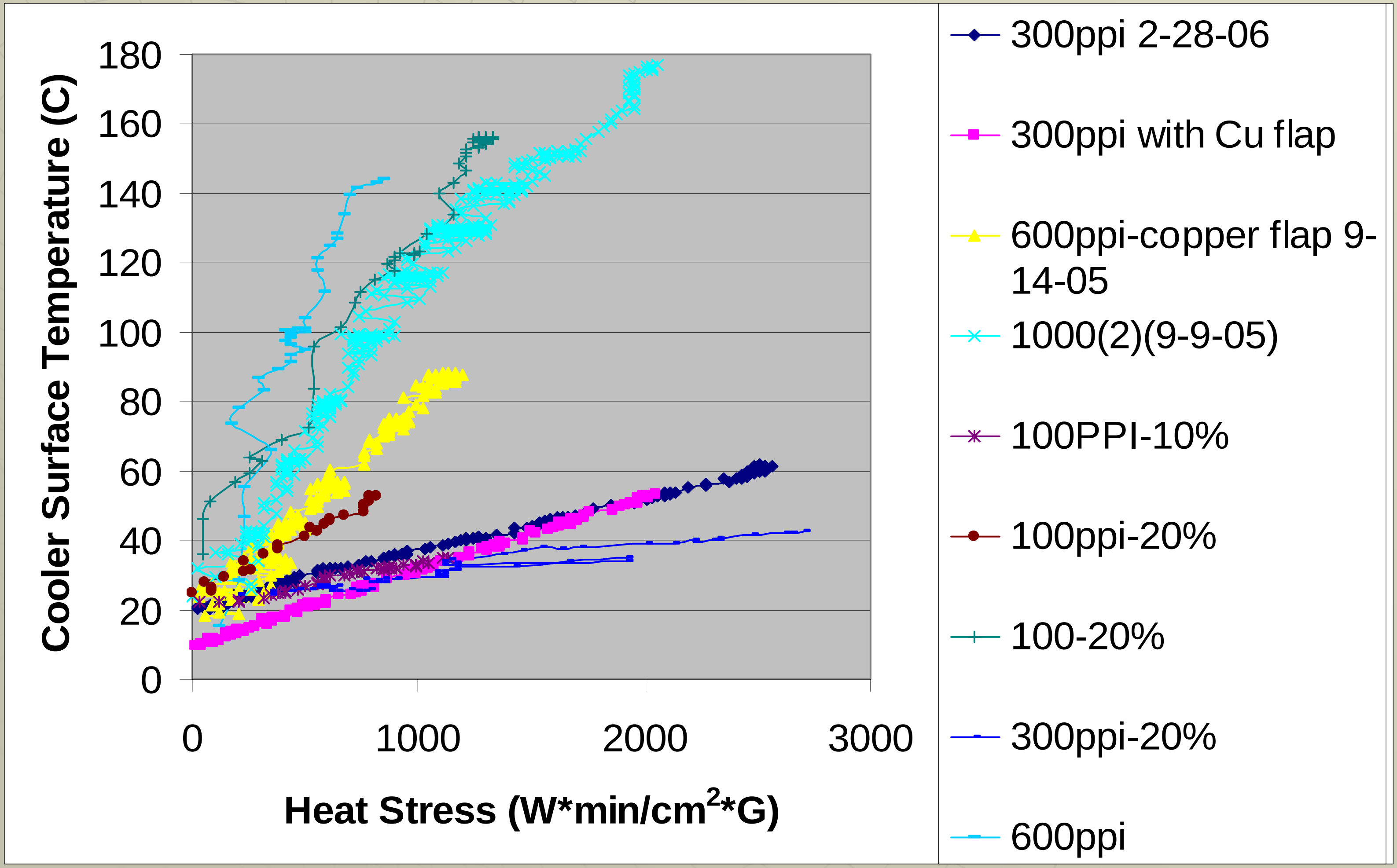
- Phase II goal: 1000 W/cm^2 while below 150°C.
- Ultramet SiC foam 1011 W/cm^2 at only 53°C!

