Carbon Nanotubes for Sensing Applications

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Introduction

The Army Research Lab, in conjunction with the University of Maryland, is researching the potential of carbon nanotube (CNT) devices for use as sensors. By measuring characteristics such as gate capacitance and conductance, these devices may be used to sense certain gases present in the air. Exploring the response of CNT devices to various environs could lead to a smaller, lightweight gas sensor.

Device Architecture

Three CNTFET devices were fabricated to measure their capacitive behavior under various conditions to determine if they can be used as gas sensors.

These devices use a single CNT as the FET channel. It is contacted on both sides of the CNT by gold source and drain contacts and is top gated by an aluminum contact. The device can also be back gated through the silicon substrate.

Al and Au were chosen as contact metals in order to explore the role of their work functions in conducting to the CNT. Al was also chosen because deposition conditions may cause a small layer of Al_2O_3 to form between the metal and the CNT, serving as a dielectric

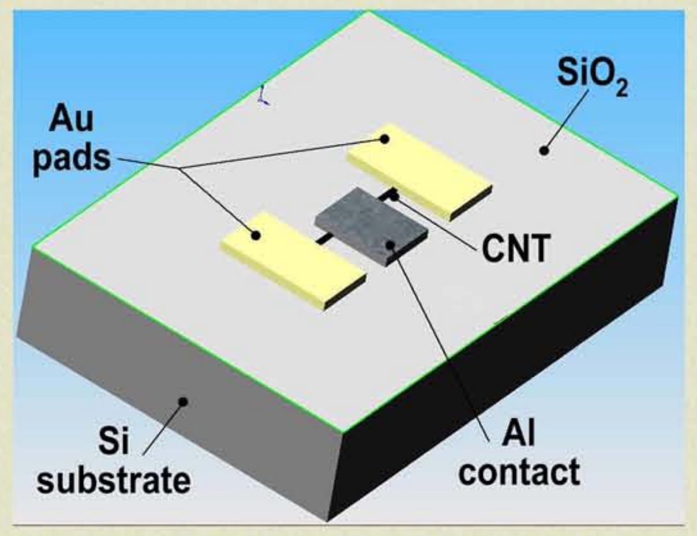

Figure 1: A 3D CAD Model of the Single CNT Device

Device Fabrication

Fabrication Process:

1: CNTs grown on doped Si/SiO$_2$ (500nm) substrate by chemical vapor deposition (CVD)

2: Alignment markers patterned onto substrate for contact positioning

3: Source and drain contacts written onto substrate using e-beam lithography

4: 5 nm Cr and 75 nm Au deposited to make source and drain contacts

5: Top gate contacts written onto substrate using e-beam litography

6: 80 nm Al deposited to make top gate contact

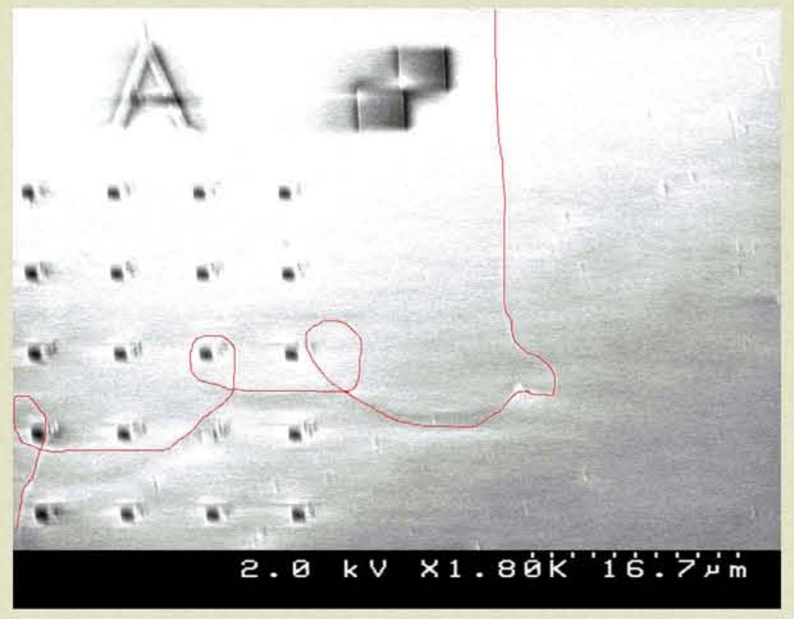

Figure 2: An SEM image of alignment markers on top of silicon. The path of the CNT is shown in red.

