Metal Nanoparticle Nanotubes

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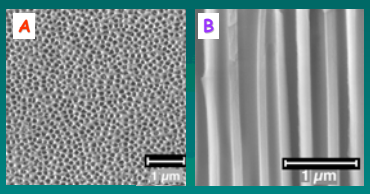
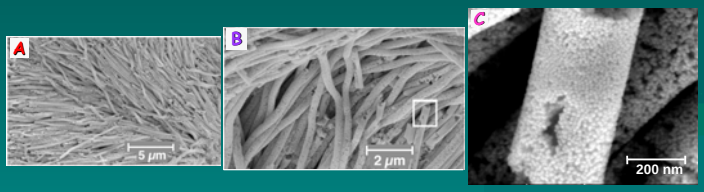
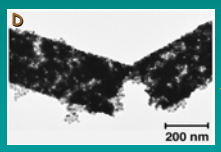


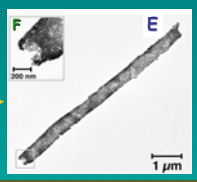
ESEM images showing top view (A) and cross-section (B) of a silanized nanoporous alumina membrane (Whatman, '200 nm').



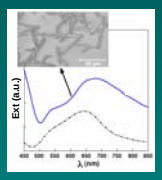
(A)-(C): ESEM images of Au nanoparticle nanotubes obtained after alumina membrane dissolution in 1.0 M NaOH, shown at different magnifications. (C) is a magnified image of the area marked in (B), showing the arrangement of individual nanoparticles.



(D) and (E): TEM images of Au NPNTs obtained after alumina membrane dissolution in 1.0 M NaOH, shown at different magnifications. (F) is a magnified image of the area marked in (E), showing the tubular structure.

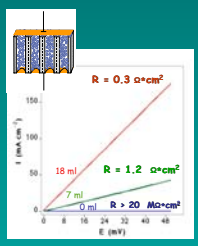


Transmission UV-vis spectra of Au NPNTs in solution (– · – · –) and on a glass slide (——). Also shown is an ESEM image of Au NPNTs on the glass slide.



Ohmic behavior of Au NPNTs measured by cyclic voltage scan (10 mV s⁻¹).

ρ ≅ 6 Ω*cm



Au

Ag

Au

Pd

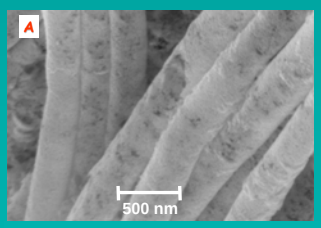
Au

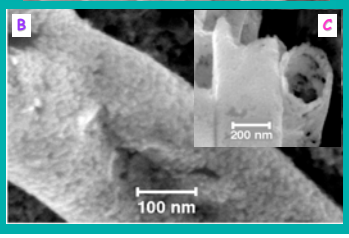
Au

Abstract

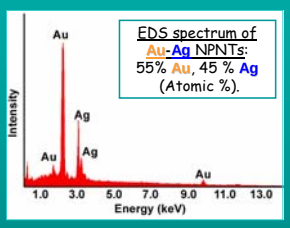
Template synthesis is a common method for producing nanostructures. Nanoporous alumina membranes are widely used as templates for the deposition of nanocylindrical materials (nanorods, nanotubes) comprising polymers, metals, semiconductors, carbon, etc. Here we demonstrate template synthesis of a novel kind of high-surface-area metal nanotubes (Nanoparticle Nanotubes, NPNTs) comprising metals (Au, Ag) as well as bi-metallic (Au-Ag, Au-Pd) NPNTs, using nanoporous alumina membranes.

The NPNTs were prepared by the following procedure: (i) Coating the inner walls of a nanoporous alumina membrane (pore size, ca. 220 nm) with 3-aminopropyl trimethoxysilane; the silyl groups react with the hydroxyl groups on the alumina walls, leaving the amine groups available for binding nanoparticles. (ii) Passing a metal colloid solution (citrate stabilized) through the modified pores by vacuum suction. The nanoparticles bind to the exposed amine groups and aggregate on the pore walls, followed by spontaneous, room-temperature coalescence to form solid, highly porous, layered nanotubes. The alumina membrane matrix can be dissolved, to yield self-sustained, high-surface-area NPNTs. The NPNTs were characterized by ESEM, HRSEM, EDS, TEM and UV-vis spectroscopy. This new procedure provides a simple means of producing highly-porous nanotubes which are mechanically stable, electrically conducting, and display a distinct surface plasmon optical absorption. The NPNTs may be useful in catalysis and electrocatalysis, as well as in sensing, microfluidic, chemistry-on-a-chip, binding of biological molecules, and future device applications.