Experimental Results



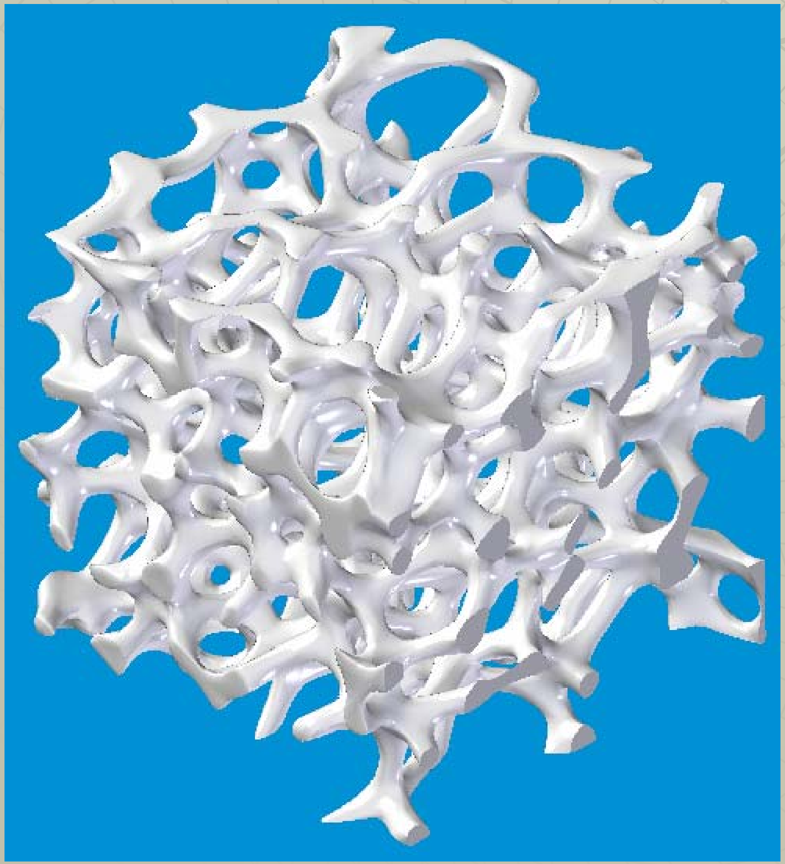
Experimental Results

Heat Stress = Heat Flux/ Flow rate (Gallons per minute)

