Electronic Supplementary Material (ESI) for Lab on a Chip

Electronic supplementary material for: Self-propelling surfactant droplets in chemically-confined microfluidics - Cargo transport, drop-splitting and steering.

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I. CHEMICALS AND SUBSTRATE PATTERNING

Silicon substrates were cut from single side polished wafers (n-type doped with Ph) with a diameter of 150 mm obtained from Silicon Quest (batch number SQ13869). Glass substrates were Gold Seal coverslips 48 mm×60 mm (product number 3334).

Both types of substrates were cleaned by immersion in a solution of hydrogen peroxide (30%, J.T. Baker product number 7047) and sulfuric acid (95%, J.T. Baker product number 6057), mixed at a volume ratio of 1:1.
The chemical surface patterns were created by photolithography and subsequent vapor deposition of 1H,1H,2H,2H-perfluorooctyl-trichlorosilane (PFOTS, purity $> 97\%$, Sigma Aldrich product number 448931) in a sealed glass jar at a temperature of 100°C. The hydrophilic regions were masked with photo-resist and the hydrophobic ones were left unmasked prior to the vapor deposition.

Liquid sub-phase films in our experiments consisted of a 0.55 $w\%$ solution of sodium dodecyl sulfate (SDS, Aldrich product number 71727, purity 99%) in anhydrous glycerol (purity 99%, Sigma Aldrich product number 49767, density $\rho = 1.26$ kg/m^3, refractive index $n_{Glyc} = 1.47$, surface tension $\gamma = 63.4$ mN/m)[1]. The sub-phase viscosity, at the room temperature our experiments were conducted at, was measured to be $\mu(25°\text{C}) = (876 \pm 3)$ mPa-s using a Brookfield DV-II+ Pro viscosimeter which agrees with literature values[2,3] for pure, anhydrous glycerol. The resulting surface tension of the solution was 47 mN/m.

The self-propelling droplets in our experiment consisted of the surfactant cis-9-octadecen-1-ol (oleyl alcohol, Sigma O8880, 99% purity, density 850 kg/m^3, Viscosity $\mu = 26$ mPa-s, surface tension $\gamma = 31.6$ mN/m)[4]. We determined the spreading pressure Π (the difference in surface tension between a 'clean' liquid surface and a surface covered by a monolayer of oleyl alcohol) of the oleyl alcohol on this sub-phase solution to be $\Pi \approx 17.2$ mN/m.

II. SUPPLEMENTARY VIDEOS

The experiments shown in appendices 2-5 were monitored using an Olympus BX-51 upright microscope. The illuminating light was passband-limited around a center wavelength of $\lambda = 650$ nm and $\lambda = 750$ nm for appendices 3-5 and 2 respectively, with a bandpass of $\Delta\lambda \approx 10$ nm. The interference fringes observed for sufficiently low film thicknesses, therefore, correspond to iso-height contour lines with a thickness increment of approximately 221 nm for appendices 3-5 and 255 nm for appendix 2.

Appendix 2: drop propulsion

The video file start.avi shows a droplet ($V_D = 19$ nl) in the initial stage of a propulsion experiment. The subphase liquid ($h_0 = 295$ μm), spreading along the hydrophilic stripe, reaches the droplet which is then mobilized and propels along the thin liquid film. Strong film thinning is observed behind the droplet.

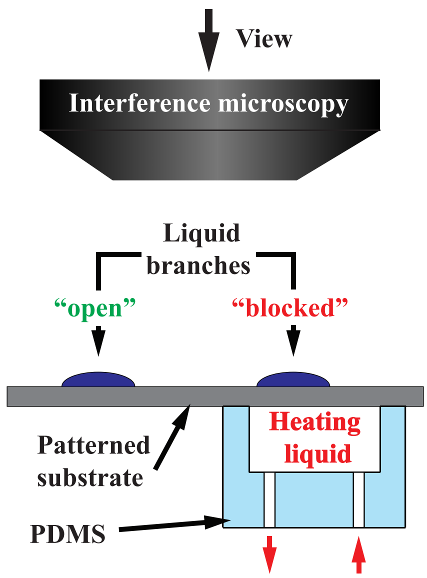

FIG. 1: Experimental configuration for heat induced droplet steering at fluidic junctions via a PDMS flow cell as used in the experiments shown in Appendix 4 and 5.

