DIRECT COMPARISON BETWEEN SIDE AND END-CONTACT GEOMETRY ON CARBON NANOTUBE FIELD-EFFECT TRANSISTORS

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Theoretical calculations for carbon nanotube (CNT) field-effect transistors (FET) have shown that end-contacted electrodes have significantly lower resistance per carbon atom than side-contacted electrodes. However, experimental confirmation is difficult because it would require devices built with identical CNTs. In this work, a comparison is made by fabricating devices with both types of contact on the same nanotube. Our group has previously prepared such a device using Ti as the electrode material, but the theoretical change for a Ti device is quite low. In this work, we attempt to prepare a device with gold electrodes as the calculated difference in resistance between side and end-contacted gold electrodes shows that end-contacted gold electrodes have 6751 times less resistance per carbon atom. FETs were prepared on Si/SiO2 wafers where catalyst patterning was done by photolithography, metals were deposited by physical vapor deposition, and CNTs were grown by chemical vapor deposition. After nanotube growth, side-contact and end-contact electrodes were patterned using electron beam lithography and deposited with physical vapor deposition. The transport characteristics were measured on a semiconductor parameter analyzer with Si as a backgate. Our attempts at finishing a device with gold electrodes have so far been unsuccessful, but the end-contacted Ti device showed ambipolar behavior demonstrating that contact geometry significantly affects performance.

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Direct comparison between side and end-contact geometry on carbon nanotube field-effect transistors

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Background

Carbon Nanotube (CNT) field-effect transistor (FET):

- Similar to metal-oxide-semiconductor field-effect transistor (MOSFET) but with a carbon nanotube as channel material in place of bulk silicon.
- Carbon nanotubes offer the potential to improve transistors by making devices smaller allowing for faster performance.
- Our group is interested in applications for sensors (such as for determination of magnetic structure).

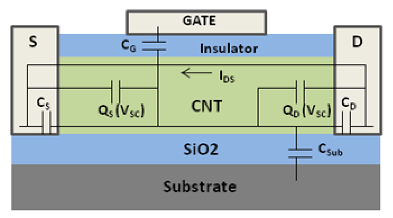
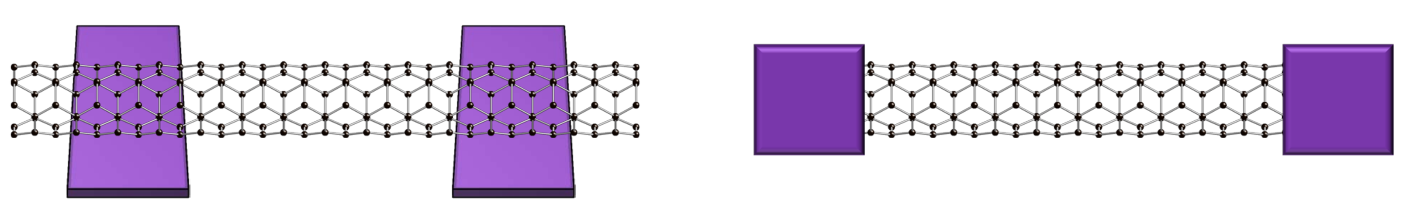


Diagram of a carbon nanotube field-effect transistor

Contact geometry:

- Source and drain electrodes can be placed on the nanotube (side-contact) or in the nanotube (end-contact).
- Side-contact is more widely studied as it is easier to manufacture.
- Theoretical calculations predict end-contact offers less resistance.