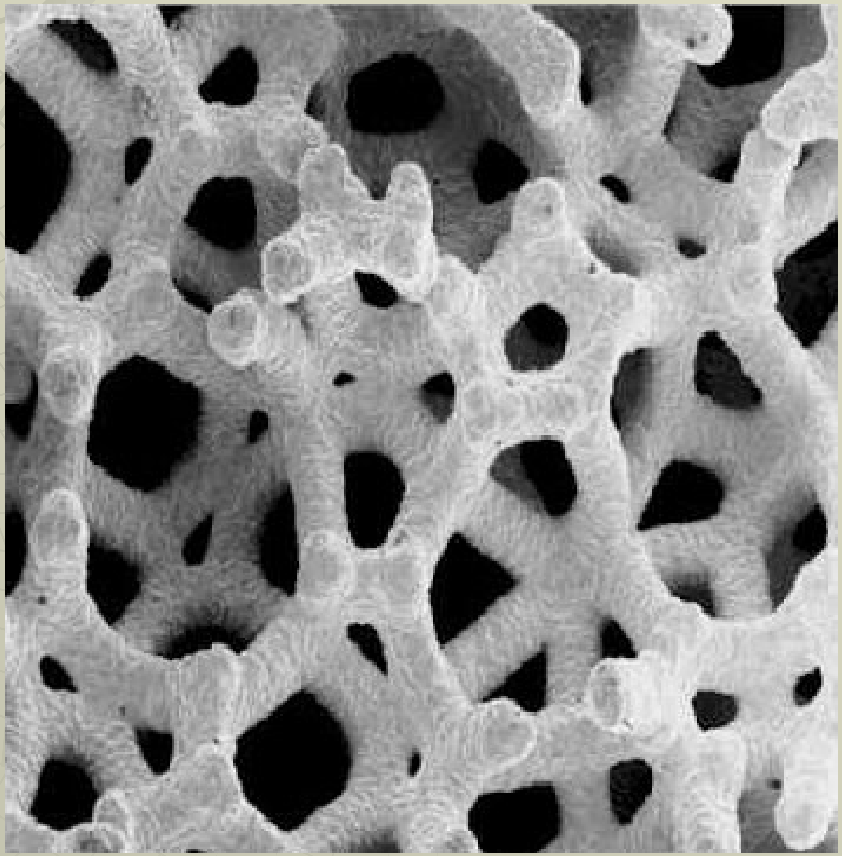


Thermal Modeling

X-Ray Tomography

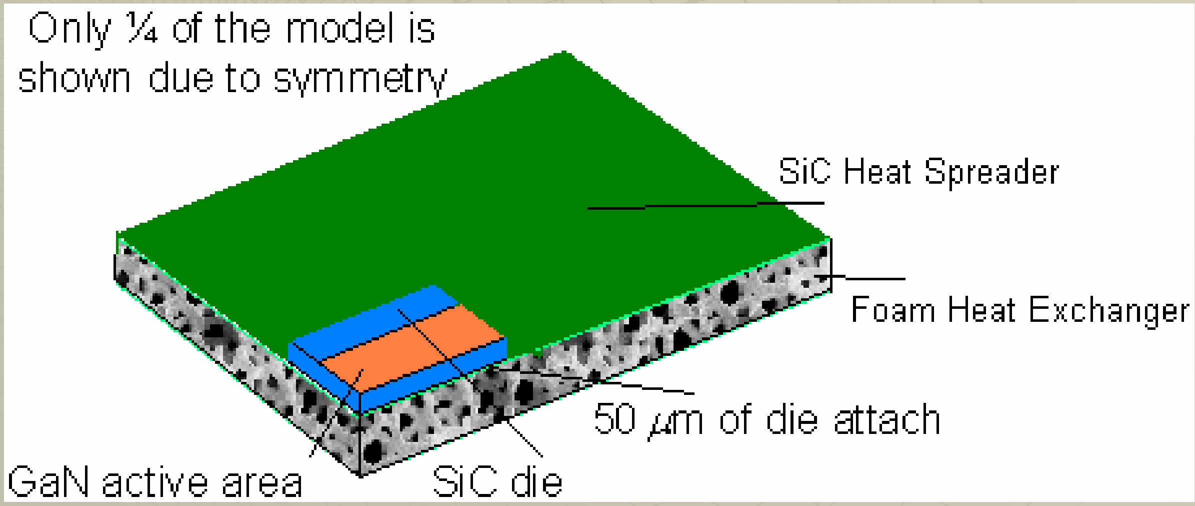


Ultramet SiC Foam



Thermal Model Input

Part	Side Dimensions	Thickness	Thermal Conductivity (W/m C)
SiC Foam	2 x 2”	0.5”	40
TIM1	2 x 2”	100 µm	40
SiC Heat spreader	2 x 2”	250 µm	200-500 (4H-SiC)
Die Attach (TIM2)	5 x 5 mm	50 µm	40
Die	5 x 5 mm	380 µm	200-500 (4H-SiC)
GaN active area	0.25 x 4 mm	n/a	n/a



