Carbon Nanotube Field Emission X-ray Generator

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Background/Introduction:

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- Carbon nanotube (CNT) field emission (FE) X-ray generators use CNTs to enhance electron emission[2]
- The gate electrode sets the voltage[4]
- Gate allows for high-speed x-ray generation[3,4]
- CNTs are deposited on the cathode which improves electron generation[2]
- These electrons travel to the anode which then frees the x-rays[2]
- Cathode design and optimization ultimately decides the performance of the x-ray generators[2]
- This is done in a vacuum environment[3]

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Introduction:

- This project initial fabrication, characterization, and testing/optimization of the devices
- The CNTs will also be manipulated for optimal x-ray generation
  - This involves the “twisting” of the CNTs into a tip
    - This allows focusing of the electrons
    - Improves overall imaging capabilities
- The recipe used is a modified version of Dr. Arith Rajapakse’s CNT detector recipe[1]

Goals:

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Short-term:

- Complete training in cleanroom
- Develop masks for the wafer
- Fabricate devices

Long-Term:

- Characterize devices
- Optimize devices
- Optimize fabrication process
- Write thesis

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General Schematic :

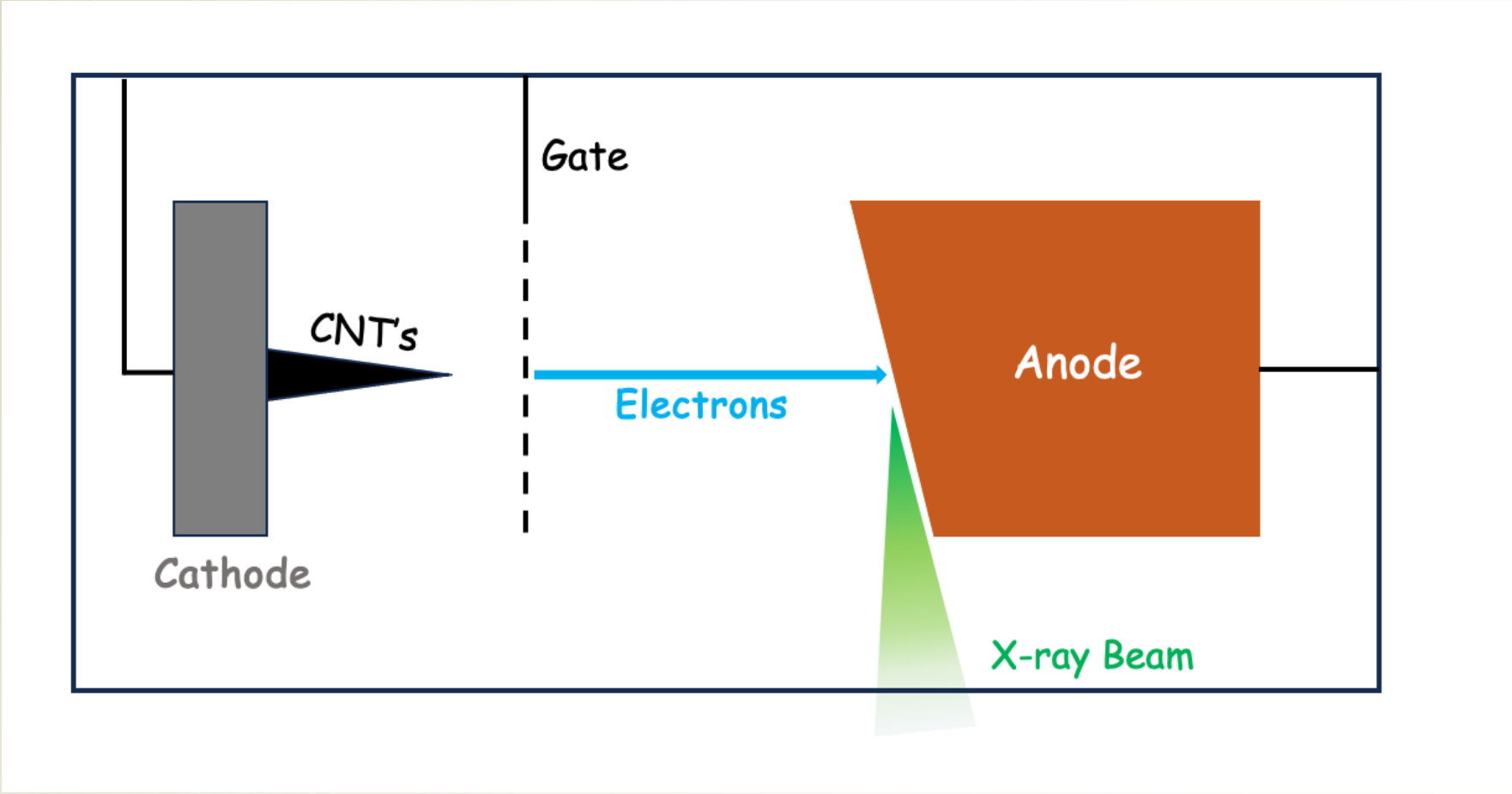

Diagram inspired by Ryu et al.[3]

General Recipe[1]:

Step 1: Atomic Layer Deposition with Cambridge Nanotech Plasma ALD

- Start with clean 4-inch O2 coated Si wafer
- Deposit 10nm of Al2O3
  - 10 cycles at 250C
  - Done for passivation

Process[5]:

- Trimethylaluminum (TMA) vapor introduced
- TMA interacts with SiO2 forming AlCH3 or Al(CH3)2
- TMA purged
- H2O vapor introduced
- H2O interacts forming Al2O3
- H2O purged

General Recipe[1]:

Step 2: Prebake wafer

- Bake wafer on hotplate at 200C for 5 minutes
- Done to ensure wafer is dry

Step 3: Deposit photoresist using spin coater

