Tipped Carbon Nanotube Field Emission X-ray Generator

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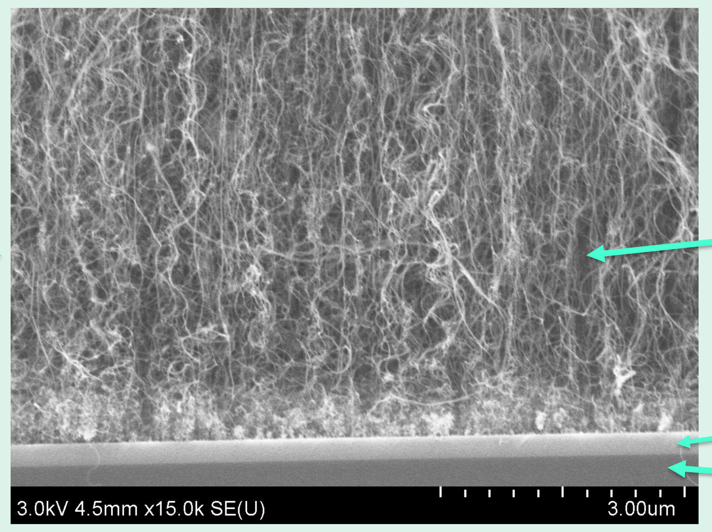
Introduction

Carbon nanotube (CNT) field emission (FE) X-ray generators use CNTs to enhance electron emission. CNTs are deposited on the cathode which improves electron generation. These electrons travel through a gate electrode which focuses them towards the anode, which then frees the x-rays. Cathode design and optimization ultimately decides the performance of the x-ray generators.

CNTs will be grown through chemical vapor deposition. CVD involves using a vapor at some temperature to react with a catalyst layer to deposit CNTs on the surface of the device. An image of CNTs grown with CVD can be seen below. CVD is also the most optimal growth method of CNTs in terms of resolution. The CNTs will then be manipulated geometrically for optimal x-ray generation. This manipulation involves the "twisting" of the CNTs into a tip through post-chemical processing. This is a novel x-ray generating device because one chip contains all components (cathode, anode, gate electrode) and the cathode has the twisted CNTs.



Goals & Objectives

This project includes initial design, fabrication, and testing/optimization of the devices. Two studies will be completed prior to fabricating the full devices to perfect CNT growth. First, the growth time of CNTs will be varied to see how this affects the length of CNTs; these results will be presented here. Second, CNTs will be grown off side-walls to optimize this new growth direction. After this, full devices can be fabricated. Post-chemical processing will then be done to shape the CNTs into tips. Devices can then be tested and further optimized.

