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

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M. Oye's research acknowledgments

- UC Santa Cruz
  - Nobby Kobayashi, J. Varelas
- Research and Educational
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- NASA Ames Research Center
  - 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

    UCSC MACS FACILITY
    MATERIALS ANALYSIS FOR COLLABORATIVE SCIENCE
    AT AMES RESEARCH CENTER IN SILICON VALLEY
  - 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

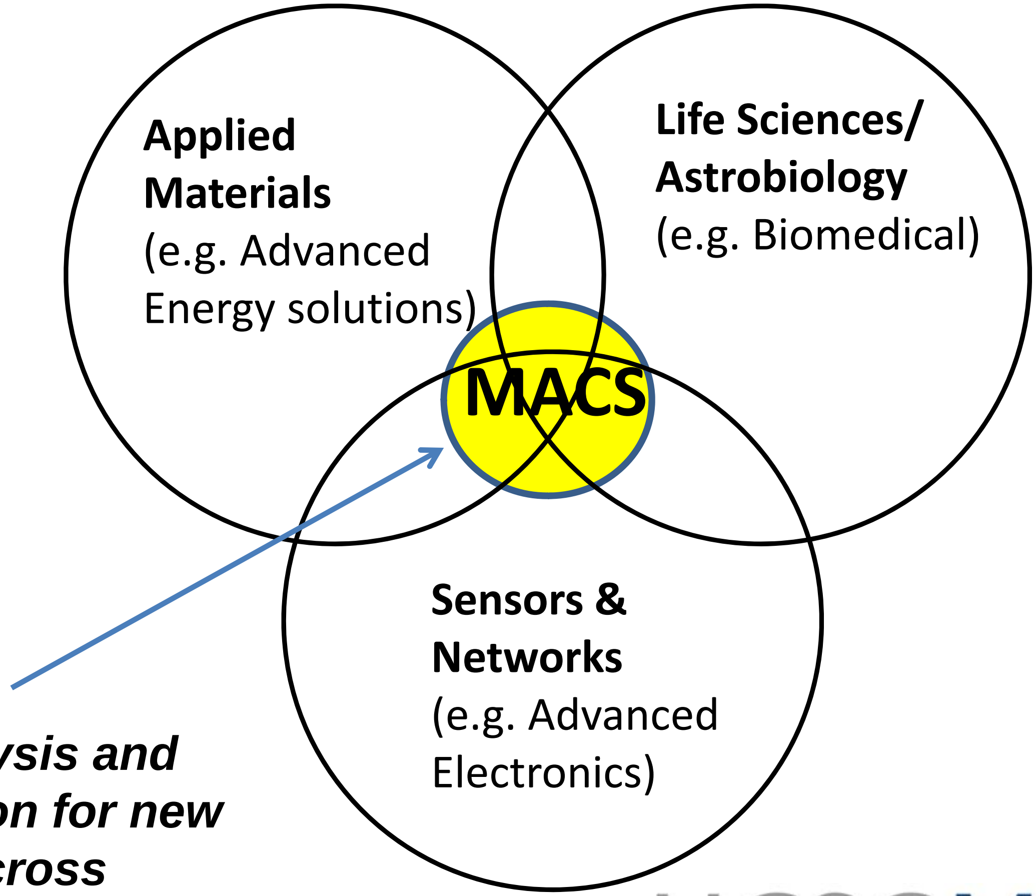
Silicon Valley Initiatives

Gordon Ringold, *Director*
Tedd Siegel, *Assistant Vice Provost, Associate Director*

March 2012

UC SANTA CRUZ | Ames Research Center | ASL The Advanced Studies Laboratories | BINRDI

Advanced Studies Laboratory (ASL) Research Areas



MACS Facility:

Materials Analysis and Characterization for new MATERIALS across traditional disciplines and establishments

UCSC MACS FACILITY
MATERIALS ANALYSIS FOR COLLABORATIVE SCIENCE
AT AMES RESEARCH CENTER IN SILICON VALLEY

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”…***<u>from what</u>***?

