High Thermal Conductivity, Mesophase Pitch-Derived Carbon Foams

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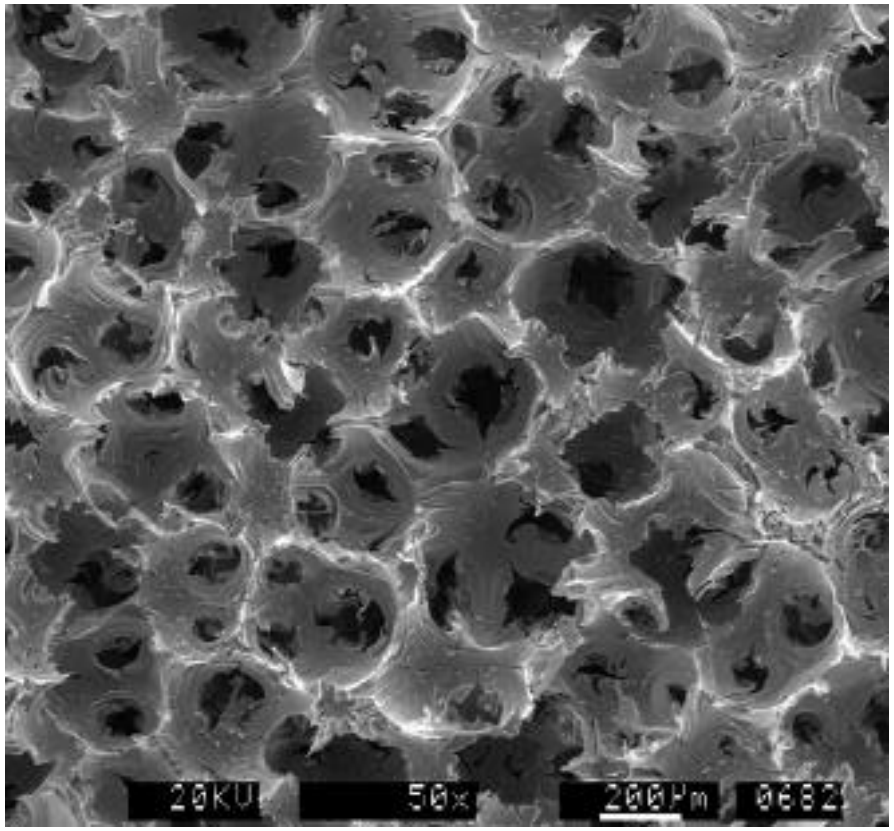
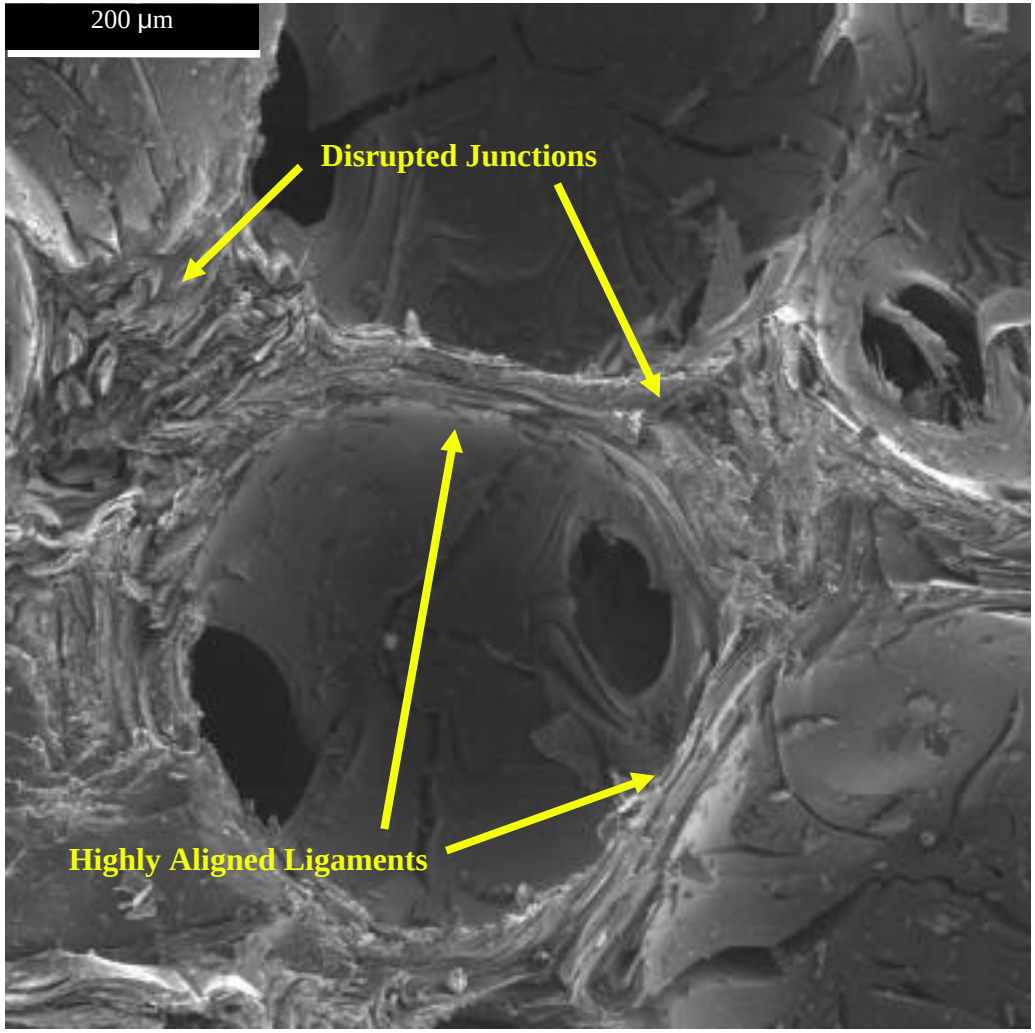
ORNL Mesophase-Derived Graphitic Foam

