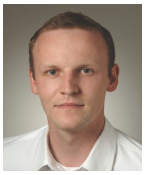
Synthesis Route for the Self-Assembly of Submicron-sized Colloidosomes with Tailorable Nanopores



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INTRODUCTION AND OBJECTIVE

Colloidosomes are hollow capsules formed via self-assembly of colloid particles on emulsion droplets and were first termed by Dinsmore et al. (2002). This type of semi-permeable capsule possesses the potential to fabricate vesicles with tailored properties for the encapsulation and sustained release of active agents, such as drugs, flavors, or fragrances. Previous investigations have demonstrated colloidosome synthesis with fine-tuned properties. These include, increased mechanical stability (Ao 2011), adjustable permeability (Miguel 2011), synthesis of pH (Cayre 2012) and temperature (Lawrence 2007) responsive systems, and the integration of materials with magnetic, catalytic, or semiconducting characteristics. The stability and porosity of the capsules can be further enhanced by merging the particles on the shell by sintering (Yow 2009). However, the utilization of sintering techniques opposes various application limits for the encapsulation of active agents. Furthermore, a major property that has not been reported to date is the assembly of colloidosomes with diameters below 1 µm. Accordingly, demonstrated colloidosome sizes and the limitations created by previously described stabilization procedures highlight the need for a novel synthesis route to fabricate inherently rigid colloidsomes of small size with intrinsic nanoporosity. In this study, we present a straightforward synthesis route for the fabrication of colloidosomes at mild pH and ambient conditions with diameters below 1 µm, featuring tailorable nanometer-sized pores.

MATERIALS AND METHODS

Our preparation method is primarily inspired by the standard procedure given by Dinsmore et al. (2002). Here, an emulsification step to prepare a water-in-oil emulsion is utilized to induce a self-assembly process of colloidosomes, which is followed by a centrifugation step to transfer the capsules from an organic into an aqueous phase (Figure 1).

Our mechanical stabilization of the colloidosomes is based on our previous study (Maas 2010), where we demonstrated the growth of silica nanoparticle thin-films at a planar water-oil (w-o) interface. We now transferred the method of a oil-soluble surfactant induced agglomeration of nanoparticles at a two-dimensional planar interface to a three-dimensional curved interface of water droplets, with the aim to obtain inherently rigid colloidosomes of submicron size. Akartuna et al. (2009) investigated a similar approach with water-soluble surfactants producing capsules with an oil core which exhibited diameters of a few micrometers.

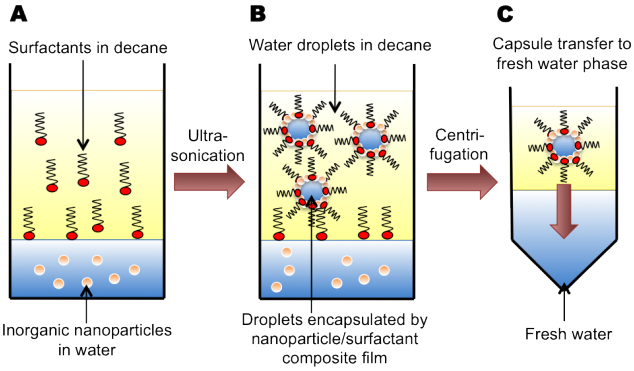

Figure 1: Submicron colloidosome preparation; (A) System before colloidosome generation; (B) Self-assembly of lipids and nanoparticles at the water-droplet oil interface; (C) Transfer of self-assembled colloidosomes to a fresh aqueous phase.

In our work, submicron colloidosome synthesis is realized by combination of oil-soluble surfactants (lipids) and nanoparticles at the w-o interface, both carrying equal net charges. In our study, three colloid/lipid-combinations of equally charged nanoparticles and lipids were employed. Ludox TMA (Sigma Aldrich), colloidal silica particles that exhibit a negative surface charge, were used with stearic acid (Sigma Aldrich), which induces a negative charge at the w-o interface. While Alu C (Evonik) as well as Ludox CL (Sigma Aldrich) both feature a positive surface charge and were used with stearyl amine (Sigma Aldrich), that shows a positive charge at the w-o interface. Using colloid/lipid-combinations of opposite charges of the nanoparticles and lipids solely produce large agglomerates and were not applicable for colloidosome synthesis.

RESULTS AND DISCUSSION

The DLS intensity size distributions obtained for the hydrodynamic diameters for the different colloidosomes types are listed in Table 1.

