Carbon Nanotube Electronics

CNF Project # 900-00

PI: Paul L. McEuen

Abstract:

Carbon nanotubes (CNTs) exhibit extraordinary properties and potential for manifold applications in different fields. Our well-established approach to mass fabricating single-walled CNT devices using photolithography has proven useful for a variety of experiments. We have combined this process with several other techniques to make more advanced and special devices, e.g., for electro-mechanical studies on nanotubes and for biological nanotube sensors. The requirements of a few applications made it necessary to develop alternative methods of producing dedicated nanotube devices using e-beam lithography.

Summary:

Due to their inherently small size (a few nanometers in diameter) and their interesting electronic and mechanical properties, CNTs have found a vast set of applications [1]. Creating large numbers of CNT devices has enabled us to rapidly explore their properties and potential applications in different environments and experimental geometries. Our well-established approach employs photolithography and lift-off to define catalyst pads and gold electrodes, with CNT growth using a chemical-vapor deposition method in between these two lithographic steps. This method allowed us to produce hundreds of CNT devices a month with 1-3 µm separation between source and drain contact.

Following fabrication, we can use an atomic force microscope (AFM) to manipulate nanotube devices individually. The AFM enables us to push, nick and cut nanotubes [2] so as to eliminate superfluous tubes and create unusual or artificial nanotube device geometries. This manipulation can be monitored readily and easily on the AFM through advanced scanned probe techniques like scanned gate microscopy and electric force microscopy.

To study the interplay of electrical and mechanical degrees of freedom, we have suspended CNTs over a trench between source and drain contacts. Such devices are fabricated from our standard process with an additional etch step at the end. As the etching must be benign to the nanotube, we etch the thermal oxide between the source and drain contacts chemically, followed by critical point drying. Using an AFM tip to mechanically stretch the suspended CNT while electrically monitoring the device resistance, we found that the electrical properties of CNTs are very sensitive to strain [3]. This relationship makes CNT devices a potential candidate for high sensitivity force sensing.

In another electro-mechanical application, suspending CNTs over narrow trenches allows us to explore their potential as high frequency nanomechanical oscillators. As the width of the trench (ranging from 100 nm to 1 µm) determines the frequency of the oscillating CNT, we employ e-beam lithography to define the trench. Such tuned high frequency devices should enable us to study the connection between vibrational and electric properties of CNTs.

Operating as field effect transistors (FETs), CNTs outperform current silicon MOSFET devices significantly. To this end, we have studied CNT FETs in solution using the electrolyte as a gate [4] and collaborated to integrate thin Zirconium oxide as gate oxide with high dielectric constant in a top gate device geometry. The top gates in between source and drain contacts were fabricated using electron beam lithography at Cornell NanoScale Facility (CNF). In both experiments, CNT FETs exhibited very high carrier mobility and transconductance with subthreshold swings approaching the theoretical limit [5].

Given their small size, sensitivity to their electrostatic environment, and compatibility with liquid environment, CNTs have potential for biosensing. As many biomolecules (like DNA) are highly charged, CNTs may detect their presence and give an electrical signal in response. Our approach towards such a nanotube biosensor involves the combination of electrical transport, microfluidics, and fluorescence microscopy. CNT devices for this experiment are fabricated using our standard photolithographic process. The microfluidic channels, made of poly dimethyl siloxane (PDMS), require the fabrication of an inverse stamp for the PDMS mold. Given the channel size (typically 10 µm wide, 30 µm tall), we use photolithography and Bosch etch.

References:

[1] P. L. McEuen, “Single-wall carbon nanotubes”, Physics World, 6/2000.
[2] J.-Y. Park et al., “Electrical cutting and nicking of carbon nanotubes using an atomic force microscope”, Appl.Physics Let., 80, 4446 (2002).
[3] E. D. Minot et al., “Tuning Carbon Nanotube Band Gaps with Strain”, Physical Review Letters, 90 (15), 156401 (2003).
[4] S. Rosenblatt et al., “High Performance electrolyte-gated carbon nanotube transistors”, Nanoletters, 2 (8), 869 (2002).
[5] A. Javey et al., “High-kappa dielectrics for advanced carbon nanotube transistors and logic gates”, Nature Materials, 1 (4), 241 (2002).