- 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 → I^2**
    Incubating *Innovation*, Incubating *Individuals*, Incubating *Ideas*, etc…

(I^2, 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**

2014

- **Expand laboratory activities in courses with UCSC Extension, Foothill College, and in MACS/ASL**

Future

- **Integration of Laboratory components to MS EE Courses for Silicon Valley Professionals**

http://www.ee.ucsc.edu/graduates/silicon-valley

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Ames Research Center

http://macs.advancedstudieslabs.org/

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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.**

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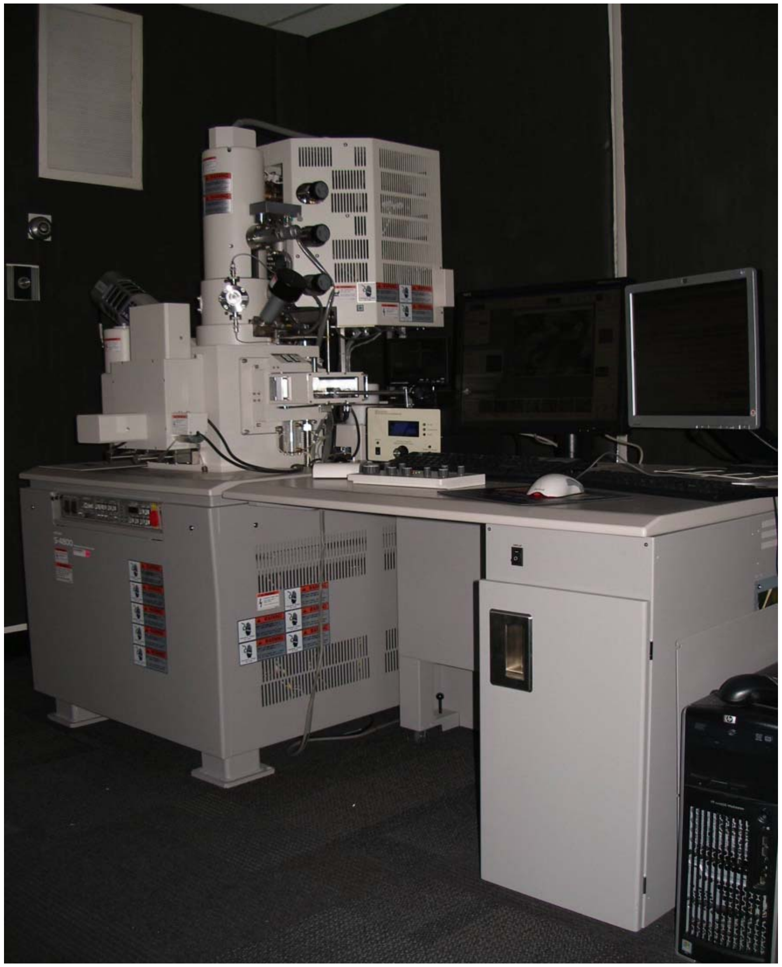
Hitachi S-4800 II FE SEM

- 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.



