Bacterium *E.coli*-Templated Synthesis of Cadmium Sulfide Nanostructures

L. Shen, N. Bao and A. Gupta

MINT Center, The University of Alabama

This project was funded by the DOE under Grant No. DE-FG02-08ER46537.

Abstract

A simple sonochemical method has been used to synthesize nanoporous hollow structures of semiconducting cadmium sulfide (CdS) using *E. coli* bacteria as template. To enable adsorption and reaction throughout the *E. coli* cell envelope, the cell permeability is enhanced by suitable ethanol treatment while preserving the morphology. CdS nanostructures in the form of monodisperse quantum dots, near monodisperse nanocrystals, and nanoporous hollow microrods are controllably formed on ethanol-treated *E. coli* with increasing reaction time. Additionally, nanorod antennas have been fabricated by utilizing the pili formed during the growth phase of the bacteria. The bacterial template route has been extended to the synthesis and assembly of other chalcogenide nanostructures including PbS and ZnS.

Motivation

Bio-templated synthesis and sssembly routes:

- DNA, RNA, and organisms from microbes to complex multicellular systems.
- Controllable size, from nano- to macroscopic scales.
- Precisely controlled shape, structure, and functionality.
- Bottom-up nanofabrication of complex functional assemblies and devices.

Nanoporous Hollow Structures:

- Large surface area.
- Strong ability to interact with reactants throughout the structure.
- A variety of possible applications in catalysis, biomedicine, novel materials, etc.

Challenges

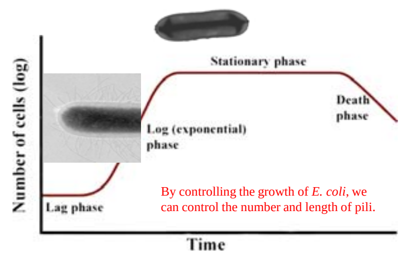
- Understanding nucleation and growth of inorganic species on bio-templates .
- Control over material properties such as phase structure, composition, etc.
- Synthesis of non-biocompatible materials.

Present Work

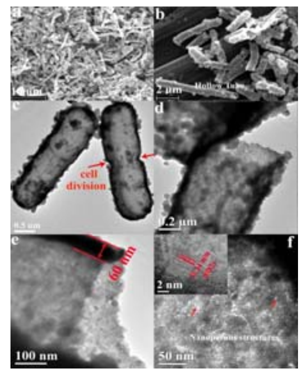
Development of novel bacterial template route for the synthesis and assembly of hollow chalcogenide nanostructures, including CdS, PbS, ZnS, etc.

Experimental

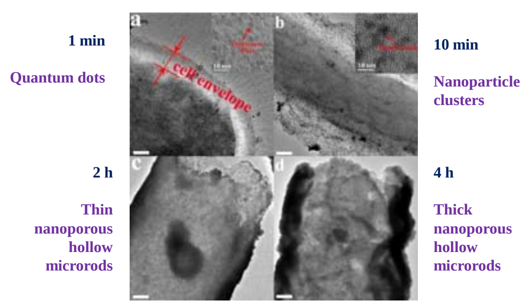
- Growth of *E. coli* cell culture under ambient conditions untill stationary growth phase. The cell concentration is ~10^8 CFU/mL.
- Ethanol treatment of cells with 95% ethanol for 3 minutes to increase the permeability of cell outer membrane.
- Synthesis of CdS nanostructures: 0.5 mmol of cadmium acetate dehydrate was first added to 50 mL of ethanol-treated ER2738 solution, and 0.5 mmol of thioacetamide was then added after 30 min. The reactions was conducted for up to 4 h in an ultrasonic bath with the temperature maintained at around 28°C.
- Investigation the time-dependence of size, shape, and structure of the bacteria *E. coli*-templated CdS structures.
- Fabrication of nanorod antennas by utilizing the pili formed during the growth phase of the bacteria.



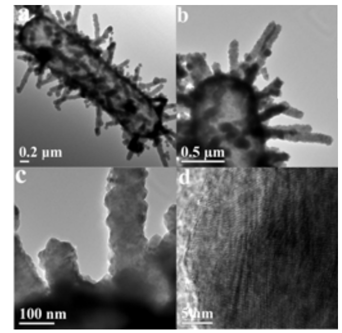
Cell Growth Curve



SEM and TEM images of *E. coli*-templated nanoporous hollow CdS microrods formed after 4 h. (a) Low-magnification and (b) high-magnification SEM images of the hollow structures, showing the high yield of product with the desired shape. TEM image of hollow CdS microrods with (c) closed ends, and (d) an open end. The magnified TEM images of (e) the cross section and (f) the body of a rod-like hollow CdS show uniform wall thickness and nanoporous wall structure of the wall, respectively.



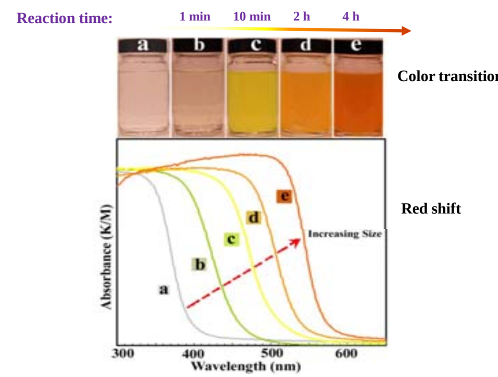
TEM images of *E. coli*-templated CdS nanomaterials sonochemically synthesized as a function of reaction time. (a) Monodisperse quantum dots formed after 1 min; (b) near monodisperse nanocrystals formed after 10 min; (c) continuous nanoparticle agglomerates formed after 2 h; and (d) uniform porous coating formed after 4 h. All scale bars are 100 nm. The HRTEM images in the inst to (a) and (b) show more clearly the formation of quantum dots and nanocrystals, respectively.



A cell: 100 to 300 pili, ~ 6.5 nm in diameter, 200 - 2000 nm in length.

CdS: ~ 100 nm in diameter, up to several microns in length.

TEM and HRTEM image of nanoporous hollow CdS microrod-supported nanorods synthesized after 4 h using *E. coli*' with pili as templates. (a, b) Low-magnification and (c) high-magnification TEM images of the CdS nanostructures show the morphology and structure of the whole CdS nanostructure, the basic hollow microrod, and the attached nanorods. (d) HRTEM image of the CdS nanorods showing crystal lattice fringes.



Optical images and UV-Vis spectra *E. coli*-templated CdS nanostructures in solution after (a) 0 min, (b) 1 min, (c) 10 min, (d) 2 h, and (e) 4 h of reaction.

Conclusion

We have used ethanol-treated *E. coli* bacteria as a template to promote controllable growth of nanoporous hollow CdS microrods via a simple sonochemical synthetic method. The morphology, micro/nanostructure, and optical absorption properties of the CdS nanomaterials have been tailored over a wide range by simply changing the synthetic conditions, including the sulfur/cadmium molar ratio of the reactants, the reaction time, and the growth condition of *E. coli* bacteria. The facile synthesis procedure can be extended to the fabrication of other sulfides and core-shell nanostructures.