SCANNING TUNNELING MICROSCOPY AND SPECTROSCOPY OF CARBON NANOTUBES COUPLED TO METAL ISLANDS

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The unique properties of carbon nanotubes (CNTs) such as a 1D structure and dependence of chiral indices make them a promising candidate for molecular electronics. However, the device characteristics of CNT transistors and photodetectors are largely determined by their electronic coupling to the various metal electrodes. Therefore, understanding and designing the electron transport across this interface with such devices is crucial. Scanning tunneling microscopy (STM) is a powerful tool for probing the physics of these types of nanostructures. We disperse CNTs on a substrate of nanometer-sized metal islands, which have been evaporated onto highly ordered pyrolytic graphite. Imaging and spectroscopy of CNTs on the metal islands are obtained using STM and the electronic structure at this junction is explored.

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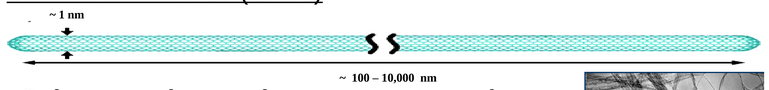
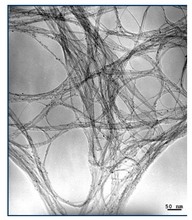
Background & Purpose

Carbon Nanotubes (CNTs)



Carbon Nanotubes is carbon quantum wires with unique properties. One of the unique properties is extremely strong quantum confinement because of large aspect ratios. A diameter of conventional CNTs is about 1nm, whereas a length of it achieves about 100-10,000 nm. Another unique point is structure-dependent electrical properties. Sometimes CNTs works as metal and other times it works as semiconductor.

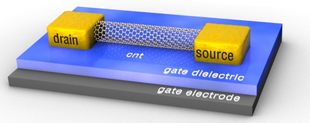


Unidym Homepage (http://www.unidym.com/)

Molecular Electronics

Molecular Electronics is the idea of using molecules for the fabrication of electrical components. Carbon Nanotube Field-Effect Transistors (CNT-FETs) is one such example. CNTs have ideal properties including high electrical conductivity for building nanoscale electronic devices.

CNT-FETs

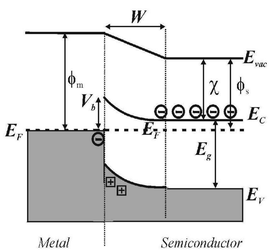


http://www.jameshedberg.com/scienceGraphics.php?sort=all&id=carbon-nanotube-FET

Aviram, A. & Ratner, M. A. Molecular rectifiers. *Chem. Phys. Lett.* **29**, 277–283 (1974)

Schottky Barrier

The device characteristics of CNT-FETs and photodetectors are dominated by their electronic coupling to the various metal electrodes. In a simple Schottky model, the Schottky barrier is determined by the energy difference between the metal work function and the CNTs electron affinity. However, the metal work function is affected by not only bulk but also surface contribution.

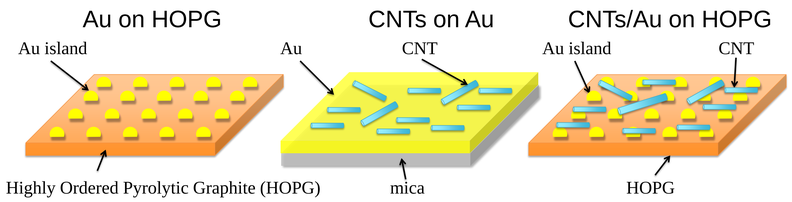


http://www.porous-35.com/electrochemistry-semiconductors-5.html

Our goal is to establish a sample preparation protocol that will allow us to perform atomic-scale spectroscopy which will allow a greater understanding of charge transfer.

Experimental method

Three kinds of samples



Substrate preparation

- Au/HOPG substrate

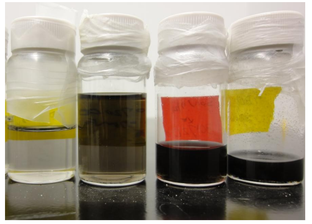
1. Cleave HOPG sample with adhesive tape
2. Evaporate Au under high vacuum

- Au substrate

1. cut a piece of gold
2. flame anneal for 10 min.

Solution preparation

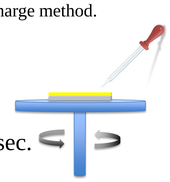
1. Dissolve CNTs in *N*,*N*-Dimethylformamide (DMF)
2. Dilute desired concentration
3. Sonicate solution for 5h
4. Wait for 2h - one night
5. Resonication for 1 – 3h



diluted solutions (45x, 14x, 5x and 1x)
SWCNT sample is P2-SWNT by Carbon Solutions Inc.
It is synthesized by the arc-discharge method.