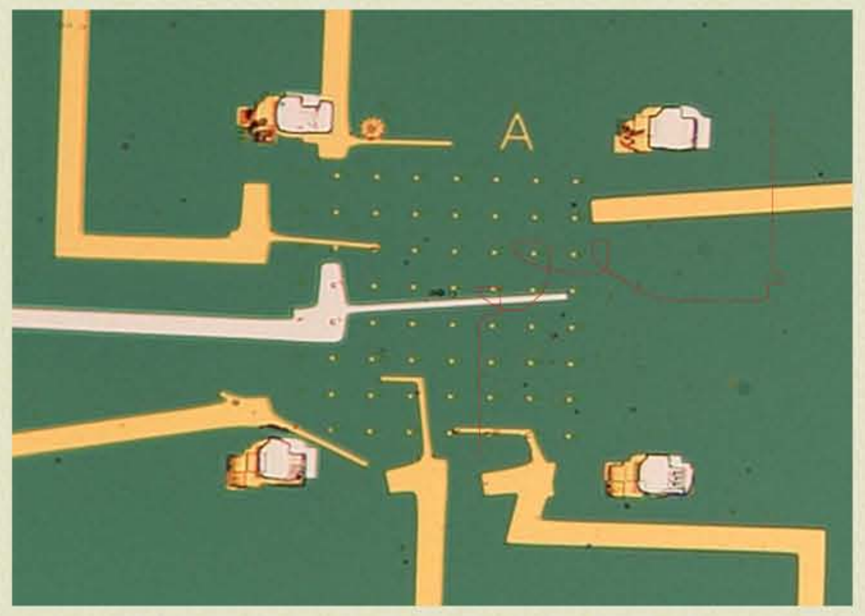

Figure 3: An optical image of a top view of one fabricated device. The path of the CNT is shown in red.

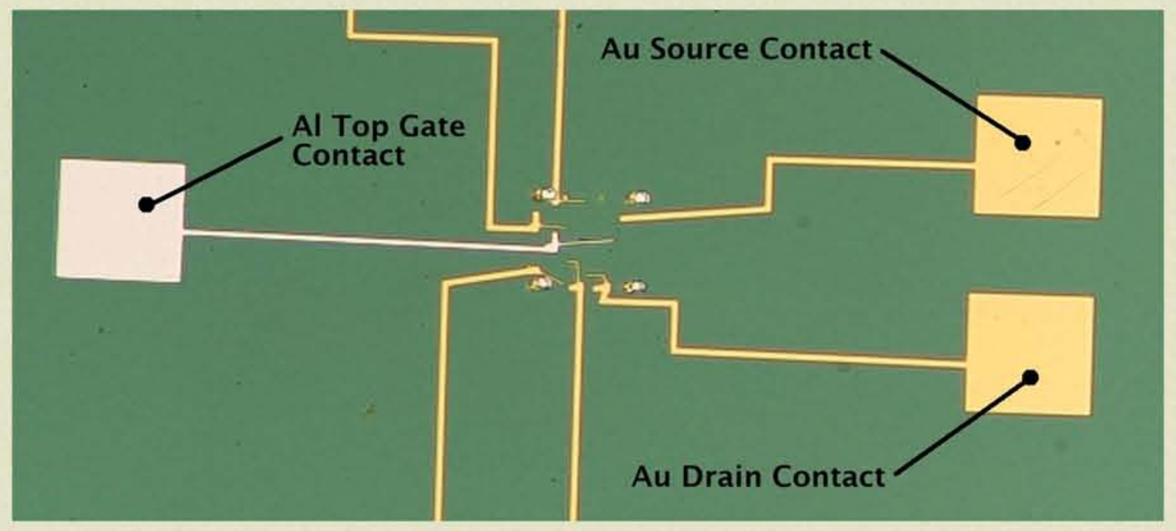

Figure 4: An optical image of a complete fabricated device.

Results

1: Determine Back Gate I-V$_G$ Behavior of Fabricated Devices

The I-V$_G$ curves of the CNT devices were observed first to see if the devices had gate dependent behavior and to determine what types of CNTs were present.