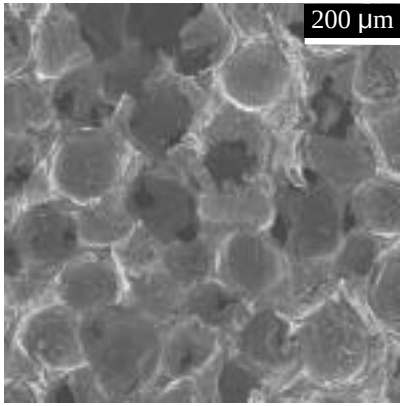
- **Graphitic ligaments**
  - **Graphitic-like properties (high κ, E, σ)**
- **Dimensionally stable, low CTE**
- **No outgassing**
- **Open Porosity**
- **Excellent thermal management material**

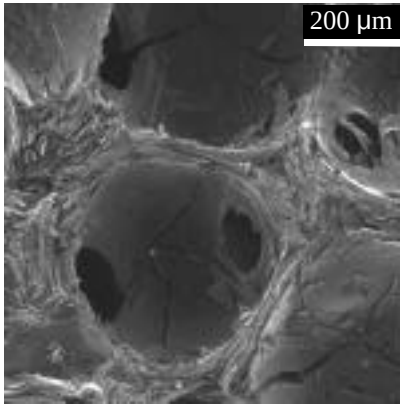


Highly Graphitic Structure



High Thermal Conductivity Graphite Foams





Physical Properties	ORNL Foam A	ORNL Foam B	Aluminum 6061	Copper	
Density	0.58	0.56	2.88	8.9	g/cm^3
Porosity	0.73	0.75	0	0	
Fraction Open Porosity	0.98	0.98	0	0	
Average Pore Diameter	60	325	0	0	microns
Coefficient of Thermal Expansion	--	4	24	16.5	ppm/°C
Max Operating Temperature in Air	500	500	600		°C
Mechanical Properties					
Tensile Strength	--	1.0	337	69	MPa
Tensile Modulus	--	1.0	69	130	GPa
Compressive Strength	5.0	3.45	330		MPa
Compressive Modulus	0.18	0.14	69		GPa
Thermal Properties					
Bulk Thermal Diffusivity	3.11	4.53	0.81	1.17	cm^2/s
Bulk Thermal Conductivity	127	175	180	400	W/m·K
Specific Heat Capacity	691	691	890	384	J/Kg·K
Bulk Specific Thermal Conductivity	218	313	63	45	(W/m·K)/(g/cm^3)

