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IMPROVING THE OPERATION OF ELECTROWETTING-BASED DIGITAL MICRO-FLUIDIC SYSTEMS BY USING WATER-OIL CORE-SHELL DROPLETS

Daniel Brassard[1,2], Lidija Malic[1,3], François Normandin[1], Maryam Tabrizian[3] and Teodor Veres[1,2]

[1] National Research Council, CANADA,
[2] Laval University, CANADA and
[3] McGill University, CANADA

ABSTRACT

In electrowetting-on-dielectric (EWOD)-based digital microfluidic devices, discrete droplets are typically transported either directly in air or in an immiscible fluid such as silicone oil. We propose herein an alternative mode of operation in which the droplets are enclosed in a thin oil shell. We show that such water-oil core-shell droplets offer several key advantages. Specifically, this mode of operation not only reduces the voltage required by the devices but also leads to higher transport velocities when compared with the manipulation of droplets directly in air or oil.

KEYWORDS: Digital Microfluidics, Electrowetting, Droplet, Silicone Oil

INTRODUCTION

Due to their high flexibility and dynamic reconfigurability, droplet-based microfluidic platforms (i.e., digital microfluidics) have emerged as a promising alternative to the traditional microfluidic devices based on continuous flow of liquid in channels [1]. In such devices, the droplets are manipulated on a 2D surface by means of an actuation force (such as EWOD) applied locally, thus eliminating the need for complex mechanical components or permanently etched microchannels.

In EWOD-based microfluidic devices, the aqueous droplets have traditionally been transported either directly in air or in immiscible fluid such as silicone oil. Until now, the choice of air or oil as the transporting medium has been a complex tradeoff as neither offers the flexibility required to fulfill the needs of several applications. For example, while the presence of a silicone oil medium prevents droplet evaporation and minimizes the contamination of the devices, it also increases the viscous drag, complicates the fabrication and handling of the devices, and prevents the use of some on-chip detection or analysis techniques [1,2]. On the other hand, transporting the droplets directly in air requires significantly higher operation voltages than in oil, which can cause a rapid degradation of the dielectric layers [1,2]. In this paper, we report on an alternative mode of operation for EWOD-based microfluidic devices in which the droplets are enclosed in a thin oil shell (Fig. 1). This mode of operation has been recently proposed as a mean to reduce the evaporation in an EWOD-based airborne particle sampler [3]. Herein, we additionally show that, by using such water-oil core-shell droplets, it is possible to minimize the various drag forces that interfere with the operation of EWOD-based microfluidic devices.

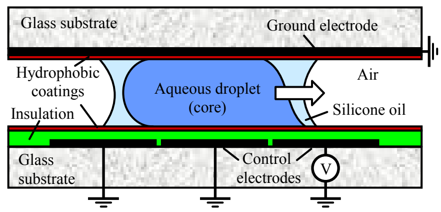

Figure 1. Schematic of an EWOD-based digital microfluidic device manipulating a water-oil core-shell droplet

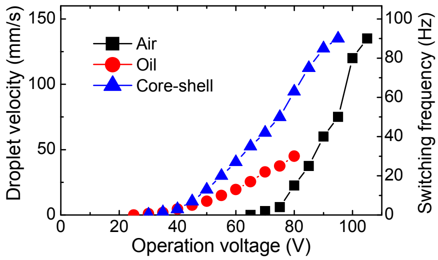

Figure 2. Effect of the operation voltage on the actuation dynamics of water droplets transported in air, in oil and in the core-shell configuration

THEORY

Both contact angle hysteresis and viscous drag are known to interfere with the transport of the droplets in EWOD-based microfluidics devices. Contact angle hysteresis ($\Delta\theta$) of the droplets, which causes contact line friction, is generally much higher in air ($\Delta\theta \sim 8^{o}$) than in oil ($\Delta\theta \sim 2^{o}$). On the other hand, in a viscous medium such as oil, viscous drag can be significant when the droplets are actuated at high speeds. Core-shell droplets thus offers the interesting possibility to achieve simultaneously a low viscous drag, as they are actuated in air, and reduced contact line friction, as the water droplet is enclosed in oil.

EXPERIMENTAL

The electrowetting-based microfluidic devices were fabricated according to the layout of the chip shown in Fig.1. The electrodes were formed by patterning 1.5 mm interdigitated squares from Cr/Au layers deposited on a piece of glass. The dielectric layers consisted of a 3 µm thick SU-8 photoresist that was hydrophobized by spin-coating a 30 nm thick layer of Teflon-AF. A piece of glass coated with indium tin oxide and Teflon AF was used for the top electrode. The distance between the bottom and the top plates was of about 150 µm during the operation of the devices. The droplets were manipulated on-chip by applying a DC potential sequentially to the control electrodes with a home-made computer-controlled electronic interface.

In this study, DI water was used for the droplets and, unless otherwise noted, the oil phase consisted of 1 cSt viscosity silicone oil. For the core-shell configuration, a small amount of oil was dispensed along with the water in the reservoirs of the chip. Due to the relative interfacial tension between the water, oil, and air, we found that the oil phase forms spontaneously a shell enclosing the water phase. As discussed next, the core-shell droplets were then formed on-chip from the reservoirs.

RESULTS AND DISCUSSION

As shown in figure 2, we found that, for a given operation voltage, water-oil core-shell droplets can be actuated at much higher velocities that water droplets manipulated in either air or oil. Additionally, as shown in figure 3, significantly lower operation voltages are achieved in the core-shell configuration than in air despite the absence of a continuous oil medium. We could also successfully dispense, merge, mix and split water-oil core-shell droplets on-chip with the same procedure as for water droplets manipulated directly in air or oil [1]. For example, we found that, during the dispensing of a core-shell droplet from a large reservoir, a part of the oil shell around the reservoir is transferred spontaneously to the dispensed droplet. Finally, our results confirm that, when a non volatile oil is used for the shell (for e.g., 10 cSt silicone oil), the evaporation rate of the water-oil core-shell droplets is drastically reduced compared to water droplets in air (Fig. 4).

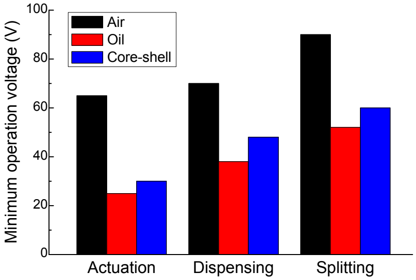

Figure 3. Minimum operation voltage required to perform various fluidic operations for water droplets transported in air, in oil, and in the core-shell configuration.

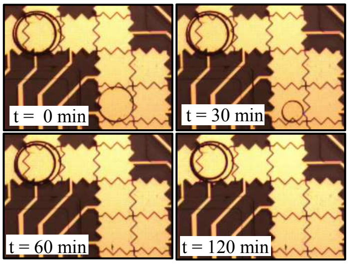

Figure 4. Comparative evaporation rate of a water-oil core-shell droplet (top left) and a water droplet in air (bottom right).

CONCLUSIONS

We have investigated the manipulation of water-oil core-shell droplets as an alternative mode of operation for EWOD-based digital microfluidic devices. Our results indicate that, despite being extremely simple to implement, this novel mode of operation offers an increased flexibility toward the realization of high-throughput and high reliability EWOD-based digital microfluidic devices.

ACKNOWLEDGEMENTS

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