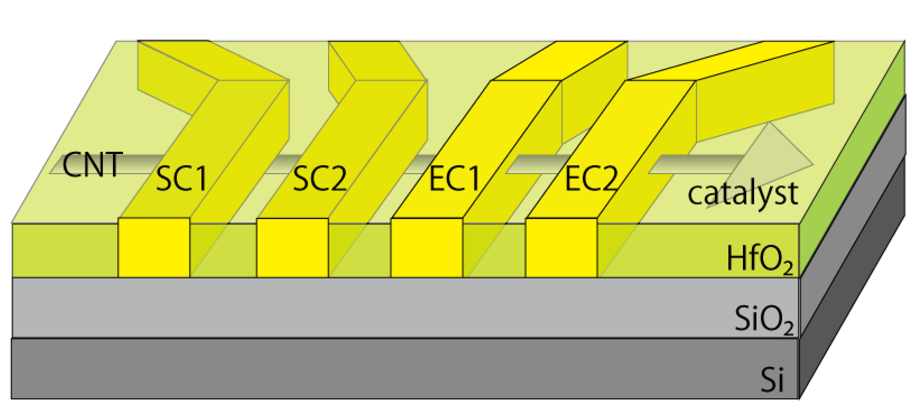
Visualization of side-contact (left) and end-contact (right).

Resistance	Ti	Pd	Pt	Cu	Au
Side-Contact (per C atom)	938 kΩ	8.57 MΩ	34.7 MΩ	630 MΩ	1.26 GΩ
End-Contact (per C atom)	107 kΩ	142 kΩ	149 kΩ	254 kΩ	187 kΩ
SC/EC	8.8	60	234	2487	6751

Theoretically calculated differences for different types of contacts.
Matsuda et al., *J. Phys. Chem. C* **2010**, *114*, 17845-17850.

Purpose

- To experimentally compare contact geometry for CNTFET
- This is difficult because it requires devices to be made on identical CNTs.
- Therefore, devices will be made on the same CNT.



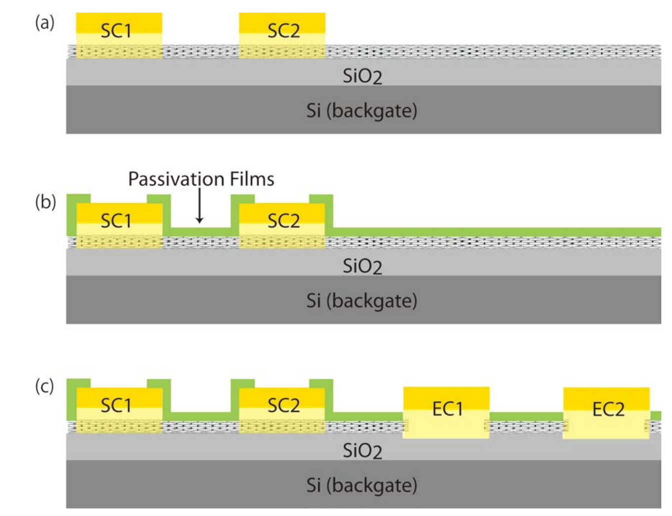
Our device configuration which will allow for direct comparison.

Methods

Fabrication:

