NANOMATERIALS FOR ENERGY APPLICATIONS

Latika Menon
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Associate Professor
Department of Physics
Northeastern University
Boston, MA 02115

Founder
Menon Laboratories, Inc.
Somerville, MA 02143
Titania Nanotubes

Nanoporous Alumina

GaN Nanowires
Titania Nanotubes

- Solar Cells
- Filtration
- Catalysis
- Photocatalysis
Nanotubes per in$^2$

$\approx \frac{1}{4} \cdot 10^{12}$

$= \frac{1}{4}$ trillion

$= 2500000000000$
Short Nanotubes

Ultra-high Aspect ratio tubes

Quasi-Periodic Arrays

Advanced Materials, 19, 946 (2007); JMR, 22, 1624 (2007); JES, 155, E7 (2008); Patent# 20100024879
Dye-Sensitized Solar Cells
Increased light absorption

Increased surface area

Lower resistance to carrier flow
Flexible AIPV/BIPV

Lin et al. Small, 2011
Photocatalytic Anodes for $H_2$ Generation
\[ \eta_e = \frac{I_{ph} \left(1.23V - V_{bias}\right)}{I_0} \]
Au-nanoparticle attached Titania

Catalysis

JMC, 19, 4483 (2009)
Nanotube Powders

Membranes

Filtration Pellets
Filtration Market: ~$8.9B (US 2010)
- Ultrafiltration Market: ~$1.2B
- Biological and Chemical Separation: ~$0.7B
- Treatment of Produced Water: ~$0.86B

Today’s Needs for Clean Water:
- Shortage of Water Resources
- Oil Contamination Due to Drilling and Fracking
- Toxic Elements Removal (e.g. Arsenic)
- Antimicrobial Treatment

Produced Water Facts
- 15-20B Barrels/Year in US (50B Worldwide)
- Water-to-Oil Ratio (WOR)
  - 7:1 US (3:1 Worldwide)
- Companies Pay $3-$12/Barrel of Produced Water
Filtration Industry Pain Points

High-Temperature Robustness
Non-Corrosive in Adverse pH Solutions
Less Susceptible to Fouling
Tight Size Control (<100nm)
Alleviate High Pressure Requirement

Our Material

Melting temperature: 1800°C
Strongly resistant in the 0-14 pH range
Capability for Selective Filtration
Tube diameter control down to 20 nm
Naturally Porous Membrane (High Active Surface Area)
Very low production costs
<table>
<thead>
<tr>
<th>Substrate Material</th>
<th>Commercial Silicon Carbide</th>
<th>Our Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Selective layer material</td>
<td>SiC</td>
<td>TiO₂</td>
</tr>
<tr>
<td>Porosity</td>
<td>40%</td>
<td>60%, easy to control</td>
</tr>
<tr>
<td>Permeability</td>
<td>High because of high porosity and hydrophilicity</td>
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</tr>
<tr>
<td>Temperature Tolerance</td>
<td>Up to 800°C in atmospheric air</td>
<td>Melting point: 1800°C</td>
</tr>
<tr>
<td>Chemical resistance</td>
<td>Resistant in full pH range 0-14</td>
<td>Resistant in full pH range 0-14</td>
</tr>
<tr>
<td>Max Cl concentration</td>
<td>Unlimited</td>
<td>Most likely unlimited</td>
</tr>
<tr>
<td>Solvents</td>
<td>Completely Stable</td>
<td>Stable</td>
</tr>
<tr>
<td>Oxidizers</td>
<td>Any concentration</td>
<td>Already an oxide</td>
</tr>
<tr>
<td>Pore size</td>
<td>0.04 – 3 μm</td>
<td>TBD (~ 0.1 μm)</td>
</tr>
<tr>
<td>Flux Rate</td>
<td>3 – 12 m³/(m²h)</td>
<td>1.2 m³/(m²h)</td>
</tr>
</tbody>
</table>
Low cost nanotechnologies

Nanoporous Alumina

Nanowire Energetics

Metamaterials
Metal-Dielectric Composites

Improved Absorption Wavelength Selectivity

Fe$_2$O$_3$ Oxidizer

Al Fuel

Light-weight, single-use, MEMS-compatible energy sources

Ignition

Au Nanodots

Low-Cost, Scalable Nanotechnology

Nanopores in Si

JES, 151, C492 (2004)
GaN Nanowires

- Multifunctional devices
- Solid State Lighting
GaN Nanowires

- Polar
- Semi-Polar
- Non-Polar

(a) 

(b) 

5 μm

2 μm
Epitaxial GaN
Northeastern University Research Funding
- NSF (CAREER, DMR, ECCS, I-CORPS)
- Airforce, Army, ONR

Lab Highlights
- Over 5M in funding to date
- Graduated 6PhDs and 4MS
- Over 40 papers on nanomaterials
- Outreach and mentoring

Menon Laboratories, Inc.
- Incorporated in March 2013
- MassCEC funding
- Oil and Gas Company funding