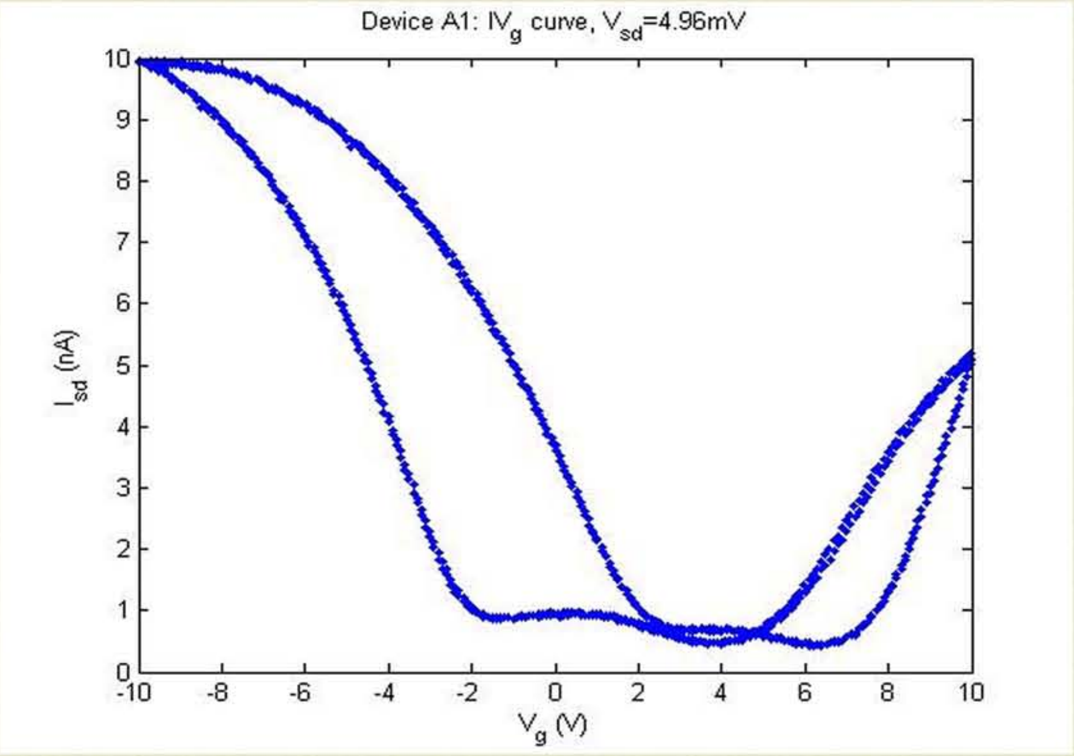

Figure 5: Back gated I-V$_G$ curve data

This CNT device shows turnoff behavior between -3 and +6 volts. This may be due to a multiwalled CNT channel. It also displays ambipolar behavior, conducting at both positive and negative voltages.

