Inorganic Nanowires as Advanced Energy Conversion and Storage Materials

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In the Past: Nanowires

Nanowire nanosensors

Nanoelectronic devices

Quantum coupling devices


Nano Lett. 5, 1519(2005)
Inorganic Nanowires

Nanowires
Diameter 1-200 nm, Length up to 100 μm

Uniqueness of nanowires
- Confinement effects
- Large surface area
- Transport carriers, photons, and ions
- Facile strain relaxation
- Well-defined nanoscale domain
Nanowire-Based Research Program

**Li Battery**


**Solar Cells**


**TCE**

With Peter Peumans

**Electrochem Bioprobe**


**Nonvolatile Memory**

Phase-change memory


Metal bridge memory


**CIGS**
1. Nanowire Lithium Battery Electrodes

Candace K. Chan, Yuan Yang
Collaborator: Prof. Robert Huggins


Battery parameters:
- Energy density: cathode and anode
- Power density: ion intercalation and electron transport
- Cycle life: strain relaxation

What nano can offer:
- New materials otherwise not possible: (high energy density).
- Large surface area and shorter distance for Li diffusion (high power density).
- Good strain release and interface control: (better cycle life).
- Continuous electron transport pathway.
Example: Si as Anode Materials

C anodes: the existing anode technology.

\[
\begin{align*}
C_6 & \overset{\leftrightarrow}{\longrightarrow} \text{LiC}_6 \\
\text{Theoretical capacity: } 372 \text{ mA h/g}
\end{align*}
\]

Si anodes:

\[
\begin{align*}
\text{Si} & \overset{\leftrightarrow}{\longrightarrow} \text{Li}_{4.4}\text{Si} \\
\text{Theoretical capacity: } 4200 \text{ mA h/g} \\
\text{Problem for Si: } 400\% \text{ volume expansion.}
\end{align*}
\]
Vapor-Liquid-Solid (VLS) Growth of Si Nanowires
Nanowire Battery Testing

Three electrode electrochemical measurements

Nanowire electrode (working)

Li foil (reference, counter)

Measured parameters: current, voltage, time.
Ultrahigh Capacity Si Nanowire Anodes

At C/20 rate

- Si nanowires show 10 times higher capacity than the existing carbon anodes.
- Si nanowires show much better cycle life than the bulk, particle and thin film.
- The significance of Si anodes: abundant, mature infrastructure, no need of high purity.
2. Nanowires for Multiexciton Generation (MEG) Solar cells

Jia Zhu, Lifeng Cui

Zhu, Cui *Nano Lett.* 7, 199, 2007
MEG Processes

(Nanocrystals)

Increase coupling

(Klimov, Nozik etc.)
Catalyst: In, Bi, Ga, Pb
Epitaxial Growth NaCl Substrate

Zhu, Cui *Nano Lett.* 7, 199, 2007
3. CuInSe₂ Nanowire Materials for Solar Cells
Hailin Peng, David Schoen, Chong Xie

CIGS: 19.5% efficiency.
CIGS Solar Cells

(R. Noufi et. al.)

Issues
- Grain boundary
- Nanoscale phase inhomogeneity
- CIGS-CdS Interface
Cu-Rich CuInSe$_2$ NWs

Cu:In:Se
26%:23%:51%

Chalcopyrite structure
Cu-Defficient CuInSe$_2$ NWs

Cu:In:Se 15%:34%:51%

- Still Chalcopyrite structure, but with superlattices
- Vacancy ordering
CuInSe$_2$-CdS Core-Shell NWs

CuInSe$_2$ NWs  \hspace{1cm} \text{CdS Chemical Bath Deposition} \hspace{1cm} 5 \text{ min}

[Image of CuInSe$_2$ NWs and CdS deposition process]

[TEM image and diffraction pattern]
CuInSe\textsubscript{2}-CdS Core-Shell NWs

EDX mapping

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Cu ions diffuse out
OVC: ordered vacancy compound
CuInSe2-CdS Nanotubes

Increase CBD time up to 16min at 60°C

Polycrystalline
Cu-In-Cd-Se-S Nanotubes

Nanoscale Kirkendal effect: