Microfluidic Dynamics in Micro-Scale Truss Structures Formed From Self-Propagating Photopolymer Waveguides for Heat Transfer Applications

Christopher S. Roper, Kathryn D. Fink, Joanna A. Kolodziejska, and Alan J. Jacobsen*
HRL Laboratories, LLC, Malibu CA, 90265
*E-mail: csroper@hrl.com

Microfabricated heat sinks and heat exchangers are of increasing interest for numerous applications, including electronics cooling, due to the enhancement of convective heat transfer with reduction in characteristic length scale [1]. High cost per unit volume and limitations on device thickness severely constrain the applicability of heat transfer devices fabricated using traditional microfabrication techniques. We present a novel low-cost 3-D microfabrication method and characterize the microfluidic dynamics of the resulting structures for heat transfer applications.

The novel 3-D microfabrication process [2] involves exposing a reservoir of photo-curable monomer to a collimated UV light beam through a mask, which results in the formation of self-propagating photopolymer waveguides Using this process, waveguides have been formed with feature resolution as fine as 10 µm, and lengths exceeding 10 mm depending on the diameter. Because the waveguides can interpenetrate without sacrificing their self-propagating nature, orientation of multiple angled collimated UV light beams results in the fabrication of micro-scale truss, or lattice structures (Figure 1). The unit cell geometry (Figure 2) can be tailored by altering the exposure mask and incident angle of the collimated UV light beams, thus controlling the open-porosity of the resulting structures.

Design of heat transfer devices involving this micro-scale truss architecture requires characterization and understanding of the fluid dynamics of microfluidic flow through the interstitial regions of the structure. Pressure drop per unit length is experimentally measured for water flow from 0.05 to 0.35 m/s through a variety of micro-scale truss structures. The fluid dynamics are characterized for varying strut diameters, strut diameter to pitch ratios, and flow angles with respect to truss orientation. The pressure drop per unit length can be controlled by altering the unit cell geometry (Figure 3). Non-dimensionalizing the data reveals an inverse square root of Reynolds number dependence on friction factor over most of the flow ranges tested, implying an intermediate flow regime between laminar and turbulent flow and demonstrates anisotropic microfluidic properties (Figure 4). An empirical correlation relating the micro-scale truss geometry to the friction factor and Reynolds number is developed.

Conversion of the micro-scale truss structures from polymer to metal through electroplating and subsequent etching of the polymer core (Figure 1d) enables use of this structure in heat transfer applications, such as air-cooled and liquid-cooled heat sinks. Characterization of water-cooled micro-scale truss heat-sinks will also be presented.

Topical Areas: Optical Lithography, Microfluidics

References:

[1] Tuckerman, D. B. and Pease, R. F. W. *IEEE Electron Device Letters* EDL-2 126-9 (1981).
[2] Jacobsen, A. J., Barvosa-Carter, W. and Nutt, S. Advanced Materials 19 3892-6 (2007).

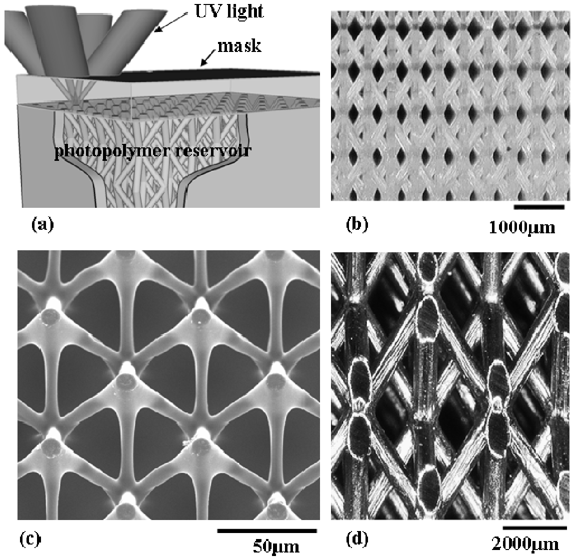

Figure 1: (a) Fabrication process schematic, (b) 3-D micro-scale truss structure with 100 μm strut diameter, (c) 3-D micro-scale truss structure with 10 μm strut diameter, and (d) nickel 3-D micro-scale truss structure .

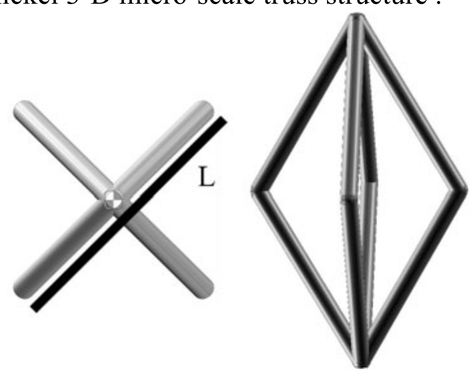

Figure 2: Micro-scale truss unit cell schematic.

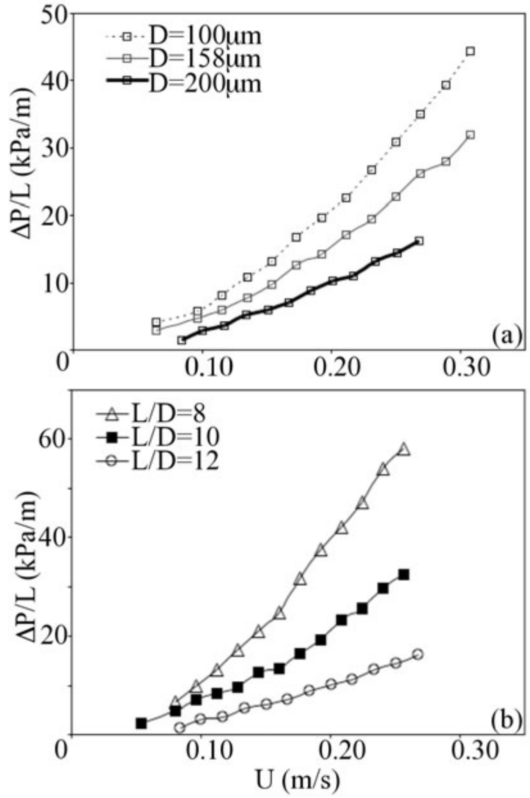

Figure 3: Pressure drop versus flow rate for varying (a) truss diameter and (b) node spacing to strut diameter ratio.

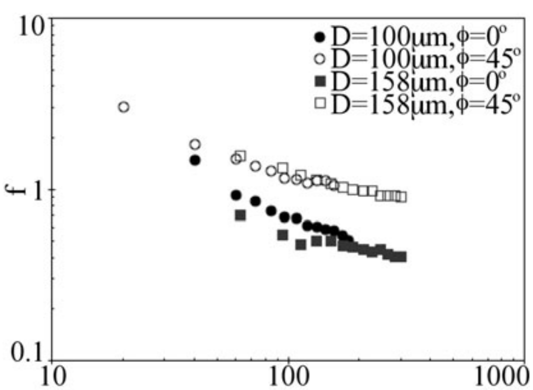

Figure 4: Friction factor versus Reynolds number data of flow through micro-scale truss for varying flow orientations and strut diameters at a node spacing to strut diameter ratio of 10:1.