Microfluidic assembly of magnetic gel particles

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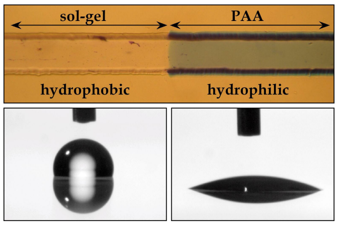
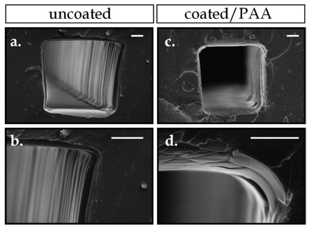
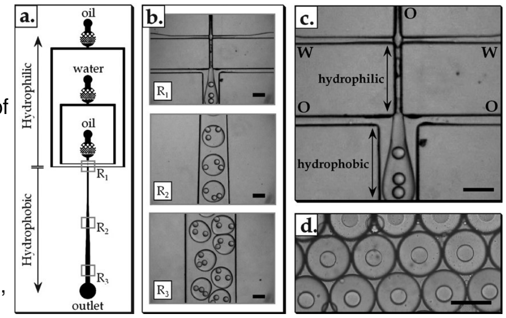
Introduction

Double emulsions of monodisperse spherical particles with magnetic cores and hydrogel shells were produced by flow-focusing drop makers with spatial wettability patterning. Since the microfluidic synthesis provides excellent control over the size, morphology and monodispersity. There are two challenges to make double emulsions by PDMS devices. First, the chemical resistance of PDMS have to be enhanced. Second, the wetability patterning needs to be controlled. With the advantage to coat a sol gel layer, we could increase the chemical resistance of PDMS (Fig. 1) and also could get wettability patterning with sharp contrast (Fig. 2). The double emulsions therefore are produced by PDMS drop makers (Fig. 3) which allows to design the droplet flexible by combing other PDMS microfluidic components (such as valves, sorting tools and injection tools.)

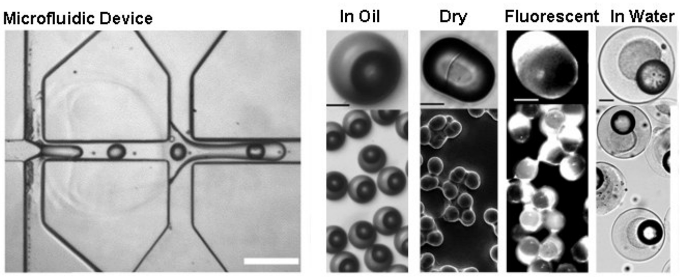






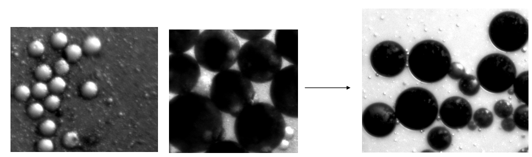
Reliability

To test the reliability of PDMS double emulsion drop makers, hydrophilic monomer and hydrophobic monomer were used to make the gel particles. Due to viscous friction, this induces a flow in the double emulsion that causes the inner drop to move towards the back of the outer drop to form the Janus (biphasic) droplets. The biphasic structure is locked by photo polymerizing the monomers inside the channels. We confirm this method is flexible and reliable to make different kinds of Janus particles / gel particles (Fig. 4).



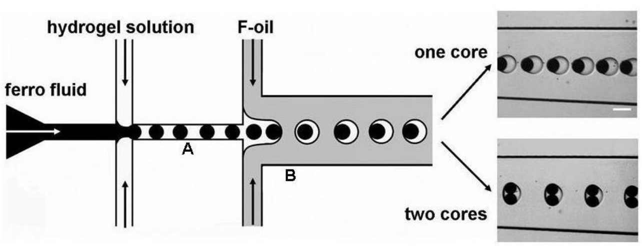
Choose the functional materials

Ferro fluid is difficult to be stabilized. Iron oxide nano particles will easily aggregate in the wrong solvents. Single emulsions of ferro fluid in water are not stable. Ferro fluid mixed with hexandiol is unstable in water. The emulsions will break and make the solution a mass. To polymerize ferro fluids, we tested several solvents, but learn the styrene did a good job. Ferro fluids are dissolved in styrene and nano particles are also stable inside.



