Polymersome-Embedded Nanoparticles

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Summary: Polymersomes are self assembled vesicles composed of fully synthetic amphiphilic diblock copolymers. Many of their properties are similar to lipid vesicles, although with often higher thermal and mechanical stability within their curved membrane. Incorporation of nanosized objects into their hydrophilic interior or hydrophobic membrane represents an important method for functionalization of these biomimetic structures. We report on the embedding of hydrophobic gold nanoparticles (Au-NPs) into polymersomes. Nanoparticles were prepared and incorporated into polymersomes made by standard film rehydration techniques from commercially available diblock copolymers. Characterization of the resulting structures was achieved by dynamic light scattering (DLS) and by TEM. Results on the preparation method, its influence on the polymersome stability and the application of these new membrane-mimetics are reported.

Keywords: nanoparticles; polymersomes; self-assembly

Introduction

Synthetic amphiphiles lead to highly ordered self-assembled structures in water. Depending on the relative hydrophobicity and the relative composition/geometry of hydrophilic and hydrophobic moieties, different aggregate morphologies have been observed.[1] Among other morphologies, such as micelles and tubules, vesicles are microscopic or nanoscopic structures with molecularly thin membranes, similar to the bilayer formation of amphiphilic molecules. Block copolymers that mimic amphiphilicity are able to self-assemble into vesicles into dilute solution, but polymer weights are orders of magnitude larger than those of biological lipids. The polymer approach to vesicle formation broadens the range of properties achievable through a widened choice of amphiphilic copolymers. When compared to lipids, polymer vesicles show higher mechanical and thermal stability within their curved membrane and in addition offer diverse functionality afforded by tuning material chemistries through polymer synthesis. Incorporation of nanosized objects into their hydrophilic interior or hydrophobic membrane represents an important method for functionalization of these biomimetic structures. Lecommandoux et al. described the introduction of magnetic nanoparticles in self-assemblies of diblock copolymers in order to generate new supramolecular structures sensitive to an applied magnetic field.[2] Ghoroghchian et al. developed emissive polymersomes based on multiporphyrin fluorophores within their thick lamellar membranes for deep-tissue fluorescence-based *in vivo* imaging.[3]

We report on the embedding of hydrophobic gold nanoparticles (Au-NPs) into the curved membrane of polymersomes (Figure 1). Characterization of the resulting structures was done by dynamic light scattering (DLS) and by TEM. Results on the preparation method, its influence on the polymersome stability and the application of these new membrane-mimetics are described.

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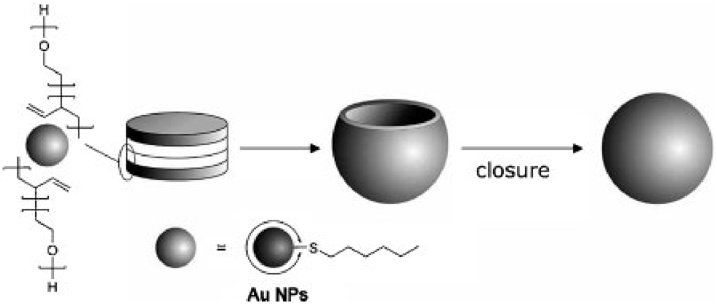

Figure 1.
Preparation of functionalized polymersomes.

Methods

Monodisperse hydrophobic Au NPs were synthesized according to the two phase method of Brust et al.[4] Briefly, $HAuCl_4$ was transferred from an aqueous solution into toluene by phase tansfer catalysis (tetraoctylammonium bromide). After addition of hexanethiol, $NaBH_4$ was used as reducing agent to yield monodisperse Au-NPs. Size and distribution of the NPs were determined by TEM- (Figure 2a) and DLS-measurements.

In order to embed a certain amount of nanoparticles, the molar mass was calculated by regarding size (TEM), density and bound thiol ligands. The molar ratio of commercially available PEO_{30}-PBD_{46} block copolymers and NPs had been varied in a large range (Table 1) to investigate the formation of the polymersomes and their stability.

