Electronic Supplementary Material (ESI) for Analyst.

The "V-junction": a novel structure for high-speed generation of bespoke droplet flows

Yun Ding, Xavier Casadevall i Solvas and Andrew deMello

Department of Chemistry and Applied Biosciences, Institute for Chemical and Bioengineering, ETH Zurich, Vladimir-Prelog-Weg 1, Zurich, 8093, Switzerland. E-mail: andrew.demello@chem.ethz.ch

1 Operational upper flow-rate limits in open-mode for varying V-junction angles

One of the fundamental characteristics of the V-junction is its ability to eliminate all the dispersed phase through the control channel when operating in *open-mode*. This feature is key to the success of important functions, such as the generation of target-sized droplets from the first one, clean switching of samples and the interruption and resumption of a running experiment. Three types of V-junction geometries possessing angles of 30°, 60° and 90° were fabricated (Fig. S1), and their operational upper limit (defined as the maximum water/oil flow-rate ratio that still prevents the dispersed phase from entering the main channel) in *open-mode* tested.

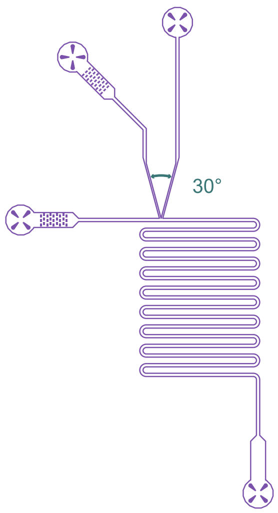

Figure S1 Chip design of V-junction with three types of angles.

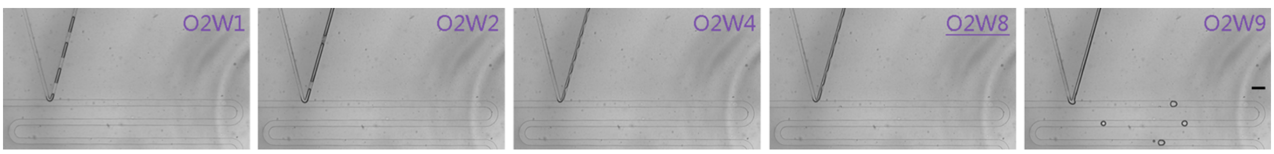

Figure S2 Determination of the upper bound of water/oil flow-rate ratio in *open-mode*. O(2) W(1,2,4,8,9) defines the flow rates of each phase in µl/min The scale bar is 200 µm.

Fig. S2 illustrates a typical upper limit test for the 30° angle configuration. The oil flow-rate was fixed at 2 µl/min and the water flow-rate was adjusted at 1, 2, 4, 8 and 9 µl/min respectively. In this case droplets were injected in the main channel at a water flow-rate of 9 µl/min. Therefore, the upper limit (water to oil flow-rate ratio for an oil flow-rate of 2 µl/min) in *open-mode* for this chip was determined to be 4.

Table S1 summarizes the operational upper limits for chip configurations of 30° and 60°, and a plot is shown in Fig. S3. The 90° chip was found not to be competent with the assignment of totally eliminating water flux through the control channel: part of the aqueous phase would always enter the main channel (see Fig. S4 and Video S1). Results indicate that the 60° chip design had the best operational capability among the three.

Chip type	Oil flow-rate (µl/min)	Max water flow-rate (µl/min)	Ratio
30°	2	8	4
	4	13-14	3.25-3.5
	8	30-40	3.75-5
60°	2	11	5.5
	4	16-18	4-4.5
	8	60-70	7.5-8.75

Table S1 Summary of operational upper limit of water/oil flow-rate ratios for 30° and 60° chips.

