Aligned Carbon Nanofibre-Polymer Composite Membranes

CNT Growth and Manipulation

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- Plasma CVD Growth – Polymer/Nanofibre Composite
- Low ambient temperature growth
- Dielectrophoretic separation of metallic and semiconducting SWNT & its use in device fabrication (if time)
**Plasma CVD Growth of Nanotubes /fibres**

- \( T = 700 \, ^\circ \text{C} \)
- **Ni catalyst** \( \text{C}_2\text{H}_2:\text{NH}_3 = 1:5, \) 4 Torr  tip-grown fibres
- **Fe catalyst** \( \text{C}_2\text{H}_2:\text{H}_2 = 1:3 \) 7 Torr  base-grown MWNT

![Diagram of plasma CVD setup](image)

![SEM images of Ni and Fe catalysts](image)
Growth Quality depends critically on Plasma Current Density

Array growth on Mo substrate

$C_2H_2:NH_3 = 1:5$

Kabir et al., Nanotech. 16 (2005) 458
Kabir et al., Nanotech. 17 (2006) 790
Optical spectroscopy shows the relative decrease in molecular/atomic precursors and also a clear increase in CN intensity beyond 30 mA (4.5 mA/cm²)

- Onset of non-catalytic deposition and increased sputtering

M. Jönsson
Can these vertically aligned CNF be used to make an anisotropically conducting polymer membrane?
Polymer – CNT Composite Materials

Array of individual nanotubes grown on a Mo substrate

Arrays after spin-coating showing photonic-crystal effects

Morjan, Gromov, Gindre
Electrical Characterisation

Two probe measurements (-5;+5)V
Deposition of gold electrodes by metal evaporation with a mask
(0.5mm in diameter and 2mm apart)
Measured resistance through film without fibre
i.e. Polystyrene alone (3 µm thick): $10^4 \, \Omega$

With CNF: 50 Ω

There are approximately 45000 nanofibres contacted for each measurement

- The average resistance per fibre is ca. 200-300 kΩ
  (compares with ca. 100 kΩ for individual fibres with 0.5 mA current carrying capacity)
Removing the polymer from the substrate

alkali base

alkali base

Leave for a couple of days

Few GΩ along the membrane (2 mm distance)
How to reduce the chip temperature to make good quality CNT at temperatures lower than 450 °C (CMOS compatibility)?

Use very local resistive heating only where you want the nanotube(s) to grow.

Mo Electrodes with narrow resistive bridge. Catalyst deposited on bridge (5nm Al₂O₃, 1 nm Fe)

14 mA, 2V for heating

Dittmer et al., Appl. Phys. A in press
Temperature simulation corresponding to conditions in the experiment
Room Temperature Growth: MWNT

No electric field applied during growth

MWNT (Fe catalyst, acetylene precursor)
$C_2H_2:H_2:Ar = 10 \text{ sccm}: 300 \text{ sccm}: 500 \text{ sccm}$

Dittmer et al., Appl. Phys. A, in press
Replace acetylene with ethylene

SWNT

Chip at 60 °C

0.7-1.8 nm diameter

AFM
Growth stops when temperature falls below ca. 500 °C
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<th>Thanks to:</th>
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<tr>
<td><strong>Array Growth and Membranes:</strong></td>
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<tr>
<td>Oleg Nerushev</td>
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<tr>
<td>Raluca Morjan</td>
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<tr>
<td>Martin Jönsson</td>
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<tr>
<td>Baptiste Gindre</td>
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<td>Andrei Gromov</td>
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<td><strong>Dielectrophoretic Separation:</strong></td>
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<td>Andrei Gromov</td>
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<td><strong>Nanorelay:</strong></td>
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<tr>
<td>SangWook Lee</td>
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<td>Anders Eriksson</td>
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<td>Jari Kinaret et al (theory)</td>
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<td><strong>Low Temperature Growth:</strong></td>
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<td>Staffan Dittmer</td>
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AC Dielectrophoresis for separating metallic and semiconducting nanotubes

\[ \vec{F} \propto \varepsilon_1 \text{Re}(\frac{\varepsilon_2^* - \varepsilon_1^*}{\varepsilon_2^* + 2\varepsilon_1^*})\nabla |\vec{E}|^2 \]

For semiconducting SWNT F is negative, for metallic SWNT the force is positive, attracting the CNT to the electrodes. (Krupke et al)

In this way metallic nanotubes can be preferentially attracted to electrodes leaving proportionately more semiconducting SWNT in dispersion.

Nanotubes left in dispersion after deposition cycles

Raman analysis

Although the interaction time is very short we get a significant increase in metallic content of lower channel on a single pass.
λ_{ex.} 785nm

> 50% metallic

Still problem with bundle formation

Reference sample suspension in Na-DOC,

Metallic fraction 6mg/L in 1% Na-DOC
Carbon Nanotube Nanorelay

high Q oscillator, logical switch, bistable memory element, Mechanical resonance frequency in GHz range, switching speed could be faster.

J. Kinaret et al. (S. Viefers), Appl. Phys. Lett. 82, 1287 (2003)

Nanorelay Fabrication

Acid free method to make suspended structure:
Introduction of critical point drying led to 75% suspension.

$I_{\text{source-drain}} \text{ vs Gate Voltage, } V_{SD} = 0.5 \text{ V}$