Nanoelectromechanical Devices Based on Suspended Carbon Nanotube and Ge Nanowire Field Effect Transistors

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Abstract:

Semi-conducting carbon nanotubes (CNT) and germanium nanowires (GNWs) are desirable field-effect transistor (FET) elements because of their unique electrical properties and physical stability. Previous electromechanical measurements on CVD-grown suspended carbon nanotubes have shown that the band-gap of the tube can grow or shrink depending upon both the tube's chirality and on a tensile or perpendicular force from an AFM tip. Shorter and smaller diameter PECVD-grown tubes exhibit higher percentages of semi-conducting rather than metallic tubes. We are developing a process to suspend PECVD-grown nanotubes and germanium nanowires in FETs and to make similar measurements to determine the mechanical as well as electromechanical properties of nanotubes and nanowires. We will be investigating the compatibility of PECVD with previous techniques for measuring CVD-grown tubes by first fabricating and then measuring nanotube devices. In parallel, we will explore techniques to suspend nanowires in FETs, which has not yet been accomplished. AFM cantilever deflection and I-V_g curves will be used to obtain results.

Introduction:

Carbon nanotubes are excellent one-dimensional elements for integrated circuitry (IC) because of their ability to ballistically transport electrons and because of their semiconducting properties. CNTs' ability to withstand high current densities makes them optimal components in nano-scale integrated circuitry. Previous experiments have shown that CNTs can be reliably grown across trenches and held in place on a substrate by Van der Waal's forces. Electrodes on either side of the trench can then be used to measure the tube's electrical properties while suspended and also while under mechanical strain. Similar suspended measurements have not yet been made on GNWs.

Until recently, there has not been a way to grow either semiconducting or metallic tube with high selectivity. Li, et al., have developed a PECVD process which produces ~ 90% semiconducting tubes [1]. Controlling the chirality of tubes is very important in developing appropriate methods for their incorporation into conventional IC processes. A challenge related to using the current PECVD growth process is to create high-quality tubes with lengths similar to those produced by current CVD growth.

Experiment:

A 1300-nanometer oxide layer was grown on heavily doped (I prime) silicon wafers. A thinner (~ 270 nm) layer of nitride was then grown on top of the oxide to assure undercutting later in the process. One-µm-deep trenches were formed by patterning using the Karl Suss MA6/BA6 contact aligner with 3612 resist, dry etching, and wet etching. The wet-etch step is necessary to assure discontinuity in the metal deposition forming the electrodes. Electrodes were formed on either side of the trench through a lift-off process. A 600 nm spin-coat of PMMA was followed by a 1.6 µm spin-coat of 3612. The 3612 resist was exposed and developed, and the exposed PMMA was dry etched. Deposition of 5Å of tungsten was followed by a 30 nm layer of platinum. The

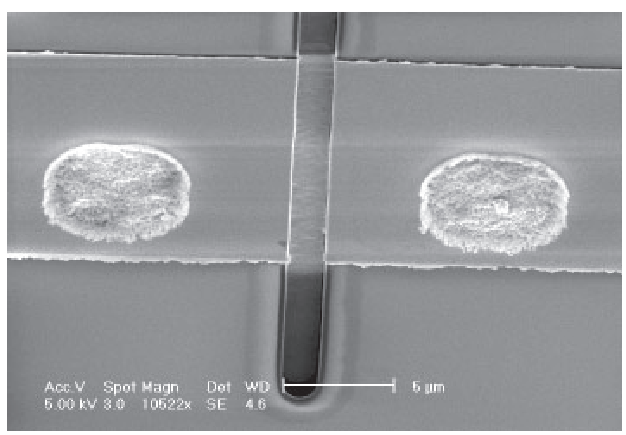

Figure 1: Scanning electron microscope image close-up of the trench, electrodes, and catalyst pads. The line outlining the trench shows the extent of the wet-etch undercut.

electrodes were patterned by an acetone lift-off. Catalyst pad windows were formed on either side of the trench through the same process.

