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Kate Gleason College of ENGINEERING

Vacuum Field Emission Devices with Integrated Carbon Nanotubes

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MicroE Microelectronic Engineering

I. Project Objectives

Goal: To design sub 100-nm carbon nanotube-based vacuum field emission devices.

	SOA CMOS* 10 nm FinFET	Vacuum FETS** Silicon vacuum tube	Proposed CLVFET Lateral SWCNT emitter
Channel gate length	10 nm (immersion lithography))	50 nm (180nm-lithography and oxidation trimming)	1 – 50 nm (vertically defined by thin film deposition/ALD)
Source-to-gate distance	0.8 nm (high-k dielectric HfO_2 - equivalent oxide thick.)	10 nm (air gap)	1 – 10 nm (high-k dielectric equivalent thickness)
V_{DD}	0.7 V	3 V	≤ 1.8 V
I_{OFF}	10 nA/µm NMOS (VDS=0.7V)	< nA (~ nm tip) (VDS=2V)	< nA/µm
I_{ON}	1.7 mA/µm NMOS (VDS=0.7V)	3 µA (~ nm tip) (VG=3V)	TBD/µm or /SWNCT

*Etienne Sicard. Introducing 10-nm FinFET technology in Microwind. This paper describes the implementation of a high performance FinFET-based 10-nm CMOS Technology .. 2017.
**Jim-Woo Han, Dong-Il Moon, and M. Meyyappan, "Nanoscale Vacuum Channel Tansistor," Nano Lett. 2017, 17, 2146-2151

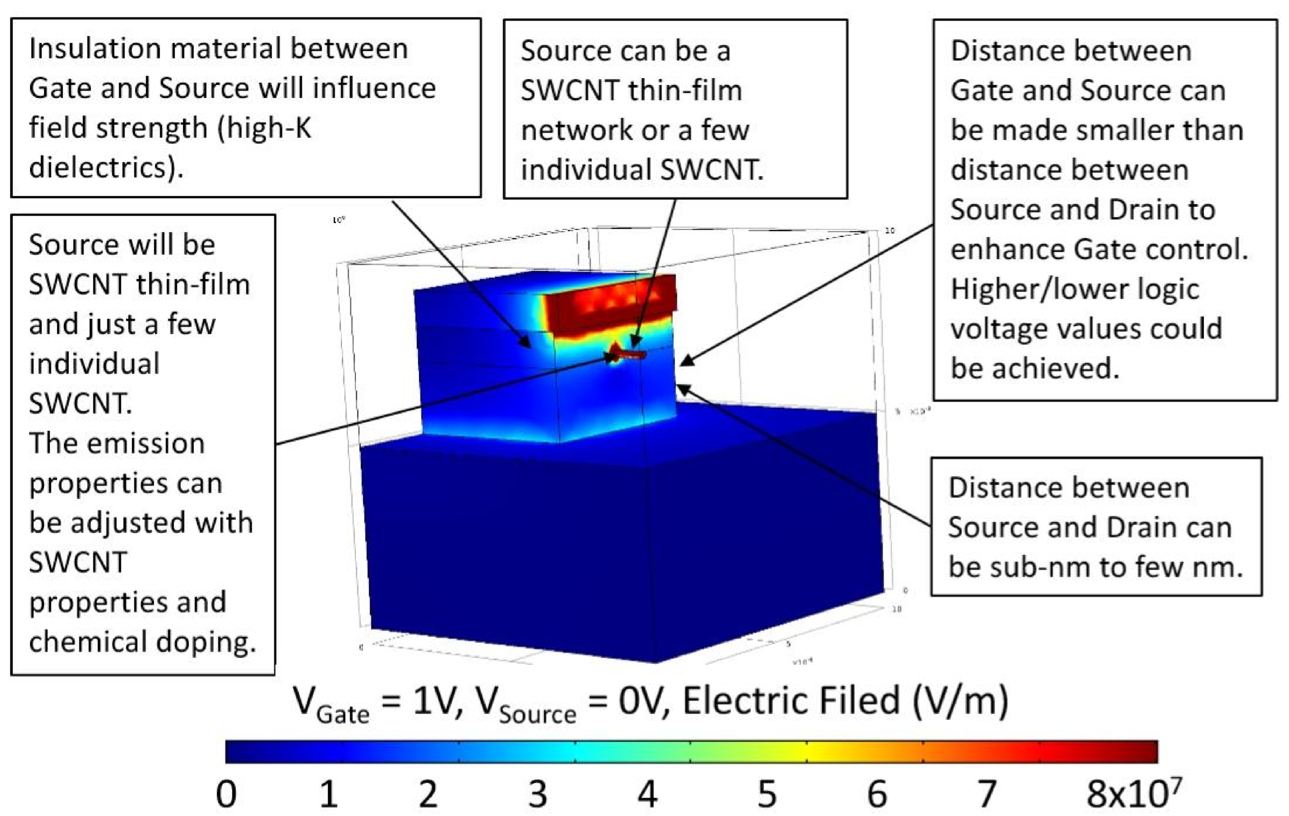
- Create working fabrication process.
  - Must have spacing for vacuum field emission.
  - Carbon nanotubes as emitter material.

II. Motivation

- Vacuum Field Emission Devices.
  - These transistors are based in the Fowler-Northeim emission of electrons.
  - These types of devices hold radiation hardened (RADHARD) capabilities due to the **absence of a semiconductor channel.**
  - The SWCNT will be used as the emitter material.
- Carbon Nanotubes
  - SWCNT (Single-Wall Carbon Nanotubes) could be the nanomaterial that replaces silicon in CMOS FETS (field-effect-transistors).

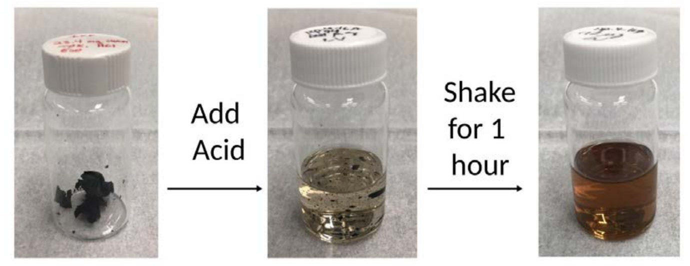
III. Design of Vacuum FET

- The design of the Vacuum FET focused around three layers.

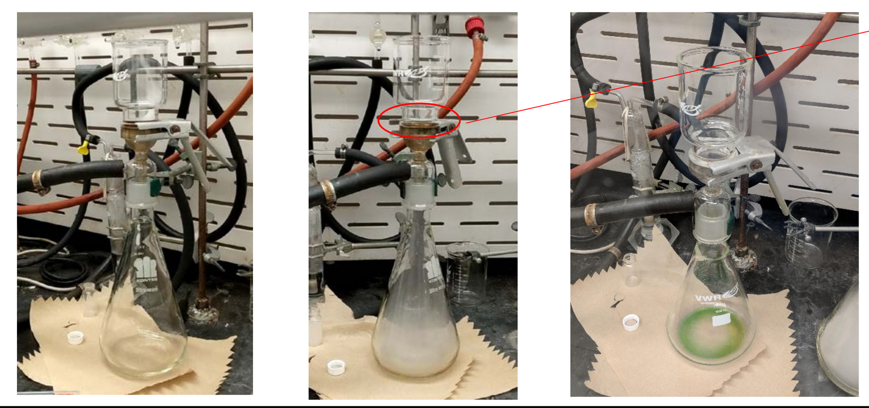


IV. Carbon Nanotube Thin Film Synthesis

- Before the SWCNTs can be transferred to the wafer, they must be turned into a film. The SWCNTs are dispersed in chlorosulfonic acid and further individualized with the aid of ultrasonic agitation.



- The dispersion is then transferred onto a ceramic filter by vacuum filtration and the acid is rinsed with acetone, as seen below The film is allowed to dry for 30 minutes with the vacuum on.



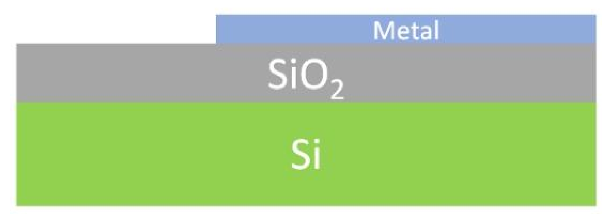
The CNTs stay on a ceramic filter that is clamped between the glass beaker and flask

V. Fabrication Process

To create a Vacuum FET with Integrated CNT, the following Fabrication process must be followed.

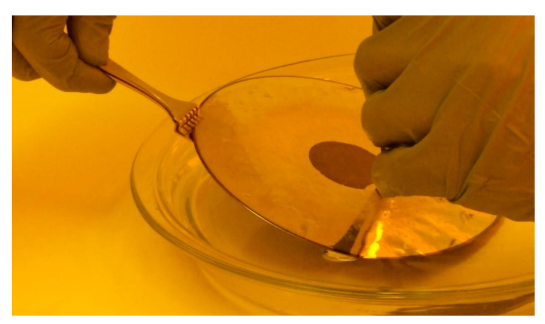
- The first layer to go down on the substrate is a grown oxide layer of SiO_2 of about 800 nanometers.

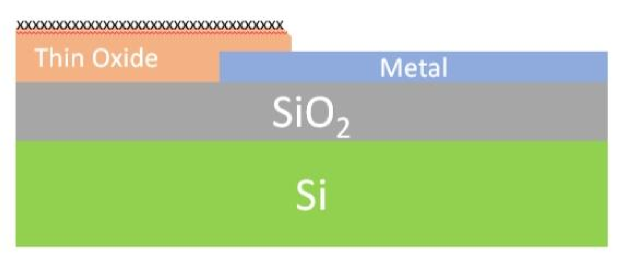
- The next layer is about 500 nanometers of aluminum that is patterned and etched back according to the design.



- Once the aluminum is complete, a thin oxide layer of about 100 nm of Low Thermal Oxide is added, patterned, and etched

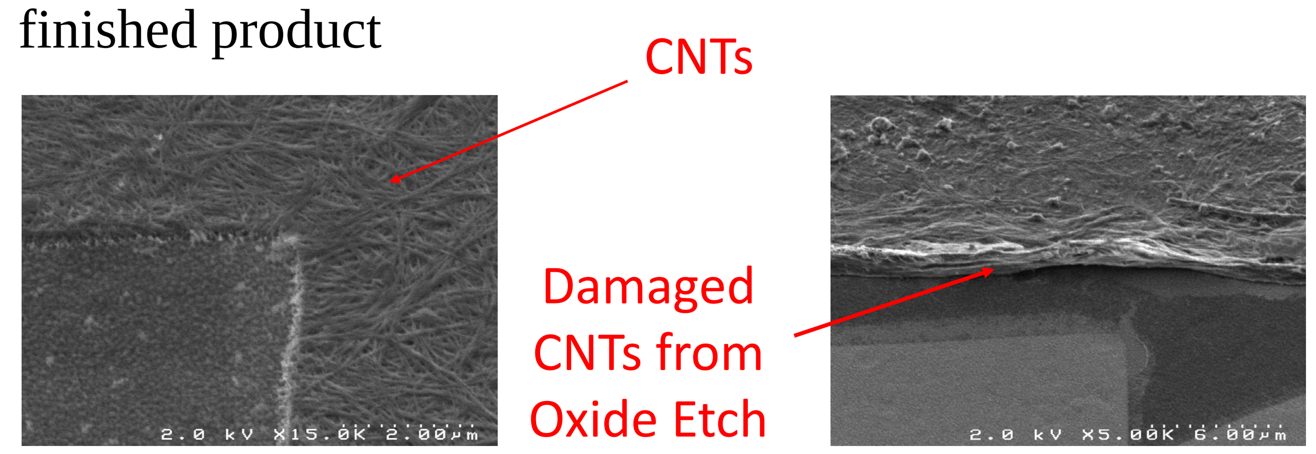
- The last layer of the process is transferring the Carbon Nanotube Thin Film onto the substrate.



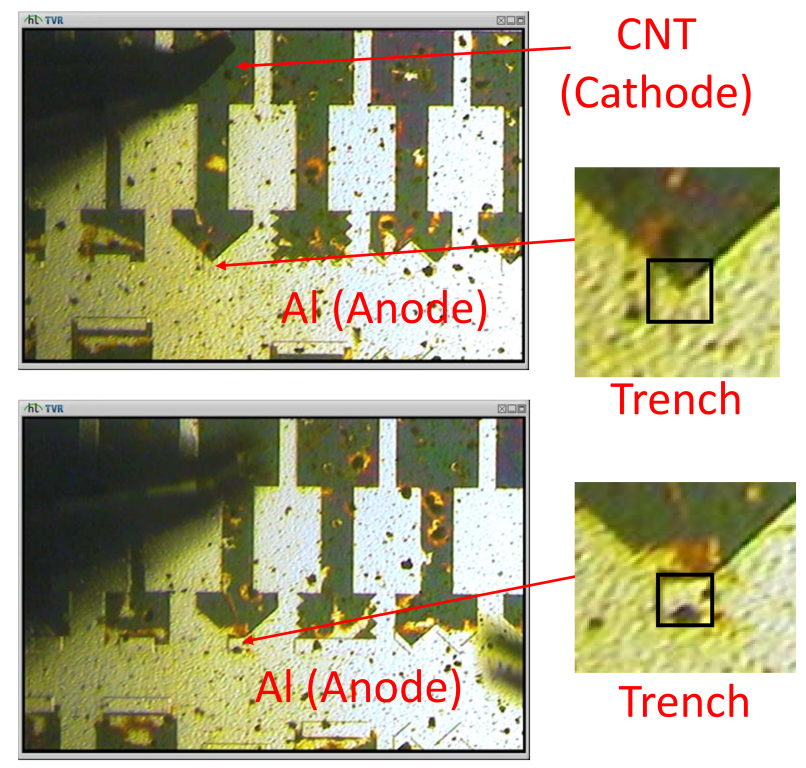


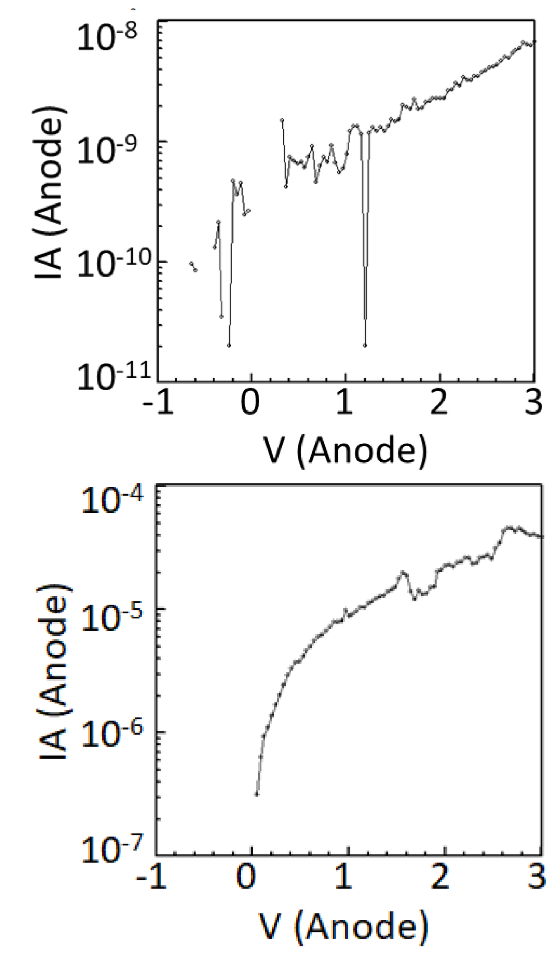
Results

- Once the fabrication was complete, we were able to use a SEM (Scanning Electron Microscope) to obtain images of the finished product



- For electrical testing, the CNT (Cathode) was grounded while the aluminum layer (Anode) was given a positive voltage, so that the electrons would move from the Cathode to the Anode.





V. Conclusions

- A field emission device based on carbon nanotube emitters with an effective anode-to-cathode distance of **100 nm** was designed, fabricated and tested.
- An improved process must prevent SWCNT from becoming damaged during fabrication.
- Preliminary test data may indicate that Fowler-Northeim emission (I = 1 nA at 1 V) has been achieved under atmospheric conditions in contrast with devices with resistive behavior (I = 10 µA at 1 V, R = 10 Kohm).
- Further analysis and characterization must be carried out to confirm these results.

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