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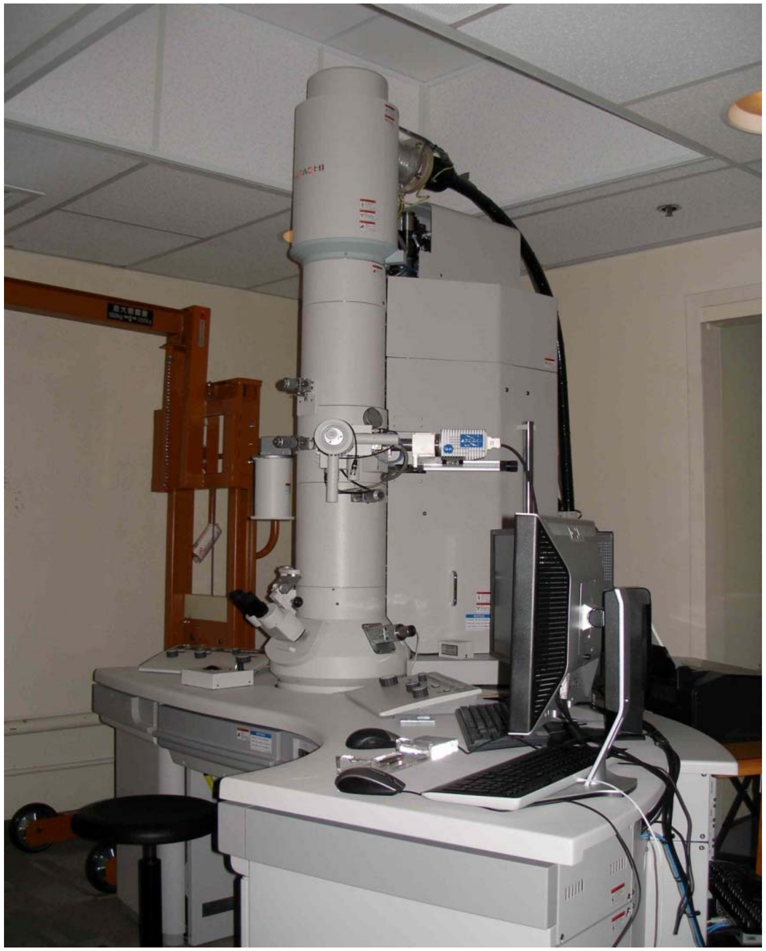
Hitachi H-9500 300kV TEM

- 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

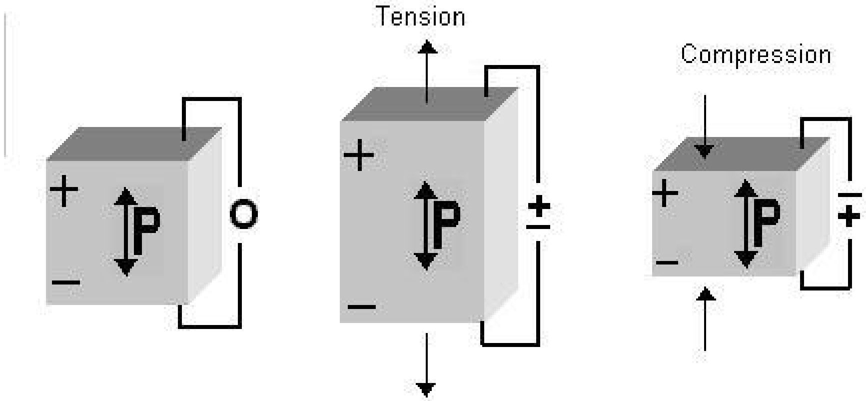
- For Low-Power Energy Harvesting
  - Take “wasted” energy that would have otherwise been lost
    - Vibrations → Mechanical to Electrical (Piezoelectric)
    - Thermal→ Heat to Electrical (Thermoelectric)

How much power?

Piezoelectric: ~330 μW/cm^3
Thermoelectric: ~40 μW/cm^3

World generation capacity	4 terawatts	10^{12}
Power station	1 gigawatt	10^{9}
House	10 kilowatts	10^{4}
Person, lightbulb	100 watts	10^{2}
Laptop, heart	10 watts	10^{1}
Cellphone	1 watt	10^{0}
Wireless sensor	1 milliwatt	10^{-3}
Wristwatch	1 microwatt	10^{-6}
Cellphone signal	1 nanowatt	10^{-9}

