Carbon Nanotube Transistor Fabrication and Reliability Characterization

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Abstract

Carbon nanotubes (CNT's) are molecular-scale tubes of graphitic carbon with outstanding properties. CNT's are stronger than steel, harder than diamonds, and also posses unique electrical characteristics such as the following: high electrical conductivity, very high tensile strength, highly flexible, high thermal conductivity, and good field emission of electrons. They have the ability to increase the tensile strength and halt crack propagation in concrete, provide stronger yet lighter sports equipment, produce artificial muscles, stronger bridges, are instrumental in production of a space elevator, and act as transistors/diodes/resistors in computer circuits. However, commercial applications have been gradual due to high production costs and issues concerning reliability. When exposed to oxygen or a natural atmosphere, the nanotubes degrade within a few days. Therefore, we suspended CNT's in various polymers which provided a medium that should protect the carbon nanotubes from the atmosphere.

By placing the suspended CNT's on devices that were built on silicon wafers, we were capable of measuring the CNT electrical characteristics. Therefore, we were able to observe how the CNT's degrade with time while being suspended in various polymers. The goal was to discover a polymer that increased the amount of time that CNT's remain effective, and hence greatly enhanced their stability and utilization.

Introduction

The proposed problem is that carbon nanotubes are degrading too quickly in ambient air. Therefore, the point of the study is to experiment with different polymers to passivate the nanotubes and increase their working lifetime. It was hypothesized that carbon nanotubes coated with a polymer will not degrade as quickly as those not coated with polymers. The theoretical implication of the study included the fact that the exact causes of CNT degradation are not known, and the results should determine how the atmosphere changes the quality of the CNT.

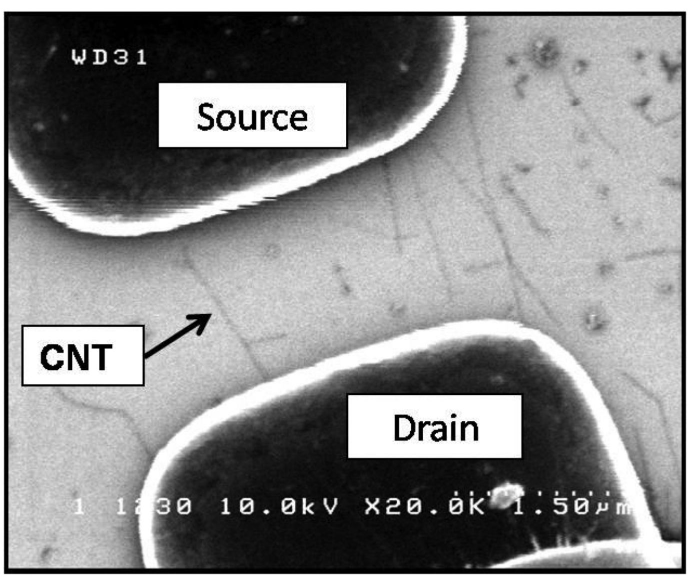

Figure 1: SEM image of CNT connected via the source and drain electrodes on the device.

Experimental Procedures

The experimental design revolved around a plan to build devices, on silicon wafers, which were capable of testing the electrical characteristics of CNT's, and then placing the CNT's on the devices. The CNT's were in the form of a liquid solution which contained completely dispersed CNT's as shown in Figure 1. In order to build the devices and coat them with the polymer, four photolithography steps utilizing different masks were required. Mask one: gold/chrome deposit and liftoff. Mask two: source drain electrodes for CNT. Mask three: isolation to separate devices via gold/chrome etching. Mask four: polymer deposit and polymer etch from bond pad. (Note: The CNT's were deposited using the dielectrophoresis (DEP) method. Experiments were completed to find the etch rate for each polymer, which was removed using the dry etching process.) Figure 2 displays a cross-section of the method for building the device, and the deposition of the CNT's and polymer.

Results

The first run results were flawed due to an issue concerning oxide breakdown, which occurred with those wafers that originally consisted of a 10 nm oxide layer. The calculated

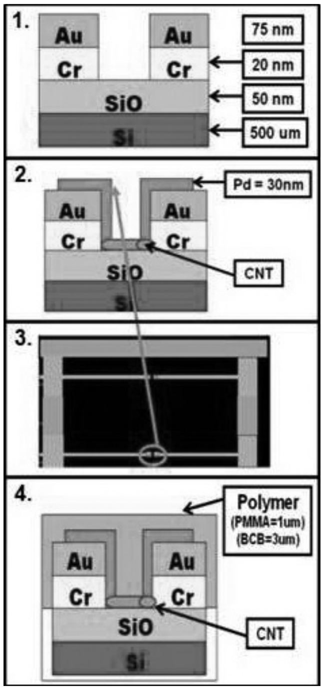

Figure 2: Cross section of four mask method.

voltage breakdown (VB) equaled 100 V. However, the measured VB was 10 V. The remaining runs utilized wafers which consisted of a 50 nm oxide layer which prevented further occurrences of oxide breakdown.

