Nanostructures for Sensing and Energy Applications

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Outline

• QDs as local thermometers to detect transient intra-cellular temperature of the living cells
• Direct synthesis, assembly for self-aligned 1D nanostructures for gas sensors
• 1D piezoelectric nanofibers as nanogenerators
• 1D nanostructures for energy storage devices
• Summary
Example #2 - Intracellular Temperature

- 655nm CdSe QDs (Molecular Probes)
- Endocytosis QDs into NIH/3T3 cells
- Multicolor Labeling
  - Red: mitochondria
  - Green: actin filaments
  - Blue: nuclei
  - White: quantum dots (temp. markers)
- Confocal Fluorescent Micrographs

![Confocal Fluorescent Micrographs](image)

![Temperature vs Emission Peak](image)
Measurement Results

**Peak Spectrum Shift**

- Peak wavelength of a single QD exhibits a red shift as the temperature increases.
- Intensity decreases with increasing temperature.
- Peak width (FWHM) increases with increasing temperature.

![Graph showing emission intensity, peak wavelength, and peak width vs. temperature.](image)
Example #1 - MEMS Device Temperature

MEMS Heater Temperature Measurement
- Joule Heating Element
- Metal Line Heater (Al)
  1200 x 40 µm

Fluorescent image with QDs coating

steady state solution:

\[ T(x) = T_r - (T_r - T_\infty) \frac{\cosh[\sqrt{\varepsilon} (x - L/2)]}{\cosh[\sqrt{\varepsilon} L/2]} \]

Test #1 Thermogenesis by Calcium

ACS Nano, Vol. 6, pp. 5067-5071, 2011
Test #2 Thermogenesis by Cold Shock
Synthesis, Assembly and Integration of 1D Nanostructures

- **Post-CMOS, site-specific** synthesis, assembly and bonding using MEMS as the “bridge”
- **Nano + MEMS + Microelectronics** with on-chip process control and sensing microelectronics

Nanostructures (nanowires, Nanotubes ....) → MEMS → Microelectronics
Room Temperature Chamber

- CMOS-compatible nanostructure synthesis & assembly
- Site-specific CVD activated by resistive heating
Electric Field Assisted Synthesis & Assembly of 1D CNTs

Si Microstructure

Output V (V)

Synthesis time (sec)

Voltage Data Acquisition

Sample A (1 MWNT connection)
Sample B (2 MWNT connections)

First MWNT (Sample B)
Second MWNT (Sample B)

1 MWNT connection (sample A)

Temperature

C2H2 gas flow

Synthesis pressure

Bias between Si (V2)

Electric field (V2/gaps)

850 – 900 °C

50 sccm

50 – 250 Torr

5 – 10 μm

0.2 – 1 V/μm
Electrothermal Single CNT Gas Sensor


\[ \frac{1}{2} W_C = k_{CNT} A \left. \frac{dT_{CNT}}{dl} \right|_{l=0} \]
ENERGIZER: UC Berkeley professor Lihui Lin works in his laboratory. Lin and his team are developing the microscopic devices that could one day power your iPod.

TECHNOLOGY

One day, microfuel cells may power your iPod
Near-Field Electrospinning

Nanoletters, Vol. 6, pp. 839-842, 2006

- Electrode-to-collector distance: 500–1000 μm
- Drive voltage: 600–1500 V
- Tip diameter: 25 μm or smaller
Large Area Deposition

- A single nanofiber in a designed trajectory
  - 4X4 cm² area
  - 15 min deposition period for a total length of 108 m, nanofiber has a diameter of 700 nm
Long Term Stability Test

- 0.04% strain applied at a frequency of 0.5Hz for 100 min
What is the Goal?

- Commercial “Electric clothing” products for energy generation
- Minimum impact to the comfort of cloth
- Nanofiber for high energy conversion efficiency

Exhalation
0.4W (1.0W)

Breathing Band
0.42W (0.83W)

Finger Motion
2.1mW (19mW)

Footfalls
8.3W (67W)

Blood Pressure
0.37W (0.93W)

Arm Motion
0.33W (60W)

Step!

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Supercapacitor electrodes by CNT Forests

(a) 

(b) 

(c) 

(d) 

Uniform height

100 µm 

500 µm 

100 µm 

4 µm 

h ~ 80 µm
Principle of Pseudo-capacitor

Mechanism of pseudo supercapacitor

- Pseudo supercapacitors balance between supercapacitor and battery
- Metal oxide (Mn, Ru, Ni, etc.) and conducting polymer all act as coating materials
- Electroplating is liquid phase, low cost and capable of selective deposition

\[
\text{Ni(OH)}_2 + \text{OH}^- \rightarrow \text{NiO(OH)} + \text{H}_2\text{O} + e^- 
\]
Electroplating results and analysis


(a) Before electroplating  (b) After electroplating
Results from Ni-plated CNT supercapacitor

- Significantly enhance the energy density up to one order
- Robust operation of over 100 times charge/discharge tests.

60µm CNT forest, 2min electroplating:
- From $C_{SP, intrinsic}$ = 8 mF/cm²
- To $C_{SP, functionalized}$ = 56 mF/cm²
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