Microfluidics, a facile platform to engineer droplet/particle morphology

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Zhejiang University

Microfluidics

- **Engineer droplet morphology at microscale: Precise control**
- **Engineer particle morphology at nanoscale: Rapid mixing**

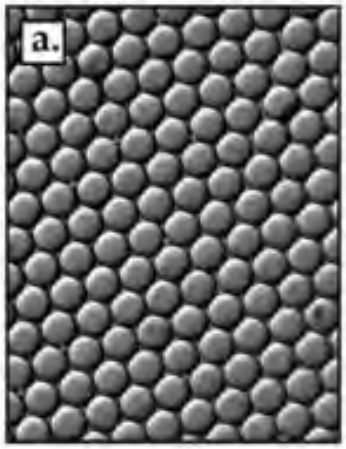
Microfluidics

- **Engineer droplet morphology at microscale: Precise control**

- **Engineer particle morphology at nanoscale: Rapid mixing**

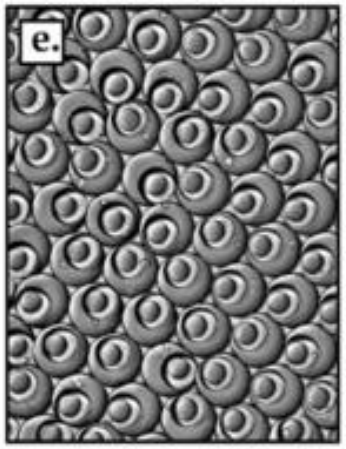
Multiple Emulsions

single



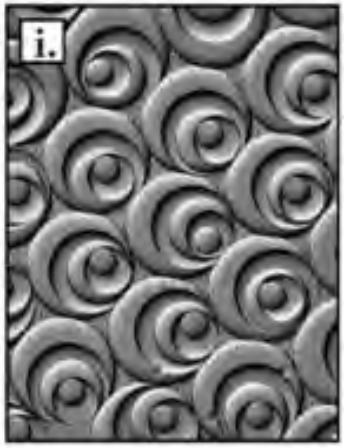
double

triple

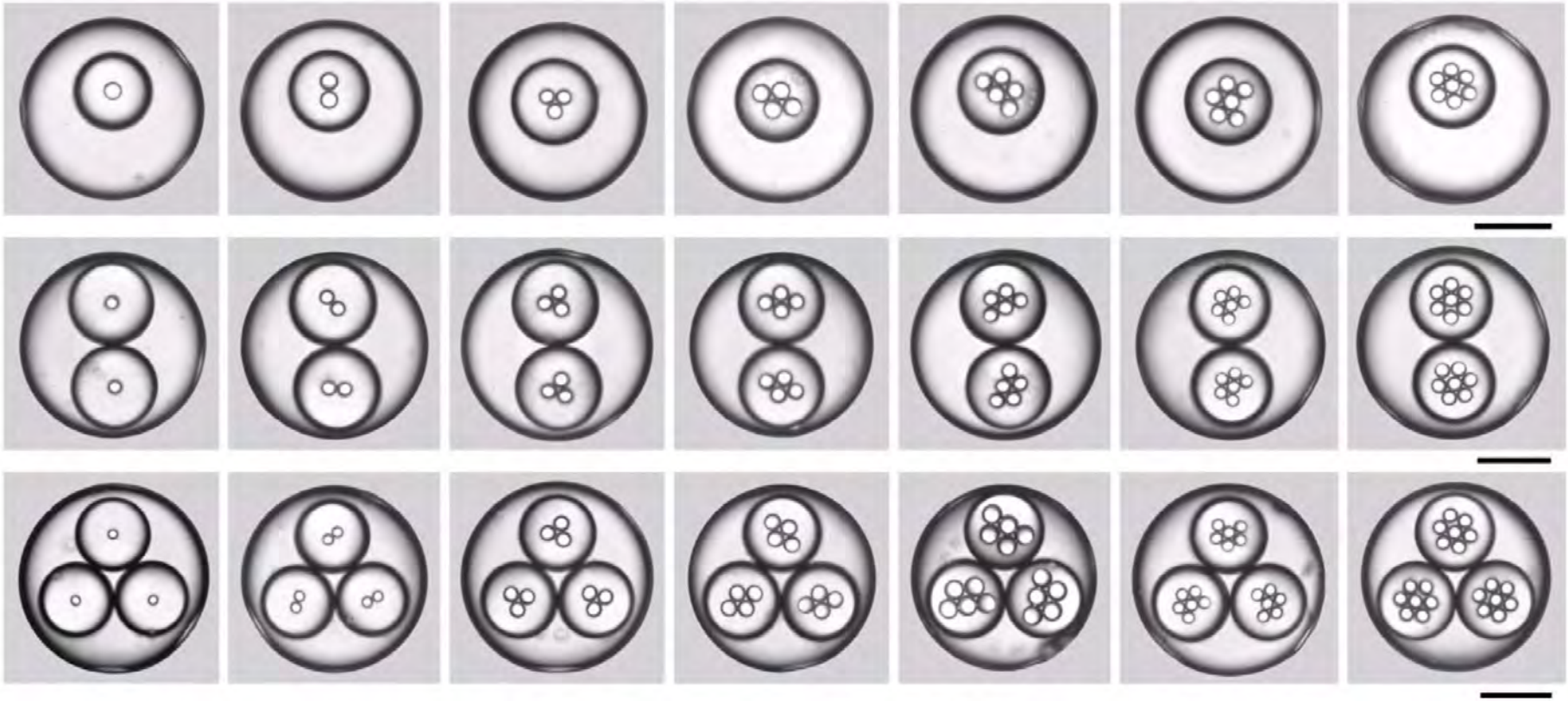


quadruple

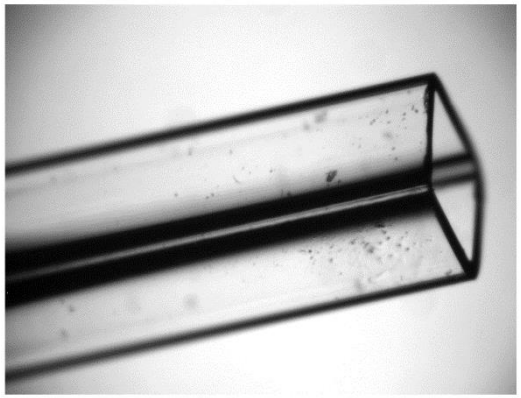
quintuple

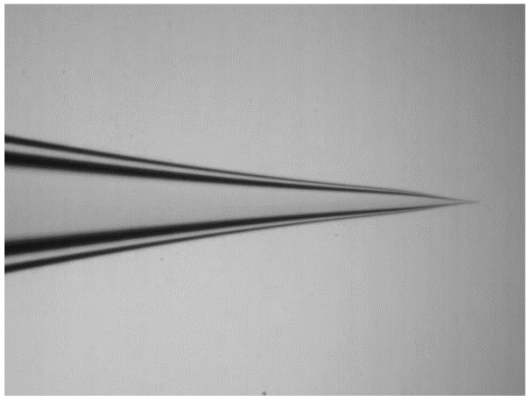


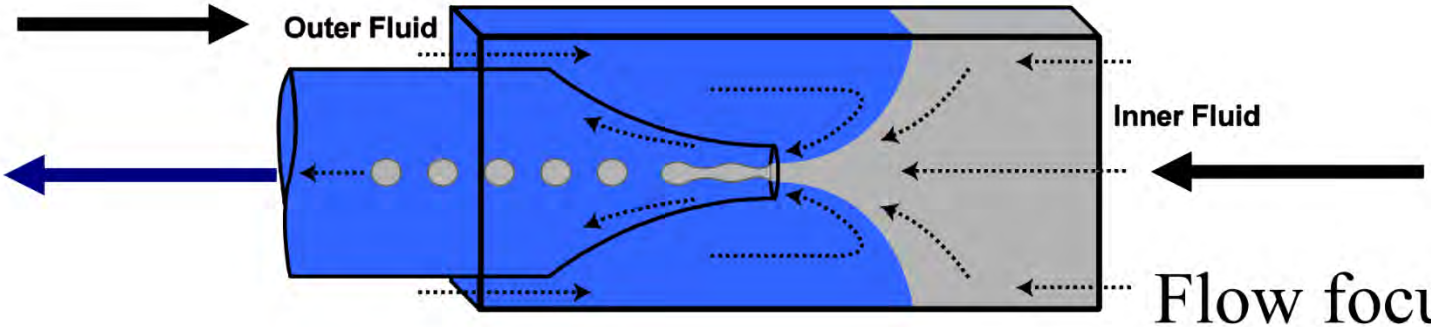
Emulsion Designer



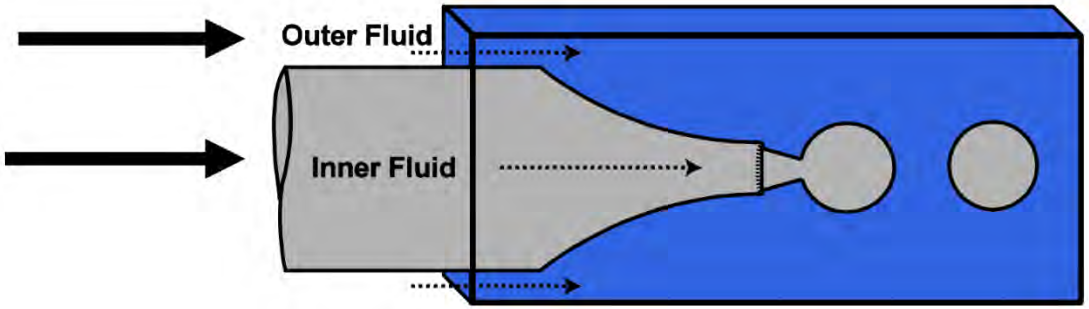
Glass Capillary Microfluidic Device







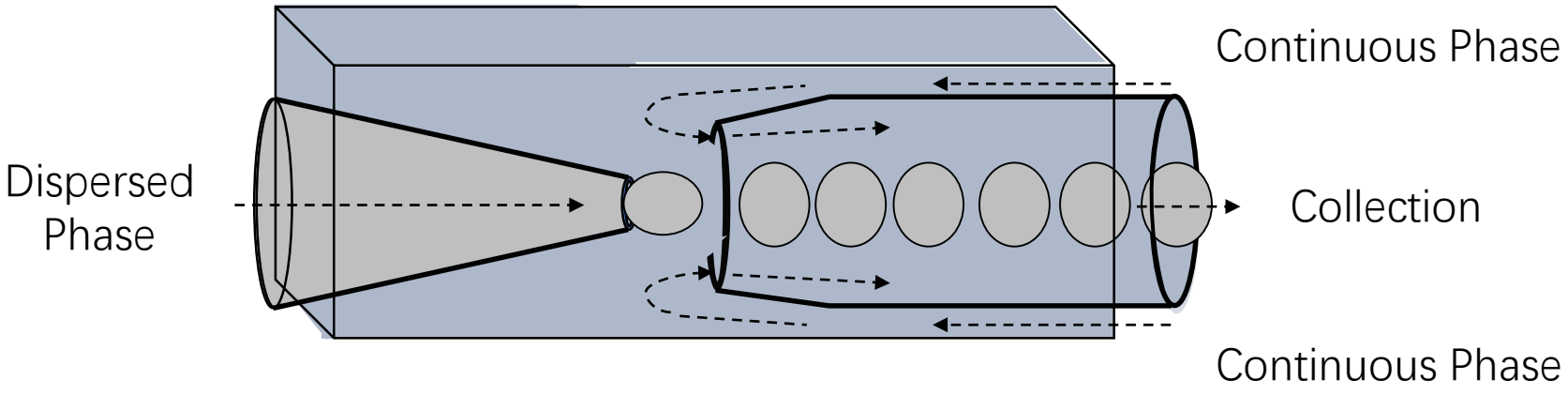
Flow focusing

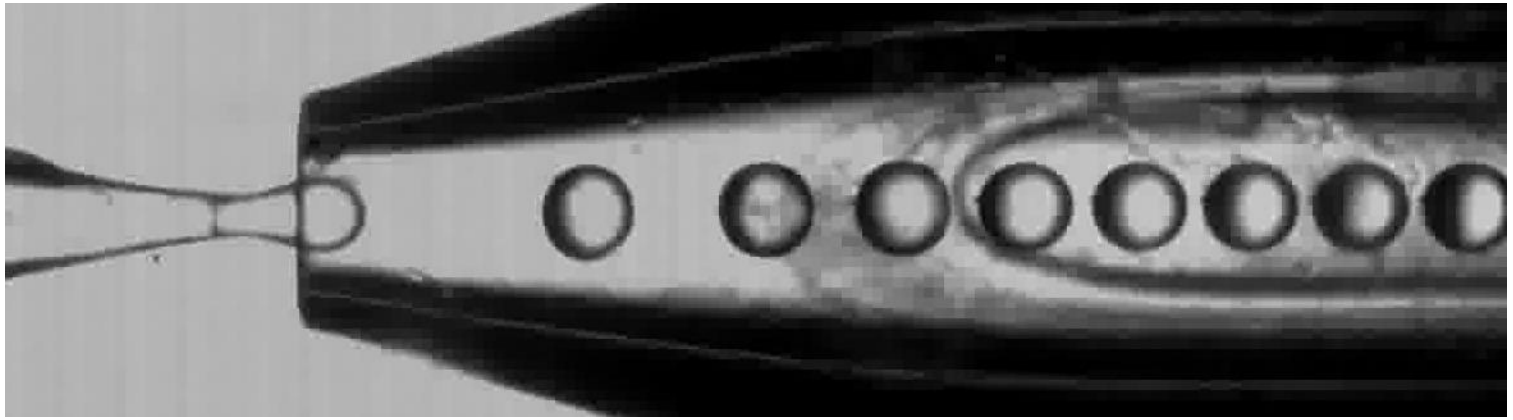


