Novel Electrode Shape to Reduce Heating in Light-Actuated Digital Microfluidics

Shao Ning Pei, Justin K. Valley, Hsan-Yin Hsu, Arash Jamshidi and Ming C. Wu
Berkeley Sensor and Actuator Center (BSAC) and Electrical Engineering and Computer Sciences, University of California, Berkeley, USA
Contact e-mail: shaoning@eecs.berkeley.edu

Abstract: A novel, ring-shaped optical electrode is employed to reduce heating in light-actuated digital microfluidics. Using thermo-sensitive hydrogel microspheres, the temperature rise is measured to be 0.35°C, about 15x lower than those using square electrodes.

OCIS codes: (350.4855) Optical tweezers or optical manipulation; (170.4520) Optical confinement and manipulation; (280.1415) Biological sensing and sensors

1. Introduction

Digital Microfluidics is an expanding field with many applications in biology and chemistry [1]. It is a powerful platform for lab-on-a-chip (LOC). Previously, we demonstrated a light-actuated digital microfluidics (LADM) device operated with a digital light projector [2]. It offers several advantages over electrode-based digital microfluidics. However, the light intensity (~1W/cm^2) used in LADM causes a temperature rise in the droplets due to absorptive heating in the photosensitive layer. Excessive heating is undesirable as many chemical or biological reactions are temperature sensitive. In this paper, we propose a novel ring-shaped virtual electrode to reduce heating. Experimentally, the temperature of the droplet is measured using temperature-sensitive hydrogel microspheres as an *in situ* temperature sensor. The maximum temperature rise of 0.35°C is 15 times lower than droplets actuated by square virtual electrodes.

2. Virtual Electrode Shape in LADM

The construction and detailed operations of LADM have been reported in [2]. Briefly, the liquid droplets are sandwiched between a photosensitive electrode and a transparent indium-tin-oxide (ITO) electrode in the LADM device. The photosensitive layer allows one to generate arbitrarily-shaped virtual electrodes by using projected light patterns. A variety of droplet manipulation functions (transport, merging, splitting, mixing) have been demonstrated using this technique. Fig. 1a shows a 2µl droplet actuated by a square light pattern. The droplet is immersed in oil, and moves at 3mm/s with a bias voltage of 24.8Vppk at 10kHz. Since the amount of heating is proportional to the *area* of the illumination, while the droplet actuation force is proportional to the *circumference* of the droplet (contact line force), we can reduce heating by using ring-shaped electrodes around the water/oil interface. This is verified experimentally. Fig. 1b shows that while the droplet transported at the same speed (3mm/s) using a half-ring-shaped light pattern, the actuation voltage of the ring electrode is only 3% higher (25.6Vpp). We have also investigated the effectiveness of the ring electrode as a function of the angle it subtends (inset of Fig. 2). Fig. 2 shows the actuation voltage required to move droplet at 3mm/s versus the angle. As expected, the minimal voltage (most effective actuation) occurs at θ = 90°. However, good movement of the droplet is achieved with angles as small as θ = 45°.

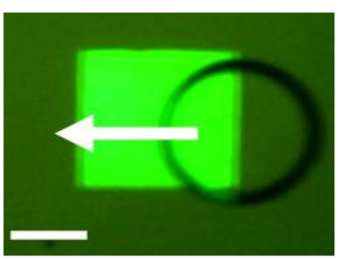

Fig. 1a: 2µl droplet actuated in the direction of arrow using square electrode. Speed 3 mm/s, voltage 24.8 Vppk, frequency 10 kHz, scale bar 1mm.

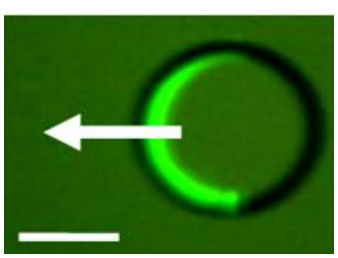

Fig. 1b: 2µl droplet actuated in the direction of arrow using half-ring electrode. Speed 3 mm/s, voltage 25.6 Vppk, frequency 10 kHz, scale bar 1mm.

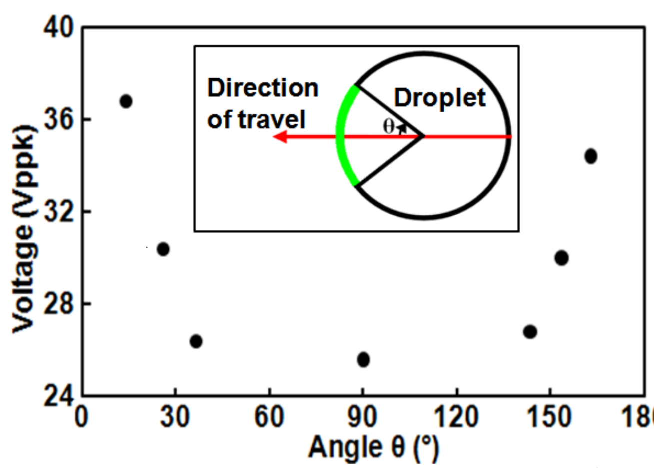

Fig. 2: Bias voltage required to move droplet at 3mm/s versus angle θ subtended by the ring electrode (see inset). Minimum voltage (strongest actuation) is obtained at θ = 90°. Effective actuation of droplets is achieved with angles as small as θ = 45°.

