Electronic Supplementary Information (Figs. S1-S3 and Tables S1-S2).

Fluid displacement during droplet formation at microfluidic flow-focusing junction

Haishui Huang[ab] and Xiaoming He[bcd*]

[a]Department of Mechanical and Aerospace Engineering, The Ohio State University, Columbus, Ohio 43210, USA

[b]Department of Biomedical Engineering, The Ohio State University, Columbus, Ohio 43210, USA

[c]Davis Heart and Lung Research Institute, The Ohio State University, Columbus, Ohio 43210, USA

[d]Comprehensive Cancer Center, The Ohio State University, Columbus, Ohio 43210, USA

*Correspondence should be addressed to:
Xiaoming He, Ph.D.
Department of Biomedical Engineering
The Ohio State University
308 BRT, 473 W. 12th Avenue
Columbus, OH 43210
Phone: (614) 247-8759
Fax: (614) 292-7301
Email: He.429@osu.edu

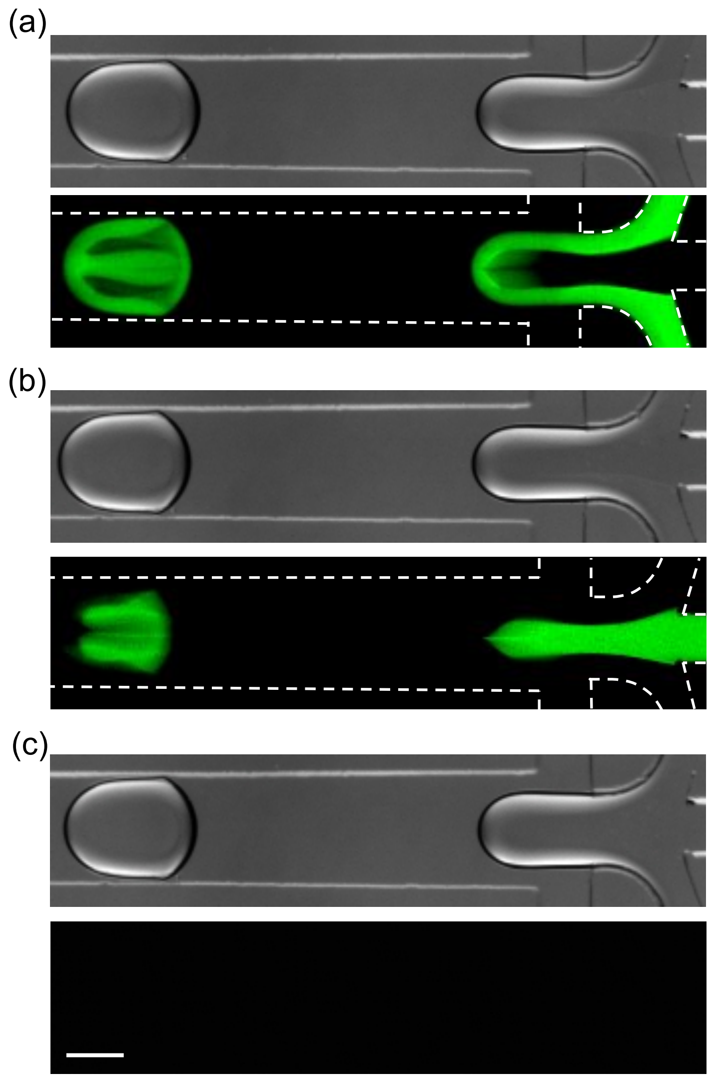

Fig. S1. Bright field and fluorescence images of pinched-off and pendent microdroplets showing the addition of fluorescein isothiocyanate-dextran (500 kDa) in the shell or core fluids does not affect droplet formation at the microfluidic flow-focusing junction. (a) The images of microdroplets formed with the fluorophore in shell fluid; (b) The images of microdroplets formed with the fluorophore in core fluid. (c) The images of microdroplets formed with no fluorophore in any fluid. Scale bar: 200 μm. Experimental condition: μ_{core} = μ_{shell} = 23.4 mPa s, μ_c = 30.9 mPa s, q_{core} = q_{shell} = 0.1 ml hr^{-1}, q_c = 1 ml hr^{-1}, and σ = 5.55 mN m^{-1}.

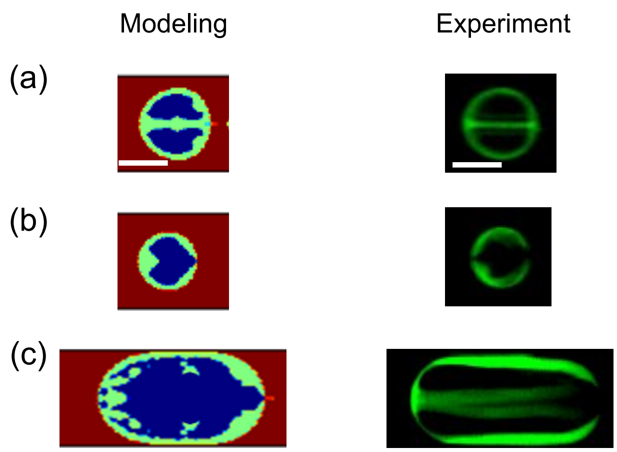

Fig. S2. Comparisons of results from modeling and experiments on the morphology of droplets generated by microfluidic flow-focusing junction. (a) ϴ-shaped distribution of the shell solution, $\mu_{core} = \mu_{shell}$ = 23.4 mPa s, q_c = 2 ml h^{-1}. (b) O-shaped distribution of the shell solution, $\mu_{core} = \mu_{shell}$ = 599 mPa s, q_c = 2 ml h^{-1}. (b) Reduced fluid displacement in large microdroplets, $\mu_{core} = \mu_{shell}$ = 23.4 mPa s, q_c = 0.2 ml h^{-1}. For all the studies, q_{shell} = 33.3 μl h^{-1}, q_{core} = 166.7 μl h^{-1}. Scale bars, 200 μm

