Rapid Droplet Mixing Using Light-Actuated Digital Microfluidics

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Abstract: We demonstrate the rapid droplet mixing ability of the Light-Actuated Digital Microfluidics device. A 3x3 array of droplets with 9 different reagent mixing ratios have been successfully generated using a digital light projector.

OCIS codes: (350.4855) Optical tweezers or optical manipulation; (170.4520) Optical confinement and manipulation

1. Introduction

Rapid mixing of analytes and reagents in microfluidic devices is important for a variety of lab-on-a-chip and µTAS (micro total analysis systems) applications. Mixing in microfluidics, however, is very slow due to laminar flow and very low Reynolds numbers [1]. Digital microfluidics [2,3] enables rapid mixing by rolling the droplets to increase the interfacial area, allowing much faster diffusion between reagents [4-6]. Previously, we demonstrated optically actuated digital microfluidics on a continuous photosensitive film [7]. In this paper, we use a projector-based Light-Actuated Digital Microfluidics (LADM) device [8] to achieve rapid droplet mixing. A 3x3 droplet array with 9 different reagent mixing ratios is successfully generated using a digital light projector.

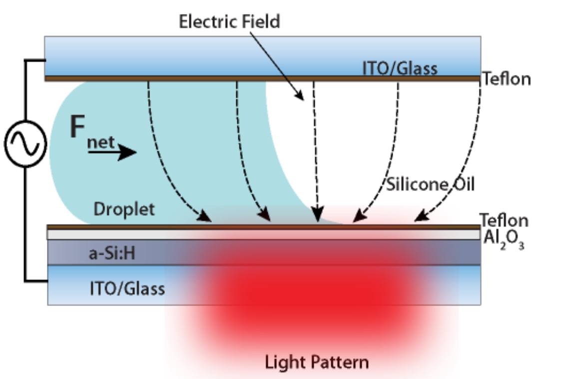

Figure 1: Device schematic showing incident light creates localized areas of high conductivity in the a-Si:H film. This creates localized electric field concentration in the illuminated region resulting in a net electro-mechanical force on the droplet.

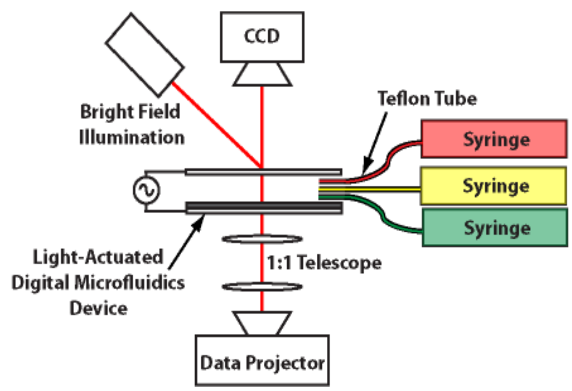

Figure 2: Experimental setup. A standard data projector (spatial light modulator) is focused onto the light-actuated digital microfluidics substrate with a 1:1 telescope. Bright-field illumination and a CCD camera allow for droplet visualization.

The LADM device concept and design is depicted in Fig. 1. The device consists of an indium-tin-oxide (ITO) coated glass substrate, a 1-µm thick photosensitive a-Si:H layer, a 100-nm film of Al_2O_3 and a 25 nm film of 0.2%-Teflon. The top substrate is formed from another Teflon-coated ITO glass wafer. The two substrates are then placed on top of one another separated by a 400-µm spacer forming the microfluidic manipulation chamber. AC bias is applied to the top and bottom ITO substrates. In the absence of light, the externally applied voltage exists primarily across the highly resistive a-Si:H layer. However, upon illumination, the conductivity of the a-Si:H increases by more than 100x. This causes the applied voltage to now drop across the electrically insulating layers (oxide, Teflon) causing the droplet to translate toward the illuminated region. As a result, the illuminated area acts as a virtual electrode to actuate droplets. To provide the required illumination, a commercially available projector is focused onto the light-actuated digital microfluidics substrate (Fig. 2). Optical patterns are generated on an external computer and sent to the projector. Bright-field illumination and a CCD camera are used for visualization and recording.

2. Experimental Results

The fluidic chamber is first flooded with silicone oil. Water droplets with conductivity of 10 mS/m, and colored with different food dyes (red, green, or yellow) are introduced into the fluidic chamber via a syringe and Teflon tube (Fig.