Piezoelectric Effect



http://bostonpiezooptics.com/images/content/Fig1-DirectPiezoEffect.jpg

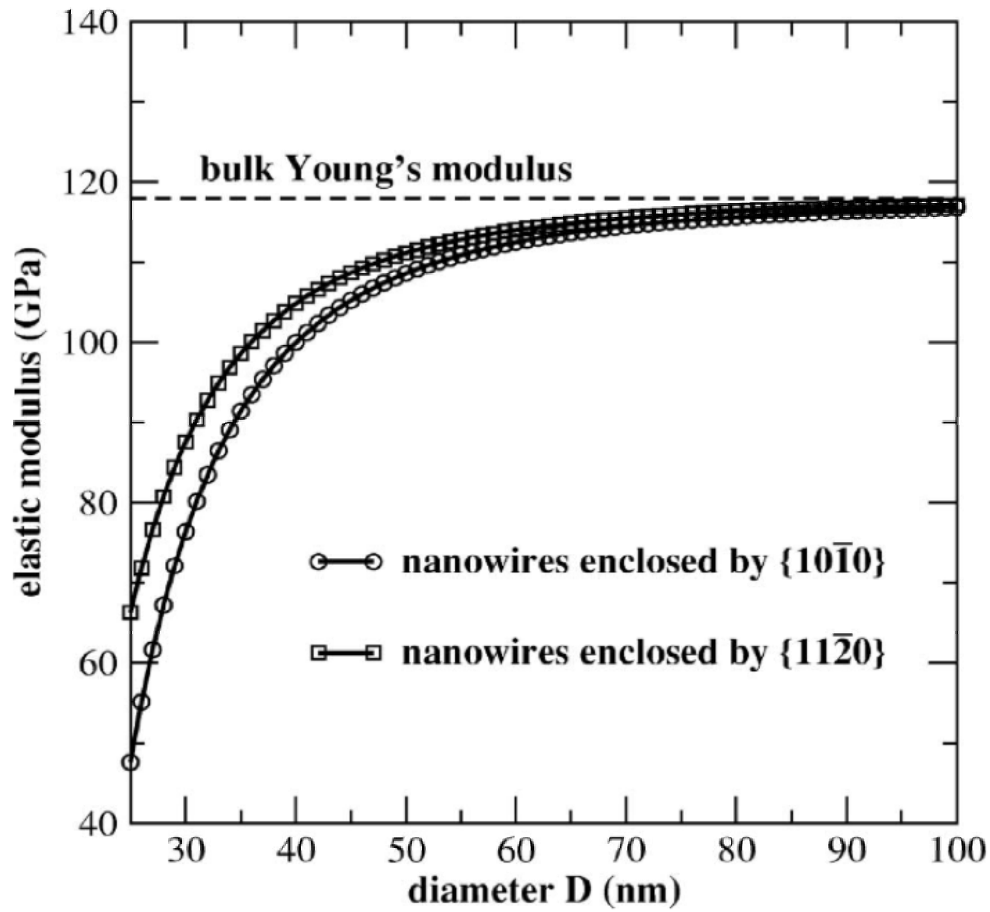
$V_{out} = h\Delta t$

h is piezoelectric constant
Δt is change in thickness

$$\frac{Force}{Area} = E\varepsilon$$

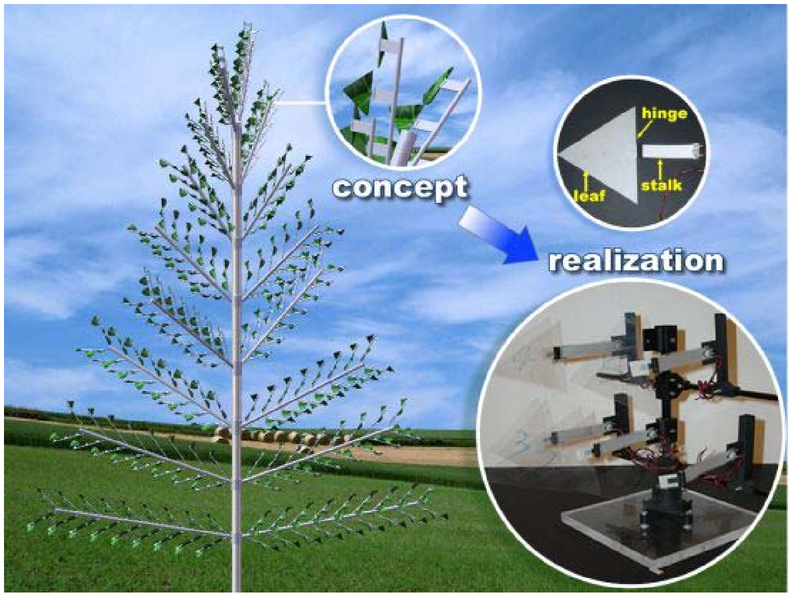
E is Elastic Modulus
ε is strain (or Δt)

