The Pressure Drop along Rectangular Microchannels Containing Bubbles

Michael J. Fuerstman[a], Ann Lai[a], Meghan E. Thurlow[a], Sergey S. Shevkoplyas[a],

Howard A. Stone*[b] and George M. Whitesides*[a]

[a] *Department of Chemistry and Chemical Biology, Harvard University,*

Cambridge, Massachusetts 02138, USA

[b] *School of Engineering and Applied Sciences, Harvard University,*

Cambridge, Massachusetts 02138, USA

* Corresponding authors:

George M. Whitesides (gwhitesides@gmwgroup.harvard.edu)

Howard A. Stone (has@seas.harvard.edu)

Supplemental Material

Fabrication of the Device

We employed standard photolithographic techniques to produce a master comprising features made of SU-8 photoresist (Microchem) on a silicon wafer. We silanized the master by exposing it to tridecafluoro(1,1,2,2 tetrahydroooctyl) trichlorosilane under vacuum. The silane ensured that the polydimethylsiloxane (PDMS) that we then poured onto the master didn't seal to the silicon irreversibly as the PDMS cured.

We followed standard techniques of soft lithography to fabricate our devices.[1-6] After curing PDMS in a 60 C oven for a minimum of two hours, we cut a slab containing the channels in relief off of the master. We drilled holes through the slab with a syringe needles to provide access for polyethylene tubing to connect into the inlets of the device, and to provide an outlet through which bubbles and liquid would eventually leave the system. We oxidized the slab of PDMS, along with a flat slab of PDMS, for 60 s in a plasma cleaner. Oxidizing the slabs caused them to bond chemically and irreversibly when placed into contact with one another, thus providing floors for the channels. We used PDMS slabs, rather than glass microscope slides, as the material for the floors, because we found that the PDMS sealed more reliably to PDMS than to glass.

After sealing the channels, we allowed the device to sit for two to three minutes at room temperature to allow the slabs to bond completely, before filling the device with water. Failure to allow time for the slabs to seal often resulted in the channels bursting open upon adding pressure to the inlet into which gas flowed.

Design of the Microfluidic Network

The inlet pads – grids of 100 um x 100 um posts, separated from each other by 100 um – filtered out large particles or flakes of PDMS that entered the system while liquid and gas flowed into it.

We used nitrogen, which entered the device through the inlet positioned perpendicular to the main channel in the system, as the gaseous phase. Nitrogen has three desirable properties: 1) it is chemically inert; 2) it is insoluble in water, a property that prevented the bubbles from shrinking appreciably while they moved through the system; and 3) it is inexpensive relative to other gases that also have the other two characteristics. The pressure applied to the nitrogen varied between ~1 psi and ~20 psi. The regulator that we used applied a minimum of ~1 psi to the gas. If more than ~20 psi was applied to the nitrogen, the device sometimes ruptured.

We controlled the rates of flow of the liquids using a syringe pump (Harvard Apparatus, etc.). The ranges of rates of flow that we used were set by the range of pressures that we could reliably apply to the inlet for the nitrogen. Typical rates of flow that the syringe pump supplied were on the order of 0.1 to 1.0 ml per hour. The liquid and bubbles exited the channel through the outlet and were soaked up into a paper towel.

We measured the surface tensions of the solutions of glycerol and Tween-20 using the pendant drop method.[7, 8] We suspended a syringe filled with the liquid in the air using a clamp, and depressed the plunger so that a drop of liquid hung from the end of a flat-tipped needle connected to the syringe. We allowed the drop to sit for two minutes to ensure that the surfactant in solution coated the interface, and then took five still images of the drop over the next two minutes. We then used software developed by the Professor David Weitz’s group to derive the surface tension of the liquid from the curvature of the droplet. We average the data that we obtained from each set of five still images. The values of the surface tensions did not vary appreciably across the data obtained for the five images; we therefore believe that the surfactant had sufficient time to coat the interface.

We normalized the data we obtained for the surface tension by multiplying each value by the ratio of the surface tension of a droplet of pure water generally accepted in the literature (0.0728 N/m) to the surface tension of a droplet of pure water that we observed in the experiment (0.0749 N/m).

References

1. M. K. Chaudhury and G. M. Whitesides. *Langmuir*, 1991, **7**, 1013.
2. D. C. Duffy, J. C. McDonald, O. J. A. Schueller and G. M. Whitesides. *Anal. Chem.*, 1998, **70**, 4974.
3. P. J. A. Kenis, R. F. Ismagilov and G. M. Whitesides. *Science*, 1999, **285**, 83.
4. J. C. McDonald, D. C. Duffy, J. R. Anderson, D. T. Chiu, H. K. Wu, O. J. A. Schueller and G. M. Whitesides. *Electrophoresis*, 2000, **21**, 27.
5. D. Qin, Y. N. Xia and G. M. Whitesides. *Adv. Mater.*, 1996, **8**, 917.
6. Y. Xia and G. M. Whitesides. *Angew. Chem. Int. Ed.*, 1998, **37**, 551.
7. B. H. Song and J. Springer. *J. Colloid Interface Sci.*, 1996, **184**, 64-76.
8. B. H. Song and J. Springer. *J. Colloid Interface Sci.*, 1996, **184**, 77-91.