Nanostructured Energy Conversion for Low-power Energy Harvesting Devices and Beyond for High-power ‘Sun-to-fiber' Solar Devices

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  – Nobby Kobayashi, J. Varelas

• Research and Educational
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  – M. Meyyappan, J. Koehne, J. Li

• Others
  – M. Sanghadasa, T. Ngo-Duc, J. Gacusan, L. Dugacyzk
Outline

• Part 1: Michael Oye
  – Activities in Advanced Studies Laboratories (ASL), @ NASA Ames in Silicon Valley
  – Educational activities in ASL (research, training, and characterization equipment)
  – Equipment in UCSC MACS Facility at NASA Ames Research Center
  – Nanostructured energy conversion for Low-power Energy Harvesting Devices
    • Piezoelectric Nanowires

• Part 2: Nobby Kobayashi
  – Thermoelectric Nanowires
  – ‘Sun to Fiber” solar devices
Welcome to the
Advanced Studies Laboratory

Advanced Studies Laboratory
Wenonah Vercoutere, ASL Co-Director for NASA Ames
Burney Le Boeuf, ASL Co-Director for UCSC
Michael Oye, Associate ASL Director for UCSC and
  Director of the Materials Analysis for
  Collaborative Science (MACS) Facility
Joseph Varelas, Lab Manager, MACS Facility
Peter Minogue, Marketing and Outreach, ASL

NASA Ames Research Center
Steven Zornetzer, Associate Center Director

University of California Santa Cruz
Silicon Valley Initiatives
Gordon Ringold, Director
Tedd Siegel, Assistant Vice Provost, Associate Director

March 2012
Advanced Studies Laboratory (ASL) Research Areas

- **Applied Materials**
  (e.g. Advanced Energy solutions)

- **Life Sciences/Astrobiology**
  (e.g. Biomedical)

- **Sensors & Networks**
  (e.g. Advanced Electronics)

**MACS Facility:**
Materials Analysis and Characterization for new MATERIALS across traditional disciplines and establishments
Advanced Studies Laboratory Mission Statement

**Purpose of ASL:** Partnership between UCSC and NASA Ames to provide cohesive management and oversight for fostering collaborative research in Silicon Valley

The **mission** of ASL is to create an open and dynamic environment supporting research, technology development, and **educational** opportunities to benefit both parties.

We are cross-disciplinary and cross-institutional.

→ **Adapting to Changing Classroom Environment**

Michael Oye (UCSC and SJSU) & Robert Cormia (Foothill College), with Wenonah Vercoutere (NASA), Nobby, Kobayashi (UCSC), Joey Varelas (UCSC), Peter Minogue (UCSC), and Burney Le Boeuf (UCSC)
“Adapting to a Changing Classroom Environment”... from what?

• Interdisciplinary Research Activities
  – *Subject and Equipment*

• Online Course Delivery
  – *Why do we even need classrooms?*
What we are doing in the Advanced Studies Laboratories in Silicon Valley to address the changing classroom environment:

• Integrating innovative methods for Silicon Valley
  – Teach what to do with information
  – Be flexible (Subject & scheduling → No “Typical” Student)
  – Interactive engagement with hands-on lab projects
  – Scalable (Infrastructure & model)
  – Place for new ideas to grow → I²
    Incubating Innovation, Incubating Individuals, Incubating Ideas, etc...

(I², term coined by Bob Cormia, Foothill College)
Timeline

Spring ’13
• UCSC EE293 Solid State class with lab component in UCSC MACS, supported by Foothill College

Summer ’13
• Course development for integration of coordinated courses between UCSC, SJSU, and Foothill College

Fall ’13
• UCSC EE293, Semiconductor Processing and Characterization
• SJSU MatE 265, Fundamentals of Nanomaterials
• Foothill College, Nanocharacterization
• UCSC Extension

Future
• Integration of Laboratory components to MS EE Courses for Silicon Valley Professionals

2014
• Expand laboratory activities in courses with UCSC Extension, Foothill College, and in MACS/ASL

http://www.ee.ucsc.edu/graduates/silicon-valley
UCSC MACS Facility has Materials Characterization instruments available, on a cost recovery, with on-site Technical Staff

- SEM w/ EDS (1-2 nm resolution)
- TEM w/ EDS (~0.1 nm resolution)
- Metal and Dielectric sputtering, and others

Educational Case Study:
- Students needed equipment for project
- Industry needed student interns and academic experience, provided cost recovery of equipment for project use.
Hitachi S-4800 II FE SEM

- Field Emission Scanning Electron Microscope with light element analysis and EDS.
- 1-2 nanometer range resolution.
- Dual Secondary Electron (SE) detector system for high resolution imaging.
- Backscatter electron (BSe) detector for analysis of insulating samples.
Hitachi H-9500 300kV TEM

- Ultra high-resolution microscope with resolution of 0.10 nm.

