ON-CHIP BLADE FOR ACCURATE SPLITTING OF DROPLETS IN LIGHT-ACTUATED DIGITAL MICROFLUIDICS

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ABSTRACT

We report on a new technique to slice droplets with integrated "Teflon blades" in the light-actuated digital microfluidic platforms. The droplet splitting ratio (10% to 90%) can be accurately controlled by the blade position. Uniform droplet generation (75.2nL with 2% variation) has been demonstrated by repeatedly slicing an elongated mother droplet. Additionally, by applying this technique to a concentrated sample of food dye in droplet, a 5-step serial dilution with consistent sample dilution factor of 6x, and total dilution factor of $6^5 = 7776$, has been achieved.

KEYWORDS: electrowetting, optoelectrowetting, digital microfluidics, droplet microfluidics, EWOD

INTRODUCTION

Digital microfluidics has been an exciting development in the past decade with many promising applications ranging from drug discovery to electronic cooling. Traditional digital microfluidics uses array of electrodes to transport droplets [1, 2]. Recently, we reported on a light-actuated digital microfluidics device [3, 4], which replaces the physically patterned electrodes in the traditional device with a continuous film of photoconductor. "Virtual" electrodes are created on the device surface when optical patterns are shone on the device. With this methodology, real-time, parallel droplet control can occur without the need for complex electrode addressing schemes.

Splitting droplet is an integral operation for digital microfluidics as it is required for both drawing droplets from reservoirs and controlling droplet volume in multi-step assays, titration, and multiplexing bioassays. Current droplet splitting method relies on hydrodynamic instability as a droplet is pulled by two opposing electrowetting electrodes [2]. It is inaccurate because the break point of the unstable neck is unpredictable. The splitting ratio is also limited by electrode size and is constrained to roughly two equal daughter droplets. Improving droplet dispensing accuracy from a reservoir is possible but requires a capacitance measurement and feedback control system [5, 6]. In this paper, we report on a novel technique to controllably and accurately slice droplets with integrated "Teflon blades" in the light-actuated digital microfluidic platforms.

THEORY

The schematic of the Teflon blade and the droplet slicing process is illustrated in Fig. 1. The Teflon blade is integrated in light-actuated digital microfluidic (LADM) device. The principle and operation of LADM has been described in [4]. The Teflon blade (3.5mm long, 400μm wide, and 130μm tall) is sandwiched between a top indium-tin-oxide (ITO) and a bottom opto-electrowetting electrodes (Fig. 1c). The blade has a sharp wedge with an angle of 55°. To slice a droplet, the droplet is first elongated by a rectangular light pattern, and then moved towards the blade at the desired cutting location. As the elongated droplet moves across the blade, it is effectively "sliced" into two droplets. Because the blade introduces perturbation at a specific location of the droplet, it minimizes instability and unpredictability in the breaking process, resulting in a more accurate and controlled split.

EXPERIMENT

The device is depicted in Fig. 1c. The device consists of an ITO (300 nm) coated glass substrate, a 1 μm thick photoconductive a-Si:H layer deposited via PECVD (Oxford Plasmalab 80plus), a 100 nm film of Al2O3 deposited by ALD (Picosun Sunale R150) and a 25 nm film of spin coated 0.2% Teflon (3000 rpm, 30 s). The top substrate is formed from another Teflon-coated ITO glass wafer. The entire fabrication process does not require any photolithographic steps. The two substrates are then placed on top of one another separated by a spacer layer of double-sided tape (100μm) forming the microfluidic manipulation chamber.

Device bias is applied between the two ITO layers (10-40 Vppk, 1-500 kHz) (Agilent 33220A). Optical patterns are generated by a commercial data projector (Dell 4210X) controlled by an external computer and focused onto the device using a 1:1 telescope. Viewing occurs through a continuous zoom lens system (Navitar 12X) connected to a CCD camera (Sony XCD-X710CR).

