(Self-assembled) Carbon nanotube Structures and Devices

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CNT Devices

Abrams et al., nano letters 2007

Gabay et al, nanotechnology 2007

Karp et al., JMM 2009

Neurochips
CNT Chemical Vapor Deposition

- Nano-sized metal catalyst
- 900 deg process
- $\text{C}_2\text{H}_4$ or $\text{CH}_4$
CNT Growth from Pillar Tops

1. **Why** are the tubes so visibly taut between the pillars?
2. **Engineering**: How can this effect be utilized?
TEM Analysis

Nanotubes grown over holes provide an equivalent testing system.

Holes in grids are 2 or 40 μm wide.

Bending, buckling, adhesion, deformation

Tube-Tube/Surface Interactions

DPD Model

- Thermal vibrations
- Tube-tube interactions
- Oscillators
  - Strain
  - Temperature
  - Slackness

O. Liba et al., International Journal for Multiscale Computational Engineering, 2009
O. Liba et al., Molecular Simulation, 34, 737 - 748, 2008.
Tube-tube interaction:  
Self assembly of coils and junctions
Application I: CNT Stamping

Application II: NEMS
CNT NEMS

Karp et al., J. Micromech. Microeng, 2009
Suspended CNT Devices

Raman

(a)

(b)

(c)

\[ I_{ds} [\text{nA}] \]

\[ V_{ds} [\text{V}] \]
CNT NEMS

**Equation:**

\[ f = \frac{1}{2} \sqrt{\frac{T}{\rho AL^2}} \]
Application III: CNT Multi electrode array (MEA)

Shoval et al., Frontiers in Neuroscience 2009
Shein et al., BioMed Micro Dev 2009
Greenbaum et al., J NeuroSci Method 2009
Gabay et al., Nanotechnology 2007
CNT Neuro Chip

Neurons (brain cells)

Electrodes

Voltage
raw data
Entanglement

Neurons

Glia

Fluorescence confocal

HRSEM

Sorkin et al., Nanotechnology 2009
Recordings from a Retina

Target: 625 electrodes, center-center spacing = 20 $\mu$m

Evelyne Sernagor and Christopher Adams, UNC
Flexible Devices
Flexible Devices

CNT film

TiN pads

Graph showing the relationship between resistance and the number of squares.

Graph showing Raman shift with intensity in arbitrary units.
CdSe QDs on CNT Electrodes
Mark Shein, Nitzan Herzog, Moshe David Pur, Lilach Bareket, Shira Snadbank, Assaf Ya’akobovitz (ME, TAU), Gabi Karp, Inbal Friedler, Raya Sorkin, Alon Greenbaum, Tamir Gabay, Gabi Karp, Orly Levy, Ze’ev Abrams

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Andreas Griner, Jan Korvink, David Kauzlaric (IMTEK)
Evelyne Sernagor, Christopher Adams (UN, UK)

Eshel Ben-Jacob (Physics, TAU)
Amir Ayali, Sarit Anava (Zoology, TAU)
Ori Cheshnovsky, Zvi Ioffe (Chemistry, TAU)
Slava Krylov (ME, TAU)

Nofar

Rafael

precede Technologies

DDR&D
Summary

- CNT can be seamlessly integrated into micro-fabricated devices
- Novel NEMS Devices
- Pristine CNTs as a new bio-material
Stimulation

Q_c = 0.8 nC

current (uA) duration (μs) (30 repetitions)
Intervals Top: 10, Bottom: 20 (μs)

\[ Q = I \times \text{time} \]

Jonas Zimmermann, Christopher Adams and Evelyne Sernagor
DPD Model

- Three types of conservative forces
- The force constants are determined by calibration through “virtual experiments”

\[ F_{ij} = -k_h(r_{ij} - r_0)e_{ij} \]

\[ u_a = -(k_a/2)(\cos(\alpha) - \cos(\alpha_0))^2 \]

\[ F = -\nabla u_a \]

\[ u_{LJ} = 4\epsilon \left( -\left( \frac{\sigma_{vdW}}{r_{ij}} \right)^6 + \left( \frac{\sigma_{vdW}}{r_{ij}} \right)^{12} \right) \]

O. Liba et al., International Journal for Multiscale Computational Engineering, 2009
O. Liba et al., Molecular Simulation, 34, 737 - 748, 2008.
Charge Injection Limit

2 μA pulse for 50 ms

\[ Q = I \times t = 1 \times 10^{-7} \text{ C} \]
\[ d = 80 \mu \text{m} \]
\[ A = 5 \times 10^{-5} \text{ cm}^2 \]

<table>
<thead>
<tr>
<th>Electrode Material</th>
<th>( Q_A )</th>
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<tbody>
<tr>
<td>CNTs</td>
<td>( 2 \times 10^{-3} \text{ C/cm}^2 )</td>
</tr>
<tr>
<td>Pt</td>
<td>( 5 \times 10^{-4} \text{ C/cm}^2 )</td>
</tr>
<tr>
<td>AIROF</td>
<td>Activated iridium oxide film</td>
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</tbody>
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