Properties of Thin Porous Copper Layers for Dissipating Thermal Energy from Microelectronics

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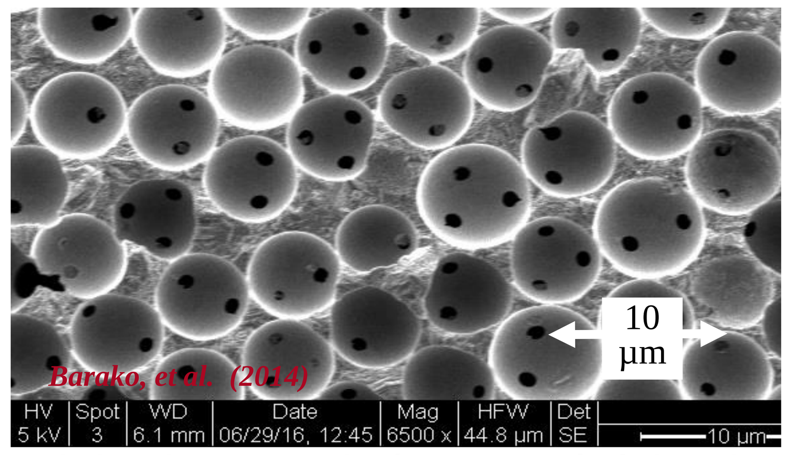
Abstract

Characterization of thin porous copper layers designed for two-phase heat dissipation was conducted through measuring resistance of the dry samples as a proxy for thermal conductivity and by measuring heat dissipation via boiling with pressurized water as the working fluid. Phase separation membranes were applied to control liquid/vapor distribution. Challenges associate with making these measurements on thin porous films were explored.

Motivation

Microelectronic components are becoming smaller and more powerful, while at the same time consumer devices are increasing the number and power of these components. Dissipating heat is thus becoming a limiting factor for future developments of these devises. Dr. Goodson's lab is exploring both the transport of heat through the components of microelectronics and innovative methods of cooling these components.

SEM of Porous Copper Layer

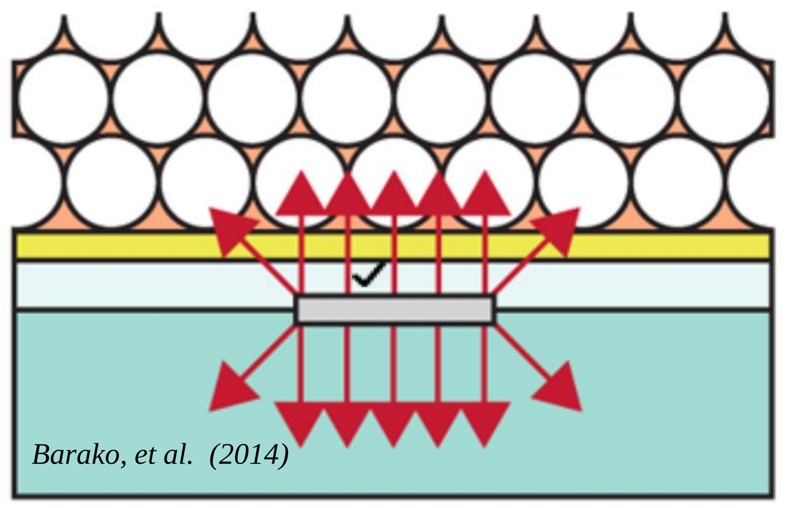


Bright rings encircle pores left by the polystyrene template. Black holes in the pores are openings for the movement of fluid.

Introduction

The NanoHeat group in Dr. Goodson's labs has shown excellent heat dissipation via boiling in thin, porous copper layers. The inverse opal layers are created using a template of packed polystyrene microspheres on a silicon substrate. Copper is electroplated around this template, which is then dissolved in an organic solvent, THF, leaving the porous copper layer.
Open channels in the layer, caused by sintering the polystyrene spheres of the template, allow water to travel through the layer. Vaporization of the liquid near the surface of the layer results in highly effective heat transfer away from the porous layer and heat source.