Co-flow

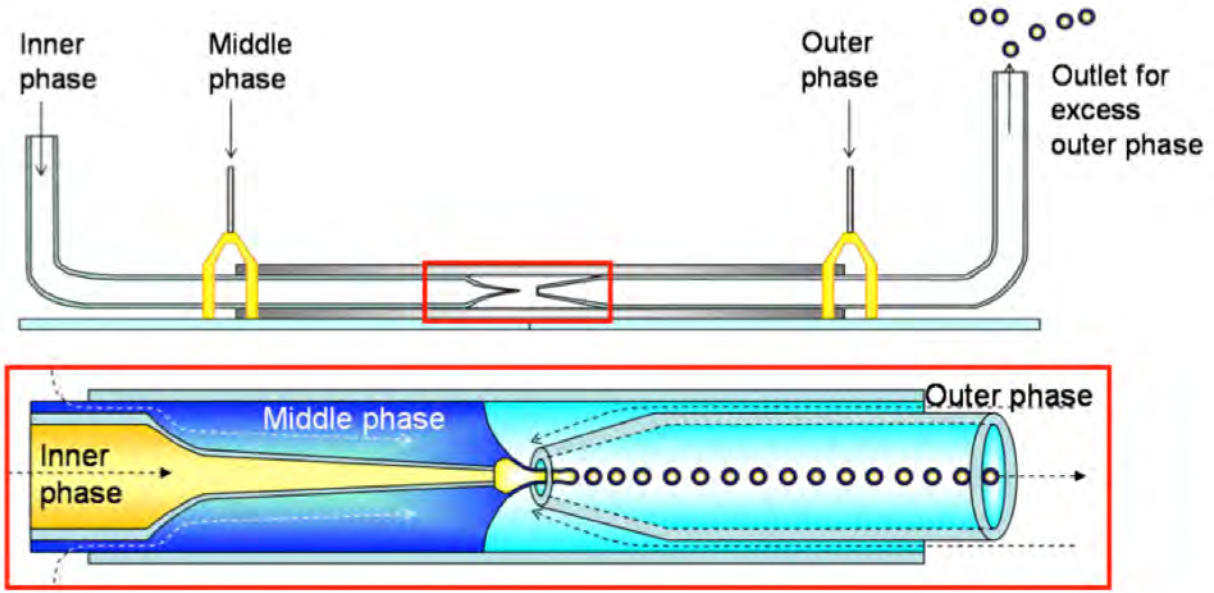
Preparation of Single Emulsions

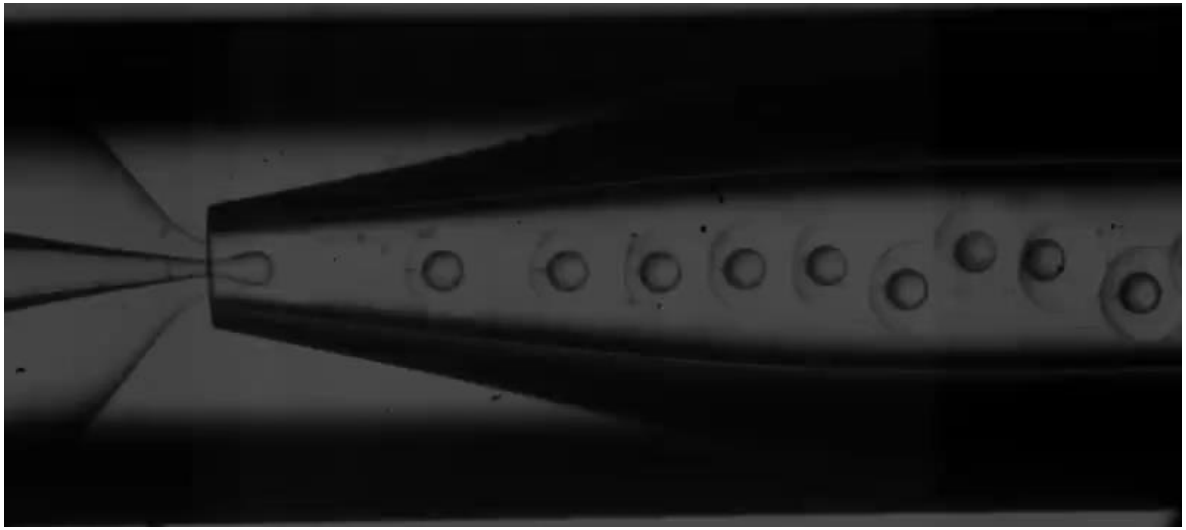
Single emulsions



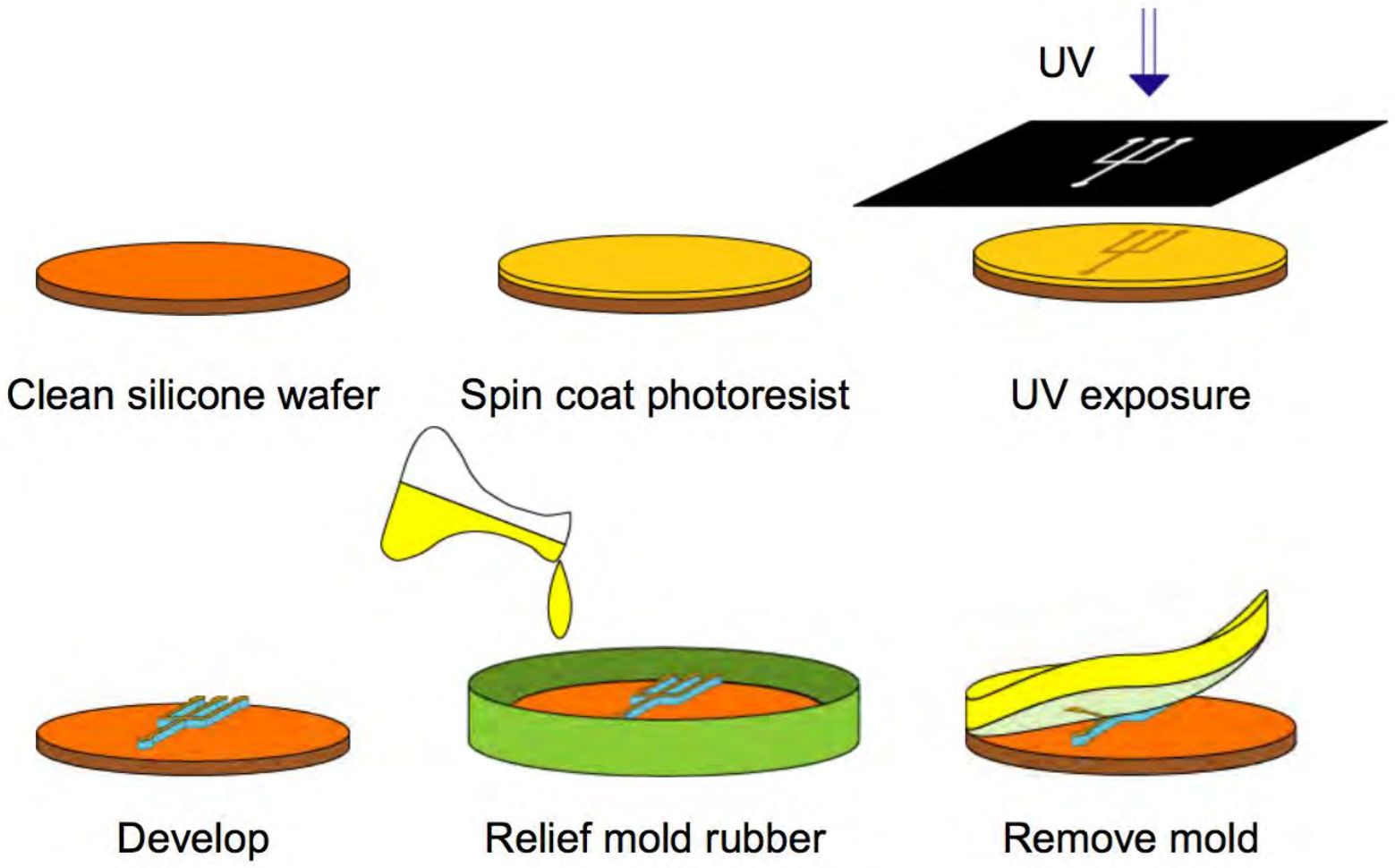


Preparation of Double Emulsions

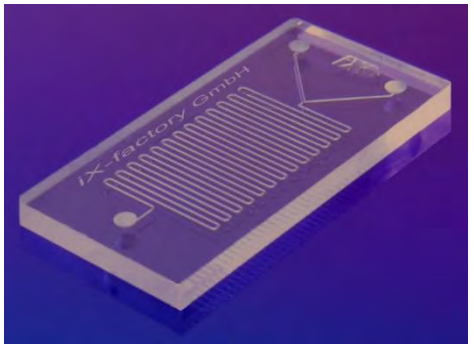


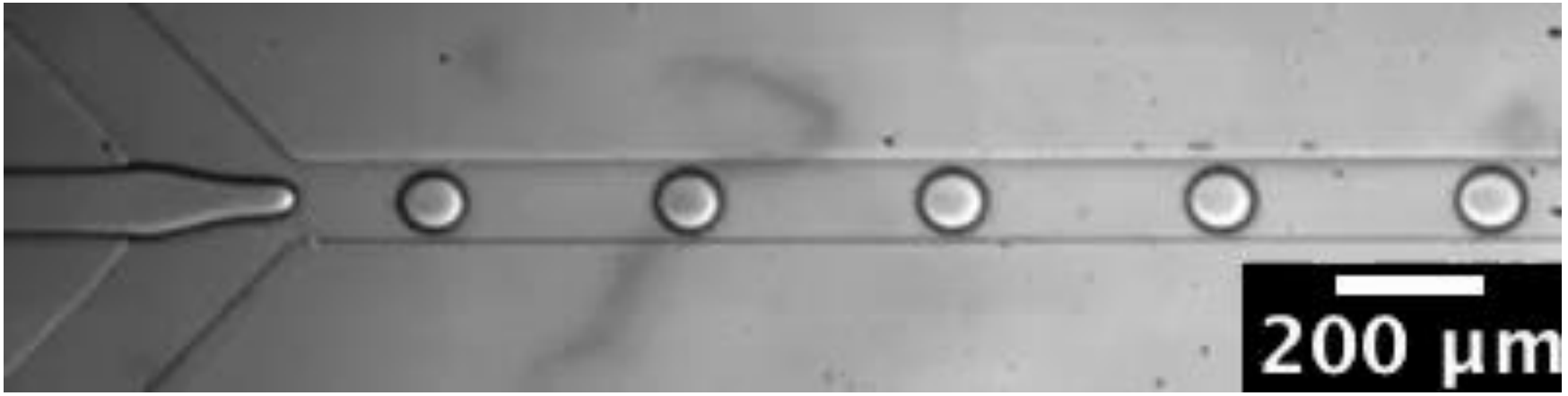


Soft Lithography of PDMS Microfluidic Device

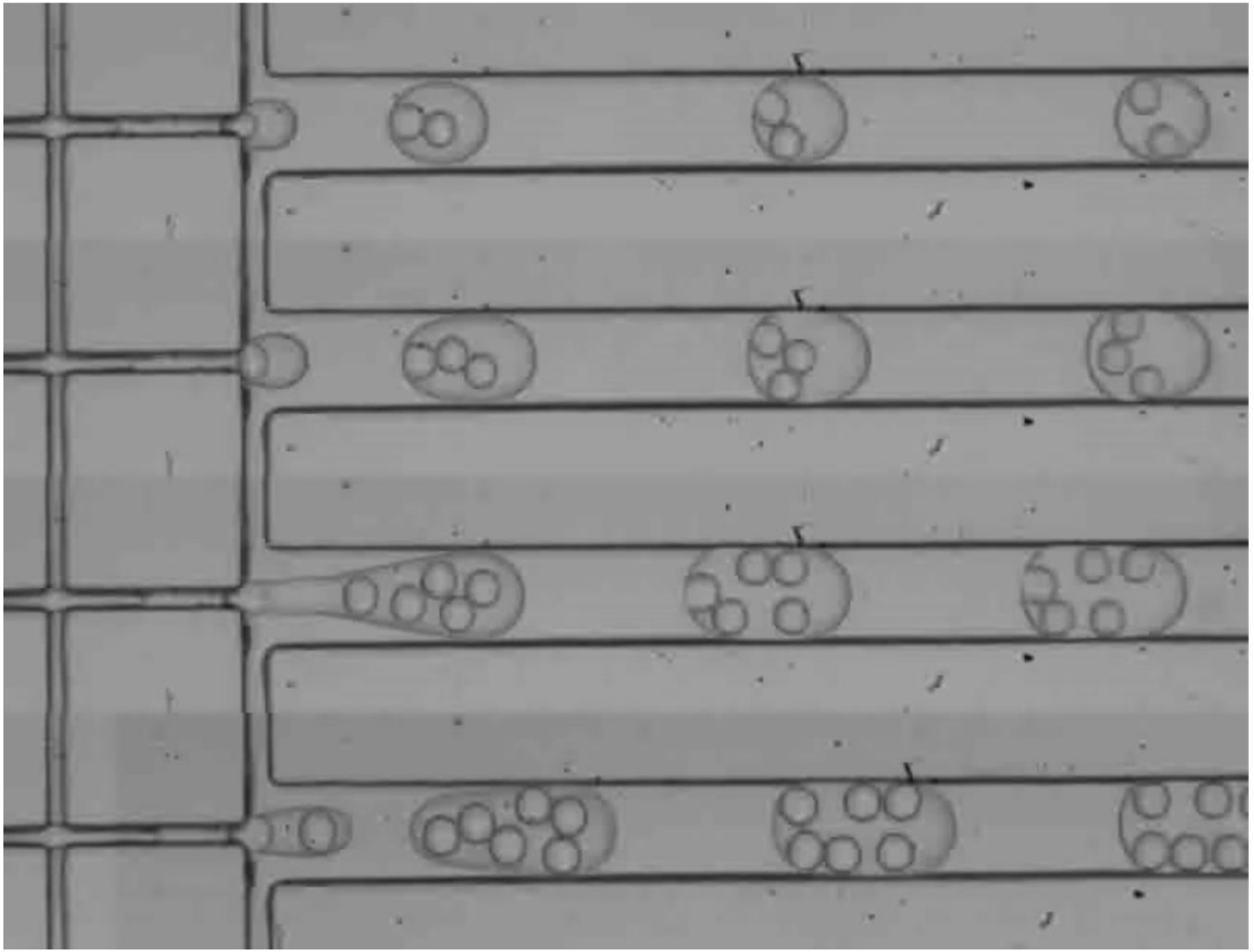


PDMS Microfluidic Device



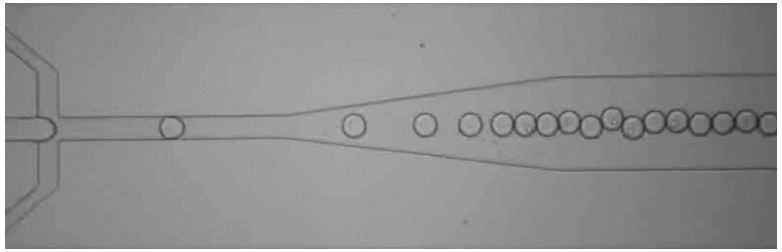


PDMS Microfluidic Device

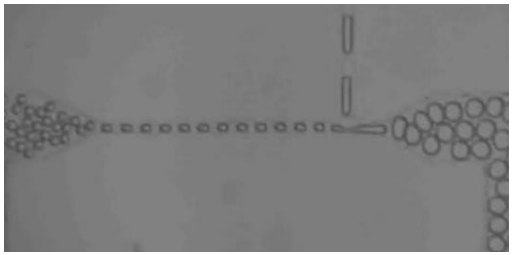


Powerful Tools of Microfluidics

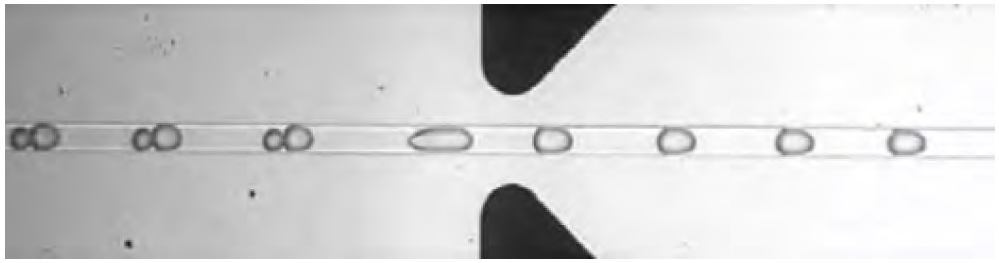
make



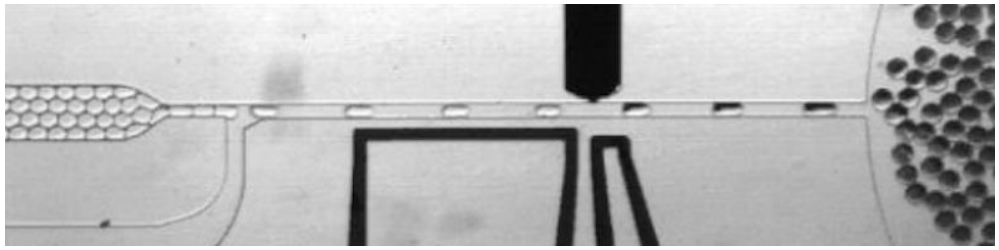
split



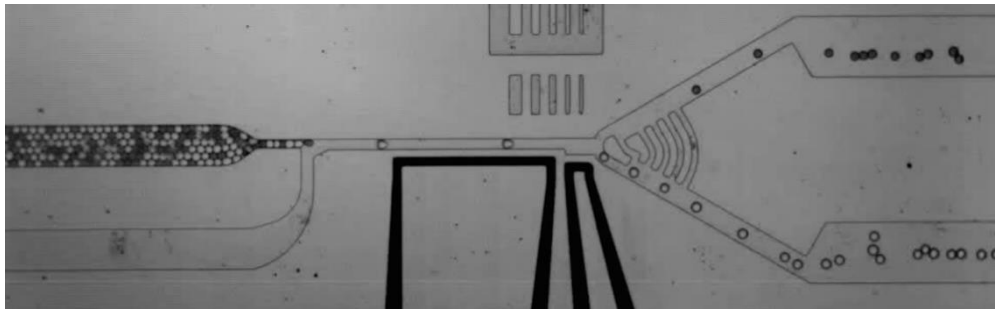
add



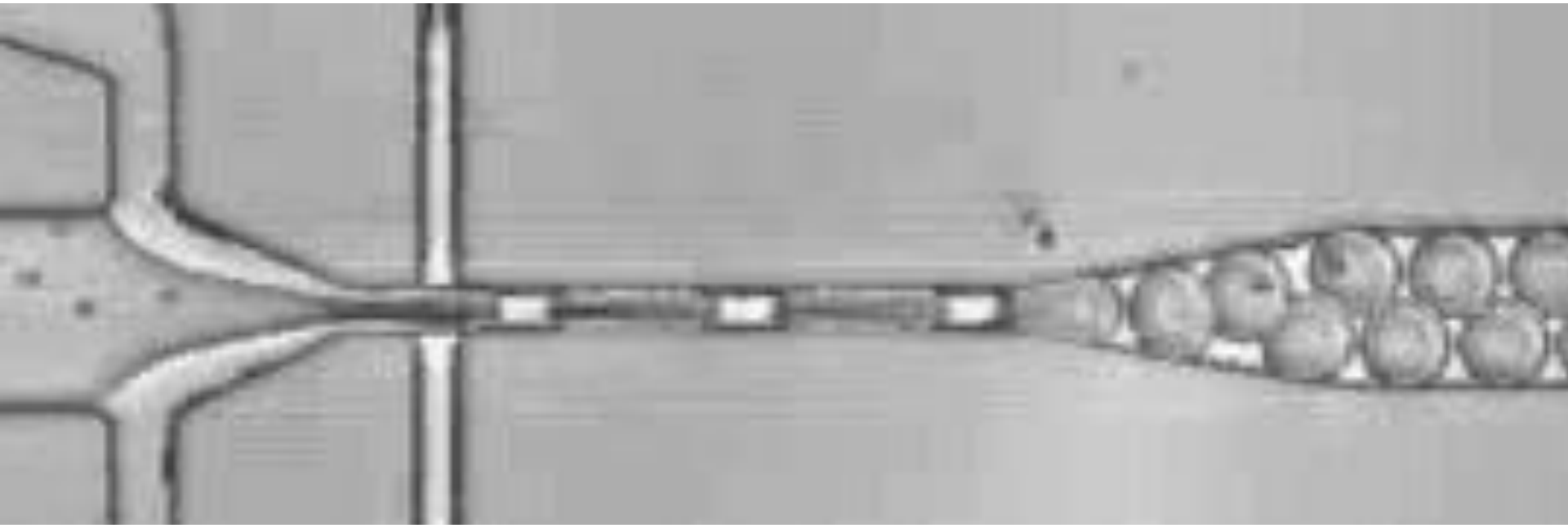
pico-inject



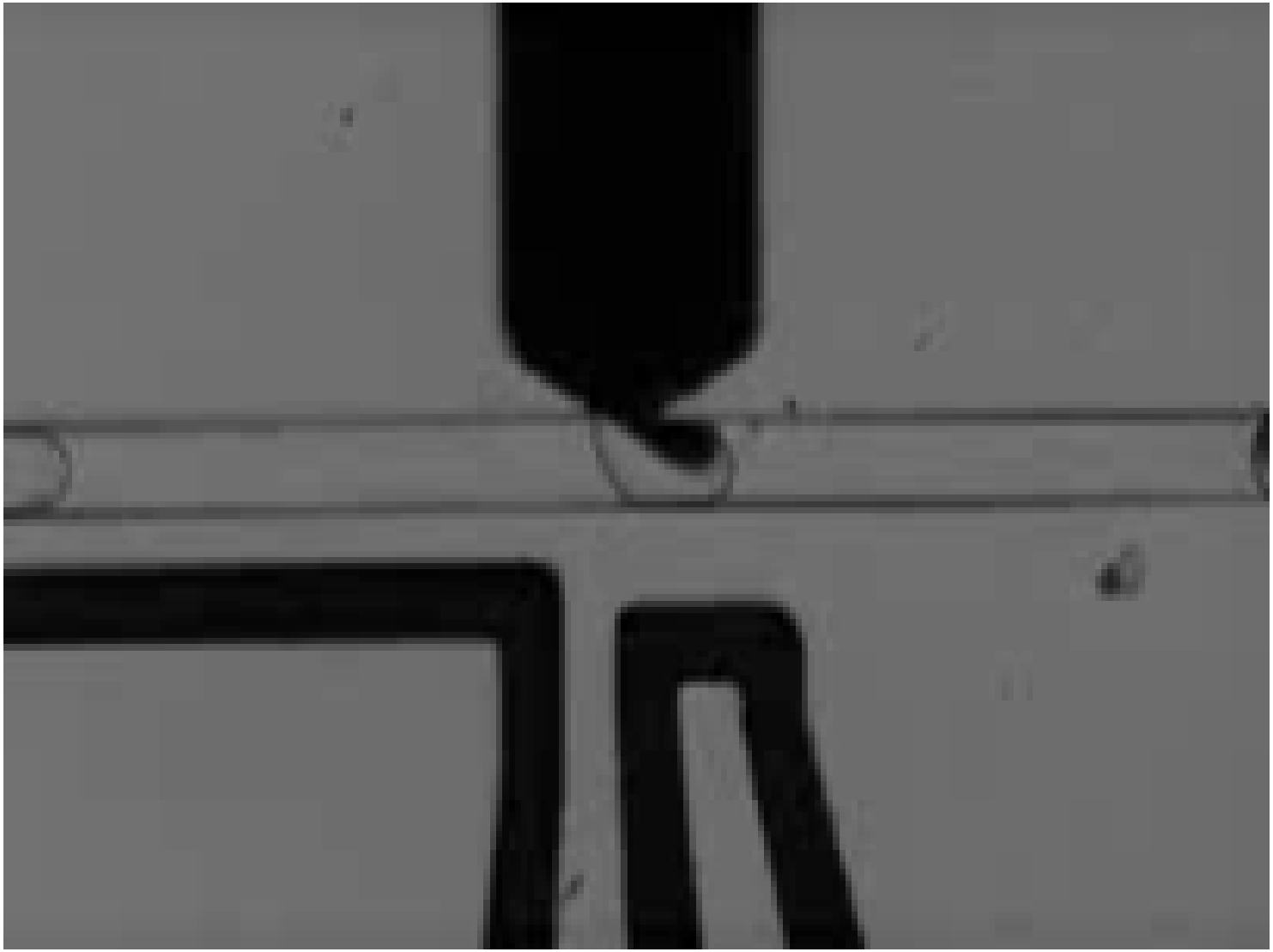
detect and sort



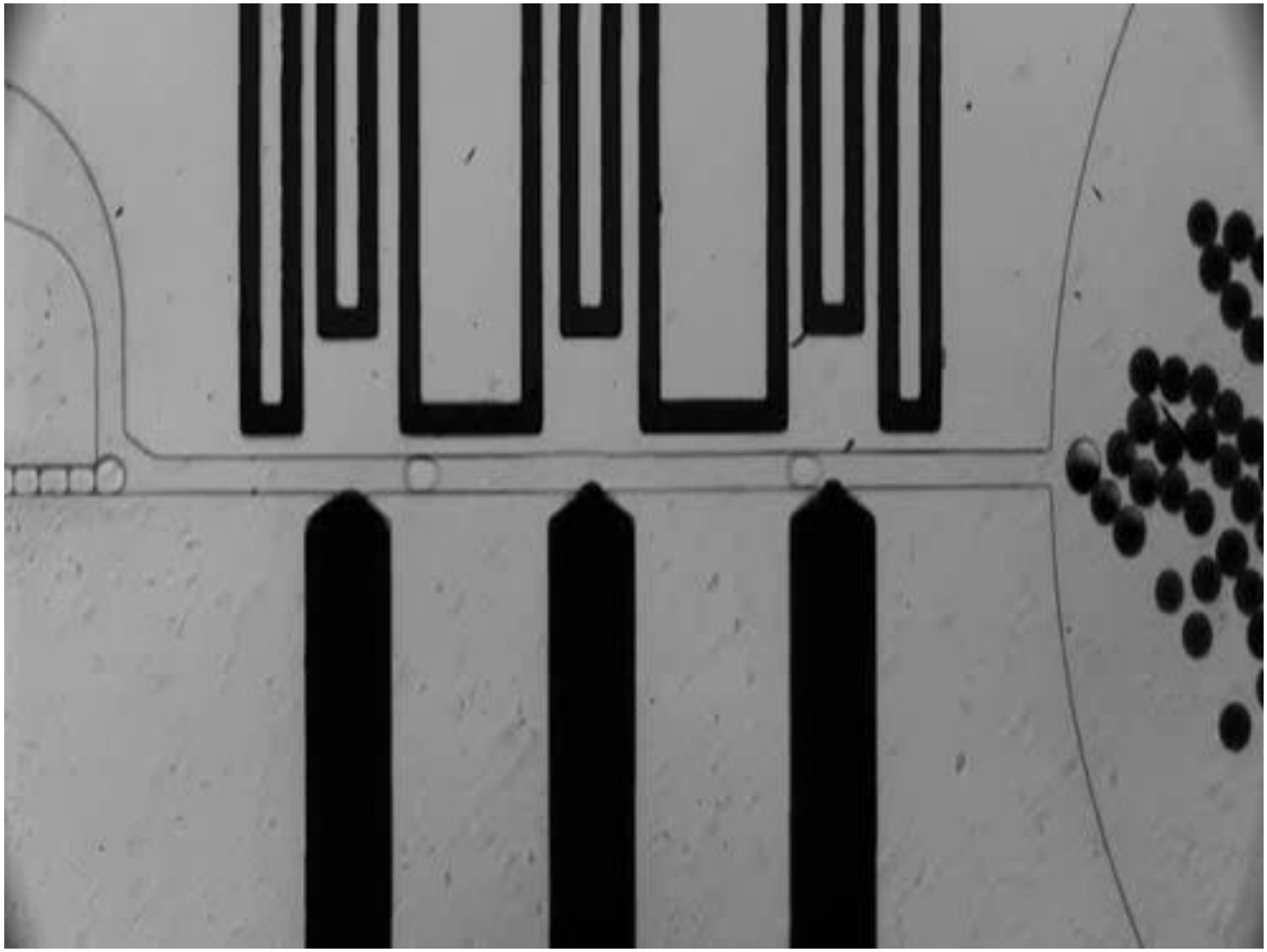
Lysis of Cells



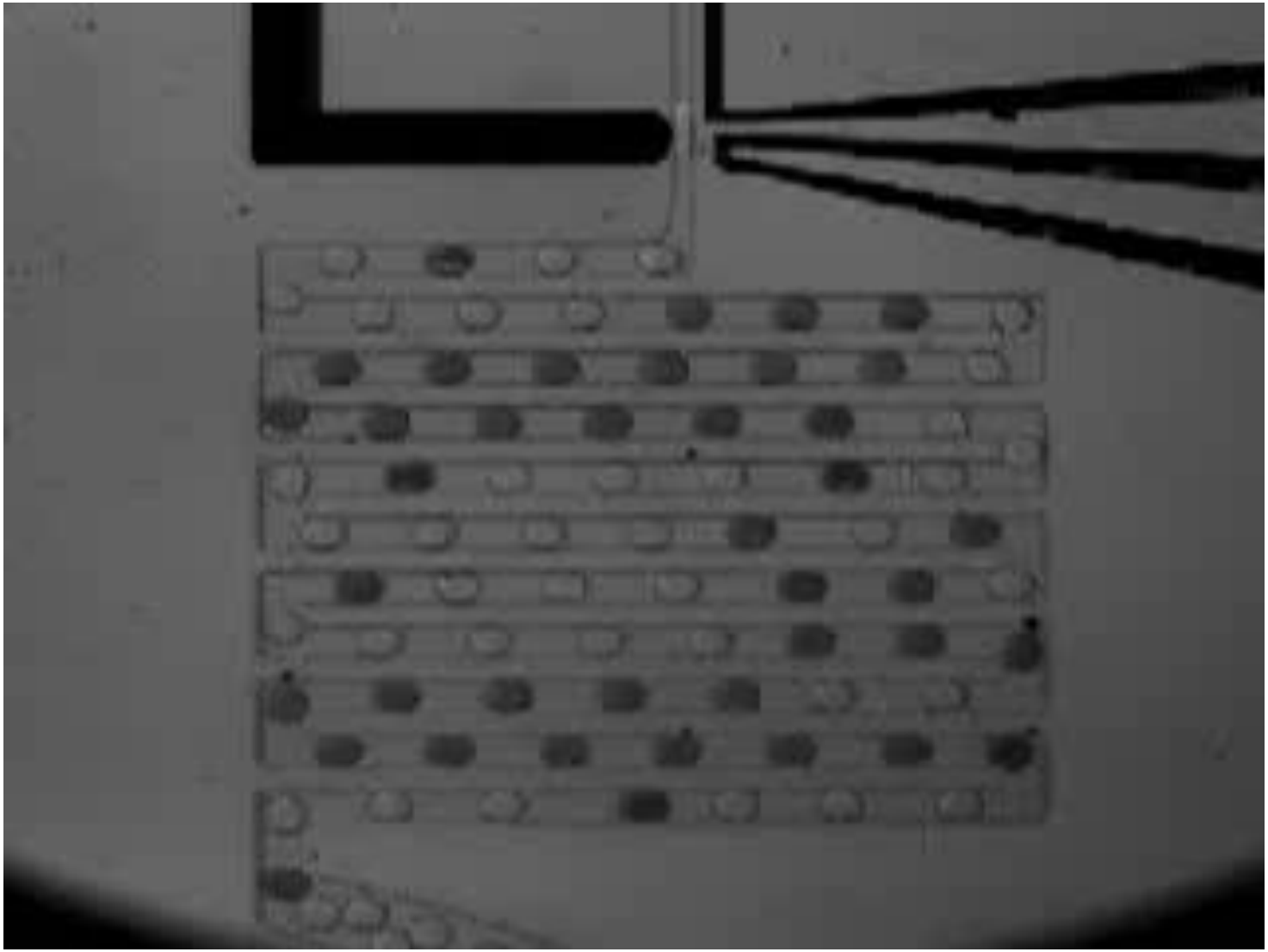
Pico-Injection



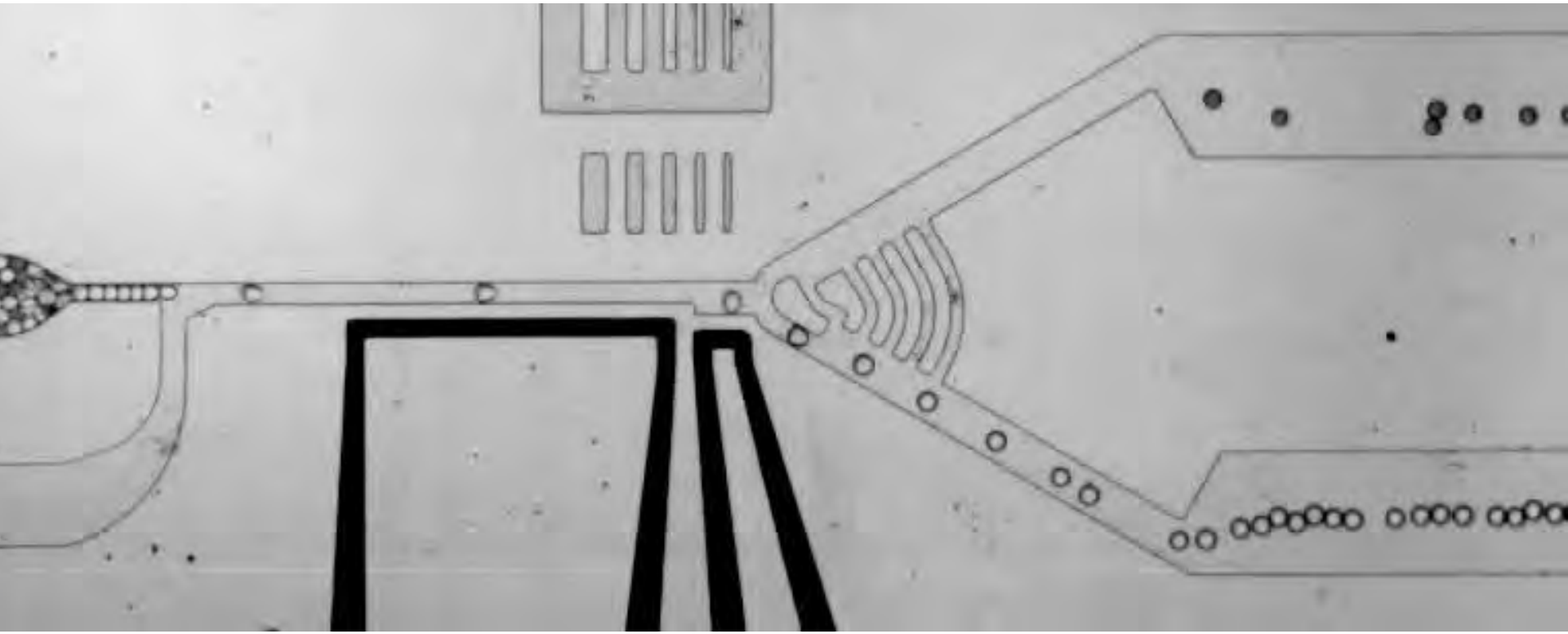
Multiple Pico-Injection