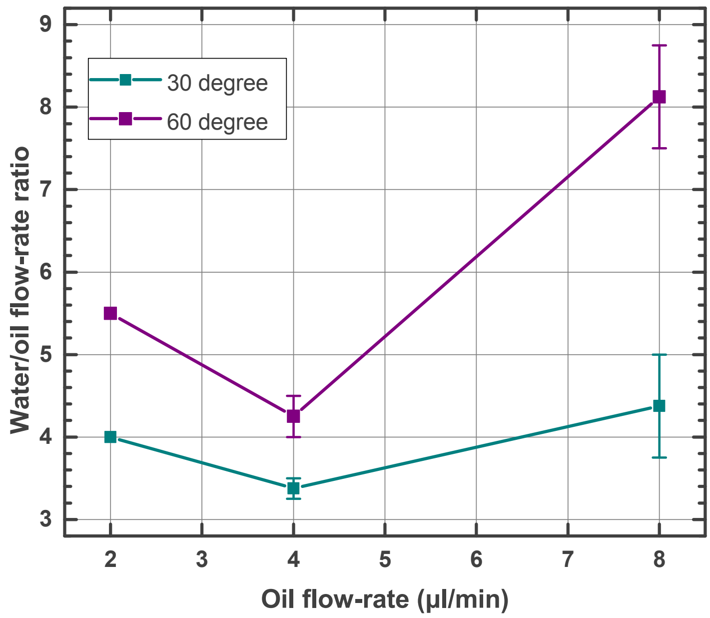

Figure S3 Graphical representation of data presented in Table S1.

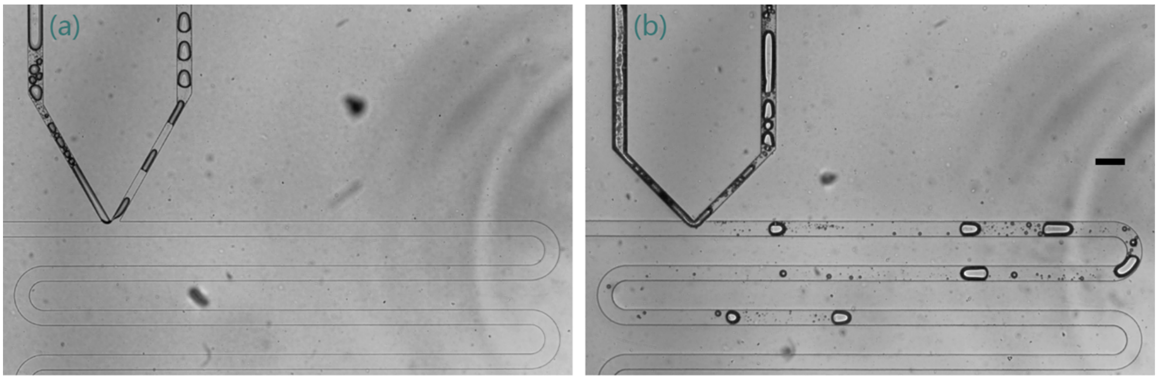

Figure S4 Comparison of *open-mode* reliability for the 60° and 90° V-junction designs. The 90° chip (b) already fails at flow-rates of 2 µl/min oil and 1 µl/min water (0.5 ratio) while 60° chip (a) is competent in the same condition. The scale bar is 200 µm.

2 Measurement of droplet volumes

The volume of droplets was estimated as follows:

$$V = \begin{cases} \frac{4}{3}\pi r^3 & small\ droplet \\ \{0.6(l_1 + l_3) + l_2\}dh & large\ droplet \end{cases}$$

For a small droplet (Fig. S5a) whose radius is smaller than half the height of the channel, volume spherical volume is calculated. For a large droplet (Fig. S5b) that contacts two sidewalls of the channel, the volume is treated as an equivalent rectangular prism with width *d* (100µm), height *h* (50µm) and estimated equivalent length *l* ($0.6(l_1+l_3)+l_2$).

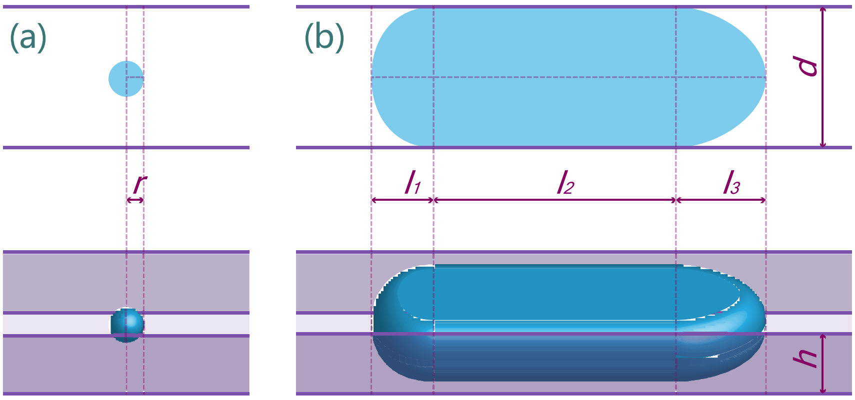

Figure S5 Illustration of droplet volume calculation and feature sizes.

3 Comparing experiments between V-junction and T-junction

3.1 Size gradients

A periodic droplet train with an inherent size gradient was created in a T-junction under similar conditions to those used for the V-junction (fixed oil flow-rate of 2 µl/min, but with a ramping flow-rate profile directly applied to the water inlet). The results of such an experiment are displayed in Fig. S6. Extracted size information for both the T-junction and V-junction formats are displayed in Table S2.

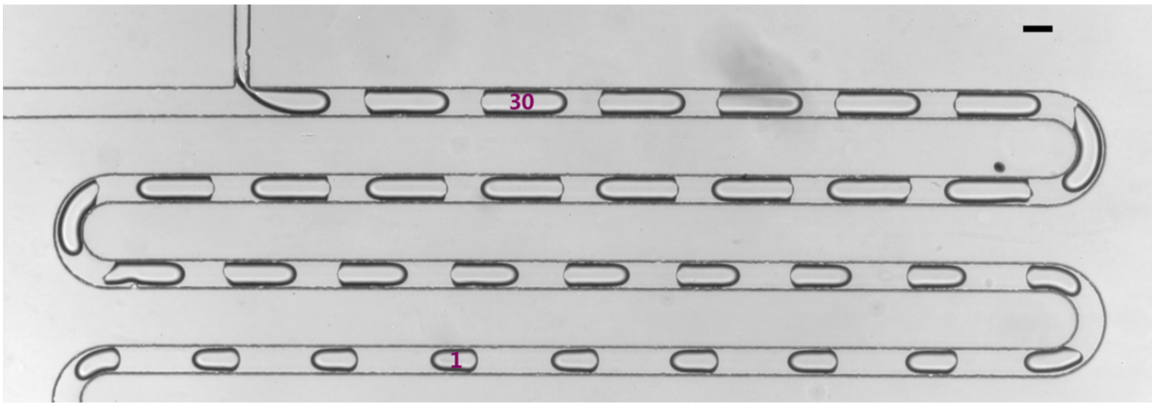

Figure S6 Droplet size gradient in T-junction. The smallest droplet is marked as (1) and the largest as (30). The scale bar is 100 µm.

Junction	Droplet ID	*r* (µm)	l_2 (µm)	$l_1 + l_3$ (µm)	V (pl)	Volume ratio
V	No.1 (largest)		141.1	66.1	903.8	110.2
	No.72 (smallest)	12.5			8.2	
T	No.1 (smallest)		107.1	66.1	733.8	1.9
	No.30 (largest)		232.1	82.1	1406.8	

Table S2 Volume of smallest and largest droplets for V-junction (Fig. 5 in main manuscript) and T-junction (Figure S6).

Chip	Related image	Area (µm²)	Frequency (Hz)	Spacing (µm)
V	a-i	545	14.8	459
	a-ii	1711	16.0	452
	a-iii	3247	16.7	413
	a-iv	5640	16.7	397
	a-v	7045	17.4	373
	a-vi	8006	16.7	391
	a-vii	9092	15.4	404
	a-viii	10100	13.8	442
	a-ix	12200	12.5	472
	a-x	13200	12.5	476
	a-xi	14400	12.5	463
	a-xii	14900	13.3	455
T	b-i	4970	4.2	1631
	b-ii	5924	5.8	1120
	b-iii	6931	7.9	811
	b-iv	8655	11.9	561
	b-v	12522	18.5	403

Table S3 Results for size, frequency, and spacing measurements

3.2 Relationship between size and frequency/spacing

Two series of experiments for creating several kinds of different sized droplets were performed both in V- and T-junctions (Fig. S7). In both cases the oil flow-rate was fixed at 2 µl/min. Droplet sizes were tuned by adjusting the water flow-rate in the T-junction and adjusting withdrawal flow-rate in the V-junction (while keeping the water flow-rate constant at 2 µl/min). The smallest stable droplets obtained in the T-junction (Fig. S7a-i) were for water flow-rates lower than 0.05 µl/min. The results for droplet size (area) and generation frequency and spacing (defined here as the distance between centres of two neighbouring droplets) are summarized in Table S3. These results indicate that both, the frequency and spacing are independent of size for droplets generated in the V-junction, which is not the case for those generated in the T-junction. The relationship between droplet size and spacing is plotted in Fig. S8.