Tradeoff is P=iV;
Charge is dependent on volume

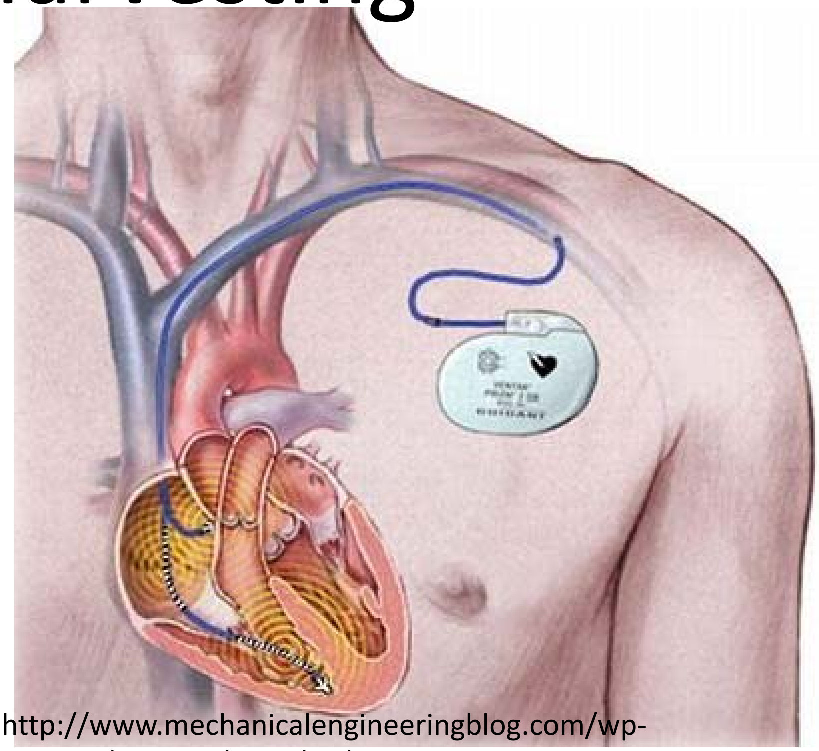


G. Wang and X. Li, Appl. Phys. Lett. **91**, 231912 (2007).

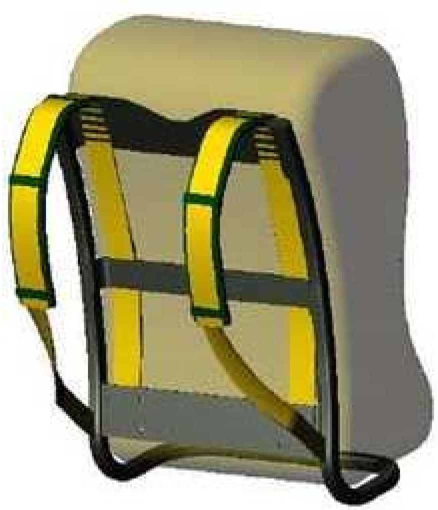
Some Examples of Low-Power Piezoelectric Energy Harvesting



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



http://www.mechanicalengineeringblog.com/wp-content/uploads/2011/04/01-heart-powered-pacemaker-insulin-pumping-by-nano-generator.jpg



http://cdn.physorg.com/newman/gfx/news/2007/EnergyHarvestingBackpack.png

http://itp.nyu.edu/~rcc273/spring2007/itpenergy/images/shoeImages/shoePlunger.jpg

