

Polymer and Colloid Highlights

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Leveraging Liquid–Liquid Interfaces to Assemble Responsive Vesicles

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Vesicles are composed of a bilayer of amphiphilic molecules; they can be used for example as delivery vehicles^[1] or as membranes of artificial cells.^[2] They are often produced through re-hydration methods where a dry, thin film of amphiphilic molecules is re-dispersed in an aqueous solution; amphiphilic molecules with an appropriate volume ratio of the hydrophobic to the hydrophilic block then self-assemble into a vesicular structure. However, because this process relies on self-assembly, the control over the composition of vesicles consisting of a mixture of amphiphiles is limited and can vary between vesicles even if they are produced within the same batch.

Vesicles can also be produced using water/oil/water double emulsion templates. In this case, amphiphiles preferentially adsorb at the liquid–liquid interfaces to form a monolayer. Upon removal of the oil, the hydrophobic parts of the two monolayers associate and form a bilayer.^[3] The degree of control over the bilayer composition strongly depends on the composition and concentration of amphiphiles in the shell of the double emulsion drop. The concentration of amphiphiles must be high enough to allow the formation of two densely packed monolayers at the two liquid–liquid interfaces. However, ideally, all amphiphiles initially contained in the oil phase go to the liquid–liquid interface such that the composition of the bilayer corresponds to the composition of the amphiphiles in the oil phase. Thus, the number of amphiphiles initially contained in the oil shell must be adjusted to the area of the two liquid–liquid interfaces. This can only be done reliably, if the liquid–liquid surface areas as

well as volume of the oil shell are well defined; this requires double emulsion drop templates to be monodisperse. We produce monodisperse double emulsions using microfluidics. We use them to assemble giant unilamellar liposomes composed of a mixture of phospholipids that phase-separate and form domains.^[4] Similarly, we can tune the composition of polymersomes by adjusting the relative concentration of the block-copolymers. By adding small amounts of a thermo-responsive block-copolymer, poly(*N*-isopropylacrylamide)-*b*-poly(lactic-co-glycolic acid) (PNIPAM-*b*-PLGA) to an otherwise only very weakly responsive polymersome membrane composed of poly(ethylene glycol)-*b*-poly(lactic acid) (PEG-*b*-PLA), we can make polymersomes thermo-responsive. We can further functionalize these polymersomes by adding hydrophobic nanoparticles, such as dodecylthiol stabilized gold nanoparticles, into the hydrophobic part of their bilayer, as shown schematically in Fig. 1; these nanoparticles make the polymersomes photo-responsive.^[5]

We can only visualize the very small polymersomes, formed from small satellite double emulsion drop templates as the large polymersomes lose their integrity as they are dried in air. However, transmission electron microscopy images of the small polymersomes indicate that gold nanoparticles with diameters as large as 10–15 nm are embedded in the polymersome membranes, as shown in Fig. 1. By contrast, the vast majority of the same nanoparticles forms the core of micelles if polymersomes are produced through re-hydration techniques. This result suggests that vesicles produced from double emulsion templates can be functionalized with moieties that would not spontaneously insert into the hydrophobic part of the vesicles.

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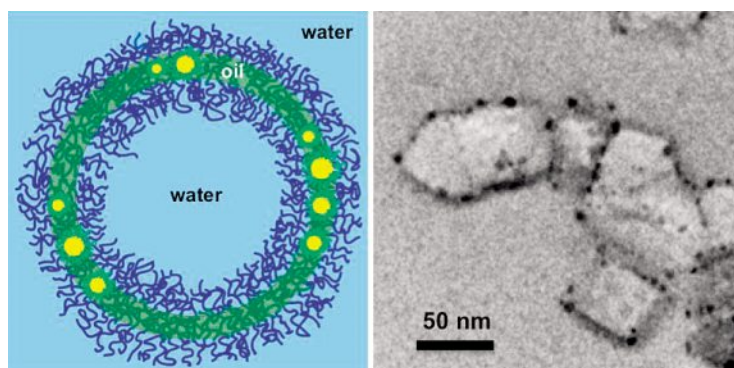


Fig. 1. (Left) Schematic illustration of the assembly of PEG-*b*-PLA polymersomes using water–oil–water double emulsion templates. The polymersomes are functionalized with dodecanethiol-stabilized gold nanoparticles. (Right) A transmission electron micrograph of the nanoparticle functionalized polymersomes.

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