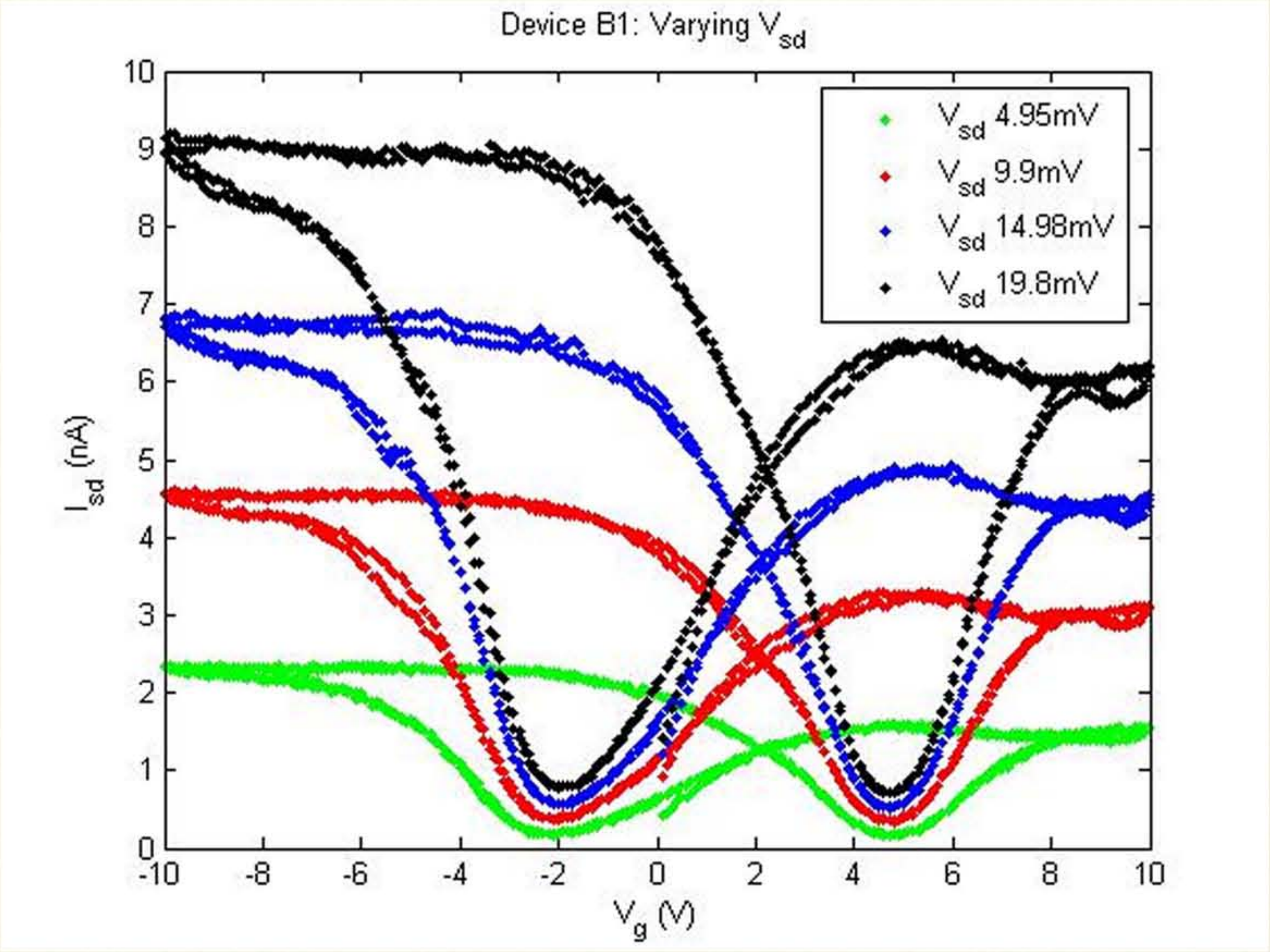

Figure 6: Back gated I-V$_G$ curve data with varying V$_{SD}$

This device has a turnoff voltage and conducts for both positive and negative values, which is consistent with ambipolar tubes. The hysteretic behavior is likely due to charge traps in the substrate.

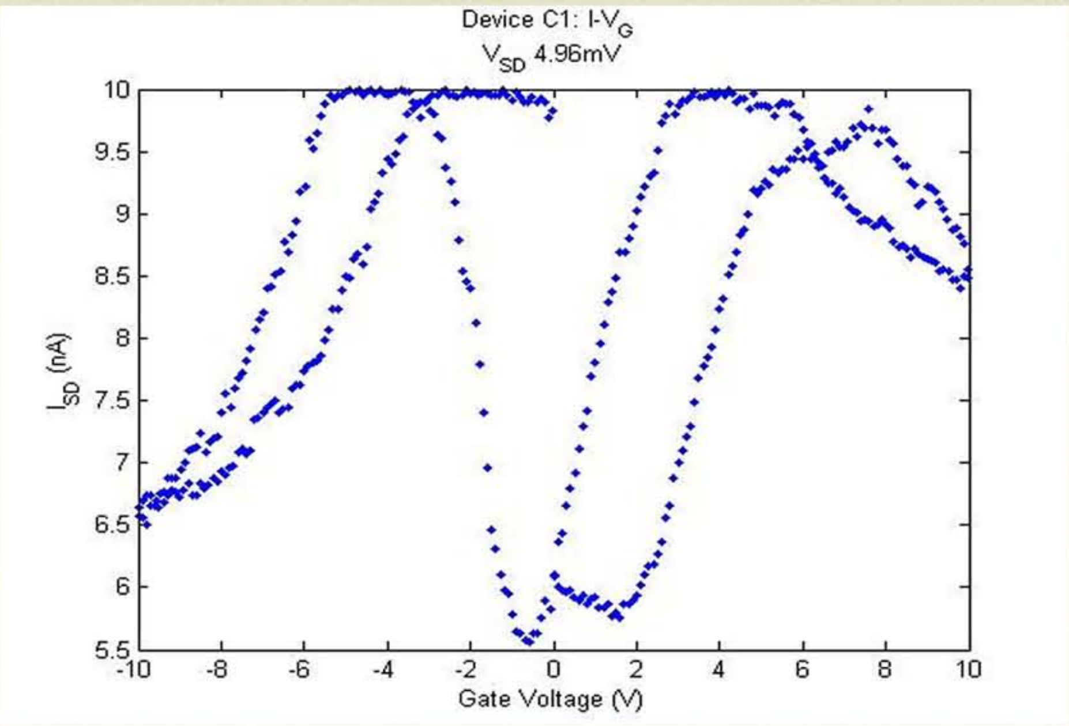

Figure 7: Back gated I-V$_G$ curve data with hysteresis

This device also shows hysteretic and ambipolar behavior. The device likely has both semiconducting and metallic nanotubes.

