Graphite Foams Reduce Size and Weight of Heat Exchangers

Large Internal Surface Area Replaces Conventional Fin Design

Background

High-conductivity, lightweight graphite foams (GF) can potentially increase heat transfer while reducing both the size and weight of heat transfer devices – significantly impacting the cost to dump or recover heat energy. In the past, high-conductivity, low-porosity GF was used as a substitute for other solid materials like aluminum and copper in traditional heat exchanger designs; these attempts yielded only marginal success. Researchers are now achieving significantly better convective heat transfer using flow-through designs that access the extensive internal surface area, but power efficiency losses associated with back pressure must be addressed.

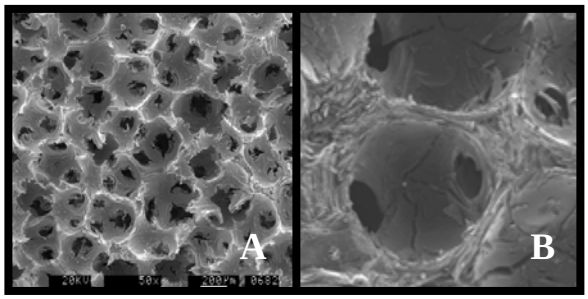
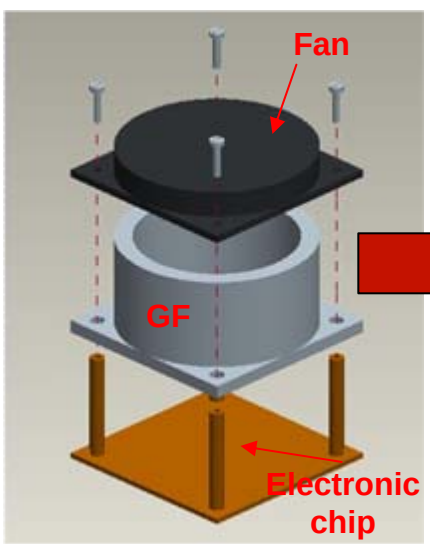


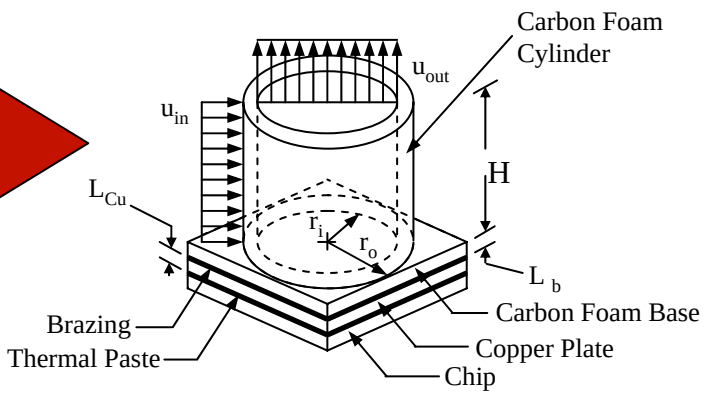
Figure A: Electron micrograph of the GF surface; Figure B: Enlarged view of GF pores and windows; porosity=0.9, pore diameter=400 µm

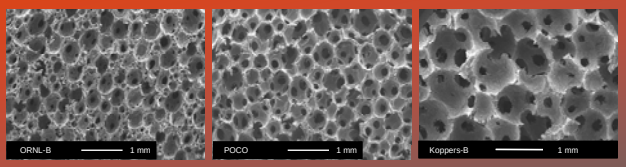
Technology

Properties that make GF well-suited for thermal management applications include its high conductivity, light weight, large internal surface area per unit volume, and low heat storage capacity. The walls of the foam are four times more conductive than copper and six times more conductive than aluminum (approximately 1500W/m·K compared to 400 W/m·k for copper and 250 W/m K for aluminum). This means that the surface of graphite foam will be hotter than metal foam or fins under the same flow conditions, resulting in increased heat transfer. This high thermal conductivity also allows a given amount of heat to be distributed over a larger surface area at the same temperature difference.



Engineering Analysis of Heat Sink to Investigate Potential Enhancements to GF

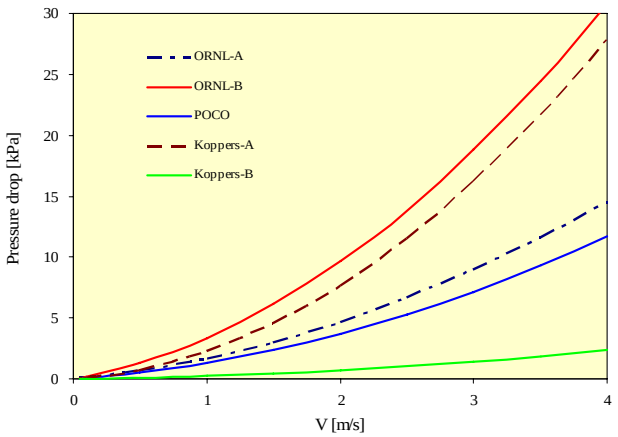




SEM images of graphite foams with varying pore structures

The permeability of the foam also has a positive effect on the heat transfer, but a negative effect on the flow required for adequate cooling. The potential benefits of GF use in electronic heat sinks has led to the use of flow- through designs where all the cooling air flows through GF. As a result, a new generation of GF is being developed – foams with larger pores and inter-pore windows that increase efficiency by better balancing thermal and flow resistances. Flow-through designs allow GF to conduct heat more deeply into the solid structure of the foam, making use of a much larger amount of internal surface area and yielding higher overall heat transfer. This simple configuration was shown to significantly out-perform conventional CPU heat sinks and similarly designed aluminum foam devices.

Empirical models of the pore level heat transfer and pressure drop have been established for a variety of existing ORNL foams (e.g., 219-3) and POCO™ foams on the basis of laboratory experiments and Computational Fluid Dynamics (CFD). CFD models have been extremely useful in elucidating the internal energy transfer and have guided the development of new foams. More recently-developed ORNL graphite foams, with larger pore diameters and more homogeneous internal structures, have confirmed substantial increases in heat transfer with significantly reduced parasitic pressure drops.



Pressure drop as a function of channel velocity, v, for several foams with varying pore structures.

Benefits

- Smaller and lighter thermal management devices
- More efficient thermal management devices
- Simpler design – reduces the machining of fins

Future Work

Future work will focus on the development of processes that control the internal structure of GF so that internal structures can be optimized for specific heat transfer applications. In addition, heat transfer devices for the electronics, automotive, and energy sectors must be designed to take advantage of the unique properties of GF. Efforts are being directed at both single and multiphase heat transfer applications.

Points of Contact:

Beth Armstrong, Oak Ridge National Laboratory, 865-241-5862, armstrongbl@ornl.gov
Nidia C. Gallego, Oak Ridge National Laboratory, 865-241-9459, gallegonc@ornl.gov