Tabel 1: Properties of sub-micron colloidosomes

Colloidosome type	Size distribution (nm)	Pore size (nm)	Surface structure
SiO_2	420 ± 160	7.9 ± 2	mostly hcp
Al_2O_3	230 ± 60	13.7 ± 9	unordered
Al_2O_3-coated SiO_2	200 ± 140	4.2 ± 1	mostly hcp

All three samples feature diameters in the range of about 100 nm up to a few hundred nanometers, confirming the submicron size of all three colloidosome types. Zeta-potential measurements indicated a high electrostatic stability of the colloidsomes in the aqueous phase after centrifugation.

The colloidosomes' shell and its pores potentially impact the diffusion path of an active agent and therefore the release from the capsules' cores. Hexagonal closed packing (hcp) provides the smallest possible pore size in colloidosomes, and can be ideally realized via the self-assembly of spherical nanoparticles of narrow size distribution. Figure 2 illustrates the surface structure of the different colloidosomes types. Pore sizes and the type of the surface packing created by the shell-forming nanoparticles are listed in Table 1.

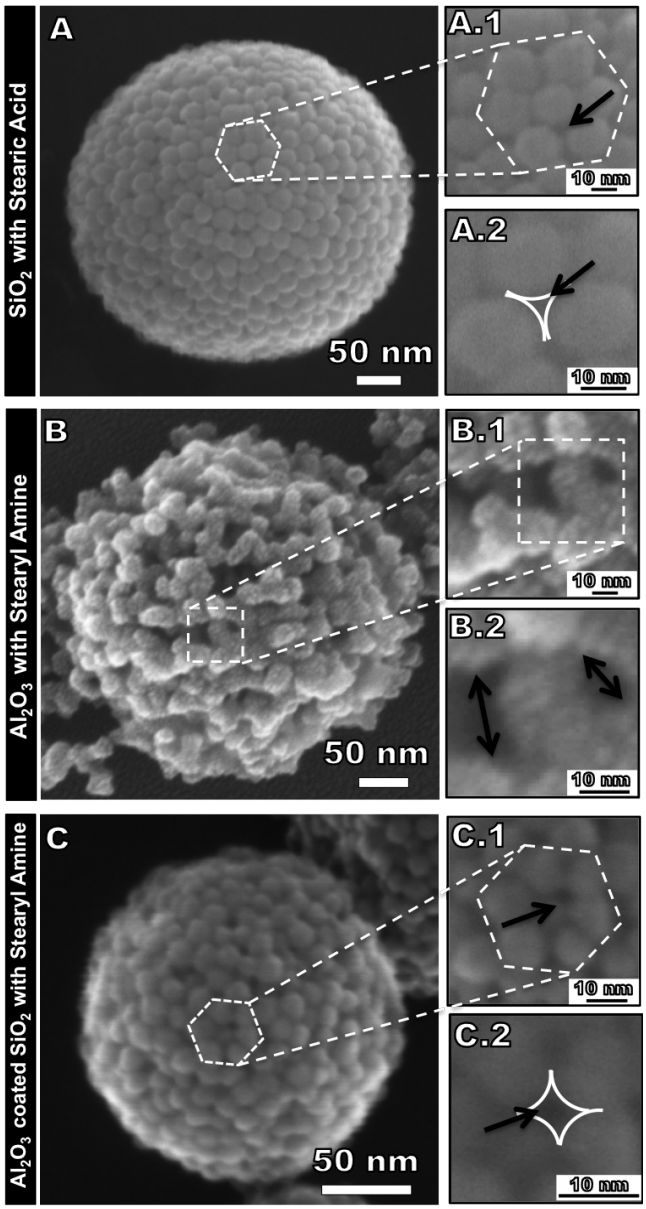

Figure 2. SEM micrographs illustrating the topological properties of the varying colloidosome types, including a detailed view of several nanopores. (A) SiO2 colloidosome (B) Al2O3 colloidosome (C) Al2O3 coated SiO2 colloidosome.

CONCLUSION

In summary, this study describes a straightforward method for the preparation of inherently rigid submicron-sized colloidosomes with tailorable nanopores. In combination with a lipid that carries the same net charge at an oil-water interface as the colloidosome-forming particles in aqueous media, we were able to synthesize colloidosomes with positive and negative zeta potentials. The capsules are both stable in organic as well as in aqueous environments. The different colloidosome types are therefore potentially suitable for the encapsulation of positively or negatively charged biomolecules. By varying the sizes and shapes of the nanoparticles, we were able to tailor the pore diameters and pore size distributions on the surface of the capsules. Tailoring the size of the colloidosome nanopores potentially allows the controlled release of encapsulated active agents of different size, such as proteins or antibiotics.

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