OPTOELECTRONIC PROPERTIES OF NANOCRYSTALS

Optical transitions in semiconductors

Absorption of metallic nanocrystals (Au NCs)

[Graph showing absorbance and PL intensity for CdSe nanocrystals of different sizes]

Size

Wavelength (nm)

Absorbance (a.u.)

PL Intensity (a.u.)

4.8 nm

12.6 nm

50 nm

2.5 nm

length/width
diameter

18 nm

4.8 nm

2.5 nm

4.8 nm

4.8 nm

4.8 nm
the charge carrier motion is restricted to a small material volume
MAGNETIC PROPERTIES OF NCs

Nanostructured ferromagnetic materials behave as single magnetic domain whose magnetization can be easily influenced by thermal fluctuations of the local environment, depending on the particle size and on a variety of surface effects.
ONION-LIKE STRUCTURES

Once the synthesis is stopped by lowering the reaction temperature, a surfactant coating layer around the NCs remains tightly bound to their surface and guarantees their full solubility in a variety of organic solvents.

Large interphase between the two materials

Lattice constants do not differ significantly
SELF CLEANING GLASSES

**Photocatalytic Process**
In the photocatalytic process, UV light from the sun energizes the SunClean self-cleaning glass to help slowly break down and loosen dirt and other organic material. Since UV light is abundant even on cloudy days or in shaded areas, this process works non-stop throughout the day.

**Hydrophilic Process**
The coating’s hydrophilic property makes water droplets spread out, or sheet, across the surface of the glass. Because of this, when rain or a light spray of water hits the window, the water helps to more effectively rinse away loosened dirt. This sheeting action, which works throughout the day and night, helps the window dry quickly with minimal spotting and streaking.
NANOMATERIALS IN EVERY-DAY LIFE
Sketch of the mechanism responsible for the reversible wettability changes of the films made of the OLAC-capped TiO2 nanorods.
Pentapeptide

Pal-KTTKS (Palmitoyl-lysine-threonine-threonine-lysine-serine)
Approx. 65 nm³
NASA Nanotechnology Roadmap

**Capability**
- Multi-Functional Materials
- Reusable Launch Vehicle (20% less mass, 20% less noise)
- Revolutionary Aircraft Concepts (30% less mass, 20% less emission, 25% increased range)
- Autonomous Spacecraft (40% less mass)
- Adaptive Self-Repairing Spacecrafts
- Bio-Inspired Materials and Processes

Increasing levels of system design and integration

**Materials**
- Single-walled nanotube fibers
- Nanotube composites
- Integral thermal/shape control
- Smart skin materials
- Biomimetic material systems

**Electronics/computing**
- Low-Power CNT electronic components
- Molecular computing/data storage
- Fault/tolerance tolerant electronics
- Nano electronic “brain” for space Exploration
- Biological computing

**Sensors/s/c components**
- In-space nanoprobes
- Nano flight system components
- Quantum navigation sensors
- Integrated nanosensor systems
- NEMS flight systems @ 1 μW

Timeline:
- 2002
- 2004
- 2006
- 2011
- 2016
Biomimetics and Bio-inspired Systems
Impact on Space Transportation, Space Science and Earth Science

2002
Extremophiles
Biological nanopore low resolution

2010
Embryonics Self Assembled Array
Mars in situ life detector
Artificial nanopore high resolution

2020
Sensor Web Skin and Bone
DNA Computing
Self healing structure and thermal protection systems

2030
Space Transportation
Biologically inspired aero-space systems
Brain-like computing

Mission Complexity

Biological Mimicking
What Is All the Fuss About Nanotechnology?

Nanotechnology influences almost every facet of every day life such as security and medicine.
BUT, IS IT POSSIBLE TO USE NANOTECHNOLOGIES FOR BENEFIT PEOPLE, ESPECIALLY IN DEVELOPING COUNTRIES?
### TOP 10 APPLICATIONS OF NANOTECHNOLOGY FOR DEVELOPING COUNTRIES

1. Energy storage, production and conversion  
2. Agricultural productivity enhancement  
3. Water treatment and remediation  
4. Disease diagnosis and screening  
5. Drug delivery systems  
6. Food processing and storage  
7. Air pollution remediation  
8. Construction  
9. Health monitoring  
10. Vector and pest detection and control
AGRICULTURAL PRODUCTIVITY ENHANCEMENT

Nanoporous zeolites for slow-release and efficient dosage of water and fertilizers for plants, and of nutrients and drugs for livestock