In brief words, 100 μl of a 1 mM PEO_{30}-PBD_{46} stock solution were mixed with a defined volume of a 10 μM NPs stock solution, followed by evaporation of the solvent at ambient temperature to yield a homogenous hybrid-polymer film. Hydration led to spontaneous formation of multilamellar hybrid-polymersomes.[5] Validation

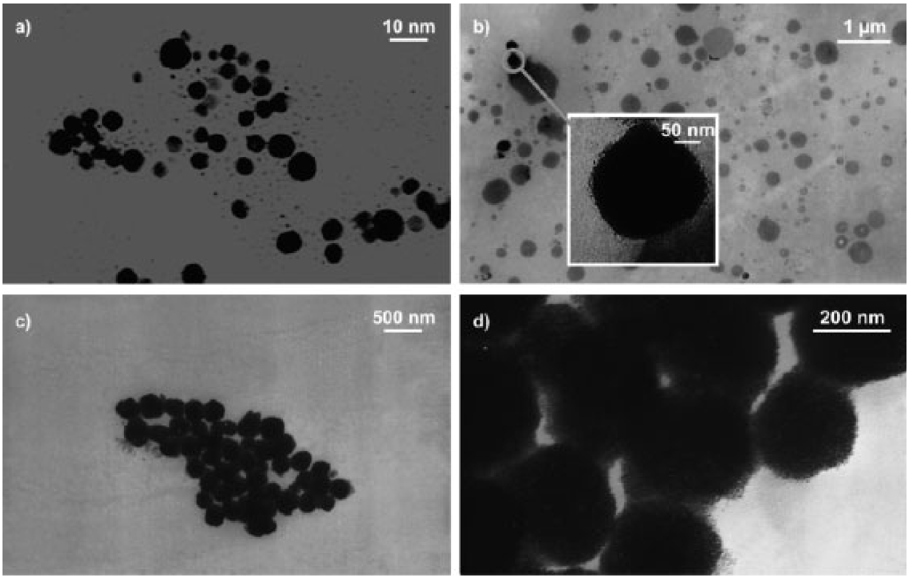

Figure 2.
TEM of hydrophobic Au NPs (a), multilamellar hybrid-polymersomes (b–d).

Table 1.
Investigation of functionalized hybrid-polymersomes by DLS- and TEM-measurements.

Entry	$n_{Polymer}$:$n_{Au\text{-}NPs}$	DLS/TEM
1	–	DLS (50–3000 nm)
2	2000:1	DLS (50–3000 nm), TEM (Figure 2b)
3	1000:1	DLS (50–3000 nm)
4	500:1	DLS (50–3000 nm)
5	100:1	DLS (50–3000 nm), TEM (Figure 2c,2d)

of these structures was done by TEM- (Figure 2b–2d) and DLS-measurements.

As seen in Figure 2b–d, the size of the hybrid-polymersomes with embedded Au-NPs varied only in a small range between 300 and 400 nm, whereas pure polymersomes showed a rather large polydispersity ranging from 50 to a few μm (obtained by DLS data). Another interesting aspect is the fact that no partial inclusion of Au-NPs was observed – either the hydrophobic part of the bilayer membrane was fully occupied with NPs or completely empty (Figure 2b).

Conclusion

In conclusion, we have demonstrated an efficient method to modify commercially available block copolymers with hydrophobic gold nanoparticles. By varying the molar ratio of block copolymers and nanoparticles two interesting aspects were revealed: first, the inclusion of nanoparticles led to hybrid-polymersomes of low polydispersity and second, no partial inclusion of the nanoparticles was noticed – either the nanoparticles were fully incorporated into the hydrophobic part of the curved membrane or the formation of pure polymersomes without incorporated nanoparticles were observed.

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