Spin coating

1. Set a substrate
2. Drop the prepared solution onto substrate
3. Wait for 3 min.
4. Start rotating at 250 rpm and maintain for 10 sec.
5. Increase rotating speed at 2500 rpm and maintain for 60 sec.

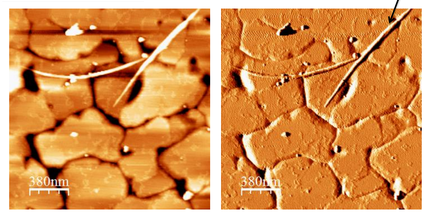


Evaluate

- Atomic Force Microscope (AFM) was used for optimization of coverage. (image scale is about 10μm × 10μm)
- STM was used for measurement of electrical geometry. (image scale < 0.5μm × 0.5μm - few nanometers)

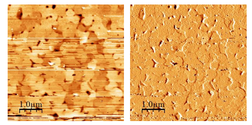
Result & Discussion

CNTs on Au



- AFM image

Image size 1.9 μm × 1.9 μm (solution diluted 5 times)

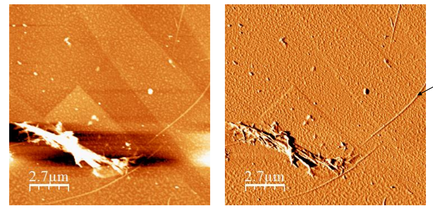


- AFM image

Image size 5.0 μm × 5.0 μm
(solution diluted 45 times)

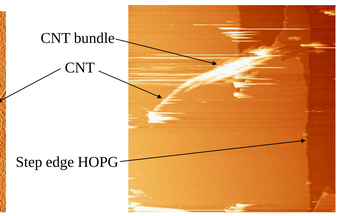
We tried 4 kinds of diluted solutions (1x, 5x, 14x and 45x). CNT"s from a sample of the 5x diluted solution were observable and CNTs from the other samples were not seen.

CNTs on Au/HOPG



- AFM image

Image size 13.7μm × 13.7μm



-STM image

Image size 420 nm × 420 nm
Vs = -1.021 V, *I* = 0.05pA

Conclusion & Future work

In this research, appropriate dilution, sonication and spin coating conditions for dispersion of SWCNT's over different substrates were acquired. These three parameters are intertwined with each other.

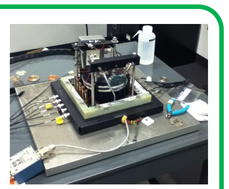
For future directions, a further investigation using STM and local work function images could be obtained. Trying with different kinds of metals would also help us understand the nature site by site of charge transfer .

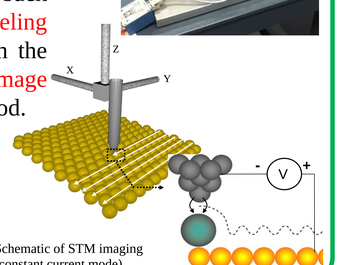
Fundamentals

Scanning Tunneling Microscopy (STM)

STM is a kind of microscopy, which uses tunneling current. Tunneling current is fed back and Z position is changed to maintain tunneling current constant. Output image is reflected in the electrical geometry. The local work function image is also able to be acquired by one kind of method.

$$I \propto \int_0^{eV_s} \underbrace{\rho_s(E)}_{\text{Local Density Of State (LDOS)}} \underbrace{\rho_t(-eV_s+E)}_{\text{Constant}} \underbrace{T(S,eV_s,E)}_{\text{Reflected in the distance between sample and tip}} dE$$

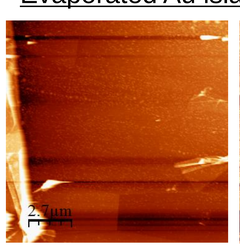


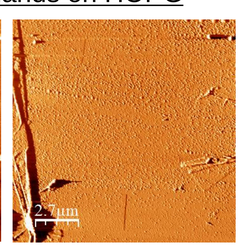


Schematic of STM imaging (constant current mode)

Result

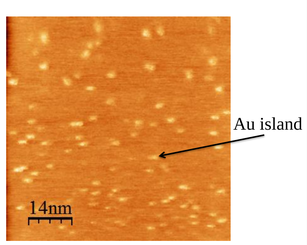
Evaporated Au islands on HOPG





-AFM image

Image size 13.7μm × 13.7μm



-STM image

Image size 70.2nm × 70.2nm
Vs = -0.506 V, *I* = 310 pA

Acknowledgement

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