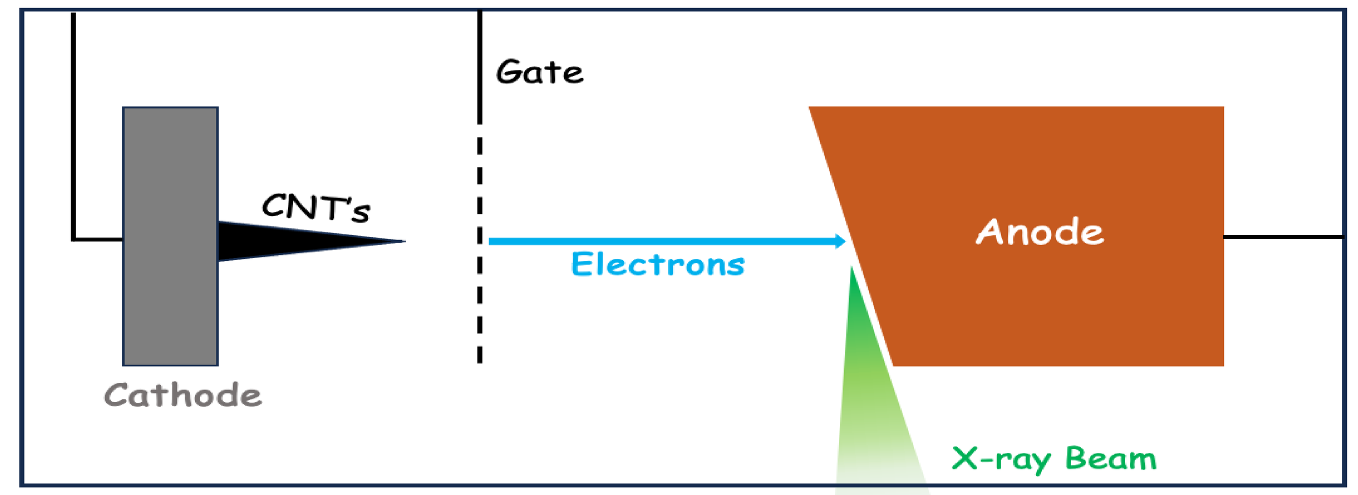
Methods

Device Recipe:

1. 4-inch SiO_2 wafers are coated in Al_2O_3 via atomic layer deposition (ALD)
2. Deposit photoresist using spin coater
3. Expose photoresist with the maskless aligner (MLA)
4. Develop/Etch wafter
5. Deposit metal using e-beam evaporator or sputterer
6. Lift-off extra metals
7. Repeat 3-6 for additional layers
8. Deposit CNTs using Aixtron Black Magic PECVD
9. Chemically process CNTs for tip formation

Growth Time vs Length Study:

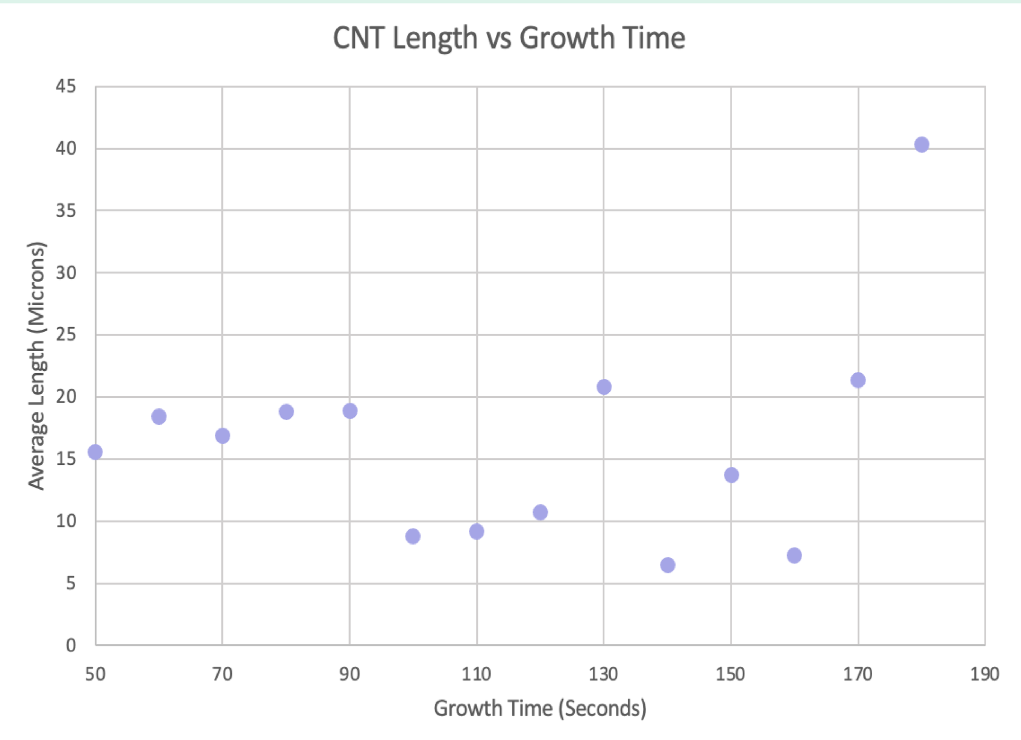
1. Deposit catalyst layer (Al and Fe) on 4-inch wafer using e-beam evaporator
2. Cut wafer into pieces using disco dicing saw
3. Clean wafer pieces
4. Deposit CNTs using ABM PECVD at growth times from 50-180 seconds in 10 second increments
5. Cleave CNT chips using diamond point scribe
6. Measure CNT lengths using SEM



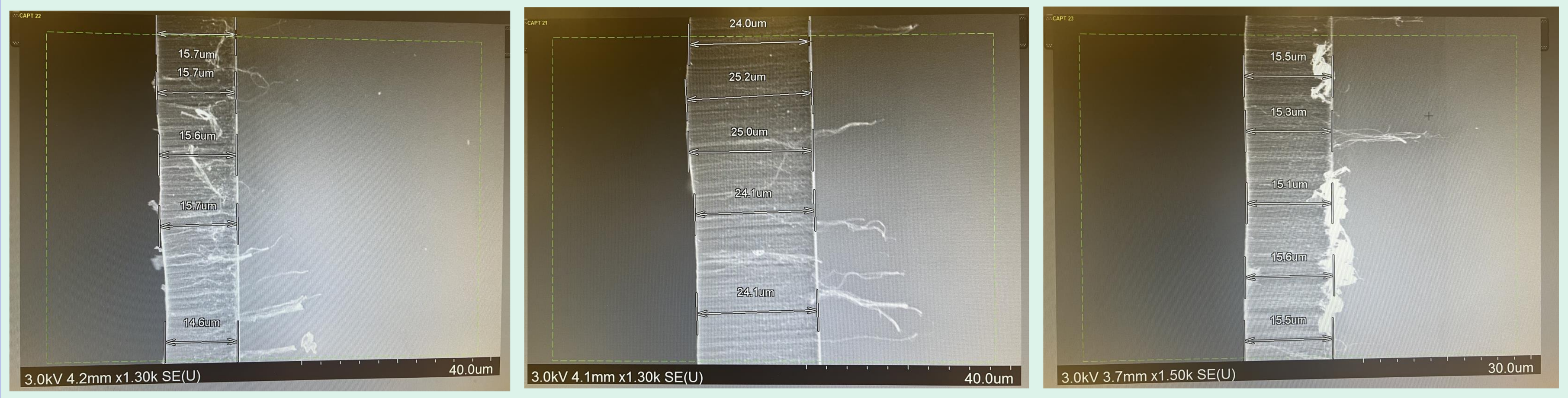
General Schematic of a Device
(Diagram inspired by: Ryu, J.H.; Kang, J.S.; Park, K.C. Carbon Nanotube Electron Emitter for X-ray Imaging. *Materials* **2012**, *5*, 2353-2359. https://doi.org/10.3390/ma5112353)

Results

The results for the CNT growth time vs length study are provided in the next column. A series of around 5 measurements were taken for each growth time at the middle of the sample, the left edge, and the right right edge using the SEM. These values were then averaged together.



Growth Time (Seconds)	Average Length (Microns)	Standard Deviation (Microns)
50	15.600	0.338
60	18.447	4.435
70	16.877	4.629
80 ☆	18.790	1.159
90 ☆	18.889	2.793
100 ☆	8.797	0.479
110	9.166	1.212
120 ☆	10.683	3.279
130	20.833	3.239
140 ☆	6.501	2.373
150	13.750	0.974
160	7.262	1.160
170 ☆	21.357	3.407
180	40.300	0.325



Discussion

The above results include the plot of CNT length vs growth time, a table of all values and associated standard deviation, and example measurements for the 60 second growth time sample (left, middle, and right edges of the sample). The stars next to the growth time on the tabulated values denote samples with the same catalyst area, as this does affect growth rate. The results are not as expected; a relatively uniform increase in length was expected with increasing growth time. This is likely due to inconsistencies within the catalyst layer.

Conclusion/Next Steps

This CNT length vs growth time study will be redone. This time alumina will be used as the first layer of the catalyst instead of aluminum, as alumina tends to be an easier layer to work with/promotes longer CNTs. Also, the catalyst area will now be kept the same for each sample, as catalyst area can alter the growth rate.

Once CNT growth time has been found, the CNT growth direction study will be performed. Full device fabrication will also begin during this time. In the future, the chemical process will be developed for CNT manipulation; then testing/optimization of devices. These devices have many applications including imaging of electronics for quality control, security inspections, and medical imaging.

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