- High mag, high sensitivity bottom mount camera for materials science and diffraction studies.

- High performance energy dispersive X-ray spectroscopy (EDS).

- Magnification: 200 – 1500kX.
Materials characterized in UCSC MACS Facility at NASA Ames

• Nanowires
  – Metal oxides & compound semiconductors
    • SEM
    • TEM
    • Ion Beam Sputtering for metals deposition

• For Low-Power Energy Harvesting
  – Take “wasted” energy that would have otherwise been lost
    • Vibrations $\rightarrow$ Mechanical to Electrical (Piezoelectric)
    • Thermal $\rightarrow$ Heat to Electrical (Thermoelectric)
## How much power?

Piezoelectric: \(~330 \, \mu W/cm^3\)
Thermoelectric: \(~40 \, \mu W/cm^3\)

<table>
<thead>
<tr>
<th>Category</th>
<th>Power Source</th>
<th>Power</th>
<th>Conversion</th>
</tr>
</thead>
<tbody>
<tr>
<td>World generation capacity</td>
<td></td>
<td>4 terawatts</td>
<td>(10^{12})</td>
</tr>
<tr>
<td>Power station</td>
<td></td>
<td>1 gigawatt</td>
<td>(10^9)</td>
</tr>
<tr>
<td>House</td>
<td></td>
<td>10 kilowatts</td>
<td>(10^4)</td>
</tr>
<tr>
<td>Person, lightbulb</td>
<td></td>
<td>100 watts</td>
<td>(10^2)</td>
</tr>
<tr>
<td>Laptop, heart</td>
<td></td>
<td>10 watts</td>
<td>(10^1)</td>
</tr>
<tr>
<td>Cellphone</td>
<td></td>
<td>1 watt</td>
<td>(10^0)</td>
</tr>
<tr>
<td>Wireless sensor</td>
<td></td>
<td>1 milli watt</td>
<td>(10^{-3})</td>
</tr>
<tr>
<td>Wristwatch</td>
<td></td>
<td>1 microwatt</td>
<td>(10^{-6})</td>
</tr>
<tr>
<td>Cellphone signal</td>
<td></td>
<td>1 nanowatt</td>
<td>(10^{-9})</td>
</tr>
</tbody>
</table>
Piezoelectric Effect

\[ V_{\text{out}} = h\Delta t \]

- \( h \) is the piezoelectric constant
- \( \Delta t \) is the change in thickness

\[
\frac{\text{Force}}{\text{Area}} = E\varepsilon
\]

- \( E \) is the elastic modulus
- \( \varepsilon \) is strain (or \( \Delta t \))

Tradeoff is \( P = iV \);
Charge is dependent on volume

Some Examples of Low-Power Piezoelectric Energy Harvesting

[Image of piezoelectric concept and realization]

http://ecofriend.com/wp-content/uploads/2012/07/piezo-tree_1_pmPls_69.jpg


Piezoelectric Nanowire Device Integration

• **Nanowire Growth**
  Some examples:
  - Template-directed
  - Free standing (or horizontal growth)
  • Vapor Liquid Solid (VLS)
  • Vapor Solid (VS)

![Diagram of nanowire growth methods](image)

• **Device integration**
  – Making electrodes
  – Extracting electrical current

Controlled Growth of Vertical ZnO Nanowires on Copper Substrate


Growth of Nanowires with varying diameters
- Engineer Piezoelectric response
- Engineer top electrode contact

Oxygen concentration has an impact

Ngo-Duc et al, APL 2013
Multiple segments

Zn flux constant
More relative oxygen → Gets narrower
O arrives before Zn adatoms can migrate

Ngo-Duc et al, APL 2013