2). The optical pattern of interest is drawn, in real-time, on a computer and sent to the data projector. All droplets are actuated at a speed of 4.2 mm/s, with an applied voltage of 42 Vppk and frequency of 15 kHz.

To demonstrate LADM's ability to rapidly mix droplets, a green color droplet (~250 nL) was made to combine with a red color droplet (~250 nL). The combined droplet was actively mixed by being transported over the device surface in a square shaped path, shown in Fig. 3. The total time required for full mixing was 2 seconds. Similar time for mixing was also observed when the mixing path was a straight line on the chip. These results agree well with previous investigations of digital microfluidics droplet mixing speed [4-6]. To compare these results with a droplet mixed by only diffusion (i.e. passive mixing), another green color droplet (~250 nL) was made to combine with a red color droplet (~250 nL), shown in Fig. 4. The time elapsed (several minutes) before full mixing occurred was significantly longer than droplets mixed with active transport mixing.

In Fig. 5, we demonstrate LADM's ability to mix arbitrarily sized droplets and place the mixed droplets in an array. Droplets colored with red, yellow and green food dye were mixed. The mixing percentage of each colored dye is presented in table 1. The mixed droplets were subsequently placed in a 3x3 array.

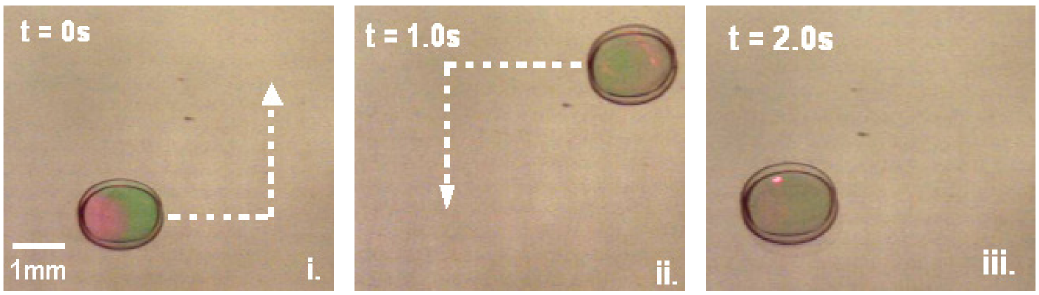

Figure 3: Active mixing of red and green droplets on LADM, the combined droplet go through a square shaped path on chip, the reddish color on the droplet in (iii.) is due to light projection on droplet, and not due to unmixed red dye in droplet.

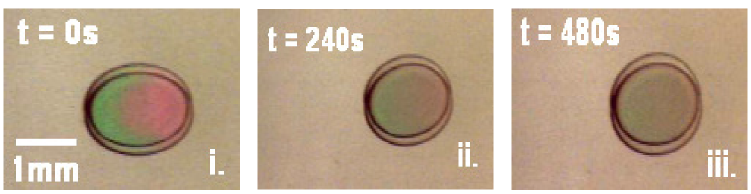

Figure 4: Passive mixing of red and green droplets by diffusion, combined droplet is not actuated; the time taken for mixing is much longer.

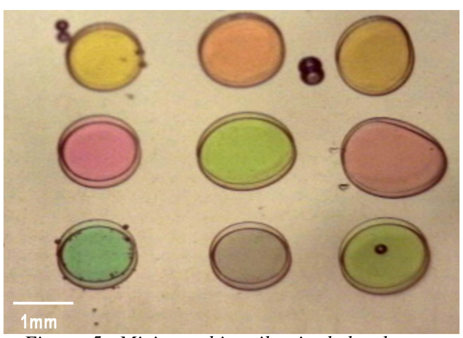

Figure 5: Mixing arbitrarily sized droplets on chip and placing the mixed droplets in a 3x3 array.

Red: 0% Green: 0% Yellow: 100%	Red: 55% Green: 0% Yellow: 45%	Red: 26% Green: 17% Yellow: 57%
Red: 100% Green: 0% Yellow: 0%	Red: 0% Green: 52% Yellow: 48%	Red: 71% Green: 19% Yellow: 10%
Red: 0% Green: 100% Yellow: 0%	Red: 45% Green: 55% Yellow: 0%	Red: 11% Green: 60% Yellow: 29%

Table 1: mixing percentage of each colored dye corresponding to each position in the 3x3 array in Fig. 5.

3. Reference

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