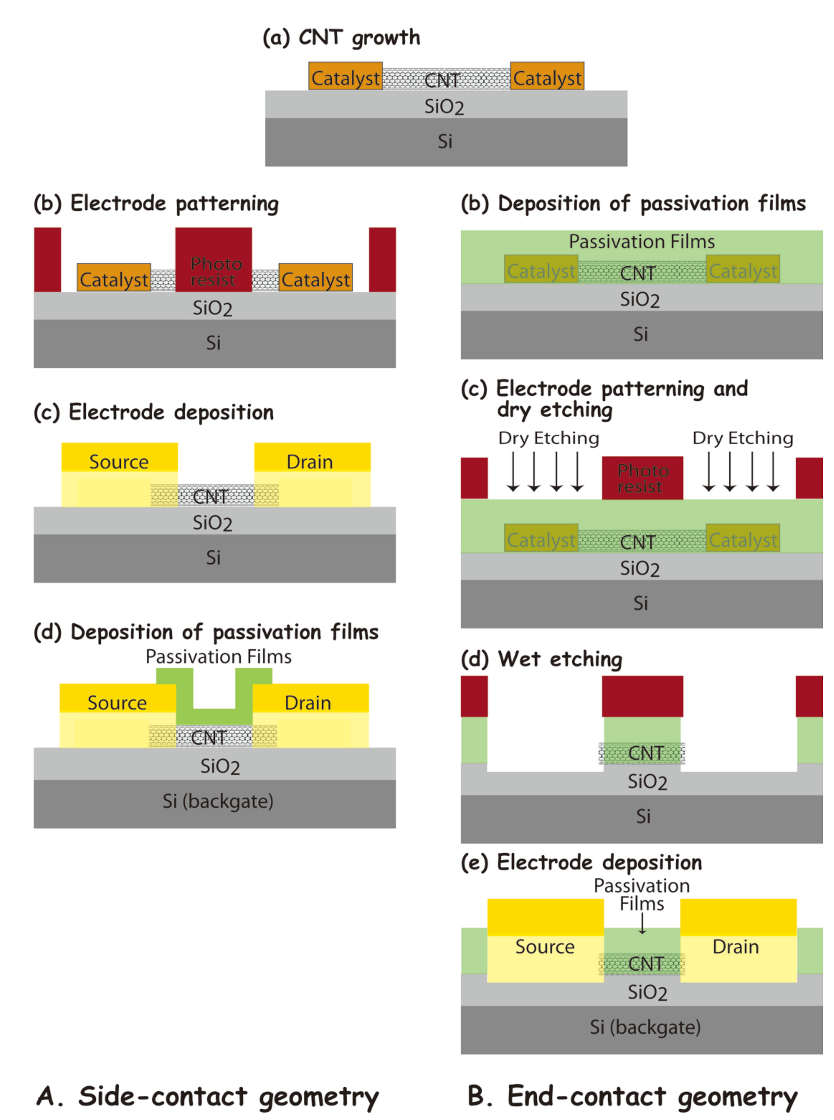
- Carbon nanotubes were grown on SiO_2/Si wafers.
- Catalyst were placed by photolithography and physical vapor deposition.
- Nanotubes were grown by chemical vapor deposition..

- To fabricate both geometries, we placed on side contacts, layered on a passivation film with atomic layer deposition, and then placed end contacts.



Steps in making our multi-contact field-effect transistor

- We have worked with two electrode materials: Ti and Au.
  - The Ti device was patterned using photolithography.
  - The Au device was patterned using electron beam lithography.



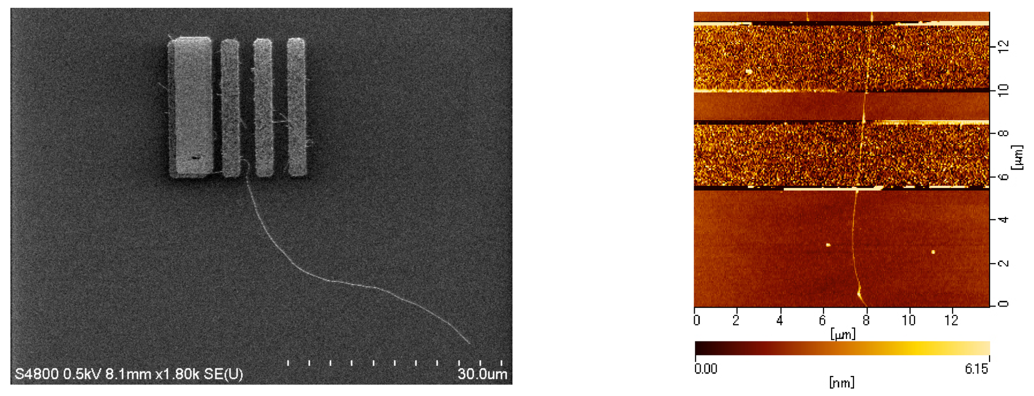
Process for make side-contacts (left) and end-contacts (right)

Characterization:

- Samples were observed on a scanning electron microscope (SEM) to find catalyst with carbon nanotubes.
- Devices were observed on atomic force microscope (AFM) to determine the diameter of the carbon nanotube.
- Transport characteristics were collected on a semiconductor parameter analyzer with Si as a backgate.