Selective Pico-Injection



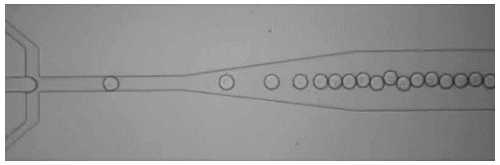
Droplet Sorting



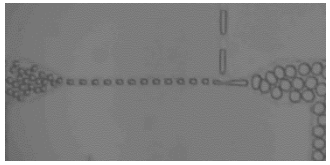
Microfluidic 3D Printing

Microfluidics

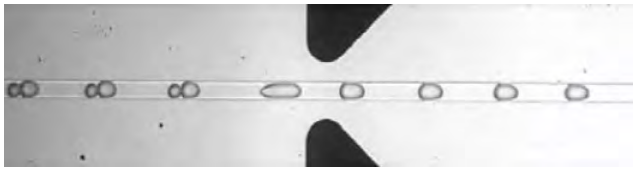
making



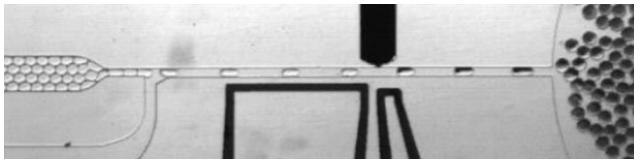
splitting



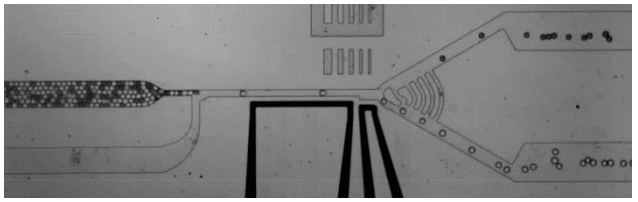
merging



pico-injecting

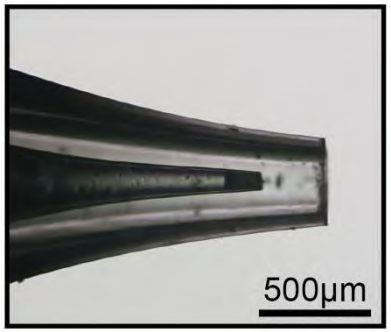


sorting

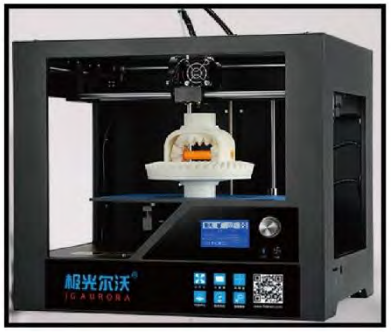


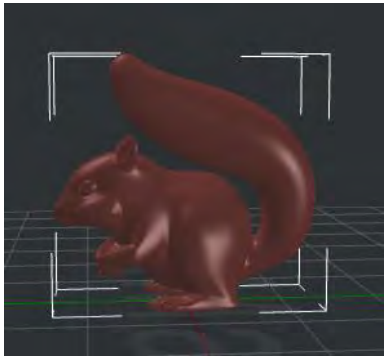
Microfluidic 3D Printing

Control of Droplet Structure

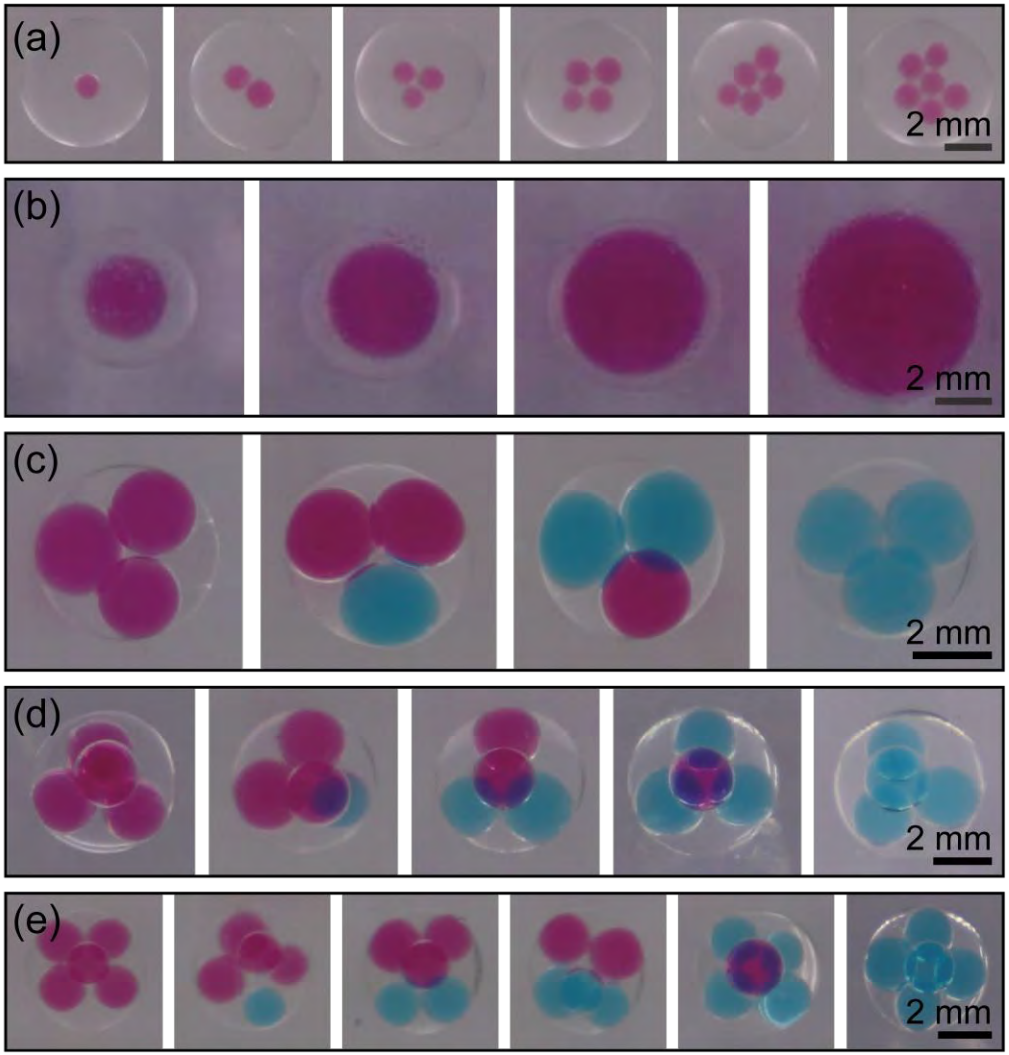


Control of Spatial Position



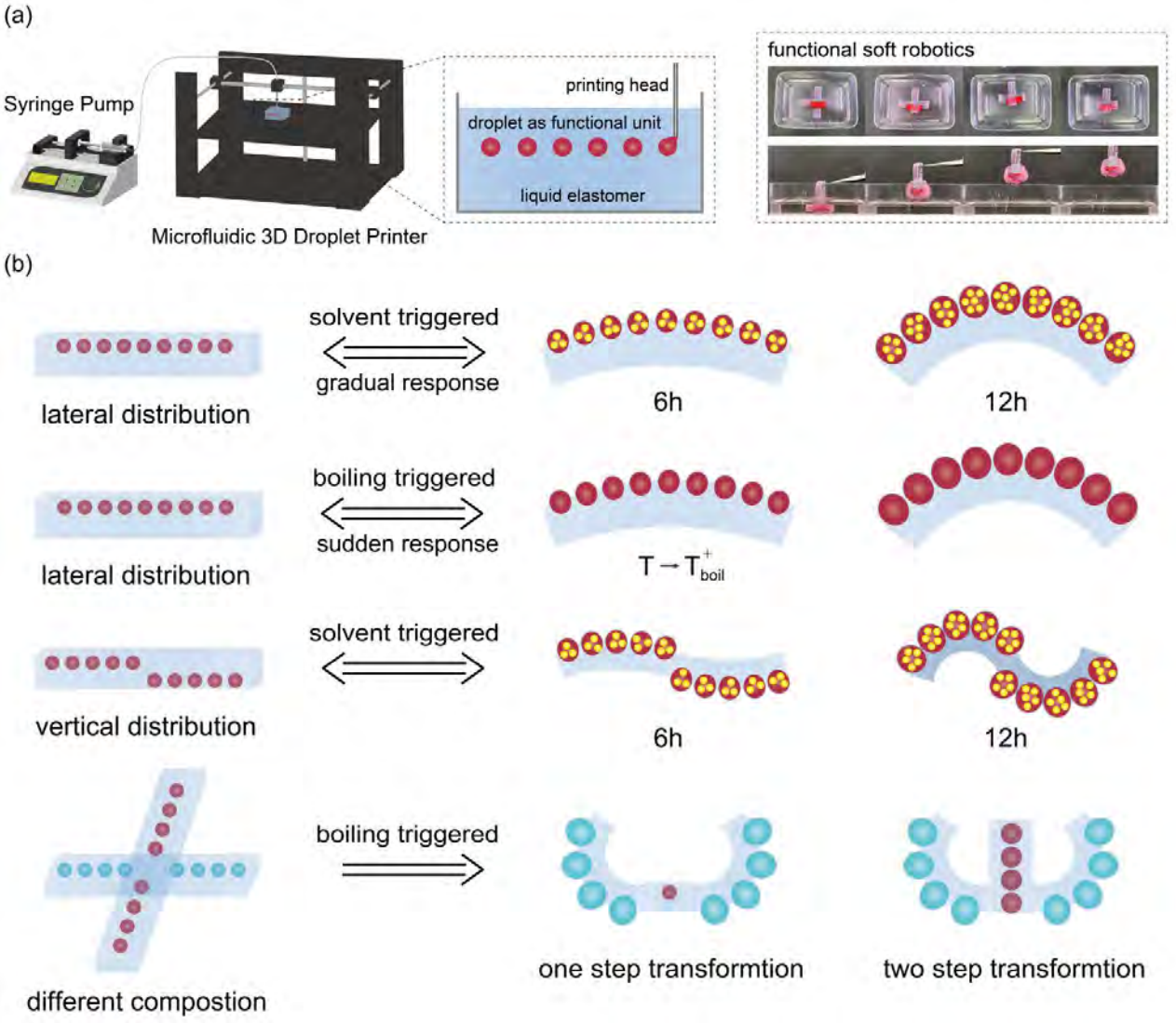


Microfluidic 3D Droplet Printing



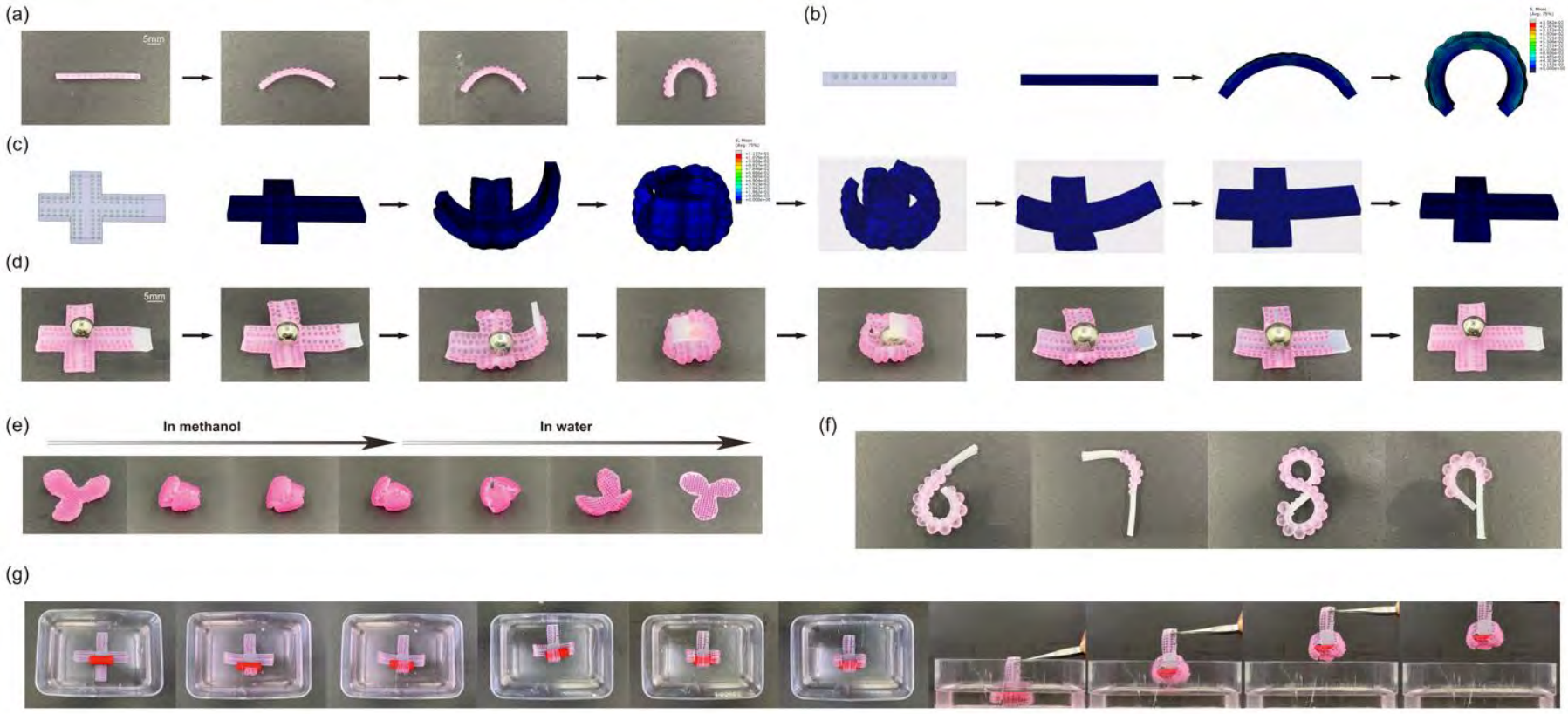
Emulsion Designer

Design of Smart Materials



Ordered Droplet Array

Materials by Microfluidic 3D Droplet Printing



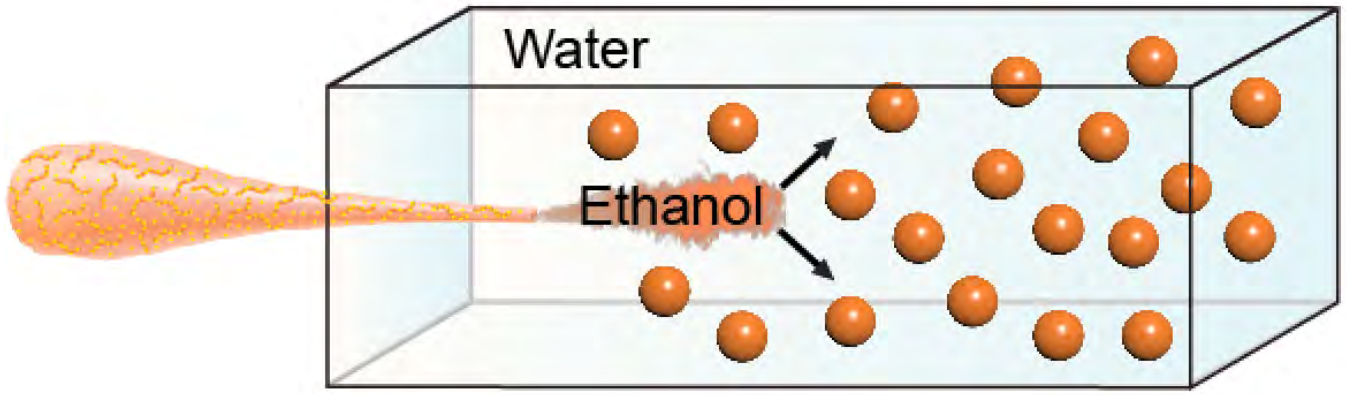
Biomimetic Design of Droplet Array for Smart Materials

Microfluidics

