REPLACING FLOWS WITH GRADIENTS OF CONFINEMENT IN DROPLET MICROFLUIDICS

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ABSTRACT

This paper presents a novel strategy for droplet microfluidics which enables the 2D manipulation of drops within microchannels without requiring any flow of the external phase. The key droplet operations such are production, transport, guiding, trapping and merging are implemented simply by modulating the shape of the top microchannel boundary. We demonstrate how to cover applications ranging from single droplet operations, common in digital microfluidics [1,2], to the high throughput available in classical flow-driven droplet microfluidics [3,4], all in simple and inexpensive devices.

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KEYWORDS

drop, droplet, interfacial tension, surface energy, microfluidic plateform

INTRODUCTION

Previously, we showed that gradients of confinement could apply sufficient forces to guide or trap drops using micro-fabricated grooves, which were called “rails” and “anchors” [5]. It has also been known for over 300 years [6] that a drop in a confinement gradient is propelled towards the region that minimizes its surface energy. The question that is addressed here is whether droplets can be produced through a gradient of confinement.

EXPERIMENT

This operation is achieved by using the emulsification nozzle sketched in Fig. 1, which consists of an inlet channel of height h_0 and width w that leads to a wide reservoir whose ceiling is inclined at a small angle α with respect to the floor. When a non-wetting dispersed phase is injected through the inlet channel, it forms an elongated fluid thread in the inlet channel, leaving out corner gutters of the continuous phase. As soon as it reaches the reservoir, it expands into an elongated tongue upon reaching the reservoir and grows until the thread pinches upstream of the reservoir and inside the inlet channel, releasing a droplet of radius R. This scenario occurs in all of the sloped nozzles investigated, spanning angles in the range $0.5° < \alpha < 4.5°$, widths from $100 < w < 500$ µm, operated at flow rates Q = 0.04 to 40 µL/min. In contrast, the tongue grows indefinitely in a flat reservoir as shown in Fig. 1C.

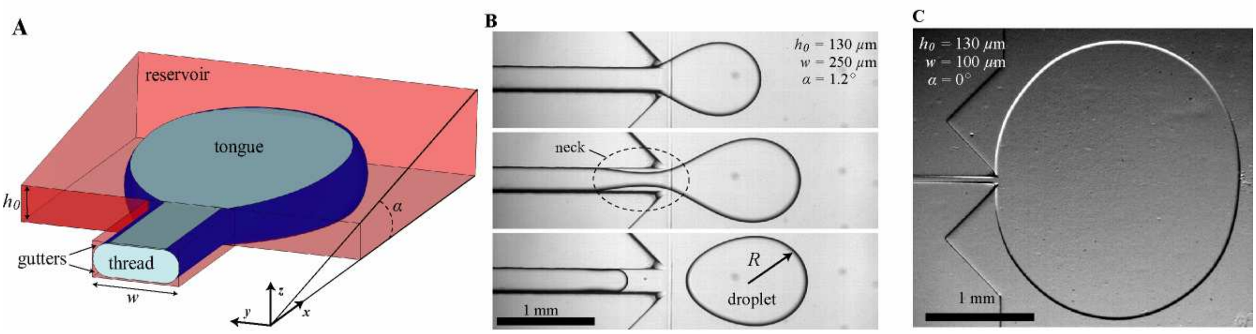

Figure 1: ***A****. Sketch of the device geometry. The dispersed phase is pushed through the inlet microchannel into a wide reservoir that contains the stationary continuous phase and whose top wall is inclined at an angle α.* ***B****. Experimental images showing the production of an oil droplet in water: the tongue elongates until a neck appears. It pinches and releases a pancake droplet of radius R which is propelled away into the reservoir.* ***C****. Experimental image of a water tongue growing indefinitely in a flat reservoir filled with oil.*

Experimental measurements the drop size R versus the injection flow rate Q for various nozzle geometries and different fluid pairs (water in oil, oil in water and air in water) are shown on Fig. 2 and reveal the characteristics of the device. First, we observe that the drop size decreases to a finite value R_0 when Q tends to zero. Second, at low flow rates, the drop size is independent of the fluids used and their physical properties, i.e. their viscosity and the interfacial tension. Second, Q has only a small influence on R: a 1000 fold increase in flow rate barely doubles drop size. All these observations indicate that Q does not play a critical role in the droplet formation mechanism, in contrast with classical methods of droplet production like the T-junction or the flow-focusing geometry [7].

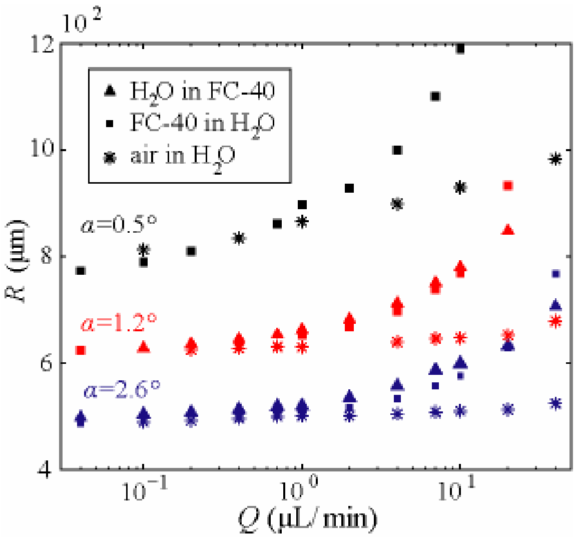

Figure 2: *Measured droplet radii R versus the injection flow rate Q of the dispersed phase for three fluid pairs (water in oil, oil in water and air in water) and three slope values.*

Owing to the low sensitivity of *R* to fluctuations in flow rate and physical properties of the fluids, the nozzles can be massively parallelized to achieve high throughput emulsification. This is demonstrated in the device of Fig. 3 which contains of 256 parallel nozzles of dimensions $h_0 = 15$ µm and $w = 50$ µm supplied in dispersed phase from a single distribution channel. The nozzles lead to a central circular sloped reservoir shaped as a dome. Here, *0.2* nL oil droplets are produced in water at a frequency of 1500 drops/second by injecting the dispersed phase at a flow rate $Q=20$ µL/min.

