GRAPHITE FOAM FOR COOLING OF AUTOMOTIVE POWER ELECTRONICS

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In recent decades, many advancements in electronic components, such as higher-power computer chips and power converters, has led to devices that generate significantly more heat in unit area and require more efficient devices for thermal management. Many techniques have been explored to improve heat transfer in electronic devices, such as micro-channels and heat pipes. These devices must incorporate very effective heat spreaders into the design of the heat sink to prevent localized hot spots and insure that the temperature of the Si-based electronic components does not exceed 125°C.

The high-conductivity graphite foam developed at Oak Ridge National Laboratory exhibit an open-cell structure with highly aligned graphitic ligaments (see Figure 1) [1-3]; studies have shown the typical interlayer spacing (d_{002}) to be 0.3356 nm, very near that of perfect graphite (0.3354 nm). As a result of its near-perfect structure, thermal conductivities along the ligament are calculated to be approximately 1700 W/m-K, with bulk conductivities of up to 180 W/m-K. Furthermore, the material exhibits low densities (0.25-0.6 g/cm^3) such that the specific thermal conductivity is approximately four to five times greater than that of copper. The high conductivity combined with the very high specific surface area results in overall heat transfer coefficients for foam-based heat exchangers that are up to two orders of magnitude greater than those of conventional heat exchangers. As a result, graphite foam-based heat exchangers or heat sinks could be dramatically smaller and lighter than conventional ones.

The recently developed hybrid and fuel cell vehicles use electric motors which require high-powered electronics to manage the switching of high electrical voltage and current for motor control. These high-powered electronics dissipate a considerable amount of heat that necessitates a heat exchanger and a separate radiator.

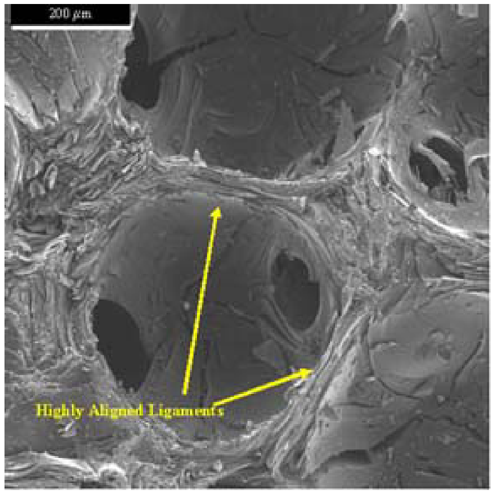

Figure 1. SEM image of graphite foam showing highly aligned graphitic ligaments.

For this project, ORNL has teamed with the University of Michigan and Ford Motor Company to explore the use of high thermal conductivity graphite foam as a heat exchanger in the cooling system of hybrid vehicle power electronics. Currently the electronics are kept cool using an aluminum cylindrical pin fin-type, heat exchanger (see Figure 2). The electronics must remain at temperatures below 125^{o}C, and operate over a temperature range of -40 to 125^{o}C. The pressure drop must be kept below 0.5 psi.

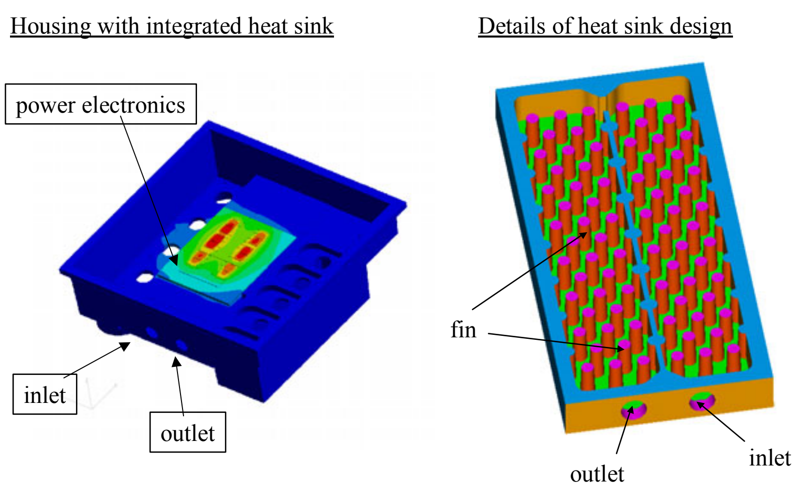

Figure 2. Housing with integrated heat sink for cooling of power electronics

Although graphite foam heat exchangers performed similarly to traditional Al-finned heat exchangers, modeling work [4] suggests that allowing improved access to the extensive internal surface area of the graphite foam would significantly enhance the performance of graphite foam heat exchangers. If heat exchanger designs could be developed to allow enhanced air flow through the foam, significant improvements over optimum AL-finned heat exchangers could be achieved. Note that the performance of a graphite foam heat exchanger is controlled more by the surface area accessed than by the high conductivity of the foam. This suggests that the porosity, pore density, ligament structure, and strength of the graphite foam should be optimized simultaneously to enhance heat transfer with minimal increase in pressure loses.

It may not be possible to access sufficient surface area of graphite foam in conventional finned heat exchanger designs. This would suggest that designs that force air through the foam and not over the foam may be required. The structure of the foam would act like the fins of conventional heat exchangers. These designs would utilize all of the available surface area because the structure of the foam would act as the "fins."

ORNL is currently working at producing graphite foam samples with different pore structures. These samples are being characterized, i.e., properties such as strength, thermal diffusivity, and pore size are being measured. The heat transfer coefficients of these samples will then be measured utilizing a heat sink test rig designed and built at ORNL. The heat transfer properties will then be correlated with the pore structure of the foam in order to determine the best structure and design for the current application.

Conclusions

An engineering model of heat flow through graphite foam was developed that indicates that graphite foam heat exchangers failed to perform as expected because cooling air flowing over the foam failed to access the extensive internal surface area. Additional research is needed to understand the relationship between materials structure and heat transfer. Findings suggested that more porous, less dense foams would exhibit additional surface area, of course provided that the graphite structure has adequate strength. The ability to control pore density (pores per inch) and to maintain an open pore structure (% of open pores) are important factors if benefits of the porous surface structure are to be realized in practical applications

Acknowledgments

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