2: Determine Al-Au Contact I-V Characteristics

I-V curves were taken with one Al and one Au contact. Instead of capacitive behavior, all three devices show conductive behavior, indicating a very small or non-existent oxide layer between CNT and Al contact.

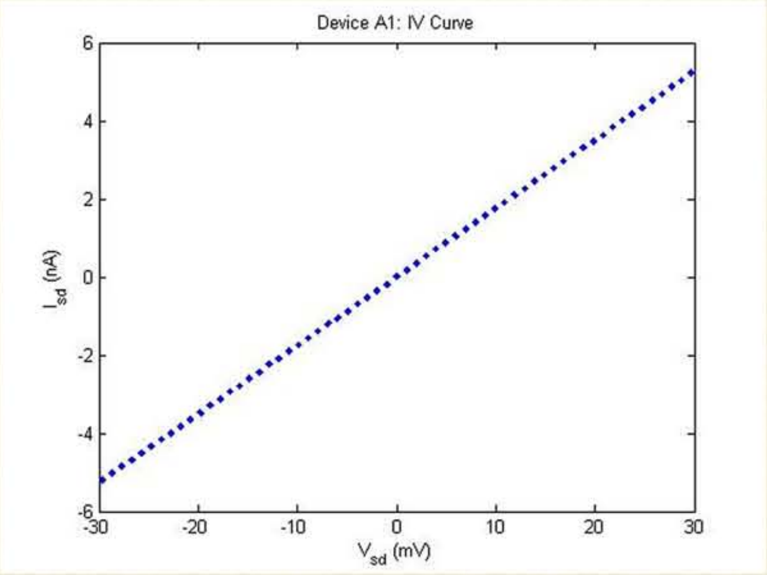

Figure 8: I-V curve data for device A1

This device shows a linear response to the applied bias voltage. It is likey that the device has purely metallic CNTs on it.

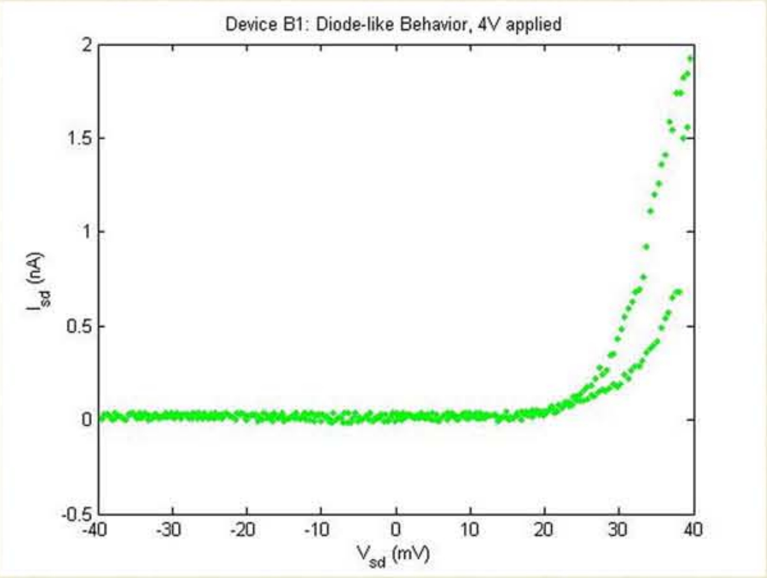

Figure 9: Two probe IV data with hysteresis for varying Vsd

One device showed diode-like behavior. This may be due to a Schottky barrier formation between the Al contact and the CNT. Because the workfunctions of Al and the CNT are very different, a large negative voltage is needed before the device would conduct. The turn on voltage of this device is approximately 20mV, much smaller than that of a PN junction diode.