Nanocapsules for herbicide delivery

Nanosensors for soil quality and for plant health monitoring

Nanomagnets for removal of soil contaminants
AGRICULTURE AND WATER

- **Nanomembranes** for water purification, desalination, and detoxification
- **Nanosensors** for the detection of contaminants and pathogens
- **Nanoporous zeolites, nanoporous polymers, and attapulgite clays** for water purification
- **Magnetic nanoparticles** for water treatment and remediation
- **TiO₂ nanoparticles** for the catalytic degradation of water pollutants
FOOD PROCESSING AND STORAGE

- Nanocomposites for plastic film coatings used in food packaging
- Antimicrobial nanoemulsions for applications in decontamination of food equipment, packaging, or food
- Nanotechnology-based antigen detecting biosensors for identification of pathogen contamination
AIR POLLUTION AND REMEDIATION

1907:

“Who should do science? People who don’t like to live in crowded environments, people who like to go to the high mountains to enjoy the fresh air, to be in harmony with nature.”

– Albert Einstein

1994:

“Is this still the role of scientists? Isn’t their role today more about cleaning the polluted cities than escaping to the mountains?”

– Ilya Prigogine, (Nobel Prize in Chemistry, 1977)
AIR POLLUTION AND REMEDIATION
ENERGY STORAGE, PRODUCTION AND CONVERSION

CHALLENGES:
✓ 1.7 – 2 BILLION PEOPLE IN THE WORLD, HAVE NO ACCESS TO ELECTRICITY;

✓ ONE THIRD OF THE WORLD’S POPULATION RELIES PRIMARLY ON TRADITIONAL, NON-RENAWABLE, CONTAMINATING FUELS;

✓ THE RICHEST PEOPLE IN THE WORLD USE NEARLY 25 TIMES AS MUCH ENERGY PER PERSON AS THE POOREST PEOPLE
Urgent Need for an Alternate Source of Fuel

Why hydrogen?
• Highest energy per unit mass for any material (2860 kcal/kg)
• Abundant
• No pollution

SOLUTIONS
• Novel hydrogen storage systems based on carbon nanotubes and other lightweight nanomaterials
• Photovoltaic cells and organic light-emitting devices based on quantum dots
• Carbon nanotubes in composite film coatings for solar cells
• Nanocatalysts for hydrogen generation
• Hybrid protein-polymer biomimetic membranes
A hydrogen fuel cell (internal combustion engine) car will require 4 (8) kg or 225 (450) liters of hydrogen to travel 400 km.

Note: DOE target is system target and will include the density of accessories depending on the materials requirement.

Hydrogen Storage Technology

Gaseous and Liquid Storage
- Gas Storage
- Liquid storage (Temperature = 20K)

Material Based Hydrogen Storage
- Physisorption (porous materials)
- Chemisorption and Chemical Reaction
  - Carbon
  - Metal Hydrides
  - Clathrations
- Metal Organic Framework
“Nano” Challenges in Fuel cells

Nanotechnology push:
- Carbon support research
  - Nanotubes
  - Graphitic carbons
  - Novel nanocarbons
- Catalyst particle size minimization - surface area maximization
- Hydrogen storage

Pt nanoparticles
~10 nm

Photovoltaics

- Capture larger spectrum of solar energy
- By 2035 photovoltaics could produce about 10 percent of the world's electricity
- Play a major role in reducing carbon dioxide emissions
- Nanomaterials used: Nanodots and Nanorods

http://www.physorg.com
http://www.konarkatech.com
HEALTH, DISEASE DIAGNOSIS AND SCREENING
DRUG DELIVERY
Typical Functionalisation and Derivatisation

Physics

Core

Mn:ZnS
Fe₂O₃

Coating

PVA, Silica

Chemistry

Biocompatible Functionalisation

Spacer

Derivatisation

Colloidal chemistry

Carboxyl

Amino

Thiol

Biology

Drug, Protein, ...