3. Results and Discussion

The temperature of droplets is monitored by thermo-sensitive hydrogel microspheres whose size changes rapidly with temperature [3]. The hydrogel microspheres are contained within droplets, as shown in Fig. 3. The size of hydrogel microspheres within droplets can be tracked, in real time, under various illumination patterns. Consequently, temperature within droplets can be referenced using temperature calibrated against hydrogel microsphere radius (Fig. 4a). When a droplet is half illuminated by a square light pattern (Fig. 3a), hydrogel microspheres on the illuminated side rapidly shrink in size. This indicates a temperature increases in the illuminated side of the droplet by 4°C within 60 seconds (Fig. 4b). Total temperature increase is 5.3°C; the increase is primarily due to the dissipation of absorbed optical energy. In contrast, by switching to a quarter ring light pattern with θ = 45° (Fig. 3b), the total temperature rise is only 0.35°C (Fig. 4b); about a 15-fold reduction from that of the square pattern. To further reduce the temperature, we can remove the optical illumination when droplets actuation is not necessary.

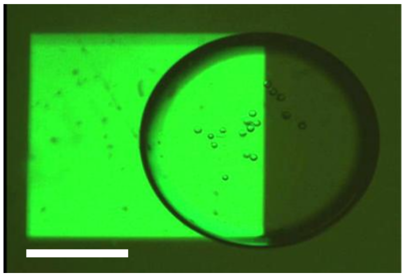

Fig. 3a: Square-shaped light pattern projected on a droplet. Hydrogel microspheres are contained within the droplet. Temperature increase of 5.3°C is observed. The scale bar is 1mm.

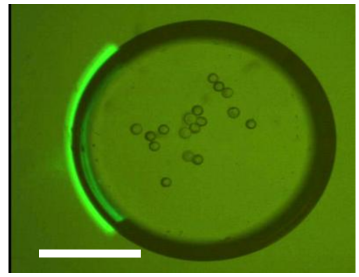

Fig. 3a: Quarter-ring-shaped light pattern projected on a droplet. Hydrogel microspheres are contained within the droplet. Temperature increase of 0.35°C is observed. The scale bar is 1mm.

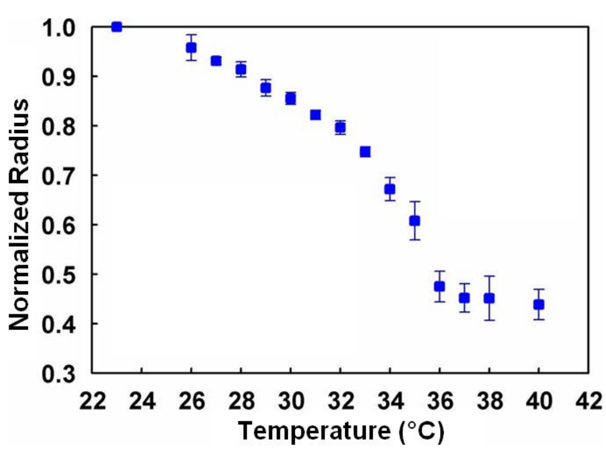

Fig. 4a: Calibration curve used to derive droplet temperature in-situ, as a function of measured hydrogel microsphere radius, as presented in [3].

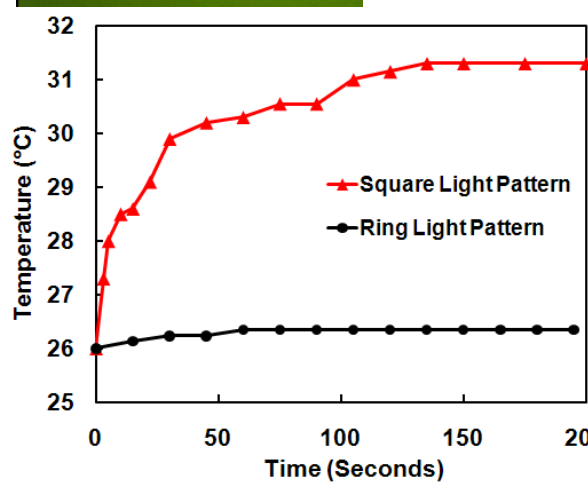

Fig. 4b: Temperature within droplet against time, for both the illuminated side of square-shaped electrode and the quarter-ring-shaped electrode.

4. Conclusion

We have shown that ring illumination pattern is very effective in reducing heating without sacrificing actuation force in light-actuated digital microfluidics. The temperatures of the droplets were measured quantitatively using thermo-sensitive hydrogel microsphere as *in situ* temperature monitors. The heating of the droplet is reduced from 5.3°C to 0.35°C using a ring-shaped electrode, without compromise on droplet actuation speed.

5. Reference

[1] M. Abdelgawad, A.R. Wheeler, "The Digital Revolution: A New Paradigm for Microfluidics", Advanced Materials, 21, 8, 920-925 (2009)

[2] S. N. Pei, J. K. Valley, S. L. Neale, A. Jamshidi, H.-Y. Hsu, M. C. Wu, "Light-actuated digital microfluidics for large-scale, parallel manipulation of arbitrarily sized droplets", 23rd IEEE International Conference on Micro Electro Mechanical Systems (MEMS), 252-255, (2010)

[3] H.-Y. Hsu, S. Vogler, A. Jamshidi, J.K. Valley, S. N. Pei, S. Pautot, M.C. Wu, "Thermo-sensitive microgels as in-situ sensor for temperature measurement in optoelectronic tweezers", 23rd IEEE International Conference on Micro Electro Mechanical Systems (MEMS), 1123-1126 (2010)