A DEVICE FOR TWO-PHASE FLOW CONTROL IN NANOCHANNELS

Lingling Shui, Albert van den Berg and Jan C. T. Eijkel
MESA+ institute for nanotechnology, University of Twente, The Netherlands

ABSTRACT

We developed a novel method to control two-phase flow in nanochannels using regulating microchannels connected to the nanochannels. The flow rate inside a nanochannel can be regulated based on the pressure drops along the channel network. Stable flows with flow rates as low as 10^{-5} $\mu L.min^{-1}$ (< $pL.s^{-1}$) can be obtained for both oil and water phases using a conventional syringe pump. We also demonstrate two-phase nanofluidics by confluence of two immiscible liquid flows in nanochannels.

KEYWORDS: Flow-control, Nanofluidics, Two-phase, Nanochannel

INTRODUCTION

Precise understanding of biological or chemical functions requires tools comparable in size to the basic components[1]. A nanofluidic device is ideal for manipulating small volumes of liquid. Nanochannels can currently be easily fabricated by the standard photolithography process. However, the specific interfacial area of a nanochannel is very high, leading to a high hydrodynamic flow resistance so that high pumping pressures are needed. Furthermore, when two immiscible fluids (oil and water) are applied into the same nanofluidic device, an additional experimental difficulty is introduced, since one of the phases typically is non-wetting, necessitating higher applied pressures for this phase due to capillarity. Moreover, typically one of the phases is non-conductive (gas or oil), making electro-osmotic-flow unavailable[2]. Pressure-driven flow by a syringe pump is therefore preferred for a two-phase nanofluidic system, even though it is experimentally difficult due to the high backpressure, the low flow rates needed (less than $\mu L.min^{-1}$) and the very long time it takes to replace the liquid due to the dead volume of e.g. the connecting capillaries. In this report, we solved these complications by designing a flow control system using microchannels connected to nanochannels to regulate the flow rate in the nanochannels. Our system is similar to the pressure-controlled system of Hibara et al.[4].

EXPERIMENTAL

The chip design is shown in Fig. 1. We used the same fabrication process and setup as reported in µTAS2008[3]. Liquids used were an 0.01M SDS aqueous solution, made fluorescent by dissolving fluorescein sodium salt (0.01M), and hexadecane as the oil phase.

RESULTS AND DISCUSSION

Liquids were introduced to the nanochannels by microchannels connecting an inlet and an outlet. The total flow was divided between the nanochannel and a flow

978-0-9798064-2-1/µTAS2009/$20©2009CBMS

regulating microchannel. The hydrophobic oil phase did not enter the nanochannel until the applied pressure in the oil phase was larger than the negative capillary pressure, which leads to the minimum applied oil flow rate: $Q_{min}=2\sigma W_m H_m^3/(C\eta L_m H_n)$, see Fig. 2. The liquid from the inlet split to the nanochannel and regulation microchannel at the junction; the split ratio was determined by the nanochannel and regulating microchannel geometry: $Q_n/ Q_m=L_m w_n h_n^3/(l_n W_m H_m^3)$.Since most of the liquid that was pumped by the syringe pump flowed through the regulating microchannel, nanochannel volume flow rates lower than $pL.s^{-1}$ could be obtained and the flow in nanochannel remained stable.

Using this method, we could study for the first time the behavior of an oil-water immiscible two-phase flow in nanochannels (Fig. 3), showing non-oil flow, dripping and threading flow regimes.

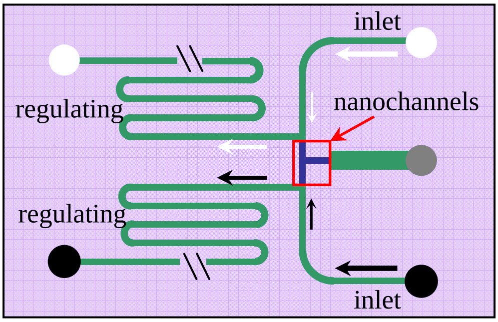

Figure 1. Sketch of the chip design. Except for the regulating microchannels the nanofluidic channel section consists of two identical inlets and a constriction channel (the leg of the 'T'). Two identical microchannel sections run from the inlet to an outlet via a flow regulating channel, and also connect to both of the nanochannel inlets. The nanochannel dimensions are of height (h) = 150 ~ 900 nm, width (w) = 10 μm and length (l) = 1000 μm; the microchannel dimensions (height(H), length(L) and width(W)) are varied to regulate the flow in the nanochannels (the split ratio).

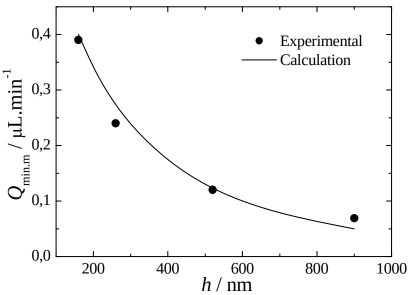

Figure 2. Plot of Q_{min} (the minimum applicable oil flow rate when oil starts to enter the nanochannel) vs. h (nanochannel depth). This flow rate is determined by the capillary pressure. Here, H = 10 μm, W = 100 μm, L = 5 mm, σ = 30 mN.m^{-1} and η_o = 3 mPa.s.

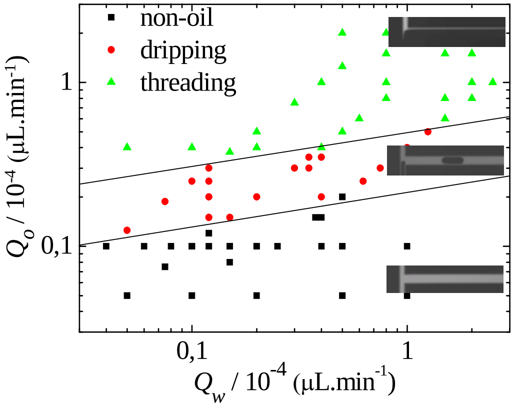

Figure 3. Flow diagram of water-oil two-phase flow in nanochannels (h = 500 nm). The micrographs were taking in fluorescent mode. Q_w and Q_o indicate water and oil phase flow rates in nanochannels, respectively.

CONCLUSIONS

We investigate the flow control in a nanochannel by using a regulating micro-channel. Stable flows with flow rates as low as 10^{-5} μL.min^{-1} (< pL.s^{-1}) in nanochannels can be obtained. Confluence of immiscible two-phase flow in nanochannels has been demonstrated using this flow control method.

ACKNOWLEDGEMENTS

We appreciate Nanoned and TheraEDGE for financial support.

REFERENCES

[1] Y. Rondelez, G. Tresset, K. V. Tabata, et al., Nat. Biotechnol.**, 23, pp. 361-365, (**2005**)**.
[2] L. Shui, J. C. T. Eijkel, A. van den Berg, Sensor Actuat. B-Chem., 121, pp. 263-276, (2007).
[3] L. Shui., S. Kooij, J. C. T. Eijkel, et al., μTAS2008, San Diego, USA, pp. 125-127, (2008).
[4] A.Hibara, T.Tsukahara, T. Kitamori, J.Chromatography A, 1216, pp. 673-683 (2009).