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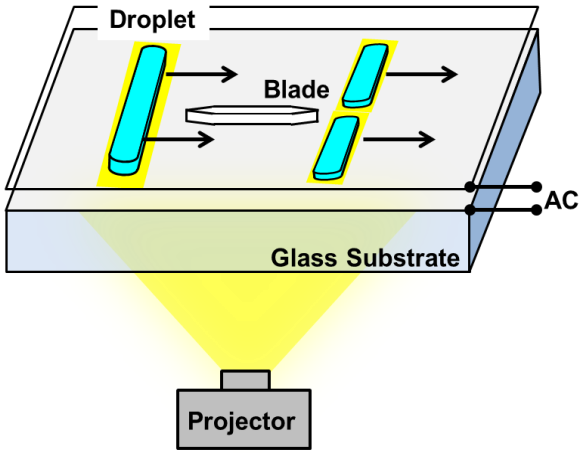
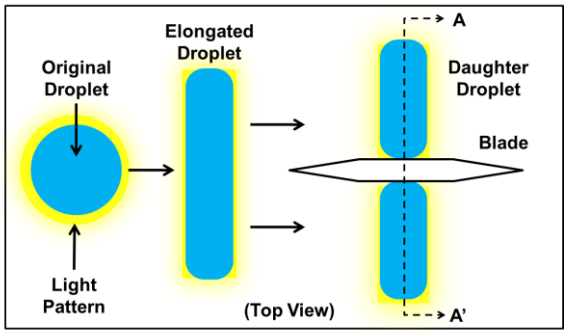
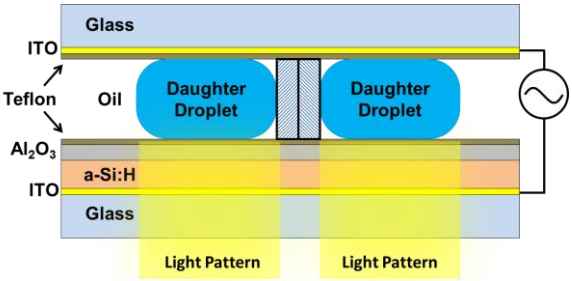




(b) Top view



(c) Cross section along AA'

Fig. 1 (a) Schematic illustrating droplet slicing with integrated Teflon blade on light-actuated digital microfluidic platform. (b) Top view. (c) Cross section along AA'. The droplet is first elongated by a rectangular light pattern. It is sliced into two droplets as it moves across a Teflon blade. The break point of the droplet is precisely defined by the position of the blade, leading to accurate control of droplet splitting ratio and volume.

RESULTS AND DISCUSSION

The volumes of the daughter droplets depend on the position of the blade. Figure 2 shows the captured video images of slicing an elongated 600nL droplet into two equal (300nL + 300nL) and unequal (120nL + 480nL) droplets. The droplet splitting ratio can be accurately controlled by the blade position. Figure 3 shows the fractional volume of a daughter droplet versus the blade position for a 600nL mother droplet. The volume varies linearly with the blade position, and agrees well with the theoretical prediction. The theory assumes a linear cut through the droplet at the tip of the blade. The good agreement attests the accuracy and predictability of the droplet cutting process by the blade. Daughter droplets with volumes of 10% to 90% have been obtained by varying the blade position.

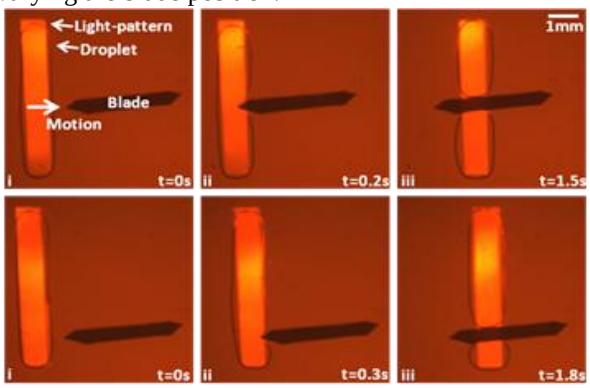


Fig. 2 Video clips illustrating droplet slicing by a blade. A 600nL droplet is stretched into a bar and moved towards the Teflon blade. (Top) Splitting into two equal droplets of 300nL. (Bottom) Splitting into two droplets of 120nL and 480nL.

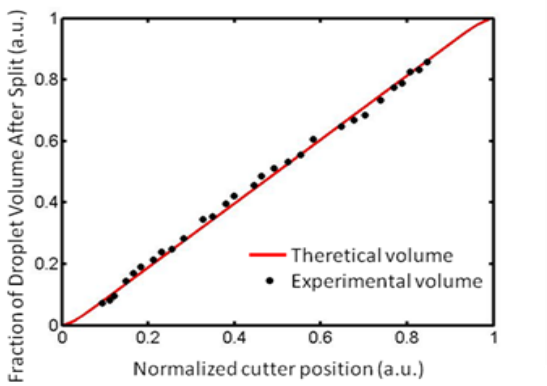


Fig. 3 Fractional volume of the daughter droplet versus the position of the blade along the mother droplet for a 600nL droplet. The volume varies linearly with the blade position, and agrees well with theoretical prediction.