Biotin

Avidin

8 nm 10 nm 2 – 30 nm
BIOLUMINESCENCE METHODS

<table>
<thead>
<tr>
<th>Parts of DNA, Proteins, Virus</th>
<th>Cells</th>
<th>Bacteria</th>
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<td>1 nm</td>
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<td>$10^5$ nm</td>
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Nanoparticles

Beads

Inorganic or Organic bead with nanoparticles
BIOLOGICAL APPLICATION IN CANCER THERAPY

Composite Nano-particle

Insoluble polymer core

Active drug

Soluble polymer surface

Circulation of blood

Tumour

Nanoparticle drug delivery Ref. The Engineer, 30 May-12 June 2003, p 15
DEVELOPMENT OF MULTIFUNCTIONAL TOOLS FOR in vivo APPLICATIONS

Blood vessel

TISSUE

magnet

...
MAGNETIC AND FLUORESCENT SYSTEM: GENERAL CONSIDERATIONS

SIZE

In vivo experiments  \( \text{nm} \quad - \quad \mu \text{m} \)  Cell separation  Magnetic separation of target molecules

PREPARATION METHOD

Inorganic synthesis  Direct reaction  Encapsulation

PERFORMANCE: MAGNETIC AND FLUORESCENT PROPERTIES

Depending on the choice of the components of the system

BIOCOMPATIBILITY

Depending for the application in vivo or in vitro
PREPARATION OF FLUORESCENT-MAGNETIC HYBRID NANOSTRUCTURES: STATE OF THE ART

ENCAPSULATION
Yoon T.J., *Small*, 2006. 2 (209)

DIRECT REACTION
Veiseh O., *Nano Letters*, 2005. 5 (1003)

INORGANIC SYNTHESIS
Mesoporous Silica Beads Embedded with Semiconductor Quantum Dots and Iron Oxide Nanocrystals

**PREPARATION**

**STRATEGY n. 1**

Sequential Doping

QD → Optically encoded Bead

Fe₃O₄ → Bifunctional Bead

**STRATEGY n. 2**

Simultaneous Doping

QD + Fe₃O₄ → Bifunctional Bead

**INTERACTION**

**FURTHER STEPS**

- SONICATION
- MAGNETIC SEPARATION
- POLYMER COATING FOR WATER SOLUBLE BEADS

Anal. Chem. 2006, 78, 5627-5632
PREPARATION

* $\text{Ab}_{\text{CD-10}}$
* $\text{Ab}_{\text{HER-2}}$

SIZE: 60 nm
Cytoplasm accumulation confirmed also by TEM

Membrane localization confirmed also by TEM
Superparamagnetic Fe2O3 Beads-CdSe/ZnS Quantum Dots Core-Shell Nanocomposite Particles for Cell Separation

Polymer coated γ-Fe2O3 beads (purchased from Indicia Biotech, France)

Covalent attachment of anticycline E to the luminescent/magnetic particle

fluorescence (a) and transmission (b) microscopy images of anticycline E labeled luminescent/magnetic nanoparticles bound to MCF-7 breast cancer cells.

Traditional View: Increasing Pore Size Increases Specific Capacitance

1. Too small pore size
2. Too large pore size
3. Ideal pore size (~ 3x solvated ion size)

Energy ~ C
Power ~ $\sqrt{\frac{C}{R}}$

Carbon
Surface
electrolyte ions + its solvation shells

$A_3 > A_1; A_3 > A_1$
Are nanoparticles harmful?

- Evidence exists that nanoparticles may be toxic to biological systems.

- When ordinary materials are made into nanoparticles they tend to be more chemically reactive.

- Particles may be able to gain entry into the body via a number of routes: skin, lungs etc.
“The places where [diverse scientific] activity is high, where many scientists are interacting, where there are outstanding people…those are the circumstances that are going to pay off the most.”

– Charles H. Townes (Nobel Prize in Physics, 1964)
The chemist Emilio Segrè
Edoardo Amaldi
Franco Rasetti
Enrico Fermi

The GUYS of VIA PANISPERNA

PHOTOGRAPHER: BRUNO PONTECORVO

MISSING: ETTORE MAIORANA
Good luck for your PhD by
The GUYS of VIA MOREGO 30!!!
Nanocrystalline Solar Cells: The Materials

Materials:
1. (2) F-SnO$_2$ glass slides
2. Iodine and Potassium Iodide
3. Mortar/Pestle
4. Air Gun
5. Surfactant (Triton X 100 or Detergent)
6. Colloidal Titanium Dioxide Powder
7. Nitric Acid
8. Blackberries, raspberries, green citrus leaves etc.
9. Masking Tape
10. Tweezers
11. Filter paper
12. Binder Clips
13. Various glassware
14. Multi-meter
• Catalysis
• Micro-/nano-electronics & optical devices
• optics, ultrafast optical
• switches
• data storage (magnetic, optical)
• Analytical analysis
• Sensors
• Monitoring toxic chemicals
• Energy storage and conversion
• Fuel cells
• Nanocrystal assemblies drastically expands the range of applications
• Collective optical or magnetic properties due to long-range dipolar interactions