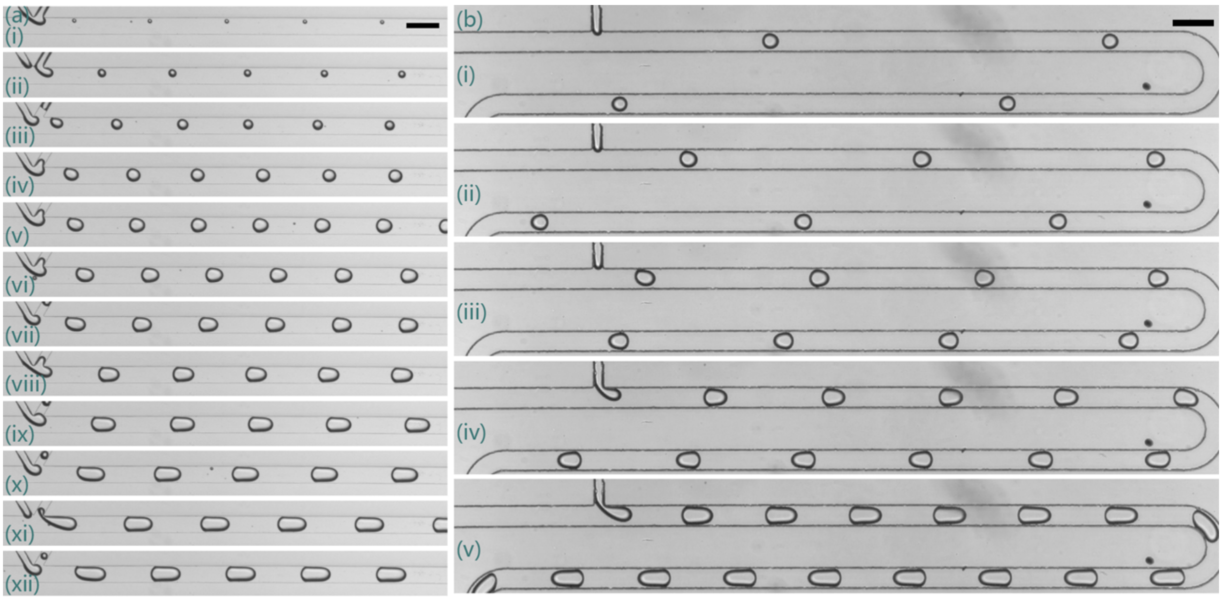

Figure S7 Comparison of frequency and spacing between droplets produced in (a) V-junction and (b) T-junction. The scale bars are 200 µm.

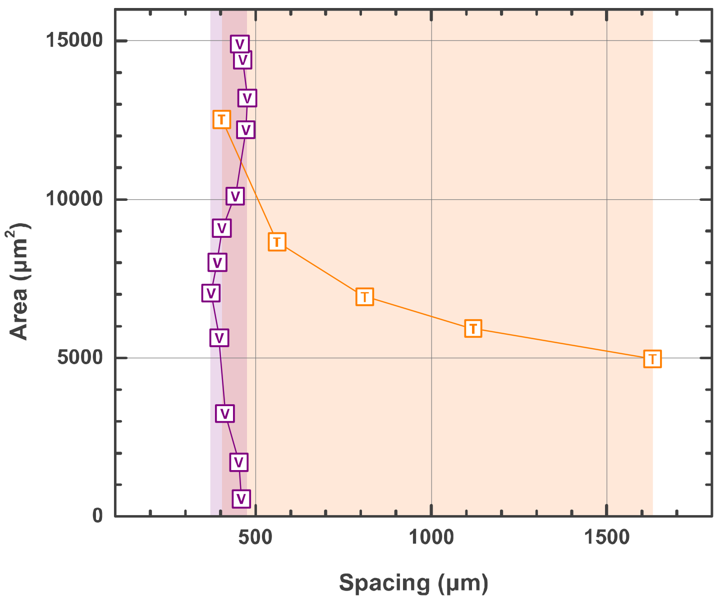

Figure S8 Plot of droplet spacing versus droplet area for V- and T- junctions.

4 Video contents

Video S1: Different performance for 60° and 90° chips in open-mode.
Video S2: Visualization of the direction of oil flow for the two modes.
Video S3: Generation of stable and size-controlled water droplets from the first one.
Video S4: Large range of droplet sizes created in V-junction.
Video S5: Formation of very small droplets in the control channel.
Video S6: A simple method for the generation of residence time gradients.