Carbon Nanotube Electronics

CNF Project # 900-00 ***PI: Paul L. McEuen***

Users(s):
Markus Brink
Ethan Davis Minot
Luke Donev
Vera Sazonova
Ji-Yong Park
Jiwoong Park
Xinjian Zhou
Sami Rosenblatt
Yuval Yaish
Joseph Scott Bunch

Principal Investigator(s):
Paul L. McEuen

Affiliation:
Physics Department, Cornell University

Primary Funding Source:
MARCO/DARPA, CNS, CCMR,
Packard Foundation

Contact:
mb235@cornell.edu
minot@ccmr.cornell.edu
ld58@cornell.edu
vas24@cornell.edu
jp276@cornell.edu
jiwoong@uclink4.berkeley.edu
xz58@cornell.edu
sami@ccmr.cornell.edu
yuvaly@ccmr.cornell.edu
jsb49@cornell.edu
mceuen@ccmr.cornell.edu

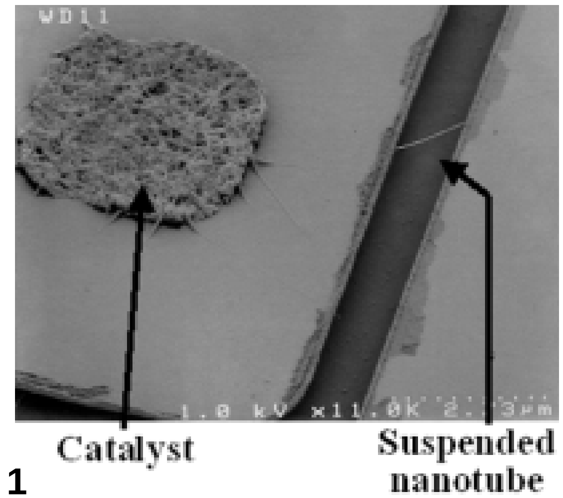
www.lassp.cornell.edu/lassp_data/mceuen/homepage/welcome.html

www.cnf.cornell.edu

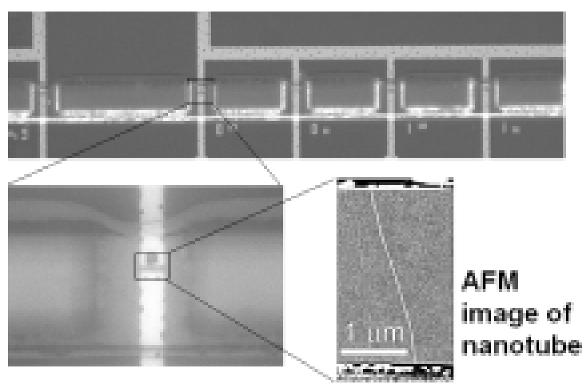
Figure 1, top right:
SEM of suspended carbon nanotube.

Figure 2, below left:
PDMS microfluidic channel over nanotube device array.

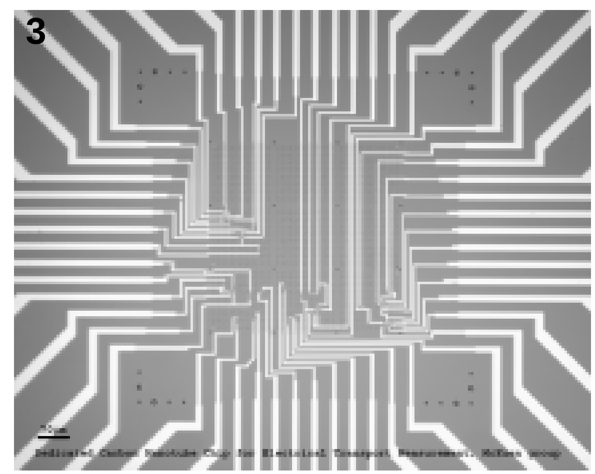
Figure 3, below right:
Dedicated carbon nanotube chip for electrical transport measurement, McEuen Group.



1



2



3