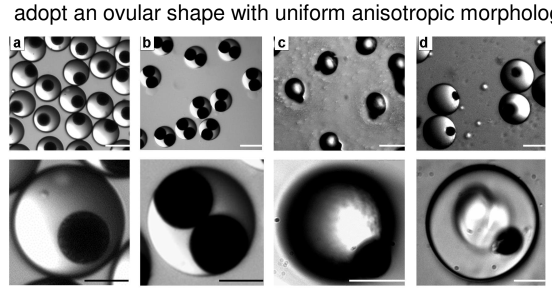
Synthesis magnetic hydrogel particles

To form magnetic hydrogel particles with uniform anisotropic features, oil-water-oil double emulsion droplets were made from polymerizable monomer mixtures as templates. The volume flow rates for forming the double emulsions with one bead were optimized to 55 mu/hr for the inner flow rate; 50 to 75 mu/hr for the middle flow rate, and 850 to 1100 mu/hr for the outer flow rate. Two inner beads were encapsulated by one droplet by increasing the inner flow rate twice to about 110 to 140 mu/hr, which offered different emulsion morphologies, (Fig. 5)

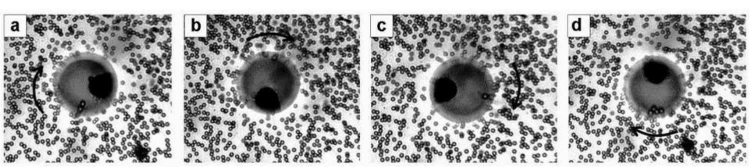


Particle collection

Once polymerized, the magnetic gel particles were robust and could be washed, dried, and re-dispersed into water. The collected double emulsions in the fluorocarbon oil are shown in Fig. 2a and 2b. Upon evaporating the volatile fluorocarbon oil and water, the particles become more compact and adopt an ovular shape with uniform anisotropic morphology, as shown in Fig. 2c. The particle diameters increase from 55 um in fluorocarbon oil to 75 um in water, see Fig. 2d.



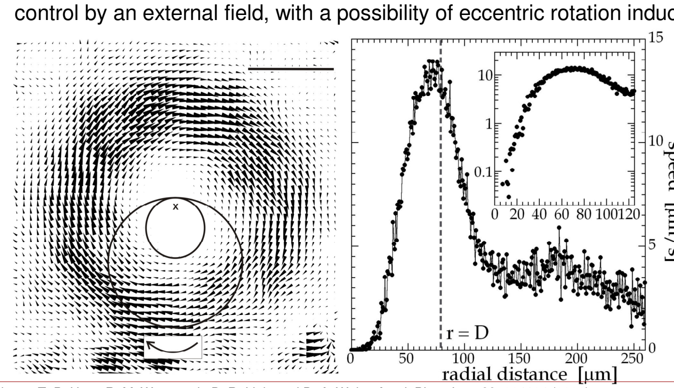
Rotational control



The rotation of the particles was observed in a glass reservoir in the presence of an external magnetic field. The reservoir was filled with magnetic hydrogel particles, suspended in deionized water with 5% (v/v) tracing colloidal particles (diameter 3 um) introduced to visualize the fluid flow. The reservoir was then placed in a rotating magnetic field produced by a standard heating plate. In addition to visually observing the flow around the gel particles, the high speed camera was used to analyze the flow velocity around a magnetic particle by recording the movements of the tracing colloids. In the presence of an external magnetic field, the iron-oxide magnetic nanoparticles of the ferrofluid acquire dipole moments. Since magnetic nanoparticles are immobilized by polymerization, the rotating external field would exert a torque on the whole hydrogel particle.

Conclusions

In conclusion, magnetic hydrogel particles with uniform anisotropic features were synthesized using double emulsions as templates. Microfluidic assembly by using flow-focusing double emulsion drop makers provides excellent control over the size, morphology and monodispersity. The particles exhibit excellent rotational control by an external field, with a possibility of eccentric rotation inducing a significant localized shear flow.



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