The catalyst pads contained less than a monolayer of discrete 300-atom ferretin particles and were patterned with lift-off. Growth occurred at 600°C, with 80% CH_4 in argon flowing at a rate of 60 sccm. The plasma power was turned on for 3 minutes (RF power ~75 W) for PECVD growth. The gases and plasma were then switched off and the system was cooled to room temperature.

Results and Conclusions:

Due to an error in an etching process, the first group of devices did not show significant response to changes in back-gate voltage. We were able to reproduce existing results to verify the quality of the second batch of fabricated devices. This included showing devices with very little hysteresis in the current vs gate voltage (I-V_g) curve sweeping from $^-5$ to 5 volts and back again. Preliminary data from PECVD tube growth shows a large amount of hysteresis compared with CVD growth, however, these results will need to be verified through many more trials.

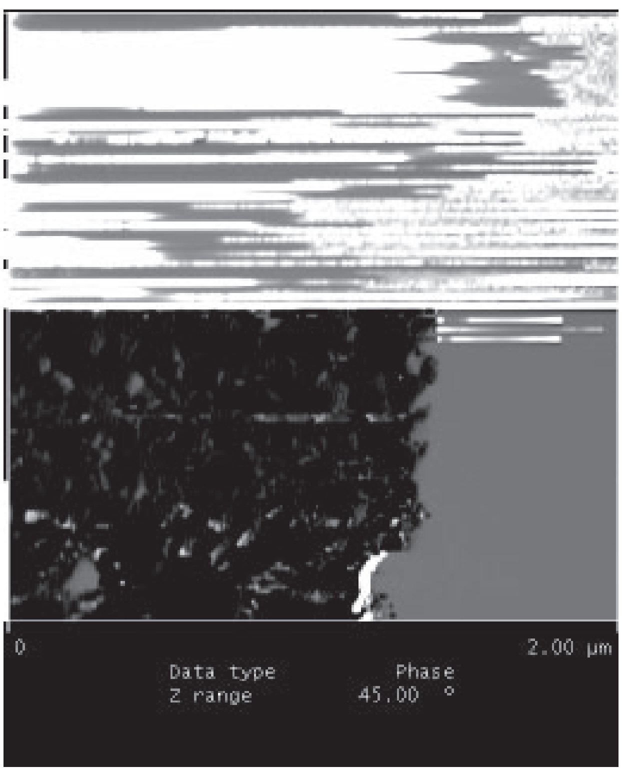

Figure 2: AFM showing the disruption of scanning due to a nanotube sticking to the atomic force microscope tip, ergo we were able to find and hit the tube.

Future Work:

Future studies will continue to focus upon PECVD tubes. Perhaps future studies will extend the study of electromechanical properties to silicon germanium and silicon nanowires. Other electromechanical measurements can be made on PECVD tubes and nanowires using a different type of suspended transistor device where the nanotube is not directly touched by the AFM tip.

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References:

[1] Li, et al. Preferential Growth of Single-Walled Carbon Nanotubes by a Plasma Enhanced CVD Method. Nano Letters, 4(2), 317-321 (2004).

[2] Tombler, et al. Reversible electromechanical characteristics of carbon nanotubes under local-probe manipulation. Letters to Nature, 405, 769-772 (2000).

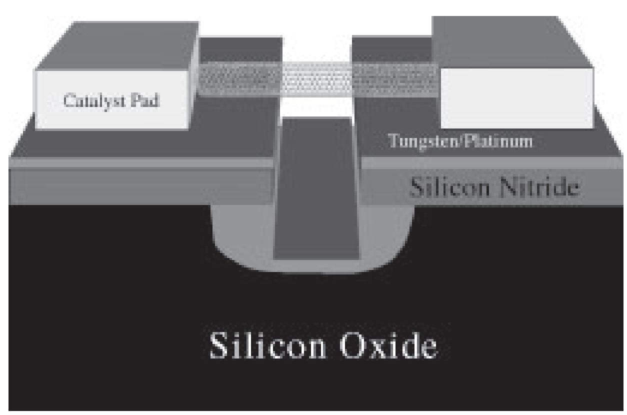

Figure 3: Conceptual representation of a suspended nanotube device.