MONODISPERSE ATTOLITER DROPLET FORMATION USING A NANO-MICROCHANNEL INTERFACE

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

ABSTRACT

We demonstrate the production of sub-micrometer diameter monodisperse droplets by using a nano-micro channel interface. A perfectly steady nanoscopic liquid filament can be formed by a geometric confinement which eventually gives rise to a stable production of nearly perfectly monodisperse droplets. In a certain range of physical parameters and geometrical configurations, the liquid filament size and therefore the droplet size is determined by the nanochannel geometry, mainly its height which determines the Laplace pressure. Droplet diameters of 0.7~3.5 μm (aL~fL volume) have been produced using different size nanochannels.

KEYWORDS: Droplet, Attoliter, Nano-microchannel, Interface

INTRODUCTION

An emulsion in which one liquid forms droplets in another immiscible liquid is a simple and elegant way of creating very small closed containers [1, 2]. Droplets can be formed using flow focusing, either by increasing shear gradients or by drawing the stream into a thin filament that breaks up by the Rayleigh-Plateau instability [3]. The droplet size is typically 10-100 μm, and droplet size depends on microchannel geometry, flow conditions and fluid properties. Many parameters make the droplet formation process complex and sensitive to a lot of environmental influences. As general characteristics, the droplets should be as fine, stable, monodisperse, reproducible, and controllable as possible. Therefore, a method is required which can not only produce monodisperse droplets, but is also stable and robust, and insensitive to changes in the flow rate.

EXPERIMENTAL

We designed and fabricated a nano-microfluidic device which integrates nanochannels and microchannels (Fig. 1). For the flow control in the nanochannel we employed a new layout which has been descripted separately in another poster of this conference. The devices were fabricated in glass using standard microlithographic techniques. We used the same setups as demonstrated in reference 4. The water phase was 1wt% Tween20 aqueous solution and oil phase was hexadecane. All chemicals were bought from Sigma-Aldrich Chemie GmbH, Germany and used without any futher treatments.

RESULTS AND DISCUSSION

The formation of a liquid filament is in most cases a mandatory preliminary step for producing a droplet. A stable and strong confinement of the filament can be obtained by solid structures (channels or holes). In our device the liquid stream is confined by the solid nanochannel walls to form a thin filament. Due to the high

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

capillary pressure inside the nanochannel the confinement is strong and stable over a wide range of flow rates.

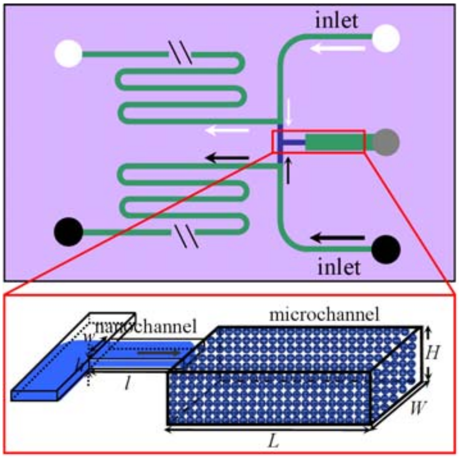

Figure 1 Sketch of the nano-micro fluidic chip design. When two immiscible liquids (oil – inner liquid and water – outer liquid) step from the nanochannel to the microchannel, monodisperse droplets form at the nano-microchannel interface.

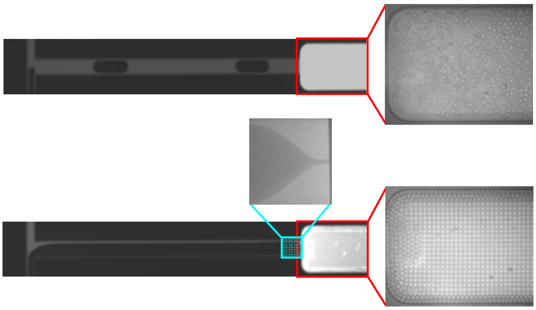

Figure 2 Snapshots of two droplet formation processes at the nanochannel-microchannel interface. (a) Oil droplets from the nanochannel split to smaller droplets at the nanochannel-microchannel interface. (b) Oil flows parallel with water in the nanochannel, thinning down to a small filament and forming droplets at the nanochannel-microchannel interface. The device dimensions are: h = 500 nm, w = 20 µm, l = 500 µm, H = 10 µm, and W = 50 µm.

When the two immiscible liquids approach the interface between the nanochannel environment and the microchannel environment, tiny oil filaments form close to the nano-micro channel interface, from which small droplets are created due to the capillary instability at the nanochannel-microchannel interface, see Fig. 2. The droplet size was found to be solely determined by nanochannel geometry (height) over a wide range of flow conditions, as shown in Fig. 3.

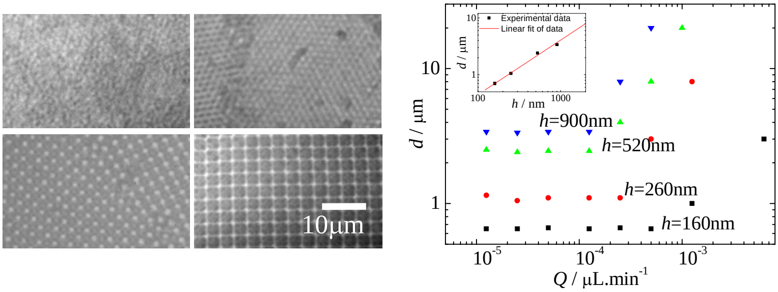

Figure 3 Top: Microphotographs of monodisperse droplets in different devices: (a) h = 160 nm, (b) h = 260 nm, (c) h = 520 nm and (d) h = 900 nm. The images were taken using transmitted light. Bottom: (e) The oil droplet diameter as a function of oil flow rates at $Q_o = Q_w$. Inset: Linear relationship between droplet diameter and nano-channel height.

The generated droplets were stable over several months, monodisperse (highly patterned in 3D arrays) and highly reproducible over time. The smallest droplet size created was 140 aL (droplet diameter 650 nm). These femtoliter to attoliter droplets are small containers which will on average encapsulate one molecule per droplet at analyte concentrations in the nM range, thus forming a promising tool for single molecular studies.

CONCLUSIONS

We have demonstrated the production of attoliter to femtoliter volume droplets using a nano-microchannel interface. The produced droplet size is mainly determined by the nanochannel height in a wide range of flow rates. Varying nanochannel height from 160~900 nm, we obtained droplet diameters of 0.7~3.5 µm.

ACKNOWLEDGEMENTS

We would like to thank Nanoned and TheraEDGE for financial support and Daniel Wijnperle for technical support.

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