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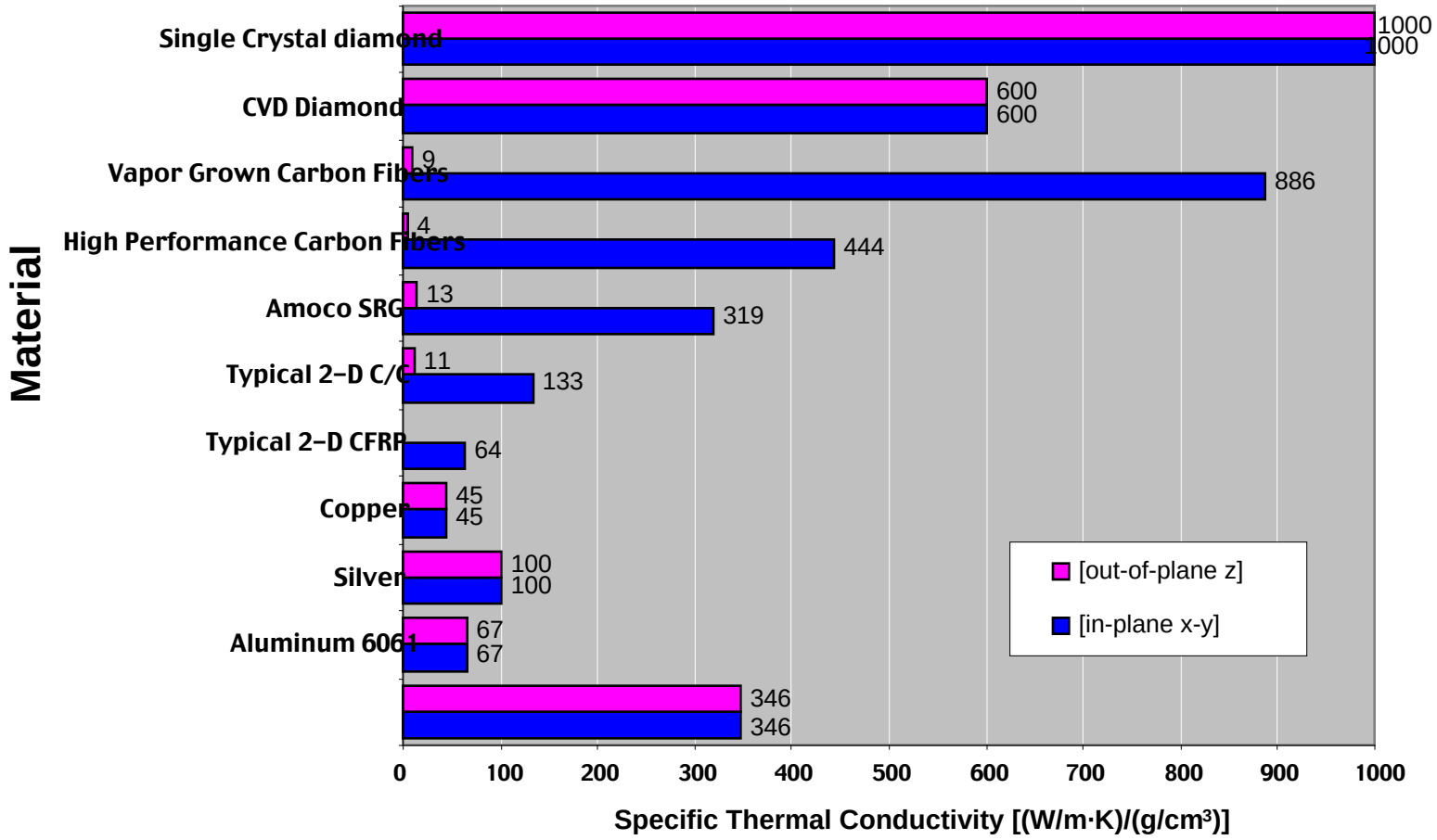
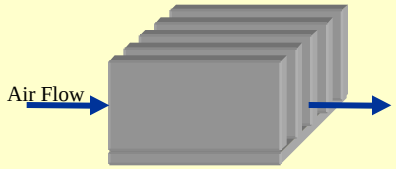
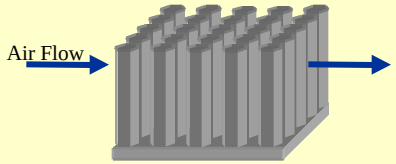
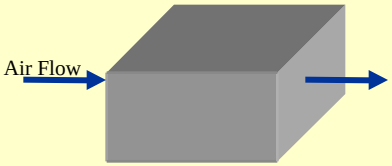
Specific Properties vs. Other Materials