Piezoelectric Nanowire Device Integration

- **Nanowire Growth**

  Some examples:

  -Template-directed

  -Free standing (or horizontal growth)

  - Vapor Liquid Solid (VLS)
  - Vapor Solid (VS)

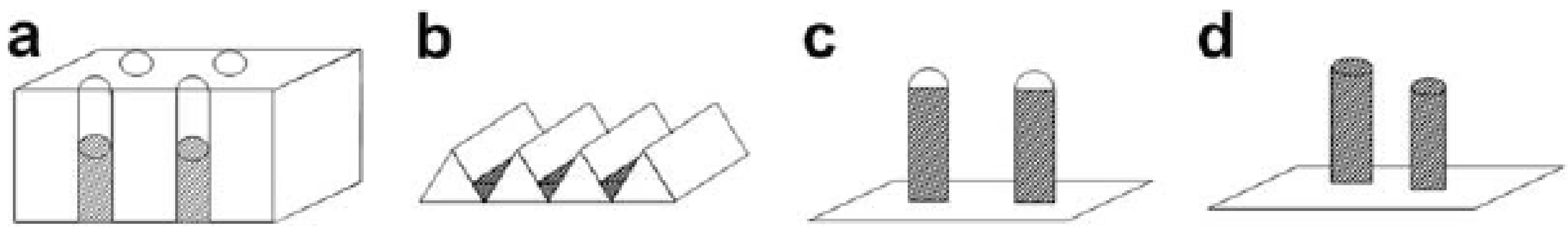


Image from K.A. Dick, Progress in Crystal Growth and Characterization of Materials Volume 54, Issues 3–4, (2008)

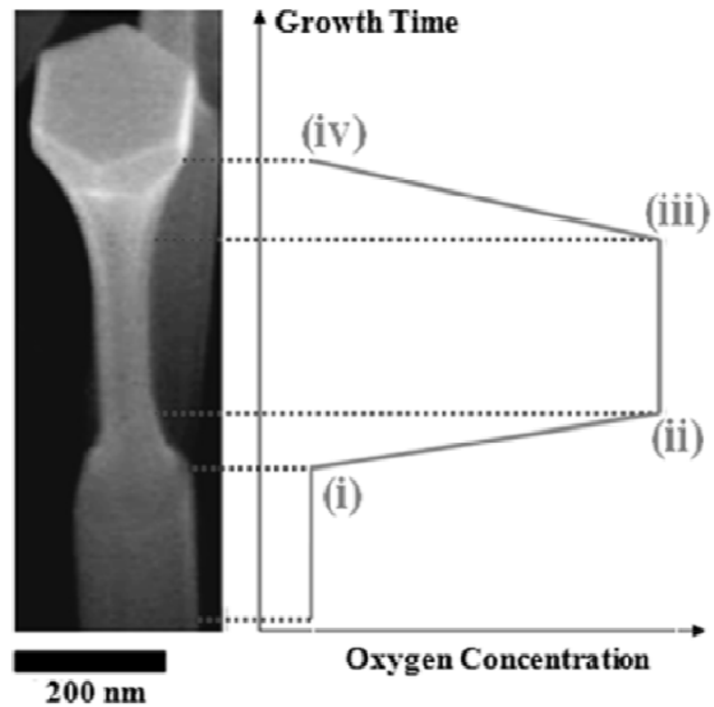
- **Device integration**
  - Making electrodes
  - Extracting electrical current

Controlled Growth of Vertical ZnO Nanowires on Copper Substrate

- T.-T. Ngo-Duc, J. Gacusan, N.P. Kobayashi, M. Sanghadasa, M. Meyyappan, M.M. Oye
  Applied Physics Letters 102, 083105 (2013)