- **Engineer droplet morphology at microscale: Precise control**

- **Engineer particle morphology at nanoscale: Rapid mixing**

Rapid Mixing in Microfluidic Channel



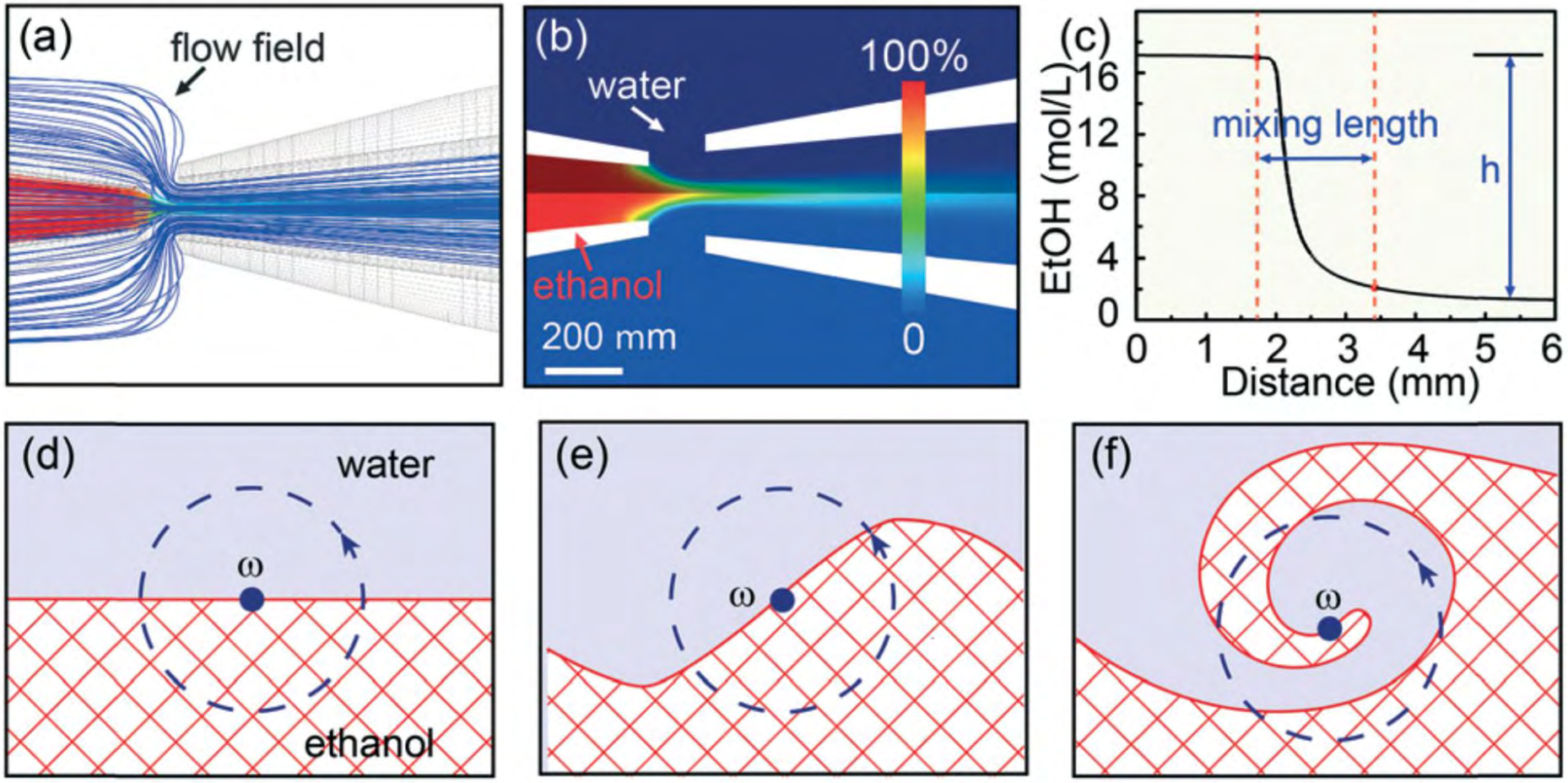
Nucleation and Growth

- Nucleation rate (strongly not linear, Key: homogeneous concentration)

$$dN/dt = K_N(c_P - c^*)^a, \quad a = 5 \sim 18$$

- Growth rate: $dl/dt = k_G(c_P - c^*)^b, \; b = 1 \sim 3$

Rapid Mixing in Microfluidic Channel

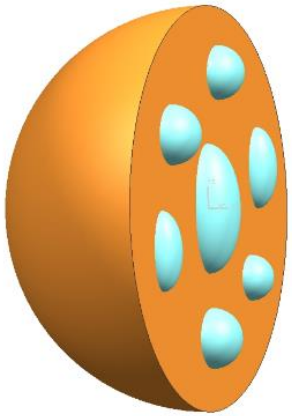


Solvent Mixing Time: ~10 ms

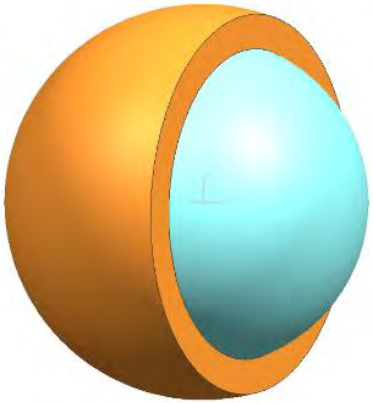
Particle Aggregation Time: ~30 ms

Morphology Control of Nanoparticles

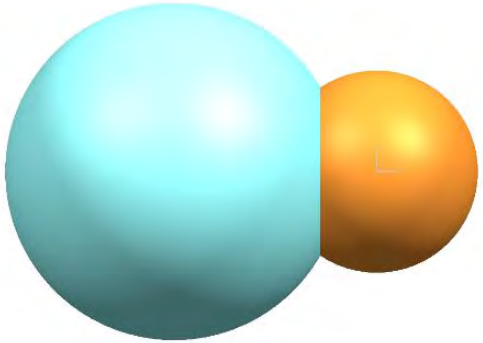
Four Morphologies of Binary Systems



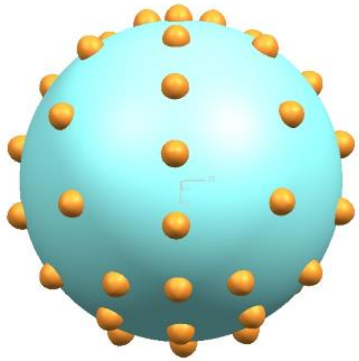
occluded



core-shell



dimer



aggregate

Energy Minimum

Spreading Coefficients $S_i = \gamma_{jk} - (\gamma_{ij} + \gamma_{ik})$

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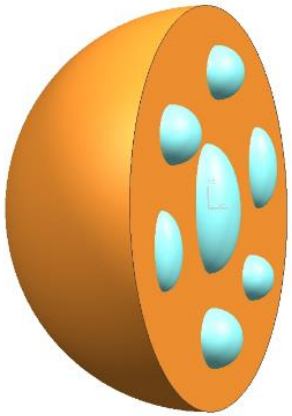
Four Morphologies of Binary Systems