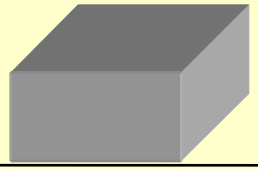
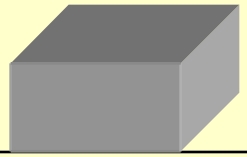


Heat Transfer of Metallic Heat Sinks

Air Cooling

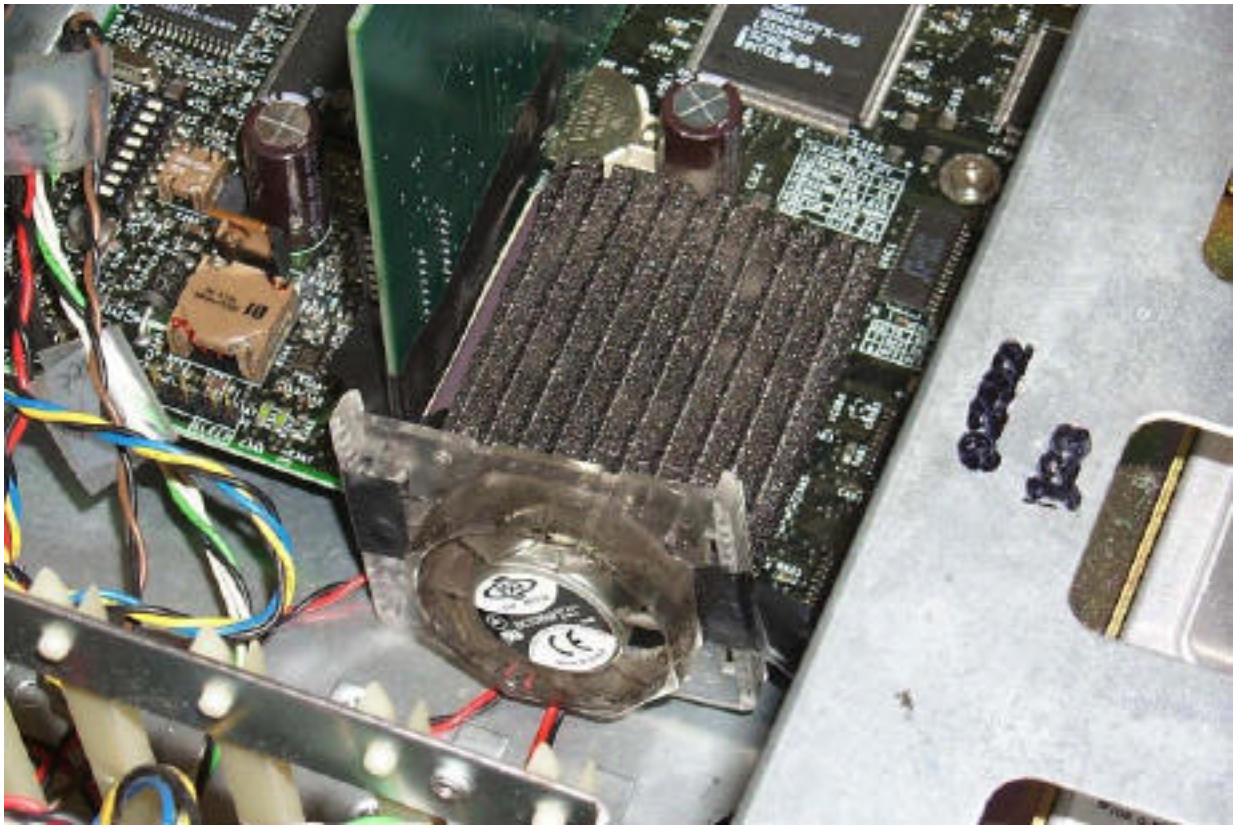
	Heat Transfer Coefficient h, (W/m²·K)	ΔP/L (psi/in)	Thermal Resistance °C/W
Aluminum Finned 	**70-350**	**<0.05**	**1-5**
Aluminum Pin-Finned 	**550**	**<0.05**	**0.7**
Aluminum Foam 	**250**	**<0.05**	**1.3**