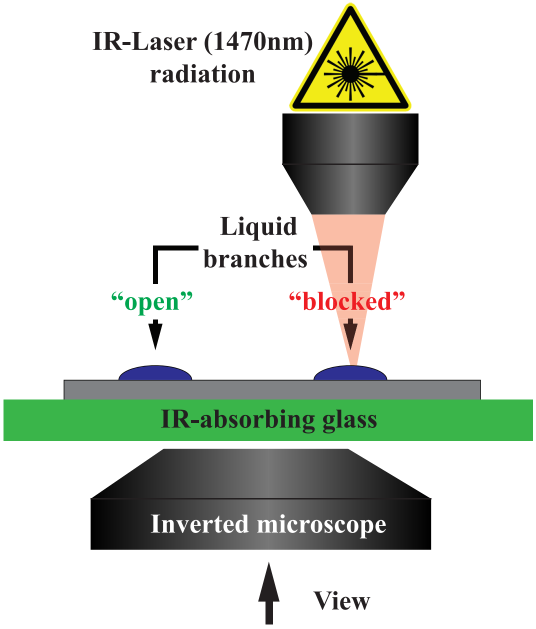

FIG. 2: Experimental configuration for heat induced droplet steering at fluidic junctions via infrared laser illumination as used in the experiment shown in Appendix 6.

Appendix 3: droplet splitting

The video file splitting.avi shows a droplet ($V_D = 11$ nl) splitting at a junction in the fluidic path ($h_0 = 250$ μm). The droplet is stretched orthogonally to its propulsion direction, thins in its center and subsequently splits. The resulting daughter droplets each propel along their respective fluidic branches.

Appendix 4: droplet steering

The video file steering.avi shows a droplet ($V_D = 24$ nl) being directed into one branch at a fluidic junction ($h_0 =$ 285 μm). When the droplet approaches the junction, water with a temperature of about 10°C above ambient temperature (25°C) is pumped in a small PDMS flow cell attached to the substrate under one of the fluidic branches, as illustrated in Fig. 1. The droplet then is stretched orthogonally to its propulsion direction, but instead of thinning and splitting as in the case of no thermal modulation (see Appendix 3), it retracts from the the heated fluidic branch and propels along the unheated branch.

Appendix 5: droplet steering with cargo

The video file cargo.avi shows an analogous experiment of heat induced steering for a cargo transporting droplet ($V_D \approx 30$ nl, $h_0 = 325$ μm).

Appendix 6: droplet steering via infrared laser

The video file laser.avi shows the steering of a cargo transporting droplet at a fluidic junction using a focused infrared (IR) laser pulse as sketched in Fig. 2. When the droplet reached the junction the IR laser was triggered for approximately 1.5 s to illuminate the lower branch in the video with a measured output power of approximately 1 W. As in the case of the steering experiments with the PDMS flow cell (Appendix 4 and 5), the droplet retracts from the subphase in the heated branch and propels with its cargo along the unheated branch. An inverted microscope setup was used to monitor the experiment. To ensure complete absorption of the IR-radiation the entire patterned substrate was placed onto an IR-absorbing glass slide (*Schott KG-3*).

[1] A. A. Newman and L. V. Cocks, *Glycerol*; CRC Press: Cleveland, 1968.
[2] D. Lide (ed.), *CRC Handbook of Chemistry and Physics*; CRC Press: Cleveland, 1982.
[3] J. B. Segur and H. E. Oberstar, *Ind. Eng. Chem.*, 1951, **43**, 2117-2120.
[4] M. Matsumura and H. Kataoka and M. Sueki and K. Araki, *Bioproc. Eng.*, 1988, **3**, 93-100.