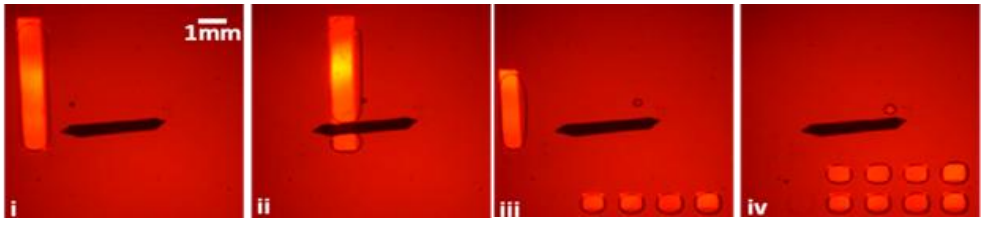


Fig. 4 Droplet array created by slicing a 600nL droplet 7 times, resulting in 8 droplets of 75nL each. The standard deviation of the droplets is 1.6nL (2%).

As another demonstration of the controllability of the droplet cutting process, a 602nL droplet is sliced 8 times to create 8 equal droplets, as shown in Fig. 4. The volumes of the 8 daughter droplets are measured to be 75.2nL, with a standard deviation of 1.6nL or 2%.

Serial dilution is an integral part of many analytical applications such as multi-step assays and titration. In this demonstration, a 360nL droplet (droplet 1 in Fig. 5) loaded with blue food dye is elongated and split by the blade into two droplets with ratio 5:1, the smaller split droplet (60nL) is merged with another water droplet of 300nL to form droplet 2, the merged droplet is rapidly mixed by rolling across the device surface [7]. Droplet 2 then undergoes 5:1 splitting using the blade and this serial dilution process is repeated such that 6 droplets are formed with progressive sample dilution of 6x, and total dilution factor of 6^5 = 7776 (Fig. 5). Transmission of red light through these droplets has been measured and the percentage transmission is presented in Fig. 6. A theoretical curve based on Beer-Lambert law is plotted for comparison, with molar absorptivity of $1.3x10^6 M^{-1}cm^{-1}$, initial dye particle concentration of 0.1M and absorption length of 100μm.

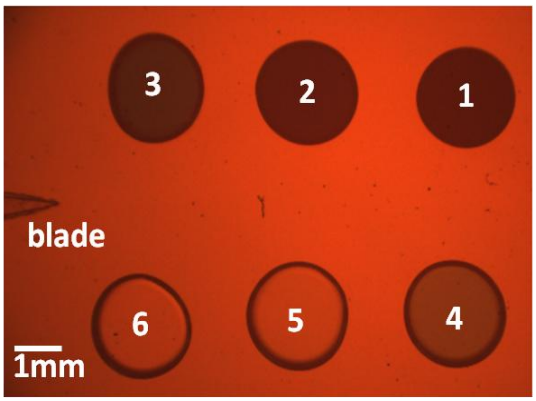


Fig. 5 Light micrograph of 300 nL droplets after serial dilution. Droplet 1, loaded with blue food dye, is split 5:1 and the smaller split droplet (60 nL) is merged with another water droplet of 300 nL to form droplet 2. The serial dilution process is repeated such that 6 droplets are formed.

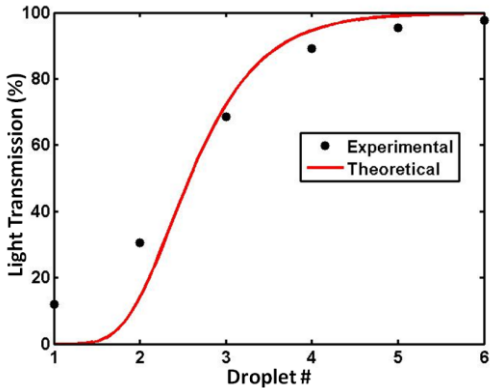


Fig. 6 Percentage transmission of light through the 6 droplets numbered in Fig 5, with droplet 1 being most concentrated with dye particles (0.1M) and subsequent droplets serially dilution by 6x. Theoretical comparison based on Beer-Lambert law is plotted for reference.

CONCLUSION

In this report, we investigated the use of integrated "Teflon blades" in the light-actuated digital microfluidic device. Using this technique, droplets can be split accurately and arbitrarily in volume ratios ranging from 10% to 90%. In addition, uniform droplet generation and serial dilution has been demonstrated. The on chip blade will be an important step towards applying digital microfluidics for quantitative chemical and biological analysis, with applications such as multiplexing bioassays and titration.

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