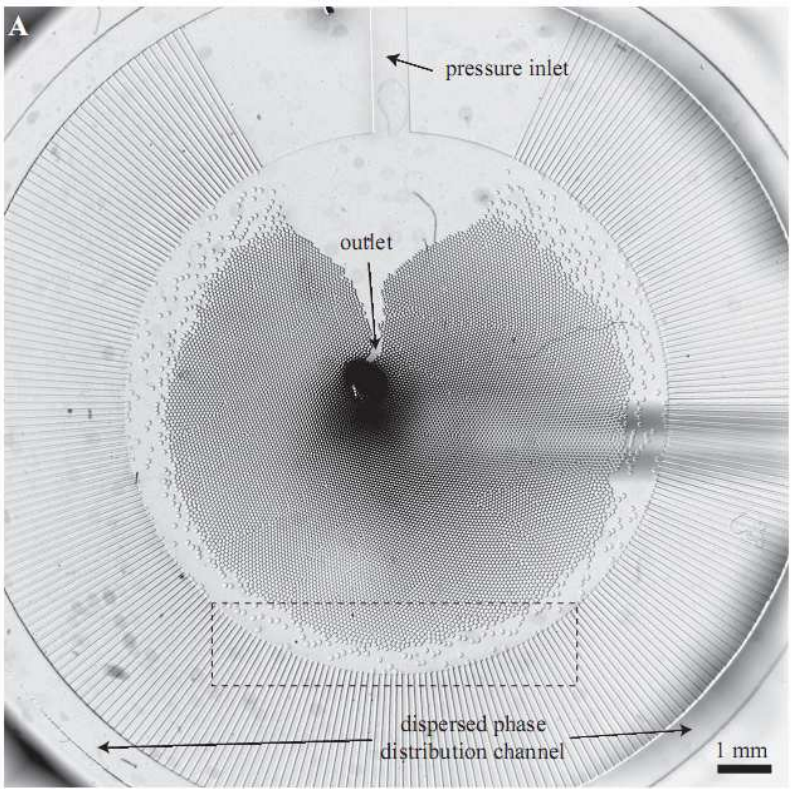

***Figure 3**: Parallelization of the channels allows the production of monodisperse emulsions, at kHz frequencies here.*

Alternatively, because the droplet size does not exhibit transients, individual droplets can be generated on demand in order to perform controlled chemical reactions for example. With the device in Fig. 4, two *170* µL aqueous drops containing different reagents are formed from two inlets by injecting the dispersed phases at *50* µL/min during *0.2* s. The rest of the experiment takes place with out any forced flows. The slope of the reservoir propels the two drops downstream and away from the nozzles while two rails, etched in the sloped surface, guide the drops towards an anchor where they meet and react together.

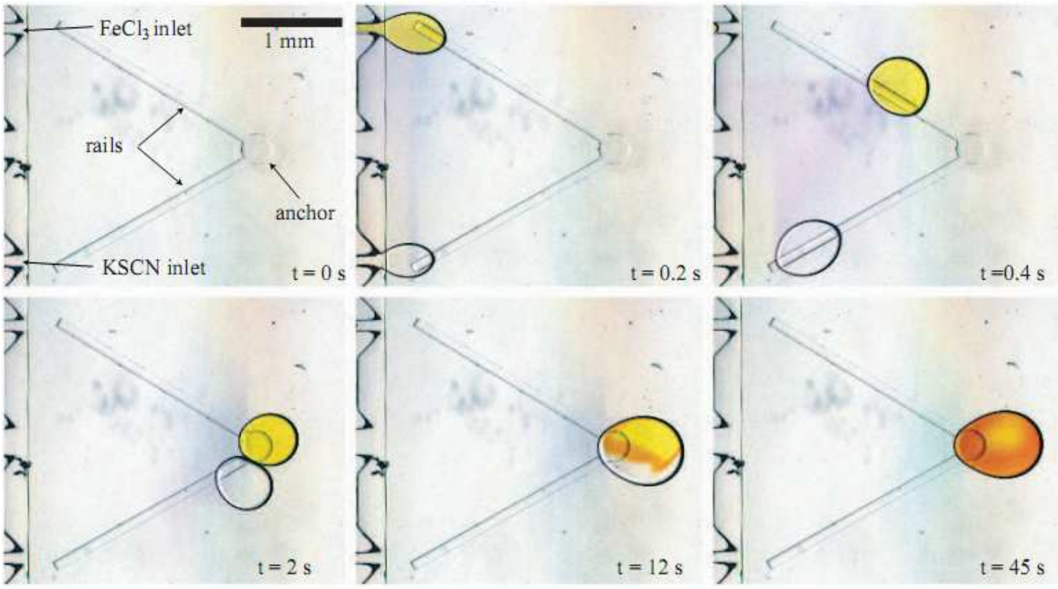

***Figure 4**: Drop-on-demand operations can be programmed by combining the drop production and the "rails and anchors" technology.*

Overall, this proof of concept paves the way for a new generation of droplet-based devices powered by interfacial tension and confinement gradients, in place of the usual outer flow.

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