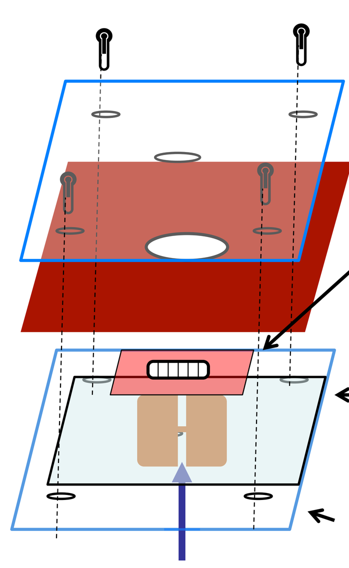
Schematic Porous Copper Layer on Heat Source



Voids remain when polystyrene template is removed.

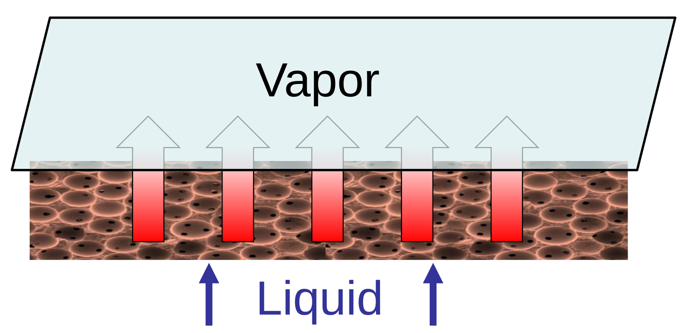
Characterization of Thin Porous Copper Layers Designed for Two-Phase Heat Dissipation

Pressurized Water Assembly Diagram



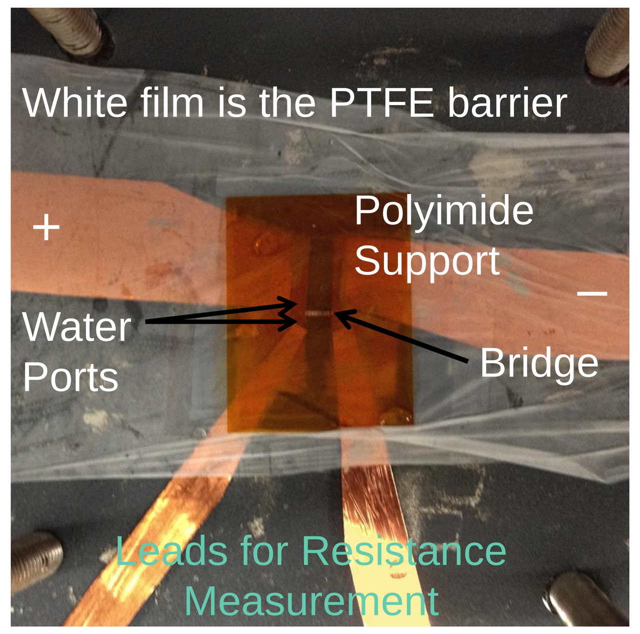
Water, under constant pressure, enters the system to be vaporized in the heated porous copper.

Separation of Liquid and Vapor



Liquid water is unable to pass through the PTFE layer, but water vapor created by boiling does pass through, carrying heat away from the system.

