Graphene Nanoribbons from Carbon Nanotubes

CNF Project # 900-00
Principal Investigator: Paul McEuen
User: Luke Donev

Affiliation: Physics Department, Cornell University
Primary Funding: Cornell Center for Materials Research and the National Science Foundation
Contact: mceuen@ccmr.cornell.edu, LD58@cornell.edu
Web Site: http://www.lassp.cornell.edu/lassp_data/mceuen/homepage/

Abstract
We make thin graphene nanoribbons from carbon nanotubes. We do this by cutting open carbon nanotubes with an oxygen plasma. We use the nanotube as a self shadow mask for a protective etch mask layer along one side of the nanotube, and remove the other side. The remaining strip of the carbon nanotube is a ribbon of graphene a few nanometers wide. This fabrication technique lets us study graphene nanoribbons and junctions of graphene nanoribbons with carbon nanotubes.

Summary
Carbon nanotubes, discovered more than a decade ago [1, 2], are straws a few nanometers in diameter made up of carbon in an sp² hybridization. Conceptually, one can think of carbon nanotubes as graphene, individual sheets of graphite, rolled on to itself to close the edges. In practice, nanotubes are grown from catalyst particles as tubes [3]. Recently, there has been an explosion of interest in graphene [4-7]. Our research is focused on opening sections of nanotubes to get back to the graphene sheet, making graphene nanoribbons from carbon nanotubes. See Figure 1. This research also provides a way to make graphene nanoribbon-nanotube junctions.

We start with a doped silicon/silicon dioxide wafer and lithographically define catalyst pads. We deposit iron nanoparticles from solution, and use the rapid heating method [3] to grow our nanotubes from a C₂H₄ and CH₄ feed gas. Electrical contacts of palladium are lithographically defined and deposited at both ends of the nanotube, followed by larger gold contact pads. We then do an initial electrical characterization of the nanotube’s conductance versus back gate voltage.

After the electrical characterization, we cover the nanotube and electrical contacts with photoresist. We expose and develop a few microns of resist along the nanotube between the electrical contacts. A thin layer of aluminum (~ 2 nm) is deposited at an angle (~ 60°) over the entire chip. The nanotube casts a deposition shadow, leaving an exposed leeward part of the tube; see Figure 2. The aluminum is oxidized, and the wafer transferred to a plasma cleaner. A short (~ 6 s) burst of low intensity oxygen plasma (~ 200 pW/µm²) is used to burn away the exposed section of nanotube. The aluminum oxide and photoresist are then removed.

Figure 1: A schematic of a carbon nanotube with localized damage, resulting in a small strip of graphene.

Figure 2: A schematic of a carbon nanotube (black circle) partially covered with aluminum oxide (grey) on a silicon/silicon dioxide wafer (hatched).
removed, and the devices are electrically characterized again. We can tune the parameters on different tubes to see from no change in the conductance to zero conductance (severing the tube completely).

After the localized damage to the nanotube, we use a variety of scan probe techniques to investigate the damaged tubes. Atomic force microscopy shows clear height changes in the section of the device damaged by plasma. In Figure 3, the height goes from 1.6 nm in the undamaged section on the left, to 0.2 nm in the damaged section on the right. We believe this is an example of a graphene nanoribbon fabricated from a carbon nanotube. Electric force microscopy shows that the voltage drop along the device comes in the area where the tube was damaged by plasma. Scan gate microscopy shows the device is most sensitive to a local gate voltage in the region damaged by the plasma. Having developed a method to fabricate graphene nanoribbons, we can now start to study their properties and the properties of nanoribbon-nanotube junctions.

References