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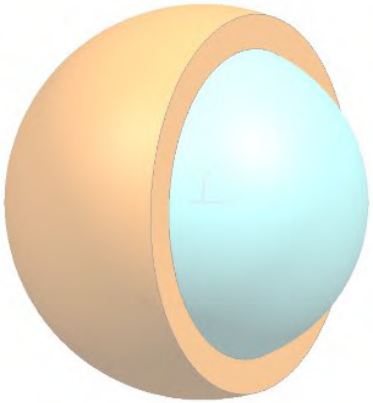
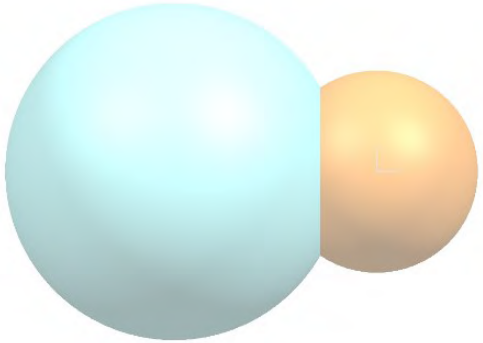
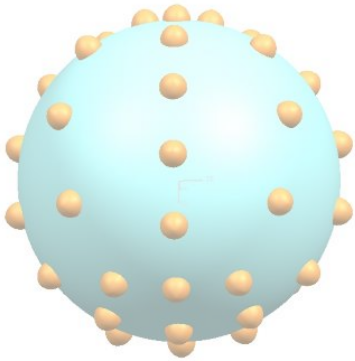


core-shell



dimer



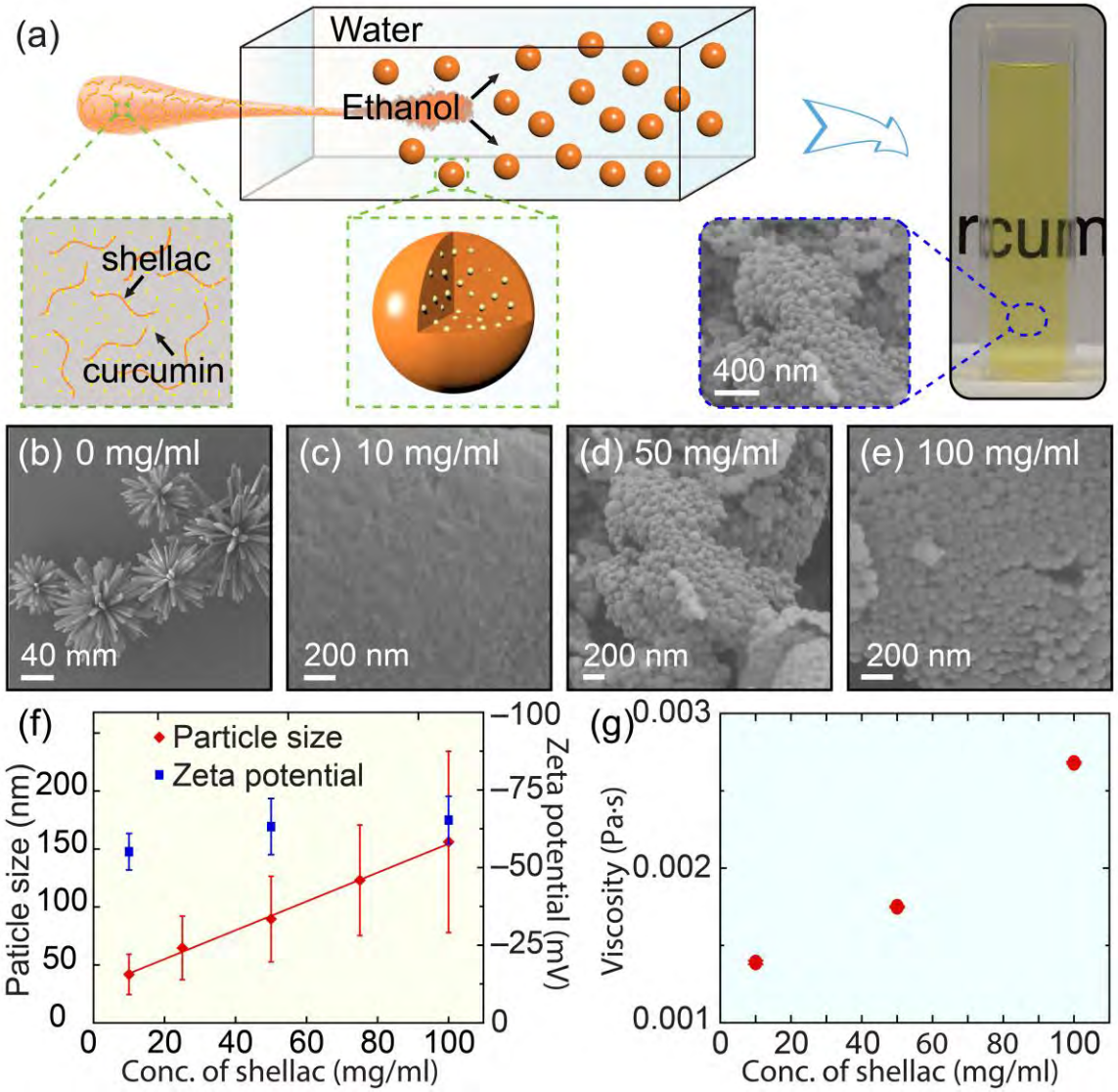
aggregate

Energy Minimum

Spreading Coefficients $S_i = \gamma_{jk} - (\gamma_{ij} + \gamma_{ik})$

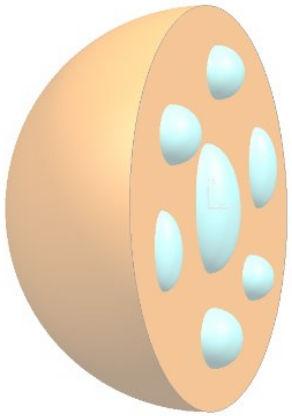
Natural Colorants-Loaded Nanoparticles

Low Water Solubility, Low Stability



Morphology Control of Nanoparticles

Four Morphologies of Binary Systems



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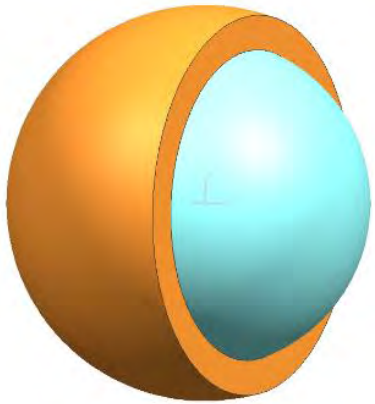
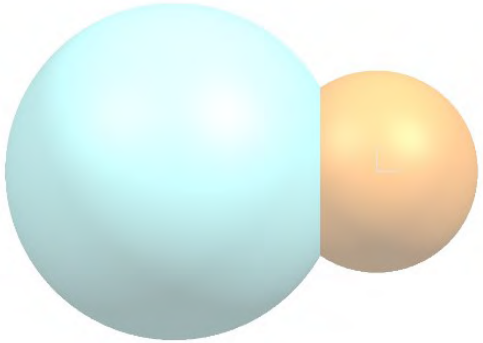
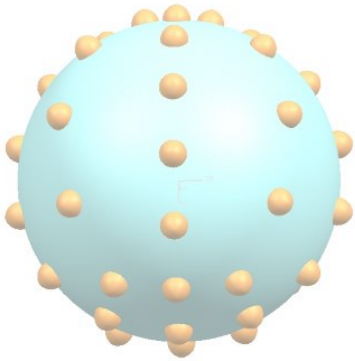


core-shell



dimer



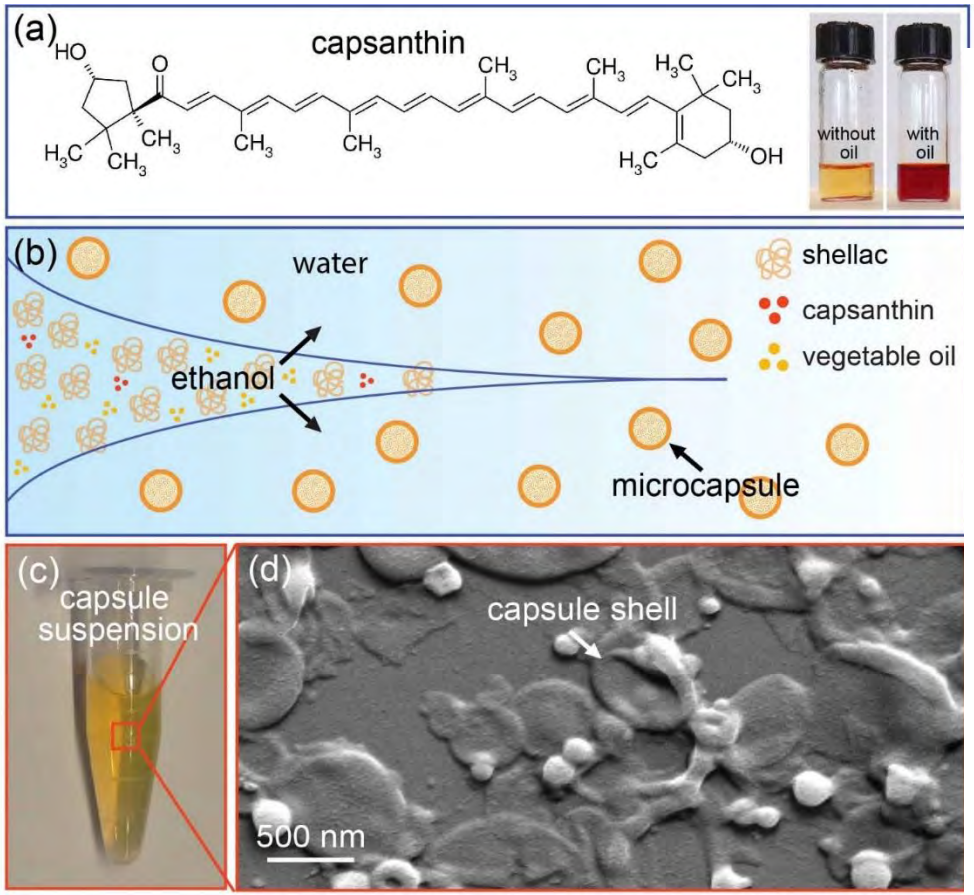
aggregate

Energy Minimum

Spreading Coefficients $S_i = \gamma_{jk} - (\gamma_{ij} + \gamma_{ik})$

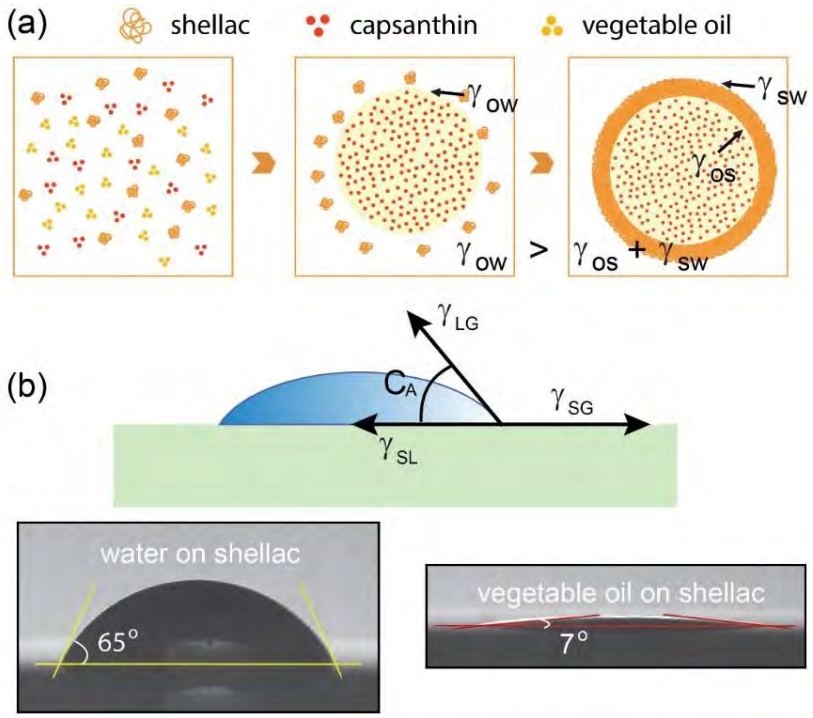
Core-Shell Microcapsules

Oil-Core Microcapsules



Encapsulation Efficiency: 98%

Energy Minimum



(c) γ_{ow} (22 mN/m) > γ_{os} (4 mN/m) + γ_{sw} (6 mN/m)

	γ_{SG}	γ_{LG}	C_A	γ_{SL}
water	36 mN/m	72 mN/m	65°	6 mN/m
vegetable oil	36 mN/m	32 mN/m	7°	4 mN/m

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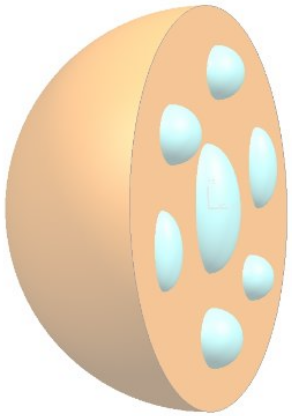

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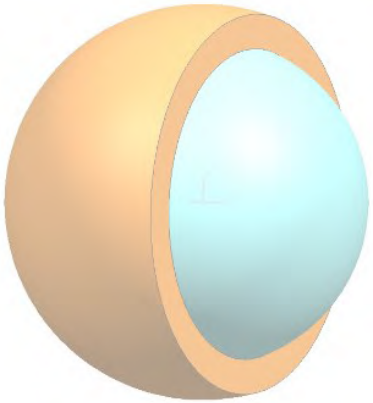
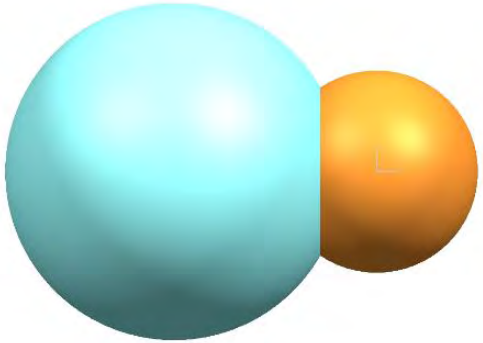
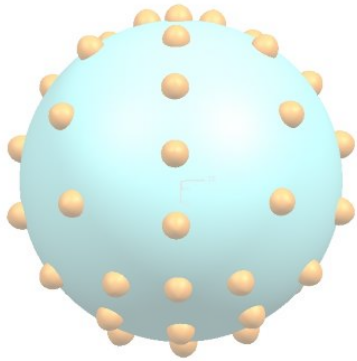


core-shell



dimer

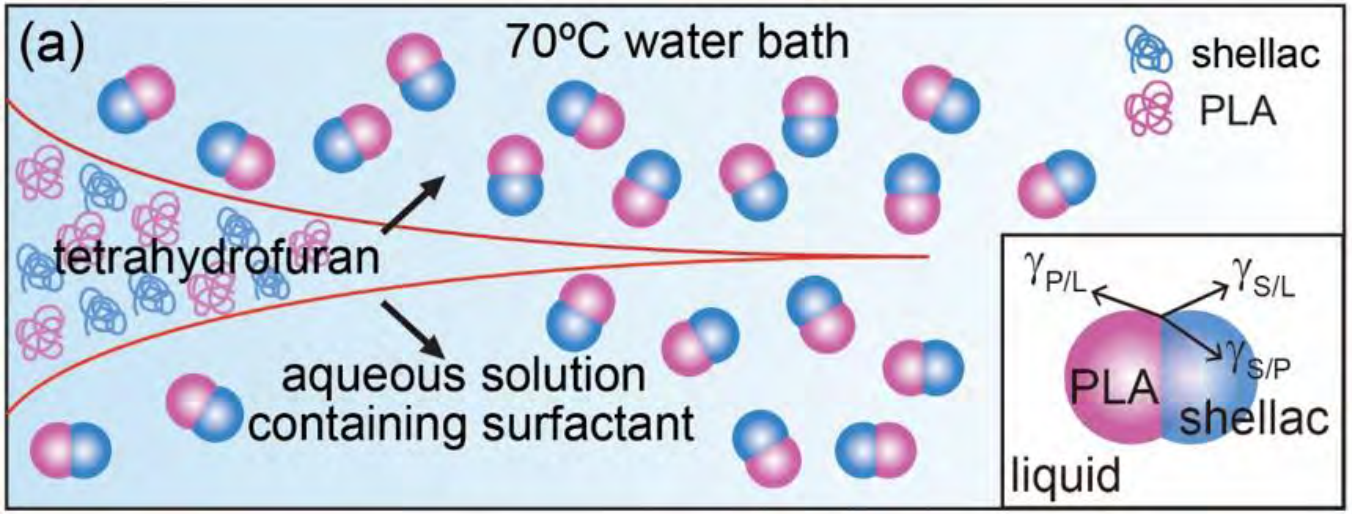


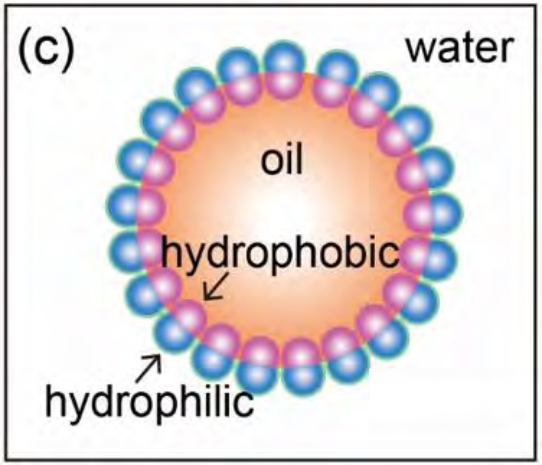
aggregate

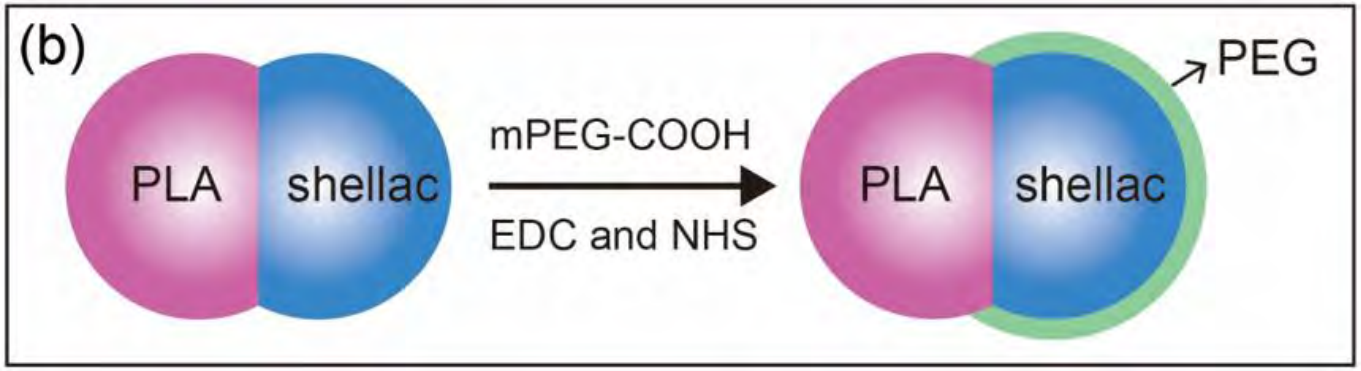
Energy Minimum

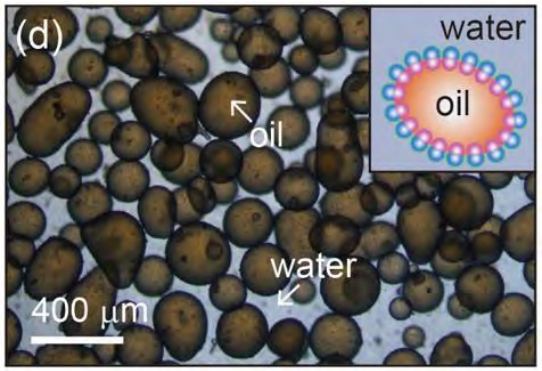
Spreading Coefficients $S_i = \gamma_{jk} - (\gamma_{ij} + \gamma_{ik})$

