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Comsol Derived Universal Scaling Model For Low Reynolds Number Viscous Flow Through Microfabricated Pillars – Applications to Heat Pipe Technology

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Introduction

Cooling of high-power density electronic devices remains a challenge. Microfluidic heat-pipes with the potential of achieving ultra-high thermal conductivities offer a low-cost technology for cooling electronics. To achieve high thermal conductivity, it is critical to maximize the rate of liquid transport inside the heat pipe. We propose a novel array of microfabricated pillars to maximize liquid transport. Such pillars generate high capillary pressure that spontaneously (no external pumps required) supports a high rate of liquid transport (Fig 1a). However, the pillars have to be ingeniously designed such that the viscous drag experienced by the liquid at the pillar surface is minimal.

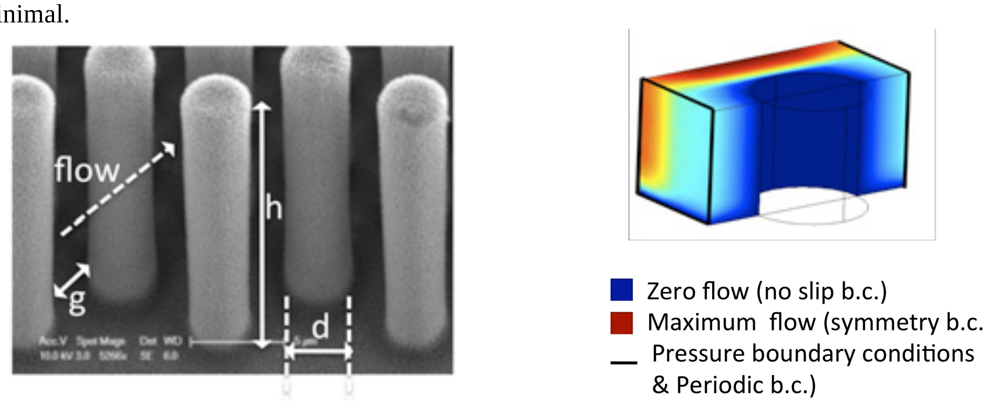

Figure 1:**(a)** Optical viewgraph of an array of microfabricated pillars. Each pillar is about 5µm (dia), 50µm (height) and 5µm (inter-pillar spacing). **(b)** Image of the model in COMSOL with a single pillar. Symmetry and periodic boundary conditions are used.

Use of COMSOL Multiphysics

We have used COMSOL Multiphysics to develop predictive scaling models that will aid in the design of pillars that provide maximum liquid transport. Because of the inherent complex nature of the problem, no existing theoretical model can currently be used to accurately predict flow within pillars. In order to obtain quantitative flow predictions, we have used the Incompressible Navier Stokes application mode in COMSOL – combined with the ALE moving mesh. A combination of ALE moving mesh and dimensionless weak form equations allow a convenient method for scanning through a wide range of pillar geometries (height, diameter, gap)– without the need for drawing each geometry separately. Pressure boundary condition (high and low) were applied upstream and downstream from the pillar (Fig 1b) and COMSOL calculated the resulting flow rates using dimensionless Navier Stokes.

Using the flow rates calculated from COMSOL for a wide range of height, diameter and gap (an order of magnitude) we applied curve fitting to develop a governing equation that will predict flow rates. We were able to derive a unique model that will accurately predict flow rates in any given random array of pillars. We have found that the pressure driven viscous flow within pillars depends almost linearly with the height (h) of the pillars while it varies inversely with the square root of the diameter (d) of the pillars. The flow rate follows a 2.33 power of the gap between the posts.

The presentation will describe the details of the COMSOL model, scaling analysis using COMSOL generated flow rates as well as experimental validation with microfabricated silicon & titanium pillars – in our efforts to establish a firm understanding of flow through a maze of pillars.