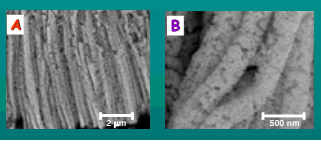




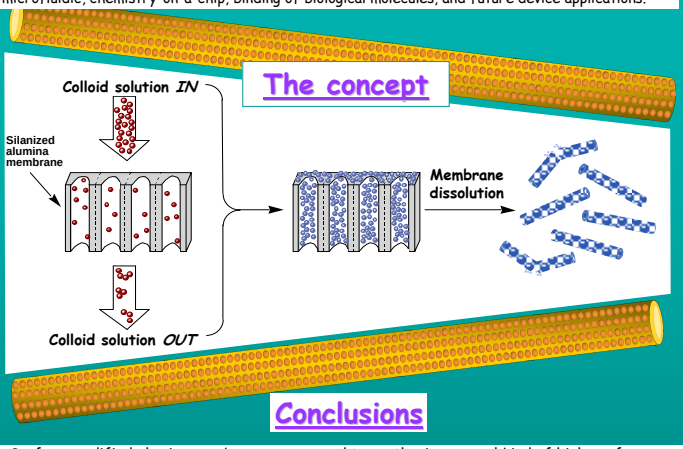
(A)-(C) : ESEM images of Ag NPNTs obtained after alumina membrane dissolution in 1.0 M NaOH, shown at different magnifications. (B) and (C) show, respectively, the arrangement of individual Ag NPs and the tubular structure.



EDS spectrum of Au-Ag NPNTs: 55% Au, 45 % Ag (Atomic %).



(A) and (B): ESEM images of Au-Ag NPNTs (1:1) at different magnifications, obtained after alumina membrane dissolution in 1.0 M NaOH.

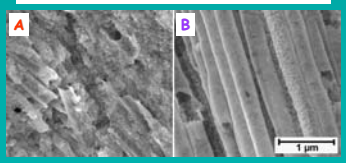


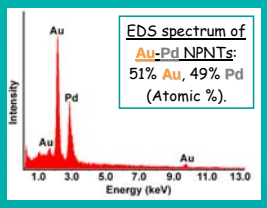
The concept

Conclusions

- Surface-modified alumina membranes were used to synthesize a novel kind of high-surface-area metallic as well as bi-metallic nanotubes ('nanoparticle nanotubes').
- NP immobilization is assumed to involve aggregation accompanied by spontaneous room-temperature coalescence, probably during membrane drying, to yield continuous, solid NPNTs.
- The nanoparticle nanotubes are highly porous, mechanically stable, electrically conducting, and display a distinct surface plasmon optical absorption.
- The new class of nanotubes is particularly promising for catalysis and future device applications.

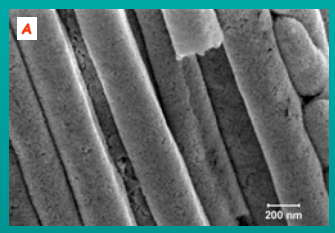
ESEM images of "Pd NPNTs" (A) and Au-Pd NPNTs (1:1) (B) obtained after alumina membrane dissolution in 1.0 M NaOH.

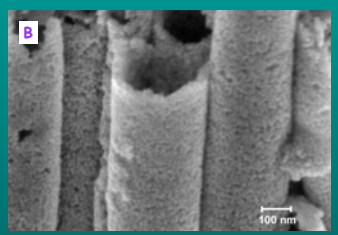




EDS spectrum of Au-Pd NPNTs: 51% Au, 49% Pd (Atomic %).

(A) and (B): HRSEM images of Au-Pd NPNTs (1:1) at different magnifications obtained after alumina membrane dissolution in 1.0 M NaOH.

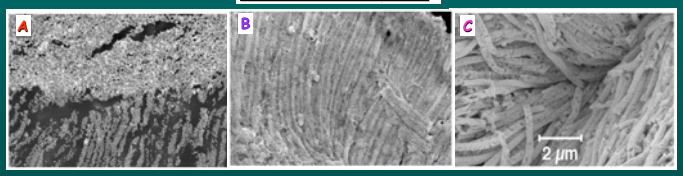




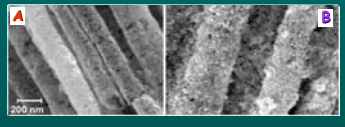
Reference

M. Lahav, T. Sehayek, A. Vaskevich and I. Rubinstein, *Angew. Chem. Int. Ed.*, in press (web release, 23/10/2003).

Au NPNT development:



ESEM images showing the progress of Au NPNT formation after passing (A) 5 ml, (B) 9 ml and (C) 18 ml of Au NP solution, followed by drying and membrane dissolution.



ESEM images of Au NPNTs obtained after passing Au NP solution, followed by (A) drying or (B) no drying prior to the membrane dissolution.