Dimer Particles as Colloidal Surfactants





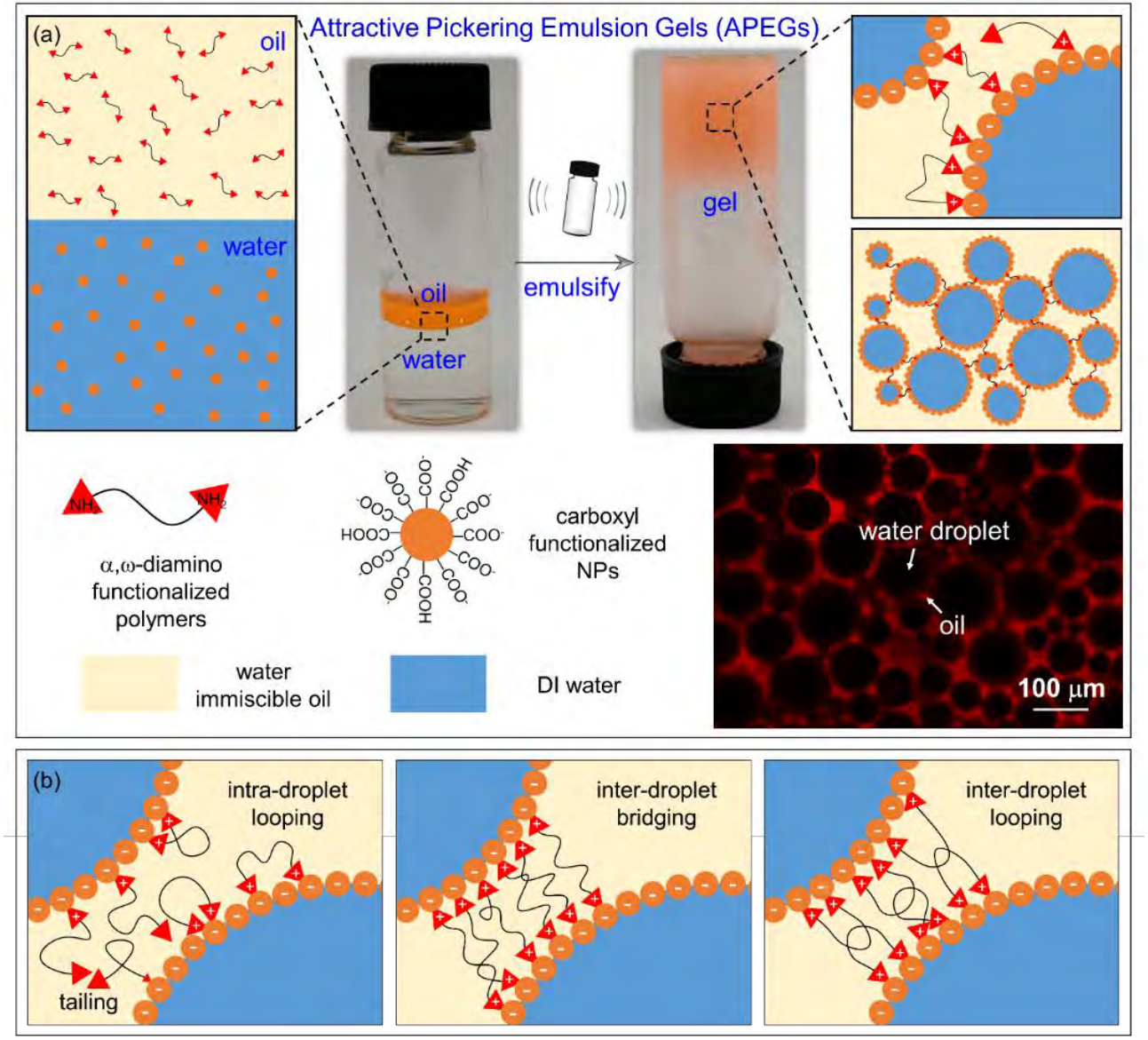




Control of Interfacial Curvature

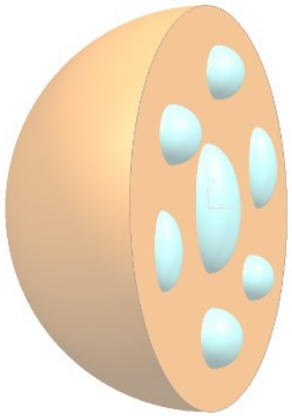
Pickering Emulsions

Attractive Pickering Emulsion Gels (APEGs)



Morphology Control of Nanoparticles

Four Morphologies of Binary Systems



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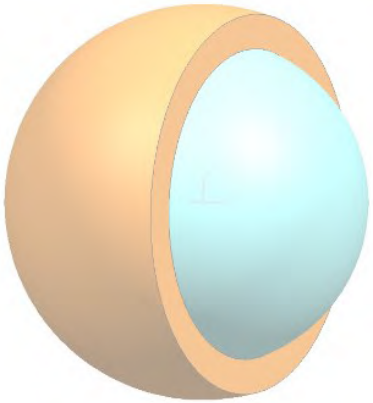
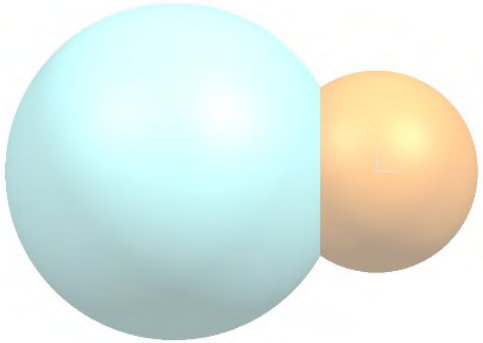


core-shell



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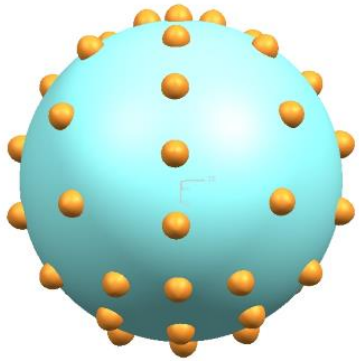
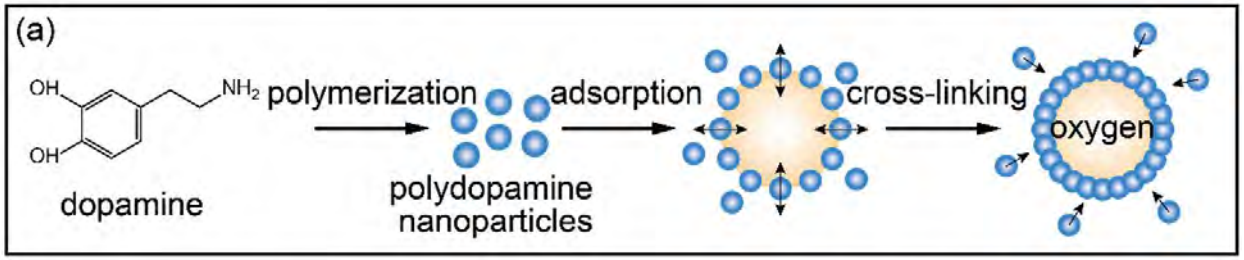


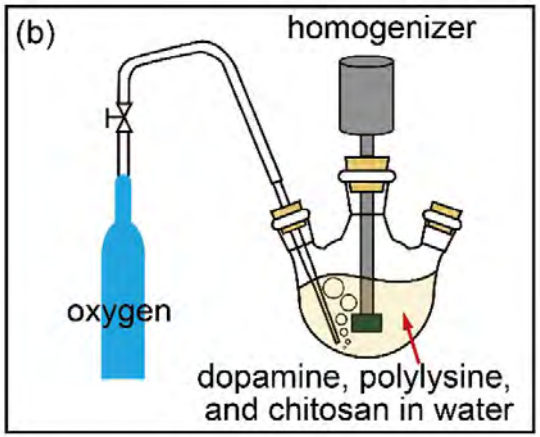
aggregate

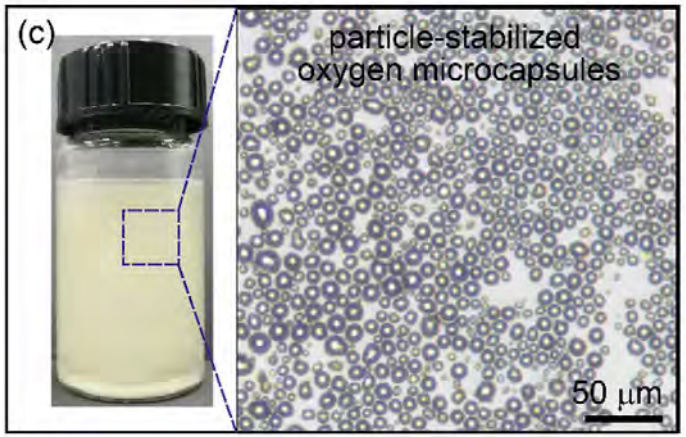
Energy Minimum

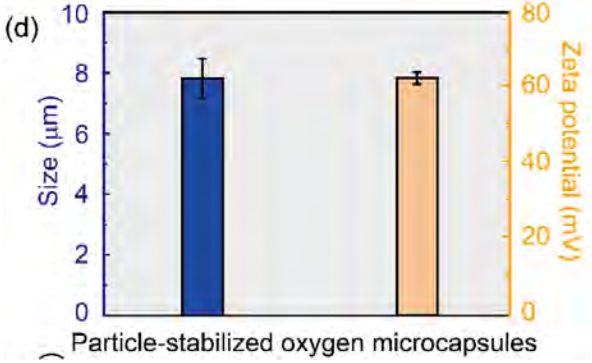
Spreading Coefficients $S_i = \gamma_{jk} - (\gamma_{ij} + \gamma_{ik})$

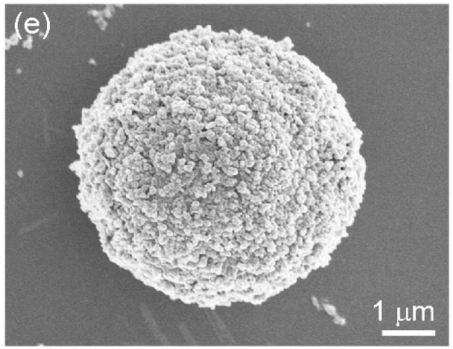
Nanoparticle-Stabilized Oxygen Microcapsules

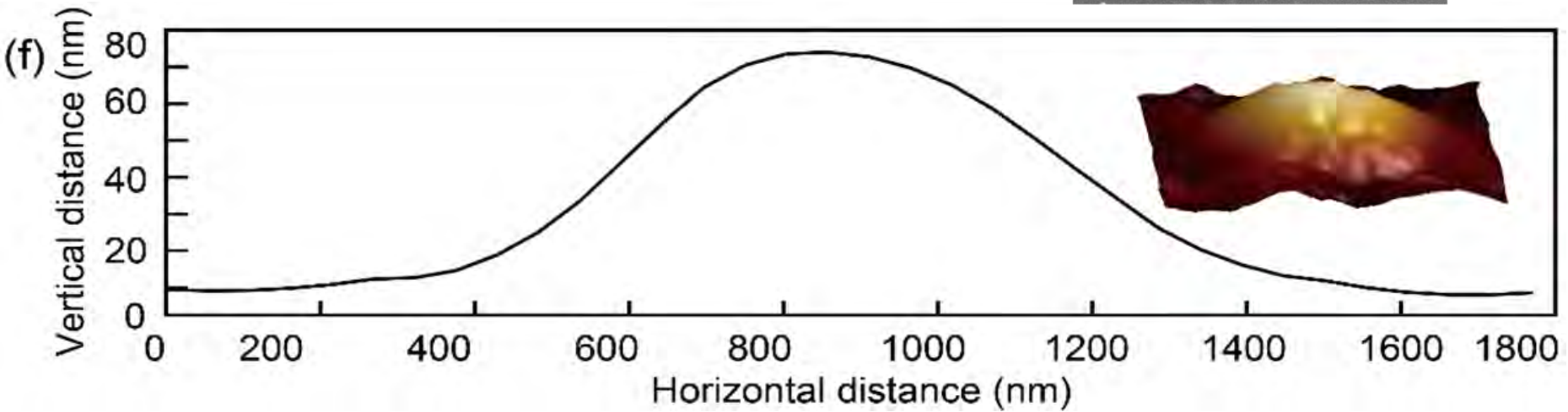






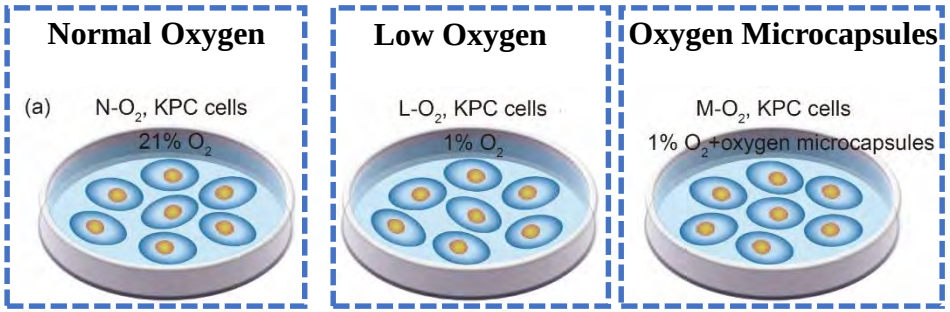


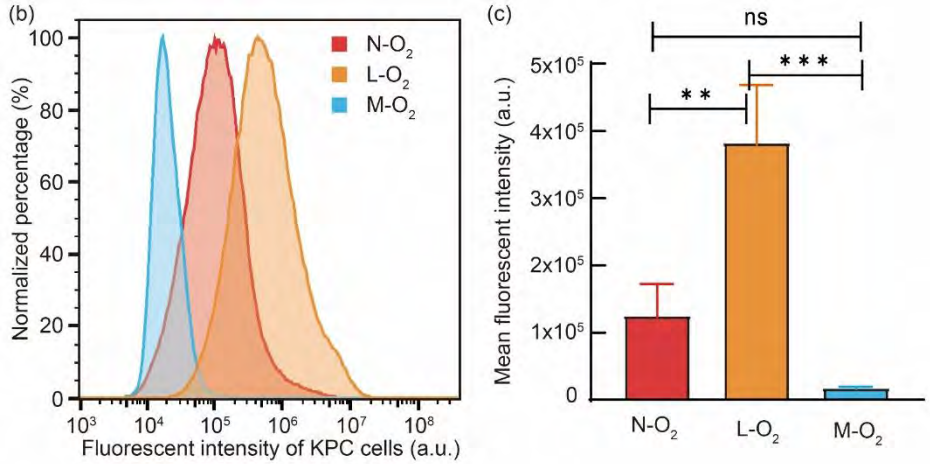




Application of Oxygen Microcapsules

Change hypoxic tumor microenvironment

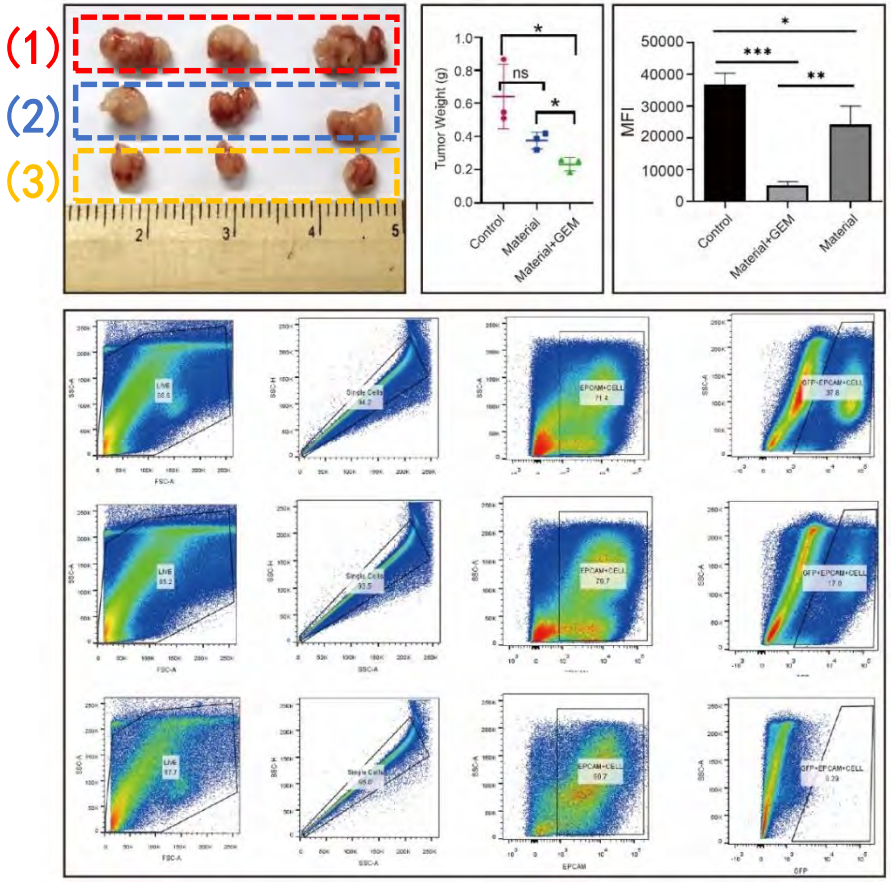




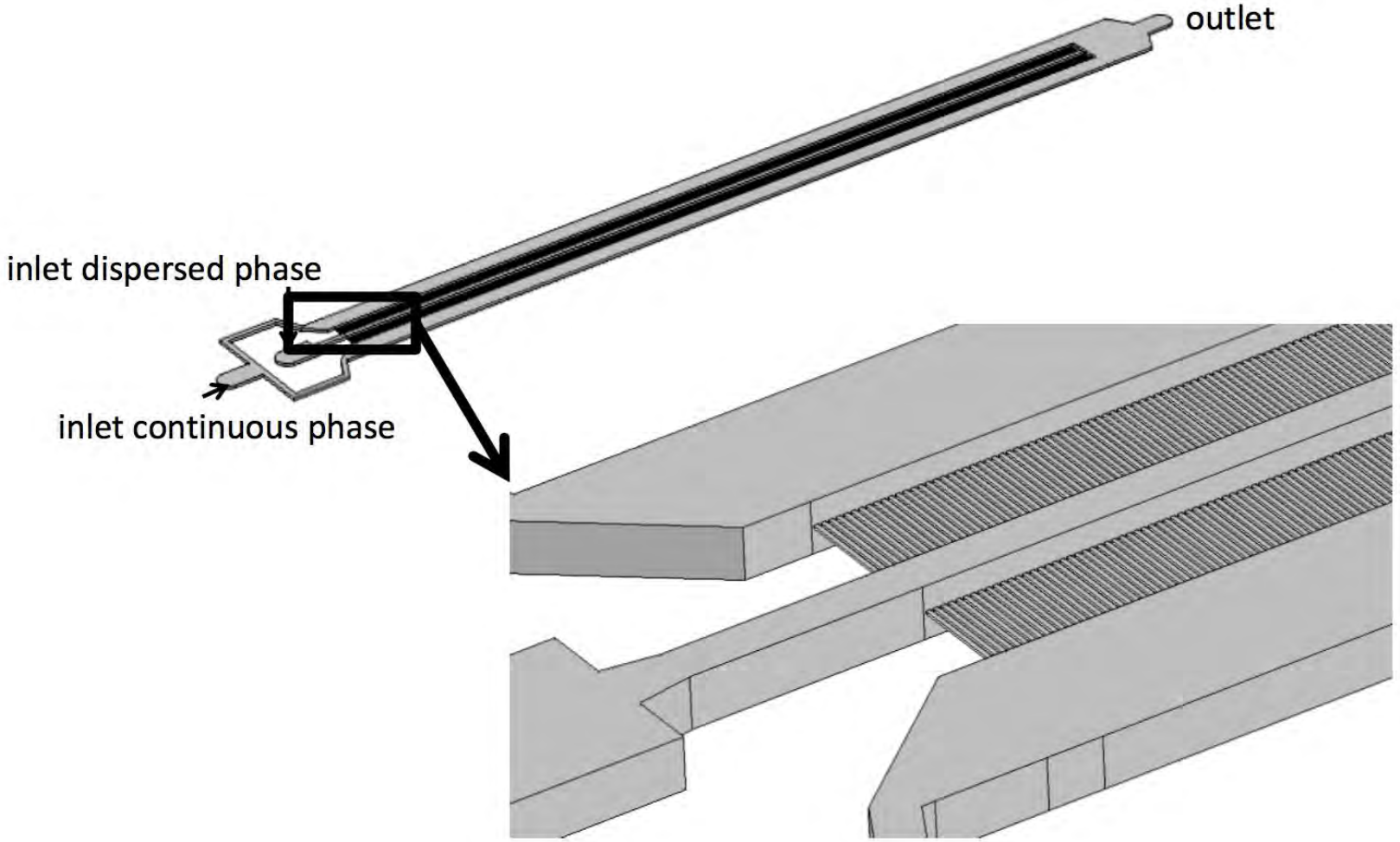
In $M\text{-}O_2$ group, KPC cells show the lowest fluorescent intensity