Repeatability test were completed to understand how the probing process may affect the results. One repeatability test showed that when the devices are probed once and a voltage sweep is applied continuously over a set period of time, the results are repeatable. However, the results are not repeatable when the devices are probed multiple times and a voltage sweep is applied each time the device is re-probed. During the first run of the multi-probed repeatability test, the gate and drain current dropped significantly after the eighth device probing was complete.

After the four mask method was complete, the wafer with no polymer had a 69% yield of good devices (see Figure 3), while the wafer covered with polymethyl methacrylate (PMMA) had a 33% yield, and the wafer covered with benzocyclobutene (BCB) had a 7% yield.

A high drain current is desired, because drain current behaves as a conductor. Gate current behaves as an insulator; therefore it needs to be relatively small. The electrical characteristics of the same devices were measured and compared each day to observe the amount of time that elapsed before CNT degradation was noticed (see Figure 4). The CNT's on the wafer without the polymer and the wafer coated with PMMA degraded at

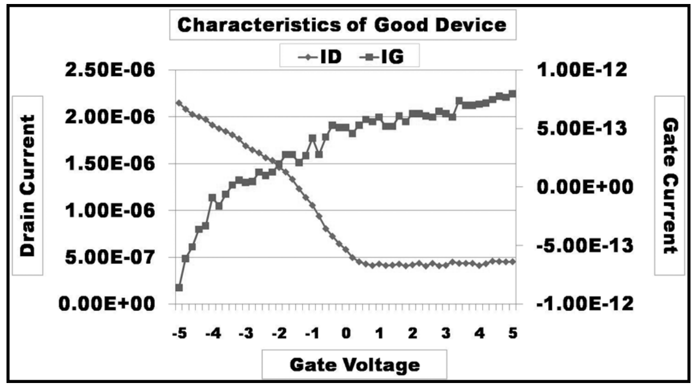

Figure 3: Example of a good semiconductor device.

approximately the same rate. However, on day eight of the experiment, 8% of the devices on the wafer without the polymer remained functional, while 31% of those on the wafer covered with PMMA remained functional. After three days, 0% of the devices on the wafer covered with BCB remained functional.

Conclusion and Future Work

The results led us to conclude that passivation does not appear to improve CNT lifetime, multiple probing appears to degrade the results, and BCB processing degrades CNT yield. The future work involves repeating the experiments with other polymers to observe how the polymers alter the CNT lifetime.

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References

[1] Sedra, Adel S., and Kenneth C. Smith. Microelectronic Circuits. New York: Oxford University Press, 2003.

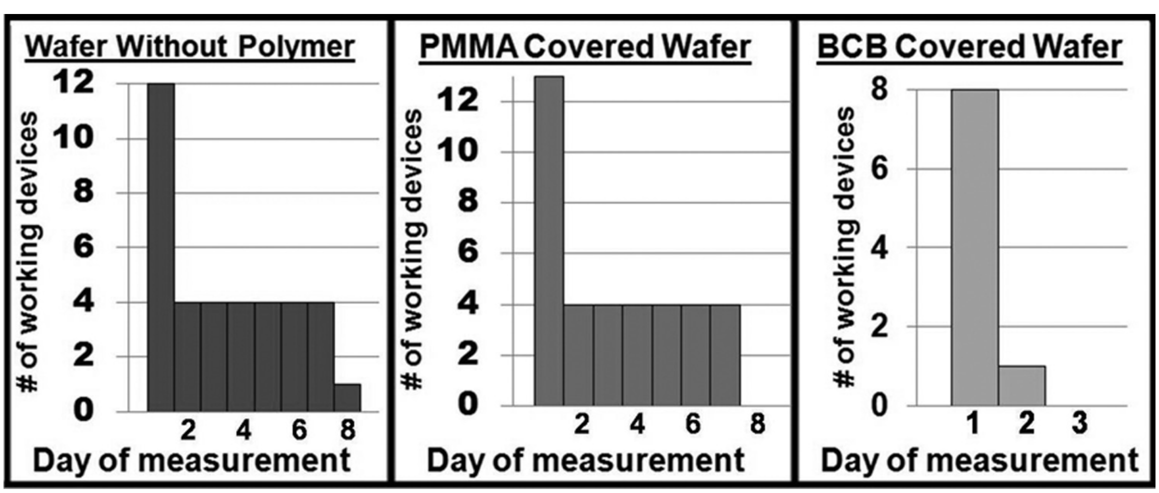

Figure 4: Results of degradation rates for each wafer.