Shape-Controlled Synthesis of Nanostructured Materials

Younan Xia

Department of Chemistry
University of Washington
Seattle, Washington 98195
E-mail: xia@chem.washington.edu

Quantum Dots: Same Material, Different Colors

Alivisatos (UC Berkeley), Bawendi (MIT), Brus (Columbia), Peng (Arkansas)
Surface Plasmon Resonance (SPR) Features of Spherical Gold Nanoparticles: Size Dependence

Dependence of SPR on the Shape (Aspect-Ratio)
SPR Modes of 60-nm SiO₂ Cores Coated with Au Shells of Different Thicknesses

Halas et al., Chemical Physics Letters 1998, 288, 243

Nanoscale Electronic and Photonic Devices

**Selenium: A Multifunctional Semiconductor**

- Intrinsic Optical Chirality
- Highest Photoconductivity ($\sim 8 \times 10^4$ S/cm for t-Se)
- Piezoelectric & Nonlinear Optical (NLO) Properties
- Thermoelectric Behavior
- Unique Catalytic Properties (Oxidation, Halogenation)
- Reactivities to Form Other Functional Materials such as ZnSe, CdSe, and Ag$_2$Se

---

**Synthetic Approach to Uniform t-Se Nanowires**

$$H_2SeO_3 + N_2H_4 \rightarrow 100 ^\circ C$$

Se (s) + N$_2$ (g) + 3 H$_2$O

---

Different Stages of Nanowire Growth

Uniformity and Purity of the Nanowires
Control over the Longitudinal Dimension

\[
\text{Te(OH)}_6 + \text{N}_2\text{H}_4 \rightarrow \text{Te} + \text{N}_2 + \text{H}_2\text{O}
\]

Mayers & Xia, Journal of Materials Chemistry 2002, 12, 1875

Single Crystalline Nanotubes Made of Tellurium

\[
\text{Te(OH)}_6 \rightarrow \text{TeO}_2
\]

\[
\text{HO(CH}_2\text{)}_2\text{OH} \rightarrow \text{Te} \text{ at 180 } ^\circ\text{C}
\]

Mayers & Xia, Advanced Materials 2002, 14, 279
Polyol Synthesis of Silver Nanostructures

\[ \text{Polyol Synthesis of Silver Nanostructures} \]

\[
\text{AgNO}_3 + \text{HO(CH}_2\text{)}_2\text{OH}
\]

\[
\text{PVP/Ag}=\text{X}
\]

\[
160 - 180 \, ^\circ\text{C}
\]

Sun & Xia, Advanced Materials 2002, 14, 833
Sun, Gates, Mayers & Xia, Nano Letters 2002, 2, 165
Silver Nanostructures with Different Shapes

\[ \text{Ag}^+ \xrightarrow{\text{ethylene glycol}} (\text{Ag})_4 \]

- PVP/Ag=1.5–2.0
- PVP/Ag=10

No PVP

(A) Decahedral MTP
(B) Single crystalline cuboctahedron
(C) Quasi-spherical MTP

Sun & Xia, Science 2002, 289, 2176
Highlighted in C&EN News, Materials Today

Single Crystalline Nanocubes of Silver

A, B, C, D: Images of single crystalline nanocubes of silver.
Silver Nanowires with Pentagonal Cross-Sections

Sun, Mayers, Herricks & Xia, Nano Letters 2003, 3, 955

Growth of the Silver Nanowires

Sun, Mayers, Herricks & Xia, Nano Letters 2003, 3, 955
Evidence in Support of the Growth Mechanism

Galvanic Replacement of Gold by Silver

Anode Reaction: \(3\text{Ag} \rightarrow 3\text{Ag}^+ + 3\text{e}^{-}\)

Cathode Reaction: \(\text{AuCl}^- + 3\text{e}^{-} \rightarrow \text{Au} + 4\text{Cl}^-\)

Sun & Xia, J. Am. Chem. Soc. 2004, 126, 3896
Titration by Increasing the Volume of HAuCl₄

Further Increase in the Volume of HAuCl₄
Metallic Pigments with Tunable Colors

Replacement Rxn between Ag Nanowires and AuCl4^-
Silver Nano-Templates with Various Morphologies

- Thin triangular plate
- Thick triangular plate
- Cube
- Sphere
- Rod
- Wire

Sun, Mayers & Xia, Advanced Materials 2003, 15, 641

Multiple-Walled Nanotubes Made of Au-Ag Alloys

- Cross section
- Side view
- Repeat

Sun & Xia, Advanced Materials 2004, 16, 264
Nanotubes Made of Au-Ag and Au-Ag/Pd-Ag Alloys

Nanorattles Made of Au-Ag Alloys

Conventional Setup for Electrospinning

Li & Xia, Advanced Materials 2004, in press
Reneker & Chun, Nanotechnology 1996, 7, 216

Electrospinning of TiO$_2$ Nanofibers

Li & Xia, Nano Letters 2003, 3, 555
Uniaxially Aligned Arrays of PVP Nanofibers

Li, Wang & Xia, Nano Letters 2003, 3, 1167
Highlighted as Editors' Choice, Science 2003, 301, 567

Aligned Nanofibers of Various Materials

Hierarchically Structured Arrays of Nanofibers

Li, Wang & Xia, Advanced Materials 2004, 16, 361

Direct Fabrication of Hollow Nanofibers

Li & Xia, Nano Letters 2004, 5, 933