Nanotechnology for water treatment and desalination

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Chair in Nanotechnology
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Concerns in water crisis

- **Drinking water production**: Disinfection: extensive chemicals treatments, e.g., chlorine, and high power UV expose.

- **Waste water treatment (industrial and municipal)**: Decontamination (metal ions): extensive chemicals treatments, e.g., chelating chemicals, and absorbents, or membrane technology

- **Seawater desalination**: reverse osmosis membrane
Engineering “natural” systems for water purification

- Next-generation systems: low-environmental-impact, low-energy-intensive, and high efficiency

  - Solar photocatalytic detoxification and disinfection: solar reactors, photocatalysts, hybrid photocatalytic-biological process, and photocatalytic membrane process.

  - Micro/nanotechnology in water purification: carbon nanotubes membranes, nanofiber membranes, nanoporous ceramics, clays, and micro/nanofluidics.

Photocatalysis

Ultraviolet light

Pollutant adsorbs to surface

Adsorbed pollutant breaks down under UV light

Final products (CO2 and Water) desorb

Catalyst Metal Oxide

Reactant Wall
Solar spectra

86,000 TW/year energy on earth (World consumption 15 TW/year)
None of the common oxides meet the criterion.

Band Engineering is so far the only option!
"There are easily 50,000 combinations of ternary oxides and almost 2 million quaternary oxides."
What do we mean by “band engineering”?
• Reduce the band gap.
• Have the right position of the band-edges.
Band engineering of ZnO

Goal is to improve absorption in this region
Defects...not always bad!

ZnO absorbs ultraviolet light. Defects in the crystal can make it absorb visible light.


http://www.sciencesway.com/vb/t17685.html
Catalyst on support

Surface area: crucial for photocatalysis!
Growth of ZnO nanowires

Poor Man’s Nanotechnology

Thiolated substrate

Colloidal ZnO solution

Zinc nitrate + hexamine

Anisotropic Agglomeration of nanowires

Seeds

Sintered at 250° C to remove residues

Zinc nitrate + hexamine

90° C

ZnO nanowires on CATALYST SUPPORTS

Polyurethane Foam (Pore size: 55-65 micron)

Stainless Steel Porous Metal (Pore size: 40μm)

Polyester Scrim-woven

Stainless Steel Screen (Mesh size: 150 x 150 μm)
Photocatalysis

Designer Photocatalyst

- Solar Photocatalytic Degradation
- Active against organic pollutants, microbes
- Active under visible light

Textile wastewater in:
- COD = 465 mg.L\(^{-1}\)
- pH = 8.37 and turbidity = 60 NTU

Textile wastewater out:
- COD = 105 mg.L\(^{-1}\)
- pH = 8.24 and turbidity < 5 NTU

S Danwittayakul, M Jaisai, J Dutta
Applied Catalysis B: Environmental 163 (2015) 1-8
Microbes in water?

49 people die over 15 min in the world due to pathogen–contaminated water.
Mechanism of Microbial Inactivation by Photocatalysis

- Photocatalyst should be in contact with the cell surface for membrane damage to occur.

Ajaya Sapkota, Alfredo J Anceno, Sunandan Baruah, Oleg V Shipin and Joydeep Dutta, Nanotechnology 22 (2011) 215703 (7pp)
Photocatalytic paper: ZnO nanorods on cellulose supports


ZnO nanorods based water purifier

The vision:

Polluted water

Pure water

Pure drinking water for everyone!

Mohammed Abbas Mahmood, Sunandan Baruah, Anil Kumar Anal and Joydeep Dutta

Impact of biofouling

- **Ships / submarines**: increase fuel consumption and corrosion
- **Membranes and pipes**: blockage
- **Floating equipment**: decrease buoyancy
- **Destroy fishnets and cages**
- **Sonar equipment**: create turbulence / barrier of acoustic transmission
- **Heat exchanges**: affect quality and performance
Bacterial density was inhibited by ZnO nano-coatings.

% Mortality after 5 hours (50 Klx)

% Settlement after 5 hours (50 Klx)

% Bugula larvae mortality

Absorbance (620 nm)
Control filter (Without ZnO nanorods) 

Test filter (With ZnO nanorods) 

Control After 5 minutes 

After 25 minutes 

DW control 

Harmful Algal Blooms (HABs)
Capacitive De-ionization

Discharge $\rightarrow$ electro desorption

Outlet

Brine water

Saline water

Inlet

Fresh water

Charge $\rightarrow$ electro sorption

Outlet

Saline water

Inlet

H$_2$O Na$^+$ Cl$^-$

Capacitance, $C = \frac{\varepsilon_r \varepsilon_0 A}{d}$

Potential

Distance, d

Bulk Solution

'0' Potential

$\%$ of charge

Time (s)

Discharging

Charging

63.2

13.5

86.5

100

99

88

95

100

0

0

1$t$

2$t$

3$t$

4$t$

5$t$

1$t$

2$t$

3$t$

4$t$

5$t$
Al Musannah well water desalination

Disinfection Properties

Well water

After desalination

Washing water
Desalination Results

<table>
<thead>
<tr>
<th>Material</th>
<th>mg of salt / gm of electrode at 1.6 V</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACC</td>
<td>7.5 mg/g</td>
</tr>
<tr>
<td>ZnO ACC</td>
<td>13.5 mg/g</td>
</tr>
</tbody>
</table>

Electrode Material

<table>
<thead>
<tr>
<th>% Desalination for different concentrations of NaCl (mM)</th>
<th>2 mM</th>
<th>17 mM</th>
<th>50 mM</th>
<th>100 mM</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACC</td>
<td>39%</td>
<td>28%</td>
<td>11%</td>
<td>5%</td>
</tr>
<tr>
<td>Z_Acc</td>
<td>53%</td>
<td>43%</td>
<td>16%</td>
<td>9%</td>
</tr>
</tbody>
</table>

Conductivity (mS/cm)

Electric field line arrows

Positive electrode attracts anions

ZnO Nanorod

Negative electrode attracts cations

Ion movement

Cl Ion, Na Ion

Graphs showing current (mA) and 1st derivative over time.
Desalination performance enhancement

Desalinated Water Output

Brackish Water Inlet

Diagram showing the performance enhancement with different numbers of cells.

Bar graph comparing efficiency of desalination (Desal) and regeneration (Regen) for 1 cell, 2 cells, and 3 cells.

Efficiency (%) vs. Number of cells:
- 1 cell: Desal 4%, Regen 3%
- 2 cells: Desal 7%, Regen 6%
- 3 cells: Desal 10%, Regen 9%
Thank You

Nanotechnology is the Future
- be a part of the revolution

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