Synergetic Cancer Therapy

(1) Control; (2) Oxygen Microcapsules; (3) Oxygen Microcapsules+Gemcitabine

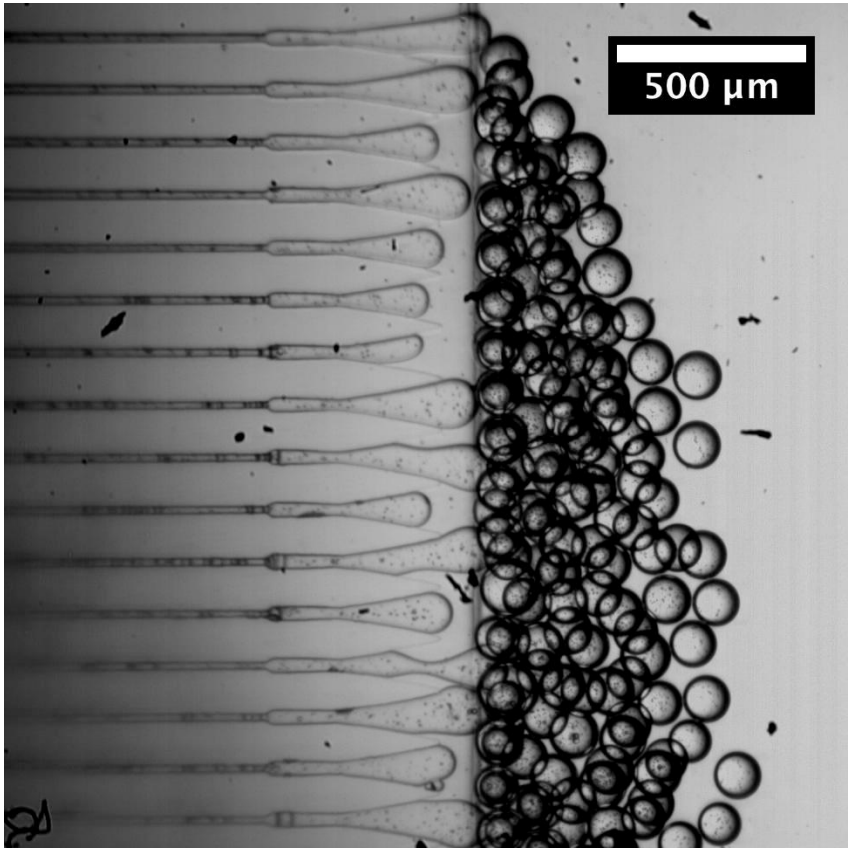


Step Emulsification

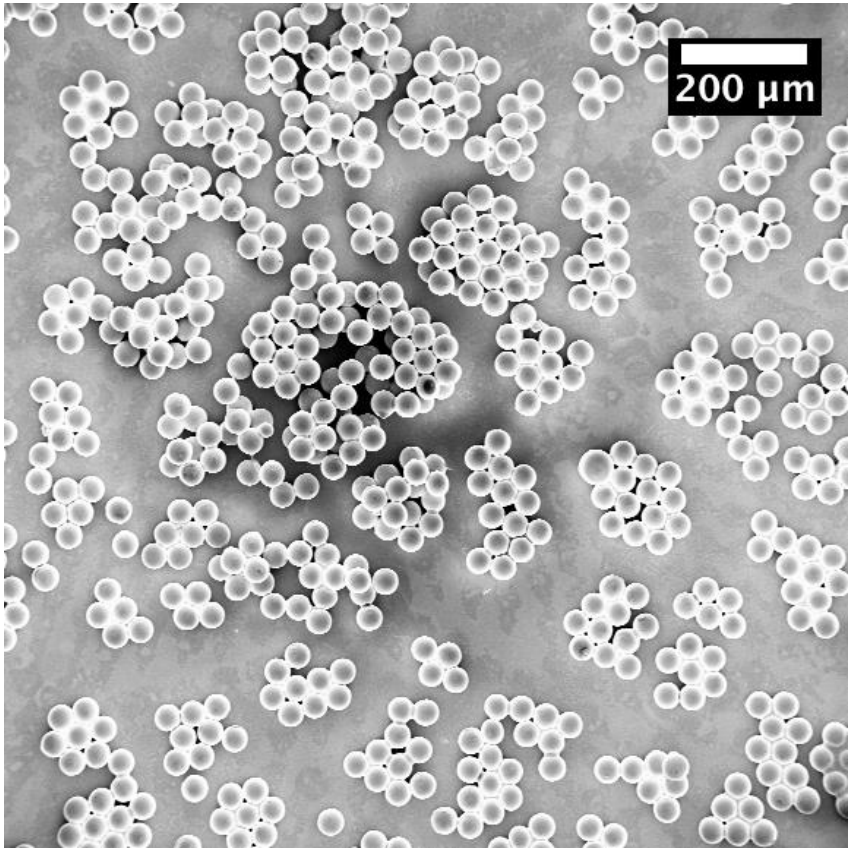


Scale-Up of Step Emulsification

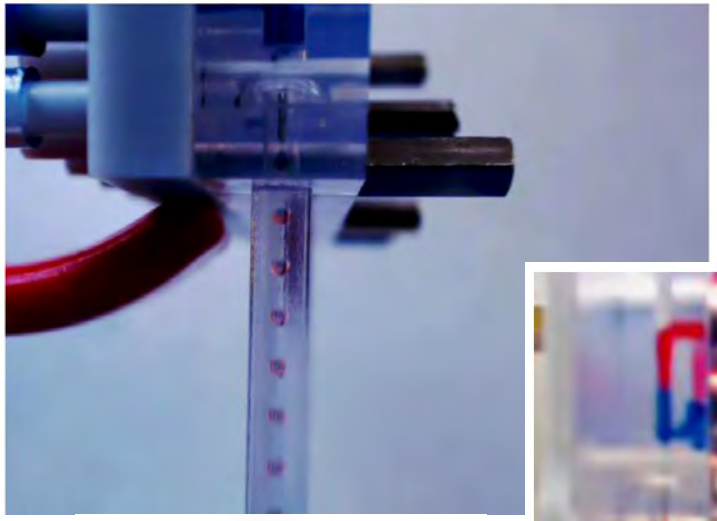
parallelization

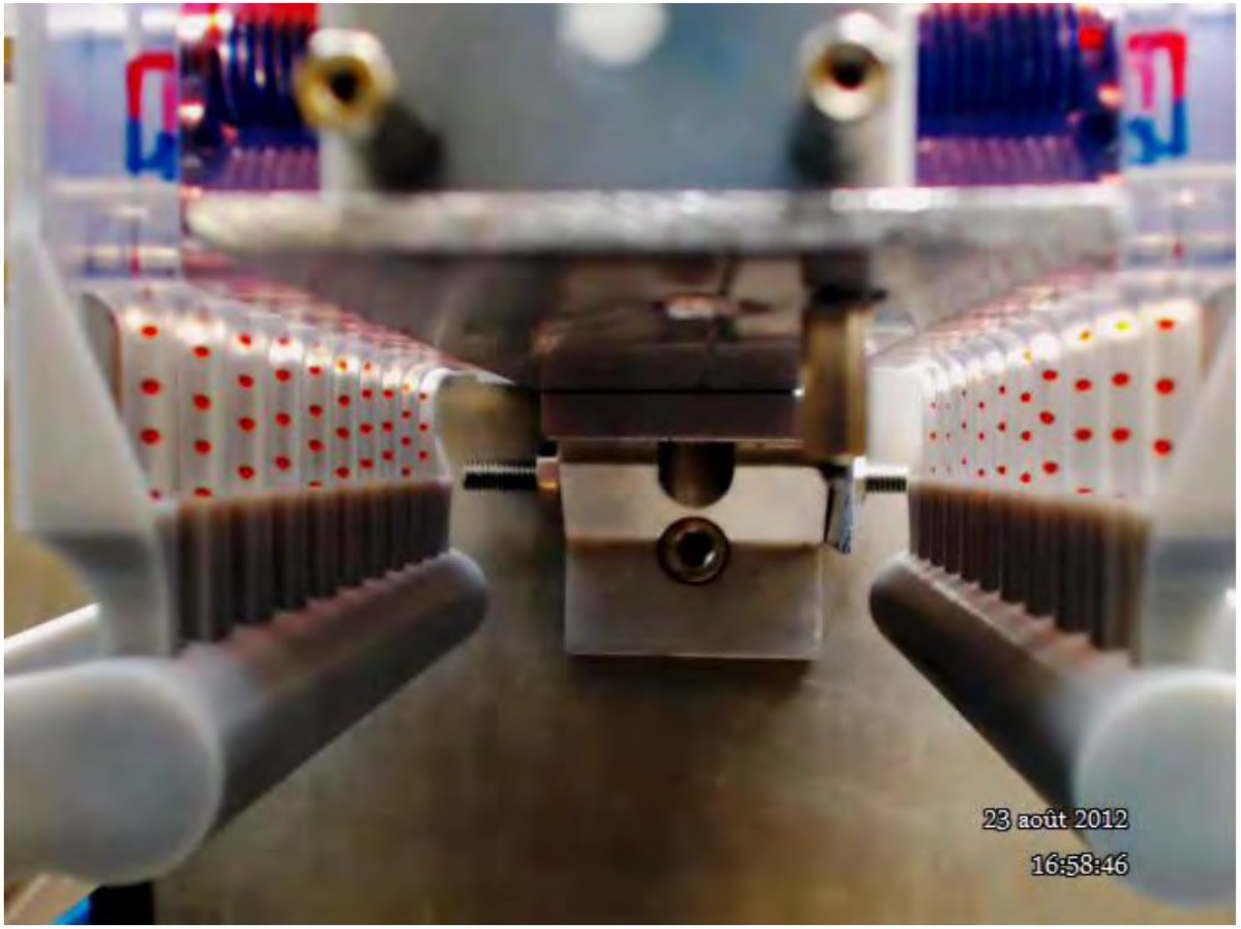


uniform size

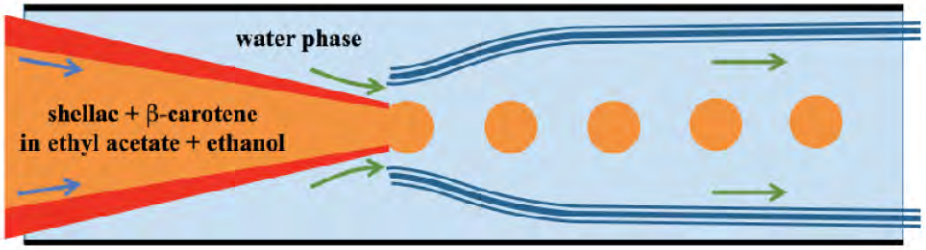


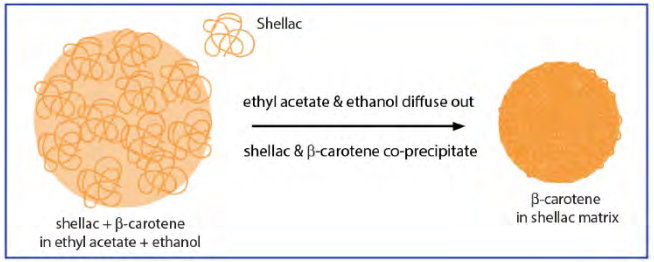
Application of Microfluidic Technology

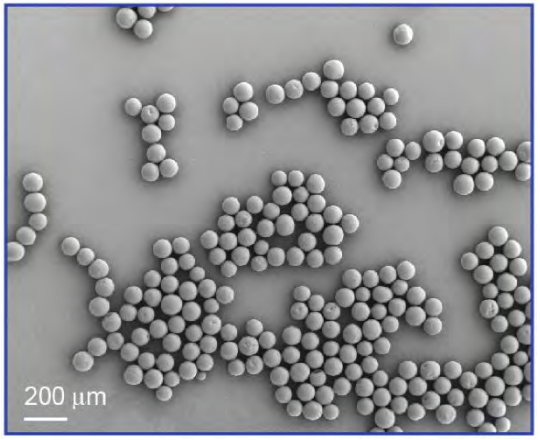


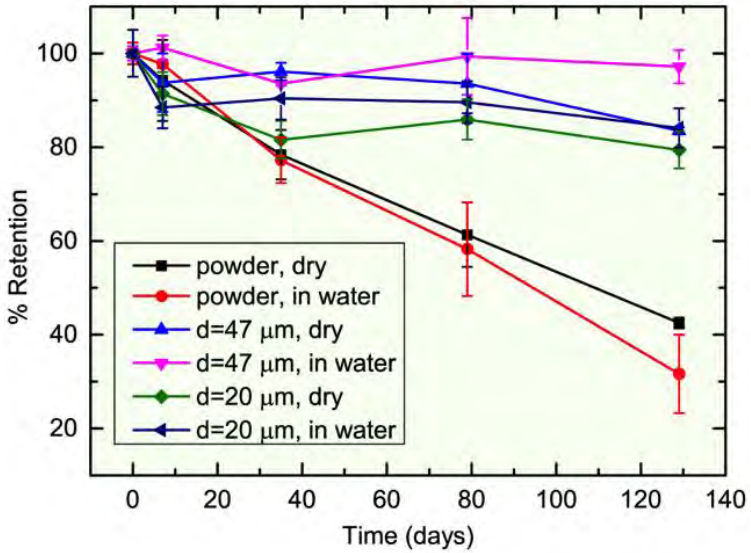


Beta-Carotene: Improved Stability



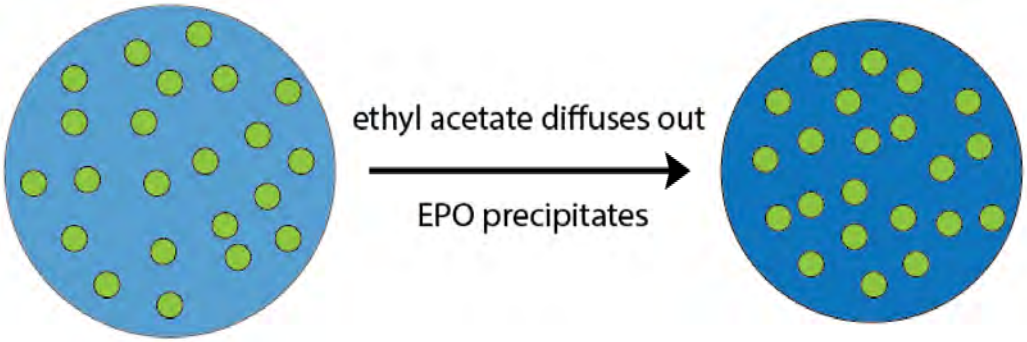


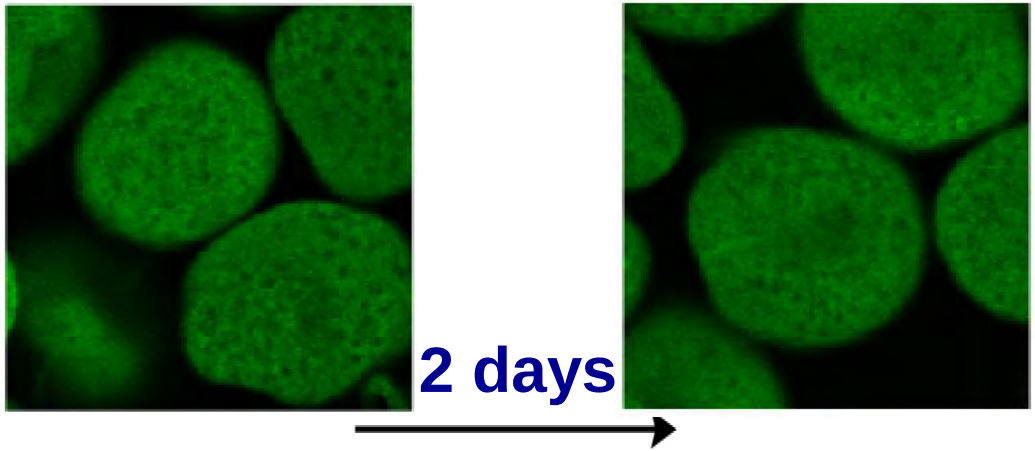




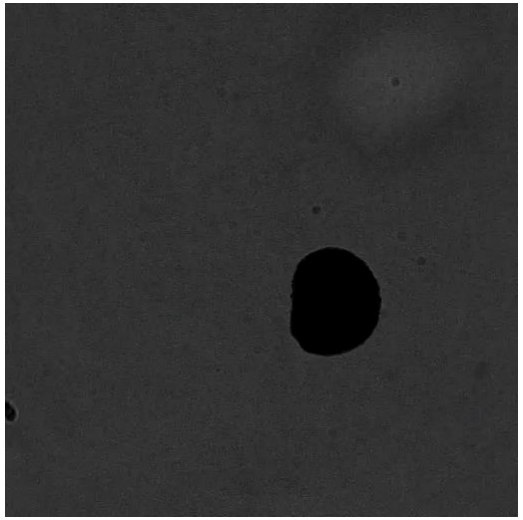
Caffeine: Controlled Release

BASF
The Chemical Company

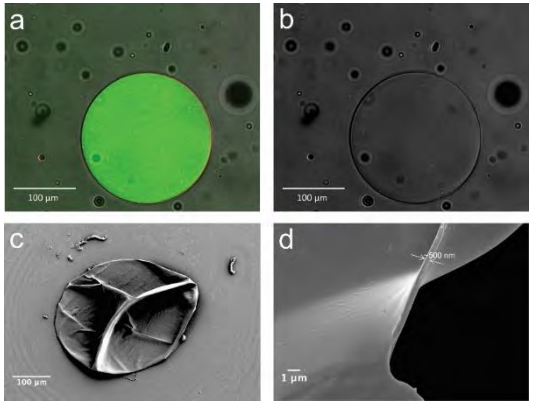


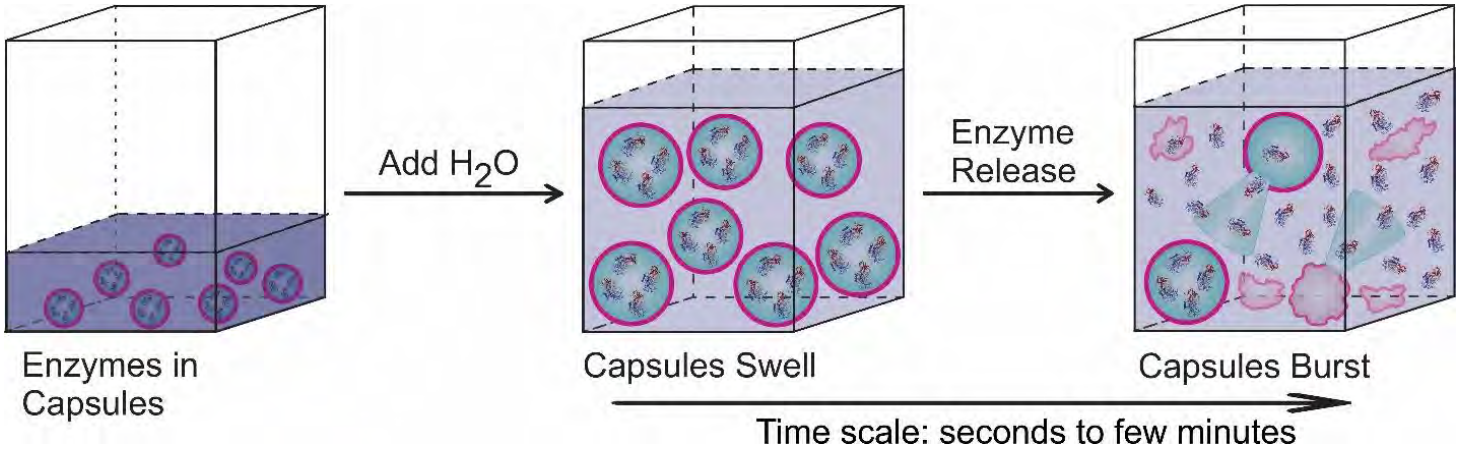


pH=4



Enzyme: Controlled Release

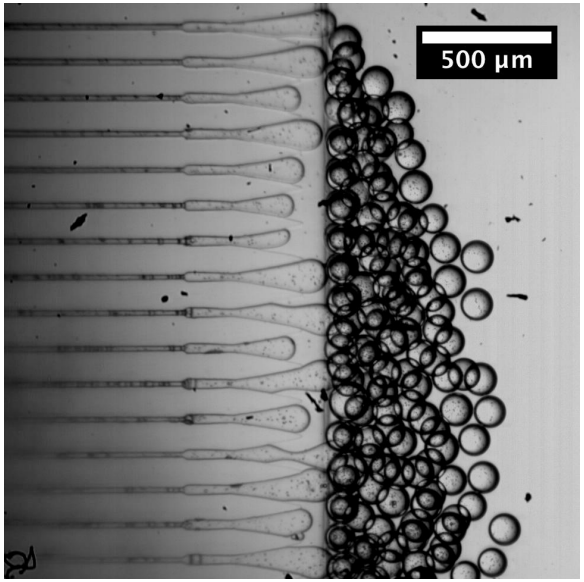


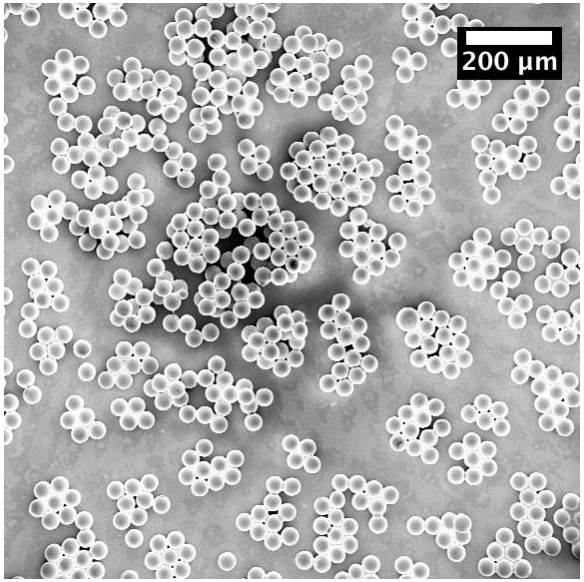


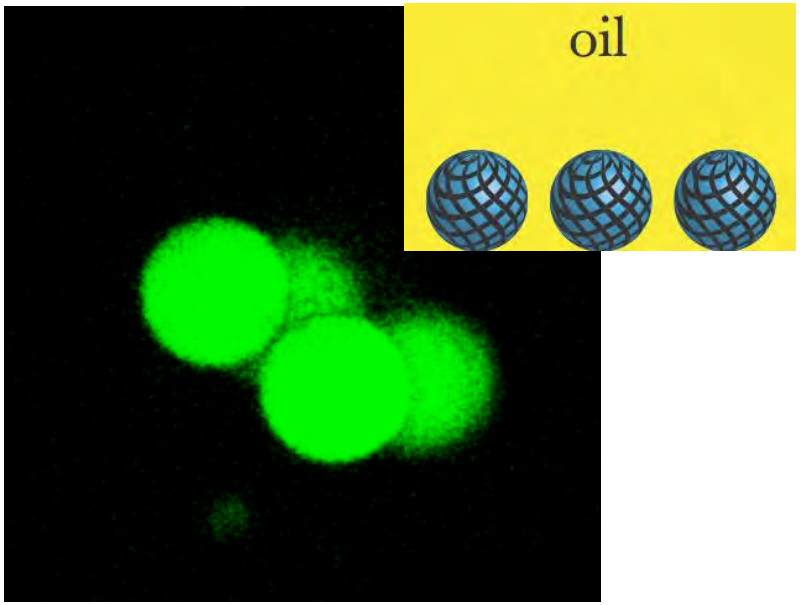