Heat Transfer for Foam Heat Sink with Air Cooling

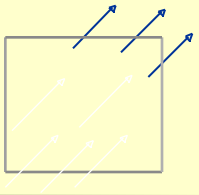
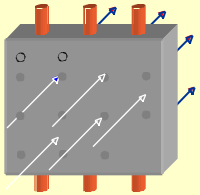
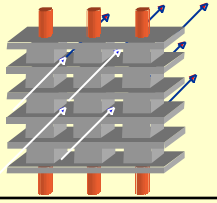
		Heat Transfer Coefficient h, (W/m²·K)	ΔP/L (psi/in)	Thermal Resistance °C/W
Solid Foam 	Air	2600	2	0.13*
	Water	9000	1	0.04
Finned	Air	1000	<0.05	0.38*
	Water	2100	0.5	0.19
Pin-Fin	Air	1500	0.05	0.26*
	Water	2500	0.5	0.15
Blind-holes (pin fin negative) 	Air	2000	1	0.19*
	Water	4600	0.5	0.09
Blind-holes (parallel to air flow) 	Air	3100	0.35	0.13*
	Water	4500	0.5	0.09

Actual devices

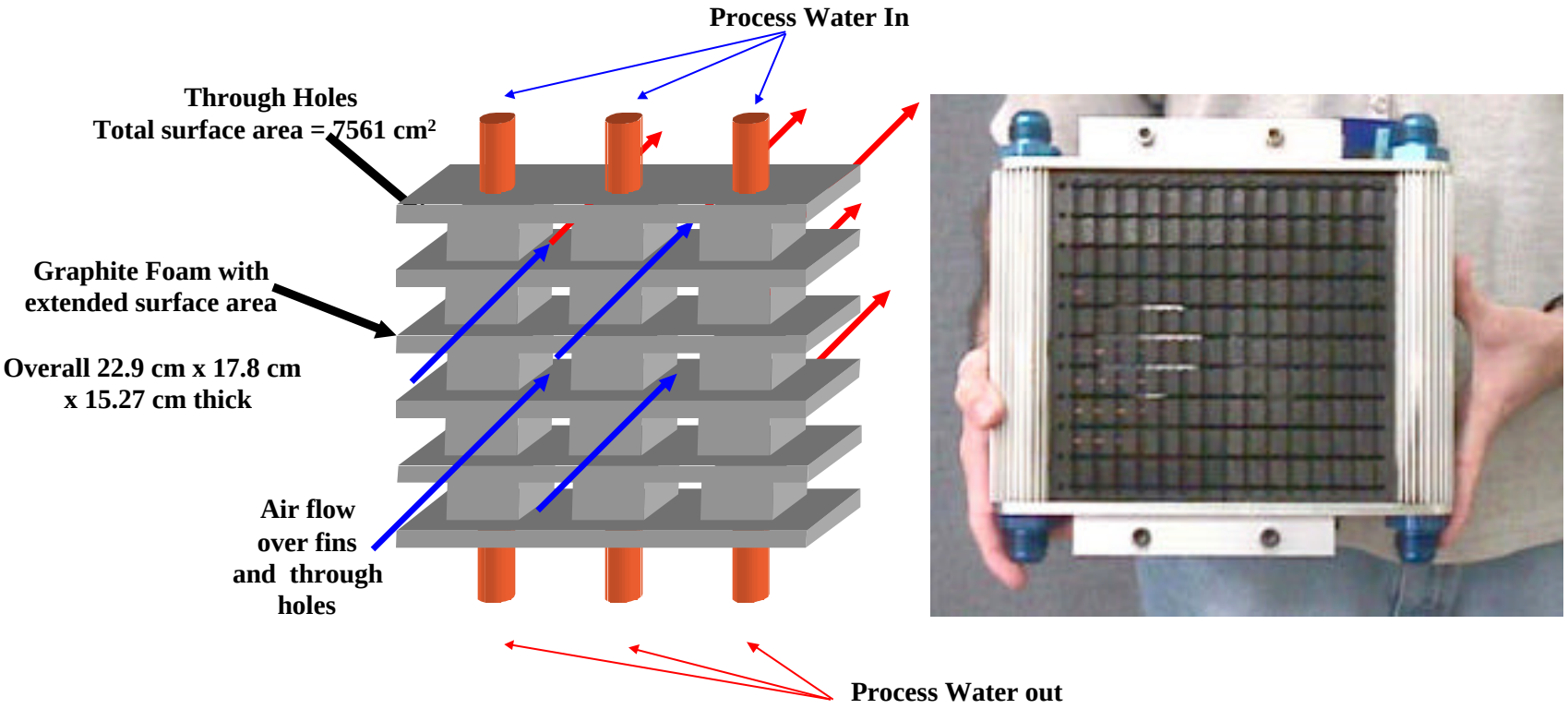
- **Finned foam heat sink running in Pentium 133 computer since December 12, 1998.**



Heat Transfer as a Radiator Design

	Heat Transfer Coefficient h, (W/m^2·K)	ΔP/L (psi/in)
Solid Foam 	10,000*	2
Through-holes 	1,000*	0.1
Finned 	1,000*	0.05
Current Radiator	30	<0.05