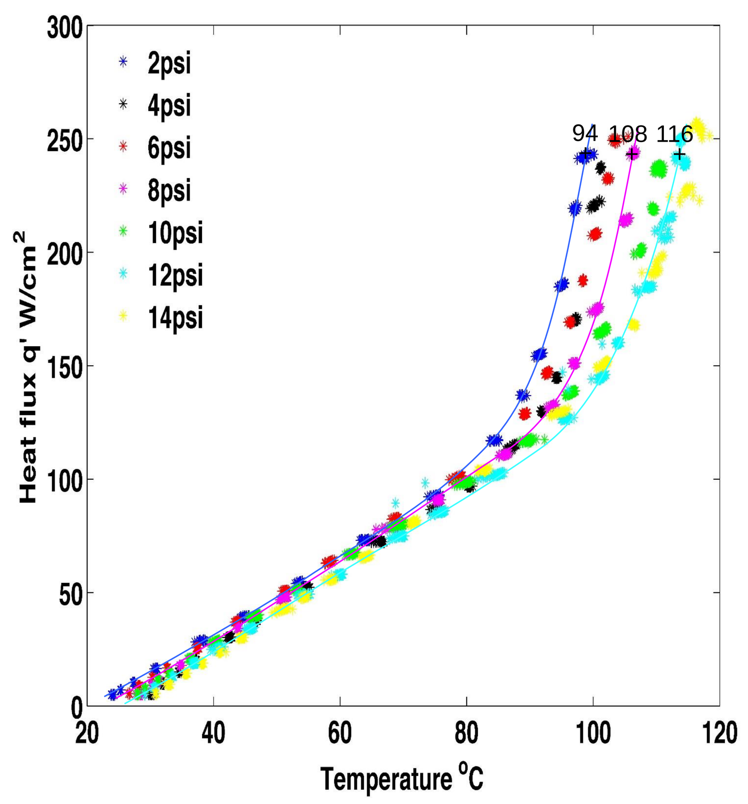
Testing of the Porous Copper Bridge



When the system is operating, the resistance is measured as current is increased. With data from a reference resistor, the temperature at the bridge can be calculated.

Data & Analysis

Temperature Differences in Two-Phase Heat Dissipation Experiment at Different Pressures



Results

Our experiment indicates that the pressure of water can be used to change the operating temperature at the porous copper bridge. Further work will continue to correlate the pressure and temperature dependence and to use new dielectric liquids to widen the range of temperatures.

Conclusions

The micrometer thick porous copper layer is a promising, developing technology being characterized in Dr. Goodson's lab. Its small size makes it not only suitable for at-site cooling purposes of powerful electronic components, but also makes it challenging to characterize.

My work in the lab has helped me appreciate the challenges of cutting-edge engineering like this work, the thoughtfulness and persistence of the researchers, the multidisciplinary nature of new explorations in engineering, and shown me a glimpse of the future of microelectronics.

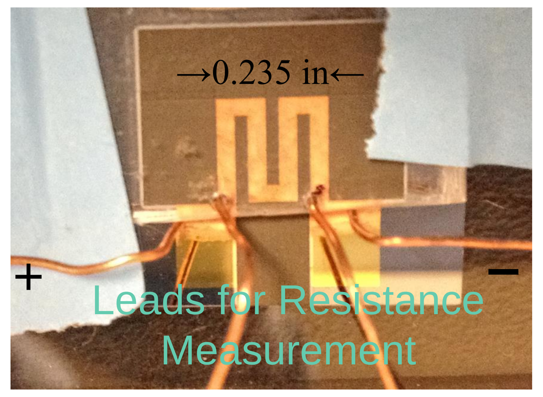
Resistance Measurements of Thin Porous Copper Films

Thermal conductivity is an important characteristic of porous media for convective heat transfer, but is difficult to measure in thin layers. I, therefore, explored the use of electrical resistivity measurements as a proxy for thermal conductivity.

Because of the small size and irregular perimeter of the copper layers it was hoped that van der Pauw resistance measurements would be convenient.

Measurements by this method were tested in several configurations and with probes of various metals at different gauges. Unfortunately, the method proved inconsistent with the highly conductive copper.

Testing of Laser Cut Porous Copper Bridge



An acrylic template guides resistance leads to reproducible placement on the sample

Laser cutting a serpentine path through the samples provided more reproducible resistance measurements using a 4-point collinear measurement.

Resistance was compared with bulk copper in foil form. The porous copper provides resistances ~3.5x that of the foil, and shows an acceptable measurement error of ~10%.

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