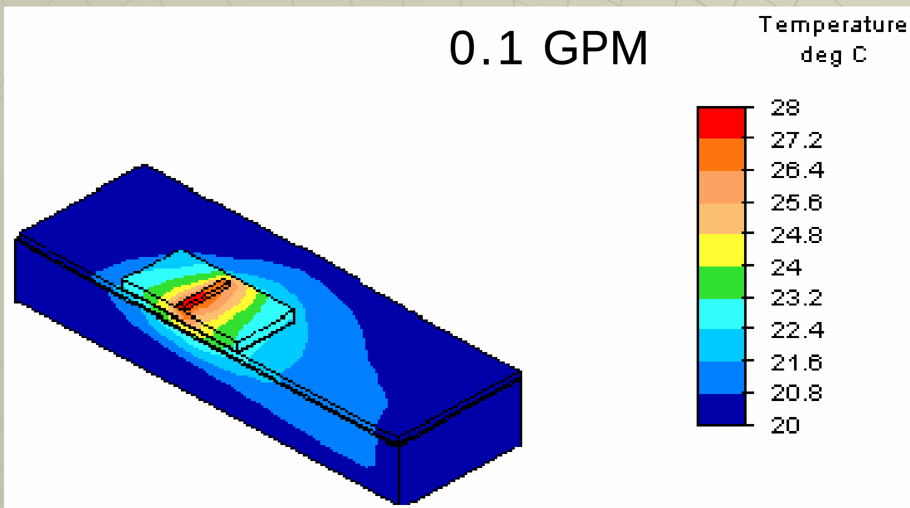
Modeling Conclusions

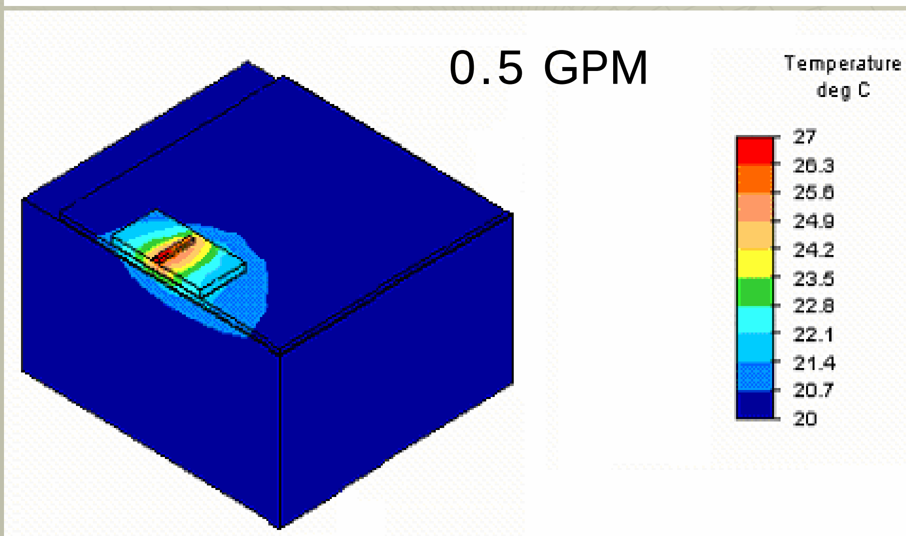
1kW/cm² with Heat Spreader

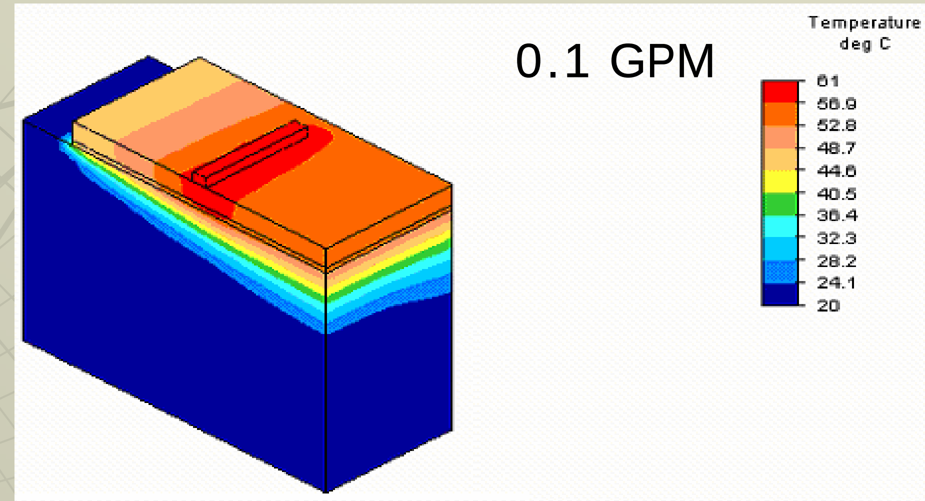
0.1 and 0.5 GPM→ 27 and 28 °C

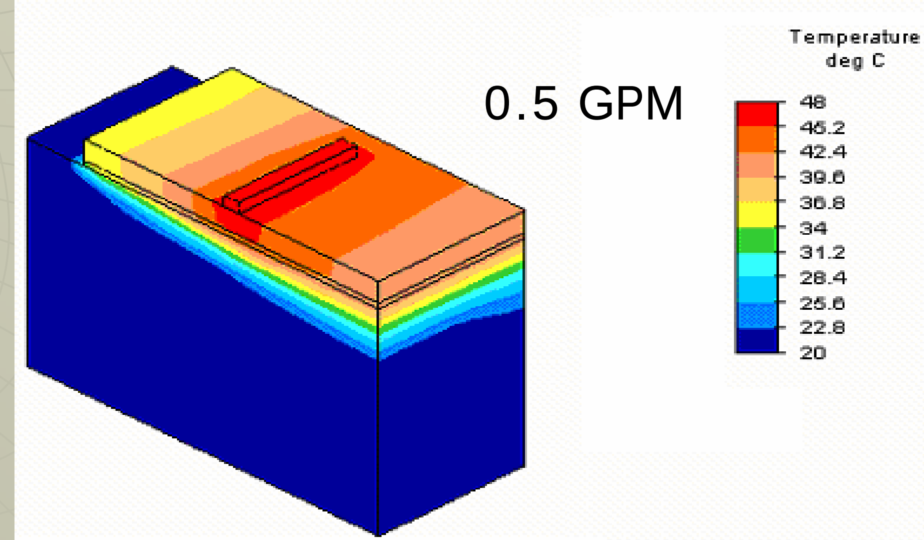
1kW/cm² without Heat Spreader

0.1 and 0.5 GPM→ 61 and 48 °C







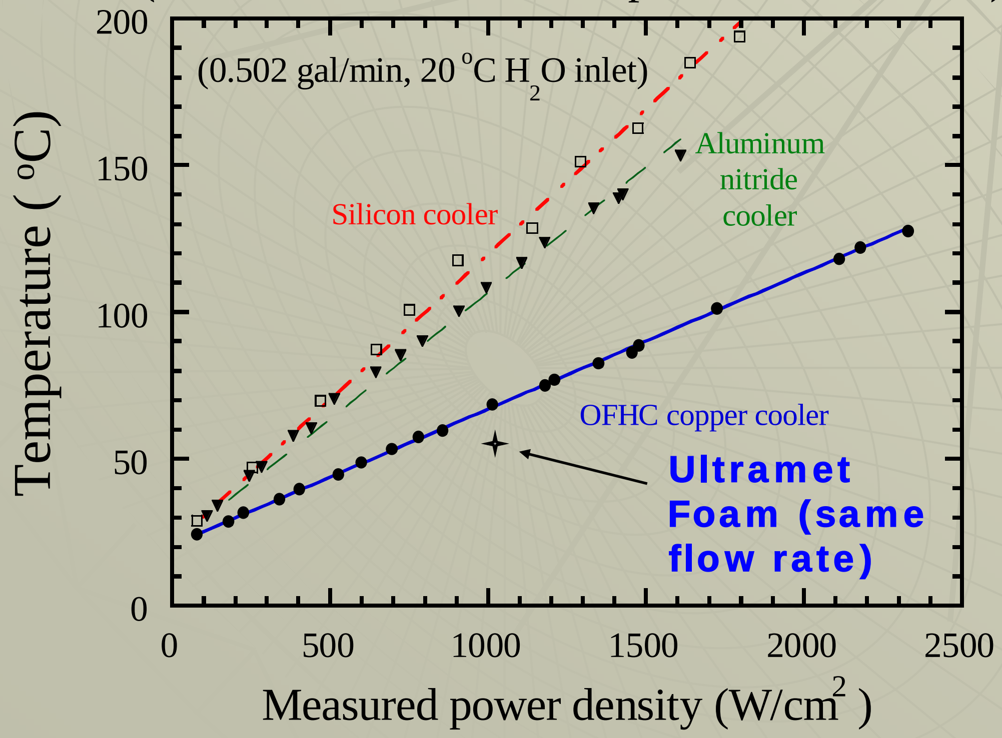


Other Work- **High Heat Flux GaN-Based RF Components and Cooling Methods**

Jeff Calame, Steve Binari, Robert Myers †, and Frank Wood †
Naval Research Laboratory, Washington, DC 20375

3rd Annual Workshop on Thermal Management of High Flux Commercial and Military Electronics
University of Maryland, College Park, MD
October 18, 2004

Experimentally measured temperatures
(Cooler surface under heat probe source center)



-Micromachined to 500µm

•Ultramet SiC foam has comparable performance to micromachined OFHC copper and single crystal silicon with diamond heat spreader.

Summary

- Effects of SiC foam:
  - 1011 W/cm^2 @53C w/ 0.5 GPM water
- Thermal Model predicts improvements by going to heat spreader configuration.
  - 27 ºC with heat spreader w/ 0.1 GPM
  - 61 ºC for 100ppi. 10% density (stock item) at low flow rate.
- Excellent heat transfer → little material is required (small volume/ light and inexpensive).
- Low coolant flow rates requires less in way of supporting systems- pumping, filtration, etc.