Prototype Radiator Demonstrated

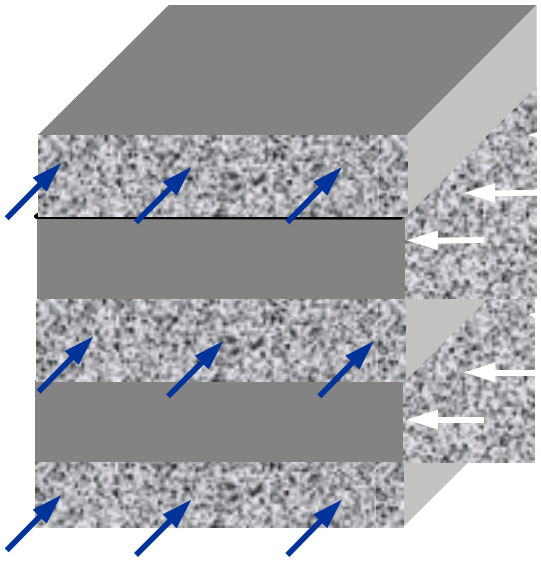


Measured U_o **= 1000 W/m² ·K depending on air humidity**

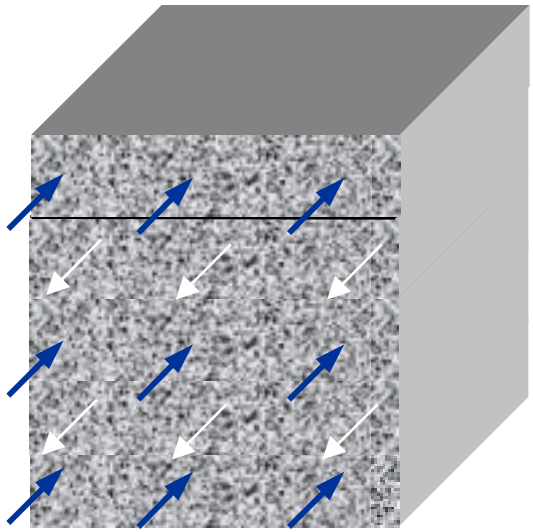
Similar design tested for 800 hp racing engine

Cross Flow Heat Exchangers

Foam rigidized with Carbon CVI for dramatic improvement in durability
Surface skin produced during manufacture would become impermeable to H_2 (already demonstrated in Fuel Cell Bi-polar plate testing)
Can be bonded together or "Glued" together during the CVI Process
porous structure allowed deposition to bond structure together



