Graphite Foam Evaporatively Cooled Heat Sinks

Lightweight Materials

U.S. Department of Energy

Energy Efficiency and Renewable Energy Program

Oak Ridge National Laboratory

UT-BATTELLE

Transportation

FOR THE 21ST CENTURY

Background

Current computer chips experience power densities up to 25 W/cm^2 and are cooled effectively with aluminum and copper heat sinks. However, as technology improves, it is expected that future high performance computer chips will experience power densities up to 50-80 W/cm^2 (the leading edge of the shuttle orbiter experiences 40 W/cm^2 upon re-entry). Currently, the only cooling technology with this capability is spray cooling. While spray cooling has demonstrated cooling capacity of up to 1200 W/cm^2, the pressures of the cooling fluid are so high that safety is a concern. This extremely high pressure is capable of killing a person if even a tiny leak is developed and, therefore, it is used only where costs are not the primary concern (i.e. NASA and military). Therefore, for the past 5 years, researchers have been exploring alternative methods for cooling which are passive and lower cost.

The Technology

In cooperation with the National Security Agency (NSA), researchers at ORNL have demonstrated novel techniques for cooling electronic computer chips with very high power densities. Current computer chips are packaged printed side up in a ceramic package with over-the-top wire bonds. Unfortunately, this design is not suited for significant heat dissipation through the top of the package to a standard heat sink as there is an insulating air gap between the silicon chip and the ceramic package.

A new concept being developed at advanced laboratories is the "flip-chip" design. In this design, the silicon chip is inverted with the back of the printed chip oriented towards the top of the package. In this case, it is simple to join a heat spreader directly to the silicon chip and immerse this in an evaporative cooling fluid (i.e. fluorocarbon). In this process, the latent heat of vaporization removes significantly more heat than the sensible heat change of the fluid and transfers it very efficiently to the fins of the heat sink. The limitations of this design are the surface area and thermal conductivity of the spreader mounted to the back of the chip. Current state of the art spreaders utilized by the NSA are polycrystalline diamond wafer with thermal conductivites up to 1600 W/m·K (more than 4 times that of copper). As a result of the limited surface area of the diamond spreader, the maximum power density achieved without over heating the system was 28 W/cm^2.

A novel high thermal conductivity graphite foam developed and patented at Oak Ridge National Laboratory under the direction of the U.S. Department of Energy (DOE) Office of Transportation Technologies promises to overcome this limitation. This material is a lightweight foam with high bulk thermal conductivity (up to 180 W/m·K) and an open porous structure with more than 2 orders of magnitude greater surface area than the diamond wafers. The cell walls are made of oriented graphitic planes and exhibit thermal conductivities greater than 1700 W/m·K.

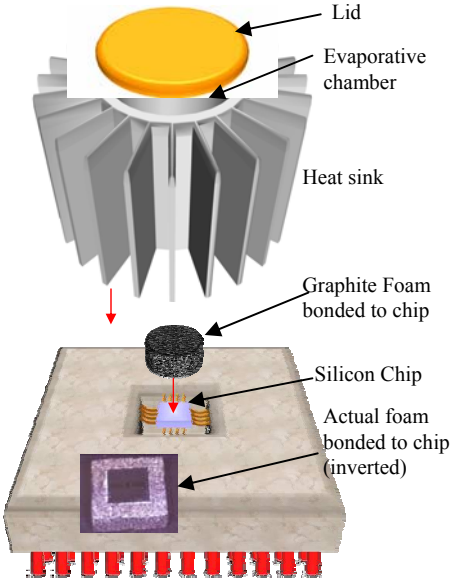
When the diamond spreader was replaced with graphite foam, a power density of 100 W/cm^2 was attained without overheating the system. Theoretically, significantly higher power densities can be attained with proper design and fluid content.

Commercialization

Poco Graphite, Inc. is commercializing the manufacture of the foam and has significant capabilities to produce foam for large volume applications at this time. ORNL is teaming with the NSA, the University of Maryland, and Thermacore to develop and optimize prototype immersion coolers for the NSA and other electronics chip applications.

Benefits

- The system maintains temperature of the boiling point of the fluid.
- Power densities more than 350% (100 W/cm^2) of current designs have been attained.
- Much higher power densities are attainable.



Exploded View of Evaporative Cooling System Mounted to Chip Package

For more information on how ORNL is helping America remain competitive in the 21st century, please contact:

David P. Stinton
Automotive Propulsion Materials Program
Metals & Ceramics Division
Oak Ridge National Laboratory
(865) 574-4556
stintondp@ornl.gov

Success Story

November 2001