Layered Nanoparticle Nanotubes (NPNTs)

Shani Eliyahu, Tali Sehayek, Alexander Vaskevich, Israel Rubinstein

Department of Materials and Interfaces, Weizmann Institute of Science, Rehovot 76100, Israel

Abstract

Our group recently presented a new method for template synthesis of metallic nanotube structures using citrate-stabilized Au, Ag, and Au-Pd nanoparticles (NPNTs) building-blocks. The role of nanotubes, denoted nanoparticle nanotubes (NPNTs), are produced by passing the NP solution through the pores of aluminosilane-modified anodized aluminum membranes. The NPNTs bind electrostatically to the pore walls and accumulate on membranes, followed by spontaneous reassembly at temperatures above the melting point of the NPs. Such NPNTs are formed to form solid nanotubes. Single-metal (Au, Ag) and composite (Au-Ag, Au-Pd) NPNTs were synthesized by this method. The NPNTs retain the NP morphology, showing high corrugation, porosity, and electrical conductivity. Detailed structural analysis revealed formation of metallic nanostructures between the membranes and lattice continuity.

The above syntheses scheme opens the way to the preparation of a variety of new tubular nanomaterials, some of which are described in the present study. The possibility to vary the size of the NP building blocks, thus controlling the nanotube porosity, was explored by comparing Au NPs of 4 ± 1 nm average diameter to the originally used 14 ± 2 nm Au NPs as the starting colloid. The kinetics of NP accumulation and nanotube formation are different for the two NP sizes tested. The smaller NPs tend to form less dense structures, and the resulting NPNTs are more porous and fragile. Layered NPNT structures were prepared by binding of ca. one monolayer of NPs of the second size to the membrane walls followed by accumulation of NPs of a third type (size, metal). High-resolution scanning electron microscopy (HRSEM) imaging suggests the formation of core-shell NPNT structures with a radial gradient of properties.

Conclusions

- Au nanoparticles (NPs) of different diameters can be used to form self-sustained nanoparticle nanotubes (NPNTs). Use of Pd NPs results in poor NPNT synthesis proceeds in two stages: 1) Primary binding of a NP monolayer via electrostatic interaction with the modified membrane walls, with a NP density allowing NPs to adsorb on membranes, followed by spontaneous reassembly of the NPs in form solid nanotubes. Single-metal (Au, Ag) and composite (Au-Ag, Au-Pd) NPNTs were synthesized by this method. The NPNTs retain the NP morphology, showing high corrugation, porosity, and electrical conductivity. Detailed structural analysis revealed formation of metallic nanostructures between the membranes and lattice continuity.

- The two-stage mechanism enables combination of different kinds of NPs to form self-sustained core–shell NPNTs.