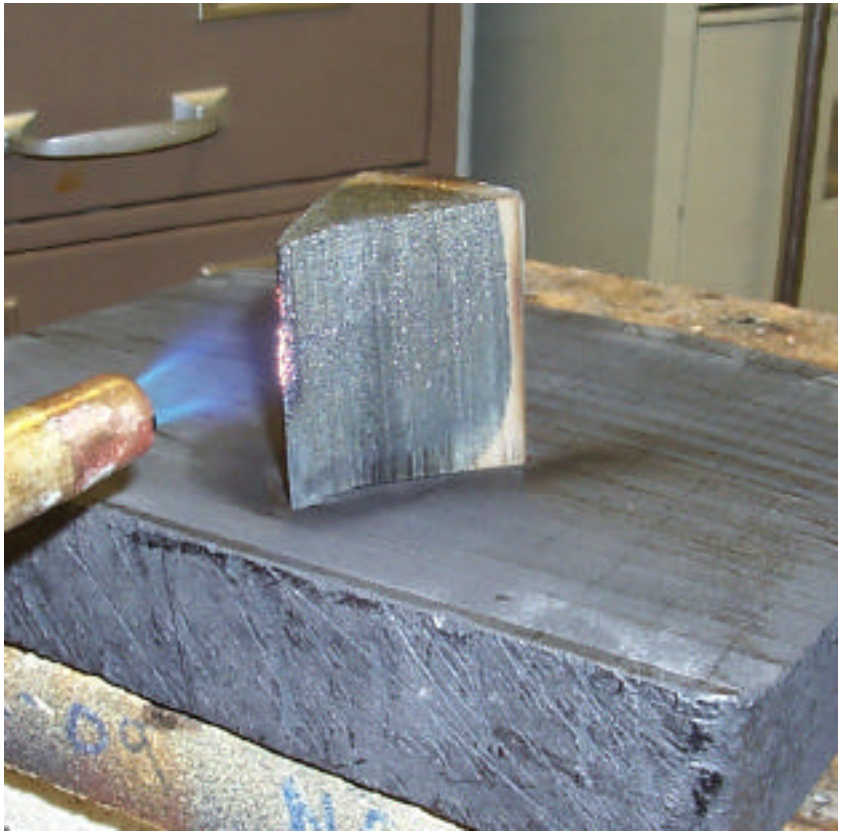
Cross Flow
Easiest to Manifold



Counter-Current Flow
Most Efficient

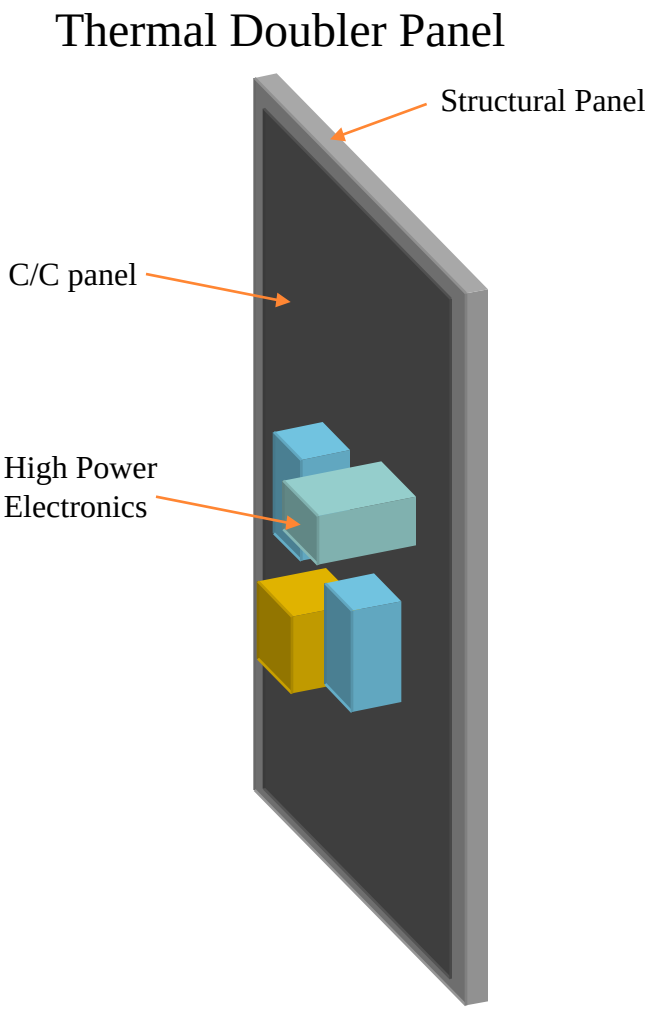
Heat Resistant Composites

Standard Polymer



Foam/Polymer

Satellite Applications?



- **Current concept spreads heat across larger area & reduces temperature**
- **Heat is rejected to space with T^4 relationship**
- **A very low through thickness thermal conductivity of current carbon-carbon (20 W/m·K) and honeycomb core limits heat rejection**
- **The higher through-thickness thermal conductivity of the foam (180 W/m·K) will increase temperature on outside surface**
- **High temperature on outside surface will increase radiation**
- **Smaller panel footprint, or more electronics can be utilized.**

Licensee - Poco Graphite, Inc.

- **Leading manufacturer of premium, specialty graphites and silicon carbides**
- **Over 35 years experience in the following major markets**
  - **General Industrial**
  - **Aerospace**
  - **Biomedical**
  - **Semiconductor**
- **Texas based manufacturing with offices in Illinois and France**
- **Applications Engineers based throughout US**
- **Applications Engineers in France, Germany, Italy and Singapore**

POCO Capabilities

- **Materials manufacturing facilities**
- **Design Engineering**
- **Machining expertise to produce finished parts**
  - **In process and finished parts inspection and certification**
- **Post processing facilities for infiltrations, impregnations, purifcation of materials**
  - **Laminations and bonding**
- **R & D Laboratories for materials testing and development**

PocoFoam Time Line

- **June 1999 - Poco Graphite, Inc. acquired the exclusive license to manufacture ORNL developed foam**
  - **Agreement includes field of use license for finished products including**
    - ***Heat exchangers***
    - ***Cooling systems or heat sinks for aerospace, chemical-process, glass, ceramic and medical industries***
- **April 2000 - Pilot production at POCO began**
- **May 2000 - First sale of PocoFoam material**
- **October 2000 - Full production of PocoFoam expected to begin**
- **Future Developments**

PocoFoam Availability

- **Material is available for purchase**
  - **Sizes up to 10 x 10 x 1 1/2” are in stock**
- **Pricing curve is consistent with developmental materials**
- **Alliances are being made with developmental partners**