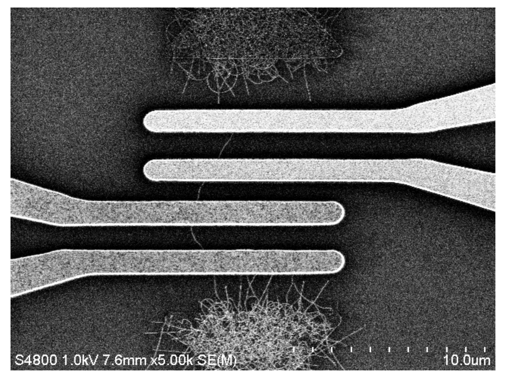
Results

- Successfully grew nanotubes and placed Au side contacts



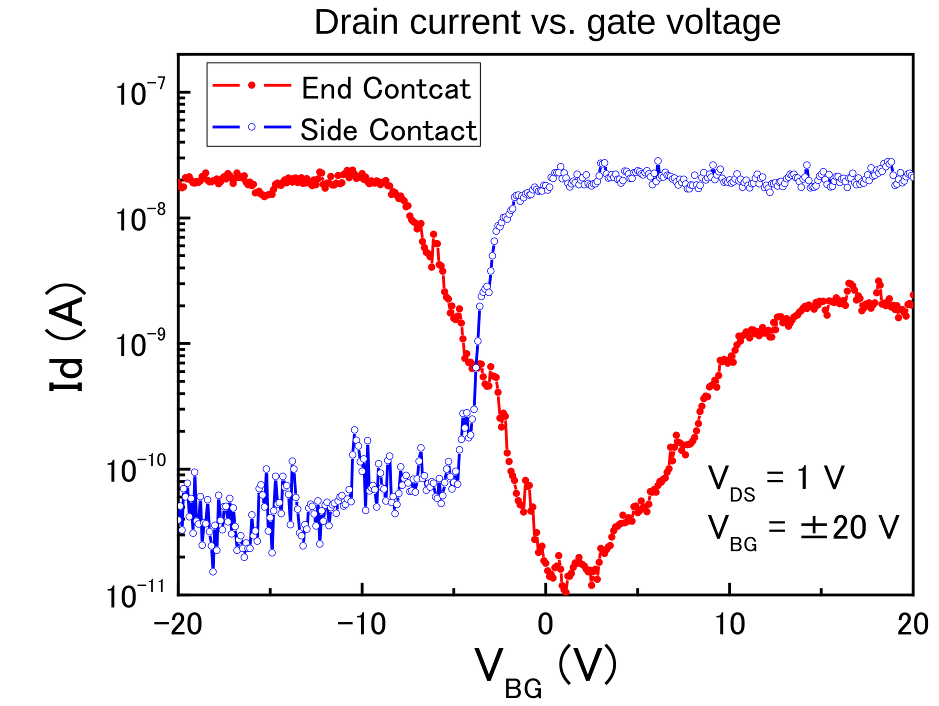
SEM of CNT (left) and AFM of CNT after deposition of side-contacted Au electrode (right)

- Device from previous student made using Ti.



SEM of device with Ti electrodes (patterned with photolithography)

Drain current vs. gate voltage



- Failed to make device with gold end contacts.

Conclusions and future work

Conclusion:

- We successfully grew CNT long enough for our devices.
- The device using Ti with end-contact geometry showed ambipolar behavior.
- More devices need to be made to test reproducibility.

Future work:

- Successfully fabricate single device with gold electrodes.
- Use low temperature measurements to estimate Schottky barrier.
- Fabricate a device using copper electrodes.

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