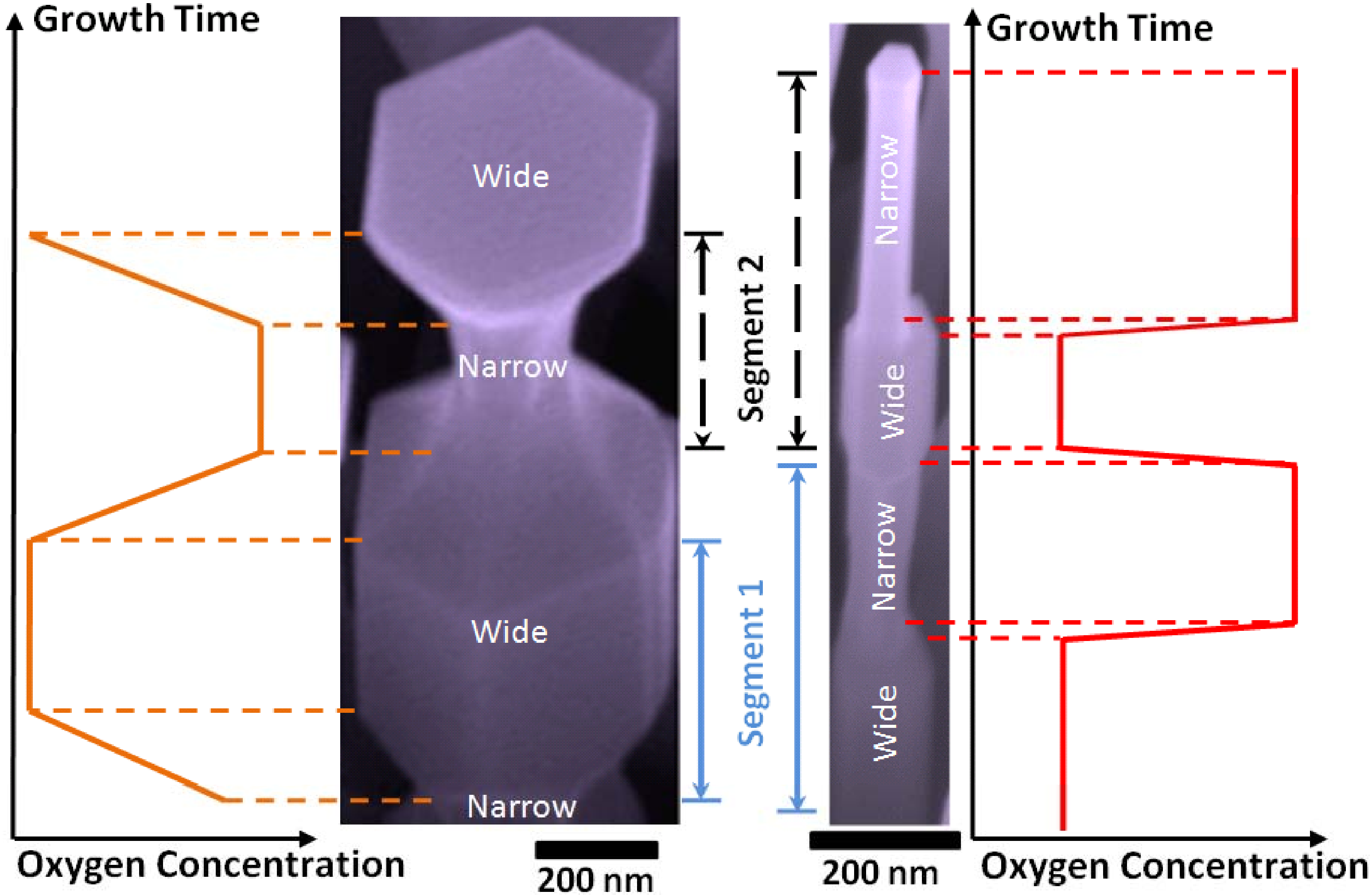
Growth of Nanowires with varying diameters
-Engineer Piezoelectric response
-Engineer top electrode contact

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