Goal: Improve the stability of enzyme during storage and release it when doing laundry.

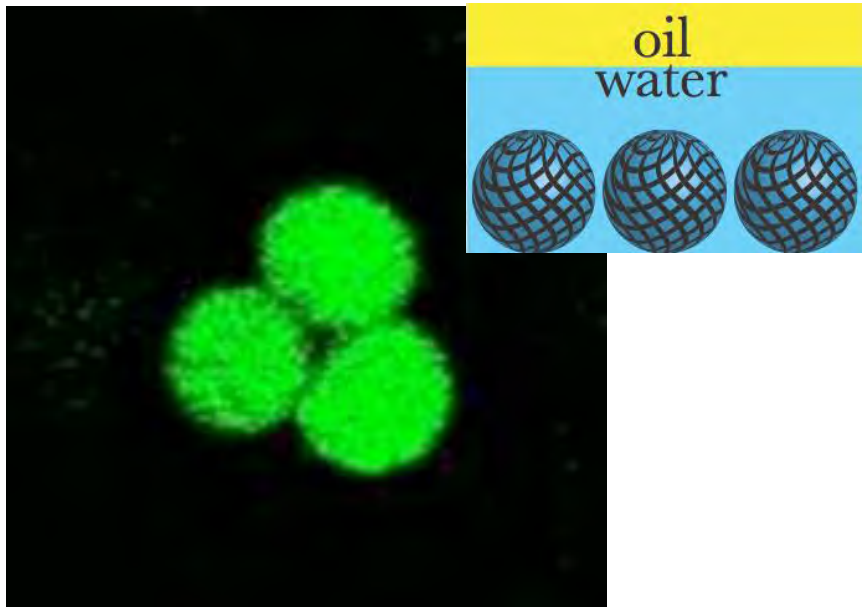
Bio Diesel: Target Release

TOTAL

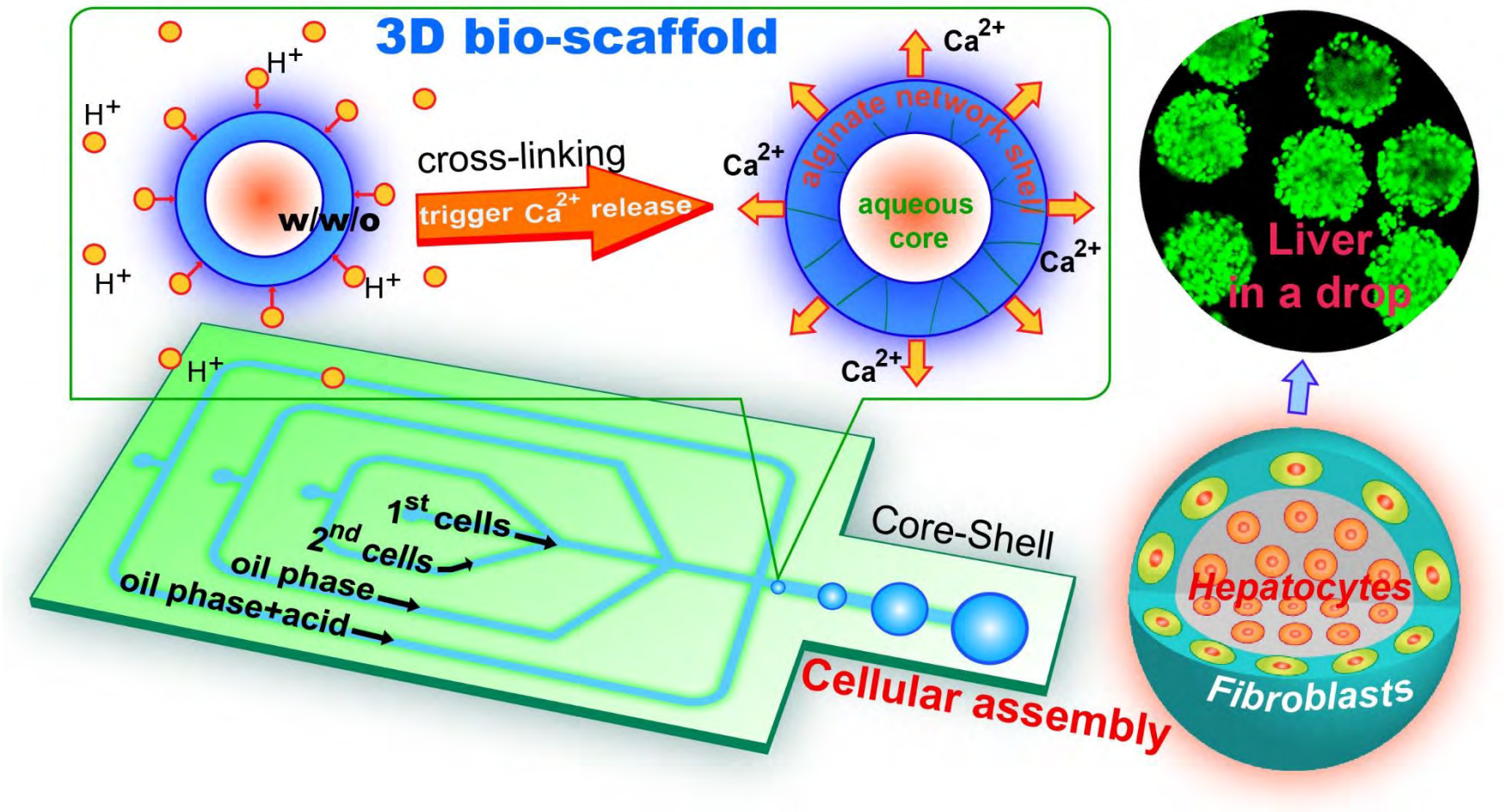






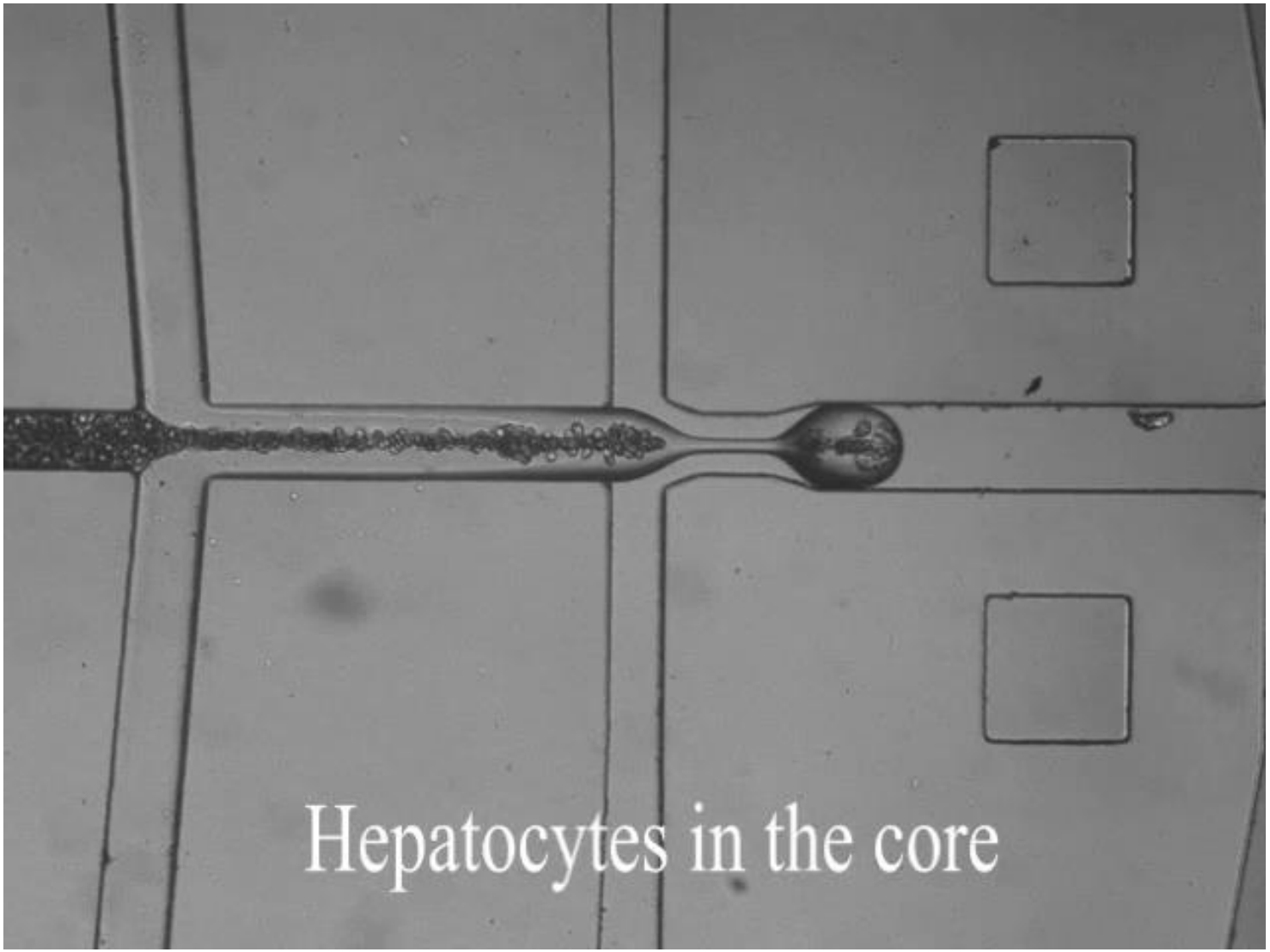


Organ on a Chip



Goal: Controlled production of 3D organs.

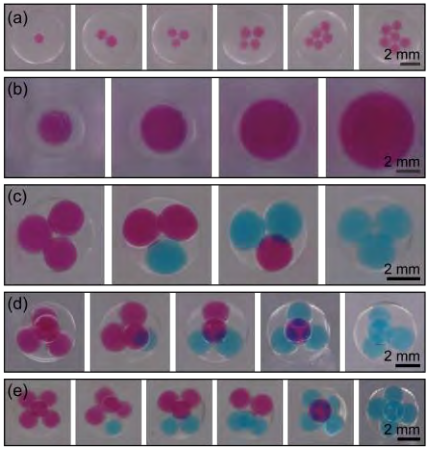
Artificial Liver in a Drop



Conclusions

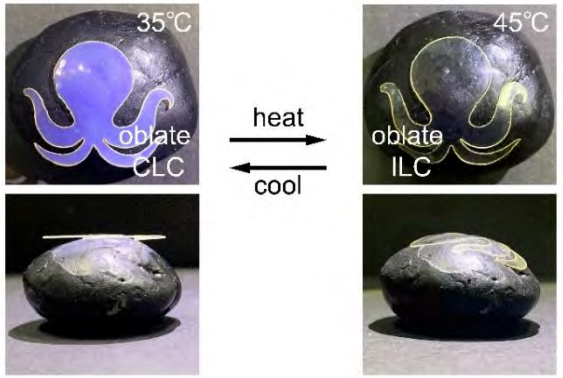
Microfluidics, a facile platform to engineer droplet/particle morphology

Platforms: microfluidics, 3D printing?



Bio Applications: drug delivery, cancer therapy?

Functional Materials: biomimetic materials, smart materials?



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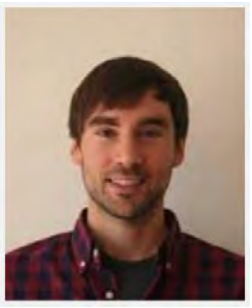

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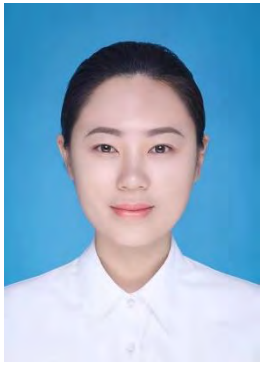
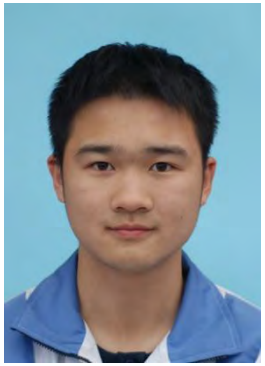


Xiaoxiao Yan



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Thank You for Listening!

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Highlight

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