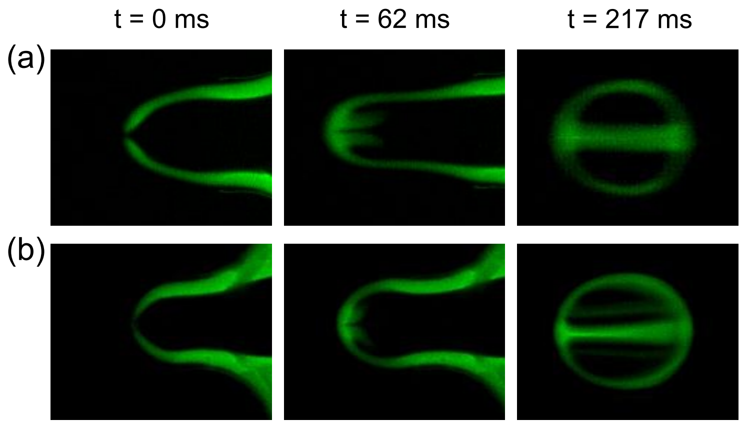

Fig. S3. The effect of interfacial tension on fluid displacement during droplet formation at microfluidic flow-focusing junction. (a) Strong interfacial tension causes fast but short-lasting capillary recoil, Ca = 339. (b) Small interfacial tension induces slow but long-lasting capillary recoil, Ca = 144. For both (a) and (b), ζ = 3.5, λ = 1.3, I_{in}/I_{out} = 1.2 in the final droplets. Scale bar: 200 μm.

Table S1. Dynamic viscosities of various fluids determined experimentally using rheometer

Fluid	Mean viscosity (mPa s)	Standard deviation (mPa s)
Water	1.0	0.1
0.5% (w/v) M cellulose* in water	23.4	0.2
1% (w/v) M cellulose in water	93.2	3.7
2% (w/v) M cellulose in water	598.8	9.3
1% (w/v) H cellulose# in water	797.1	41.5
Mineral oil	30.0	0.0
1% (v/v) span 80 in mineral oil	30.9	0.0
2% (v/v) span 80 in mineral oil	32.4	0.0
5% (v/v) span 80 in mineral oil	33.2	0.3
10% (v/v) span 80 in mineral oil	36.8	0.5
20% (v/v) span 80 in mineral oil	42.6	0.5
30% (v/v) span 80 n mineral oil	49.2	0.7
Mineral oil-$CaCl_2$ emulsion	107.7	1.5
2% (w/v) alginate in water	23.6	0.4

*Medium viscosity carboxymethyl cellulose from Sigma

#High viscosity carboxymethyl cellulose from Sigma

Table S2. Interfacial tension of various fluid pairs determined experimentally using contact angle goniometer

Fluid pair	Mean interfacial tension (mN m^{-1})	Standard deviation (mN m-1)
Water - mineral oil	60.0	0.6
Water - mineral oil with 1% (v/v) span 80	6.3	0.1
Water - mineral oil with 2% (v/v) span 80	5.3	0.1
Water - mineral oil with 5% (v/v) span 80	5.2	0.3
Water - mineral oil with 10% (v/v) span 80	5.0	0.2
Water - mineral oil with 20% (v/v) span 80	4.7	0.2
Water - mineral oil with 30% (v/v) span 80	4.5	0.1
0.5% (w/v) M* cellulose in water - mineral oil with 1% (v/v) span 80	5.6	0.2
0.5% (w/v) M cellulose in water - mineral oil with 2% (v/v) span 80	4.6	0.2
0.5% (w/v) M cellulose in water - mineral oil with 5% (v/v) span 80	4.2	0.1
0.5% (w/v) M cellulose in water - mineral oil with 10% (v/v) span 80	4.1	0.2
0.5% (w/v) M cellulose in water - mineral oil with 20% (v/v) span 80	4.0	0.3
0.5% (w/v) M cellulose in water - mineral oil with 30% (v/v) span 80	3.8	0.3
1% (w/v) M cellulose in water - mineral oil with 1% (v/v) span 80	4.8	0.1
1% (w/v) M cellulose in water - mineral oil with 2% (v/v) span 80	3.9	0.0
1% (w/v) M cellulose in water - mineral oil with 5% (v/v) span 80	3.7	0.2
1% (w/v) M cellulose in water - mineral oil with 10% (v/v) span 80	3.5	0.3
1% (w/v) M cellulose in water - mineral oil with 20% (v/v) span 80	3.3	0.4
1% (w/v) M cellulose in water - mineral oil with 30% (v/v) span 80	3.0	0.5

*Medium viscosity carboxymethyl cellulose from Sigma