Supplementary Material (ESI) for Lab on a Chip

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Supplementary information

S1 ***Fabrication of the microfluidic platform, detail dimension of the microfluidic platform, setup of experiment for droplet generation and droplet trapping/fusion***

The microfluidic structure was fabricated using soft lithographic technique with poly(dimenthylsiloxane) (PDMS) as building blocks[1]. ITO Electrodes on glass was obtained by standard lithography process followed by ITO etching in HCl : H_2O : HNO_3 (4:2:1 by volume) solution. Microfluidic platform was formed by aligned bonding of PDMS slip with the ITO patterned glass assisted by oxygen plasma pretreatment. As shown in Figure 1.d, the ITO electrode embedded in the microwell located with its 60^0 tip at center of the microwell. The opposite electrode has a rectangular shape (width = 360 µm) with its lower edge 210 µm close to center of the main channel. The thickness of the ITO thin film was around 150 nm.

The T junction for droplet formation has a dimension of 150 µm (channel width) for the disperse phase and 100 µm (channel width) for the continuous phase at the phases merging region. All microwells have a dimension of 450 µm in diameter and joint with the main channel with 300 µm channel width. The distance between the center line of the main channel and center of the microwell is 360 µm. All channels have the same depth as 400 µm.

For the droplet formation, the flow rates are 120~300 µl/hour for the continuous phase and 10 µl/hour for the aqueous phase. For the droplet trapping, DC voltage pulse (1000 ~ 2000 DC volts) was applied across each paired ITO electrodes.

S2 Flow resistance calculation to determine how the droplet flow by microwells

In Figure 1a, flow resistance of path 1 and path 2 are much different (path 1 --- without going through the microwell; path 2 --- going through the microwell;). Ignoring the flow resistance of big round area (microwell opening) for path 2, and ignoring the flow resistance due to the 90 degree turn for path 1, the flow resistances for path1 and path 2 could be estimated by [2]:

$$R = 12\mu L\left[\left(1+\frac{5}{6}\alpha\right)abR_H^2\right]^{-1} \qquad \text{Equation (1)}$$

where R is the flow resistance of the channel path, μ is the dynamic viscosity of fluid, L is the length of the channel path, a and b are the depth and width of the microchannel, respectively, $\alpha = \frac{a}{b}$ or $\frac{b}{a}$ such that $0 \le \alpha \le 1$, R_H is the hydraulic radius of the microchannel defined as the ratio of the channel's cross-sectional area to its perimeter and given by $\frac{ab}{a+b}$.

For path 1, dimensions of L, a and b are 715 μm, 400μm and 300μm, respectively. For path 2, dimensions of L, a and b are 285 μm, 400 μm and 100 μm, respectively. Then the ratio of flow resistance of path 1 to that of path 2 is $\frac{R_1}{R_2} \approx \frac{1}{10}$ and the flow resistance for R_1 is $1.5\times10^{10} Pa\cdot s\cdot m^{-3}$ ($\mu = 10 mPa\cdot s$).

S3 Deduction of Equation 1 --- condition for preventing the droplet from escaping

Considering a trapped droplet as shown in the Figure 3a, for preventing the trapped droplet from escaping from the narrow neck, it is necessary to have

$$P_{in} - P_2 < \gamma\left(\frac{1}{r_{drop}} + \frac{2}{w}\right) \qquad \text{Supplementary Equation (1)}$$

where P_{in} and P_2 are the local pressure indicated in Figure 3a, r_{drop} and $w/2$ represent the radii of curvature of the part of droplet extended in the narrow neck of the microwell.

Because of little volume of the part of droplet extended into the neck, the r_{drop} can be approximately chosen as the radius of the droplet with no extended part in the narrow neck.

Since the hydrodynamic pressure drops along two flowing paths shown in Figure 3a are the same, we can have an identity:

$$(P_{in} - P_2) + (P_2 - P_3) = (P_{in} - P_1) + (P_1 - P_3)$$

Then $(P_{in} - P_2) = (P_{in} - P_1) + (P_1 - P_3) - (P_2 - P_3)$ Supplementary Equation (2)

For path 1, $P_1 - P_3 = Q_1 R_{path1} < Q_{main} R_{path1}$ Supplementary Equation (3)

where Q_1 and Q_2 are the flow rates of path 1 & path 2, respectively and $Q_{main} = Q_1 + Q_2$ is the flow rate of oil phase before the microwell junction.

Applying Young's Laplace equation for the part of droplet left in the microwell,

$$P_{in} - P_1 = \gamma \frac{2}{r_{drop}}$$ Supplementary Equation (4)

Here because of little volume of the part of droplet extended into the neck, the r_{drop} can be approximately chosen as the radius of the droplet with no extended part in the narrow neck.

For the part of droplet extended in the narrow neck,

$$P_2 - P_3 = Q_{path2} R_{path2} > 0$$ Supplementary Equation (5)

Here $Q_{path2} R_{path2} > 0$ as the neck channel is not fully blocked by the droplet.

Combining Supplementary Equation 3, 4 and 5, we have

$$(P_{in} - P_1) + (P_1 - P_3) - (P_2 - P_3) < Q_{main} R_{path1} + \gamma \frac{2}{r_{drop}}$$ Supplementary Equation (6)

Combining Supplementary Equation 2 and 6 gives

$$P_{in} - P_2 = (P_{in} - P_1) + (P_1 - P_3) - (P_2 - P_3) < Q_{main} R_{path1} + \gamma \frac{2}{r_{drop}}$$

--- Supplementary Equation (7)

From Supplementary Equations 1 and 7, it shows that as long as the following is satisfied,

$$P_{in} - P_2 = (P_{in} - P_1) + (P_1 - P_3) - (P_2 - P_3) < Q_{main} R_{path1} + \gamma \frac{2}{r_{drop}} \le \gamma \left(\frac{1}{r_{drop}} + \frac{2}{w} \right)$$

--- Supplementary Equation (8)

the condition for non-escaping of the droplet is fulfilled.

Supplementary Equation (8) leads to

$$Q_{main} \le \frac{\gamma}{R_{path1}} \left(\frac{1}{r_{drop}} + \frac{2}{w} - \frac{2}{r_{drop}} \right) = \frac{\gamma}{R_{path1}} \left(\frac{2}{w} - \frac{1}{r_{drop}} \right)$$ Supplementary Equation (9)

R_{path1} can be calculated as $1.5 \times 10^{10} Pa \cdot s \cdot m^{-3}$ as shown in the supporting information -- S2.

With the interfacial tension γ as $35\, mN \cdot m^{-1}$, we have $\frac{\gamma}{R_{path1}} = 2.3 \times 10^{-12} m^4 \cdot s^{-1}$.

Therefore, we can obtain a plot of the velocity of flow $\left(\frac{Q_{main}}{Channel\_Depth \times Channel\_Width} \right)$ vs. r_{drop} as shown in Figure 2.b ($velocity\_of\_flow = 1900 \left(0.02 - \frac{1}{r_{drop}} \right) cm/s$, here r_{drop} is in µm).

Reference

(1) McDonald, J. C.; Duffy, D. C.; Anderson, J. R.; Chiu, D. T.; Wu, H. K.; Schueller, O. J. A.; Whitesides, G. M. *Electrophoresis* **2000**, *21*, 27-40.

(2) Zimmermann, M.; Schmid, H.; Hunziker, P.; Delamarche, E. *Lab on a Chip* **2007**, *7*, 119-125.