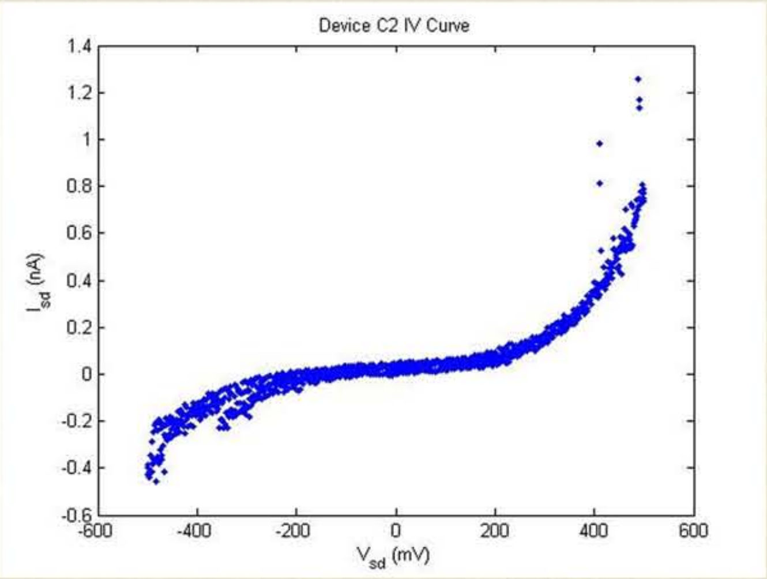

Figure 10: Two probe IV data with hysteresis for varying Vsd

This device shows non-linear tunnelling I-V characteristics. The I-V curve is fairly symmetric around 0V, indicating a small oxide barrier has formed in between the Al contact and the CNT.

3: Fit IV Behavior to Traditional Device Models

$$I_D = I_O(e^{qV/nk_BT} - 1)$$

can be used to compare the behavior of the CNT diode to a PN junction diode. In this equation, n represents the ideality factor- ranging from 1 for a perfect PN junction to 2 for a very impure semiconductor. The best fit to the data is n=1, indicating that the CNT-Al junction closely approximates a PN junction.

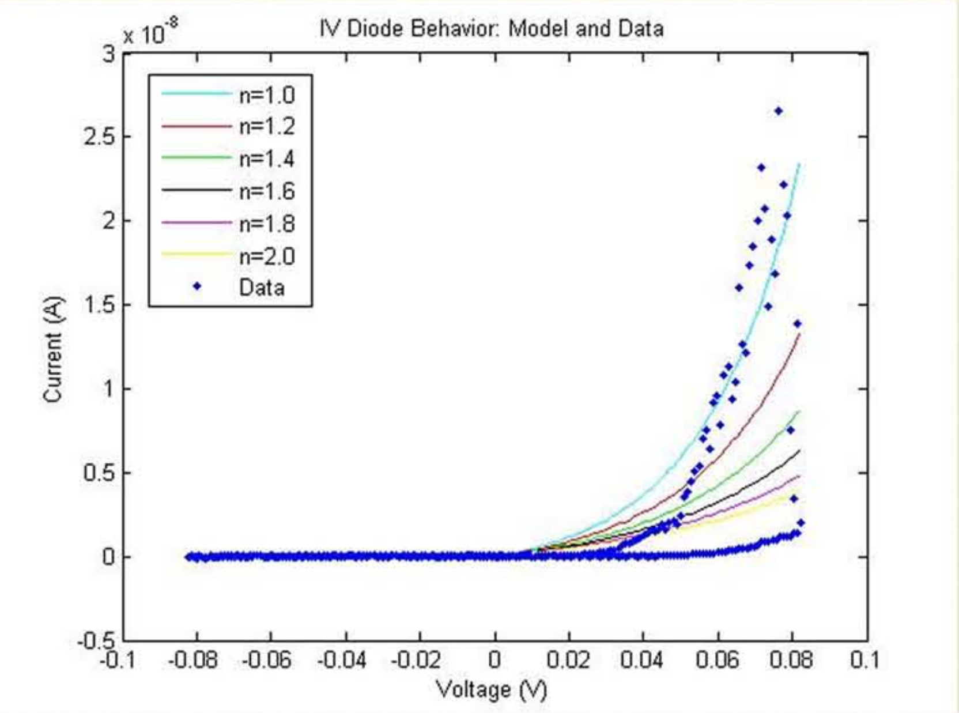

Figure 11: IV Data with Model for Varying Ideality Constants

Future Work

- Measure device response to temperature and various gases
- Fabricate a CNT device using Al and Au contacts to make an n-type transistor
- Fabricate a CNT device using dielectrics under the top gate contact
- Further explore the role of contact metals in diode-like CNT devices