- Dispense Shipley 1813
  - 10s RAMP then 5s DWELL at 500 rpm
  - 10s RAMP then 30s DWELL at 4000 rpm
- Bake at 115C for 60s on hotplate
- This is the first photolithography layer

General Recipe[1]:

Step 4: Expose wafer using MLA150 (maskless aligner)

- Do dose test to find best dose/defocus
- Choose dose that produces sharpest lines and corners
- Laser wavelength – 375 nm
- Done to expose photoresist

Step 5: Develop photoresist

- Soak in MF-319 for 60s
- Rinse with DI for at least 60s

Step 6: Hardbake photoresist

- Bake on hotplate for 5 minutes at 90C

General Recipe[1]:

Step 7: Plasma etch wafer using RIE (reacting ion etching)

- Descum 30s
- Done to clean wafer

Step 8: Etch the exposed Al2O3

- Soak in Transetch-N for 5 minutes at 60-65C
  - This is 65% diluted Transetch-N
- Rinse thoroughly in DI

Step 10: Deposit metal using electron beam evaporation

- Deposit 55nm of Cu
- This is done to create the anode

General Recipe[1]:

Step 11: Lift-off excess metal

- Soak in PG remover for 45 minutes
- Soak in PG remover at 60C for 45 minutes
- Soak in IPA for 15 minutes
- Rinse thoroughly with DI

Step 12: Repeat steps 3-11 for additional layers

- Next layer is for the cathode
  - Depositing 5 nm Ti followed by 50 nm of Pt
- Final layer is catalyst layer
  - Deposit 10 nm Al followed by 1 nm of Fe
  - Done in preparation for CNT growth

General Recipe[1]:

Step 13: Remove back oxide

- Coat frontside in photoresist (Step 4)
- Soak wafer (backside up) in buffered oxide etch (BOE) for 5 minutes
- Make sure SiO2 is removed, it will be hydrophobic
- Deposit 5 nm Ti followed by 50 nm on backside
- Done to make back gate electrode

Step 14: Grow CNT's using Aixtron Black Magic PECVD

- Grows vertically aligned CNT's from Fe catalyst
- Length has not yet been decided but will be microns long []
- Undecided if CNT's are grown into 'tip'

Possible Step 15: Chemical processing of CNT's

- Done to form CNT's into 'tip'

Conclusion:

- Design, fabricate, characterize, and optimize a novel CNT FE based x-ray generator

- This high-speed device can be used for:
  - Medical Imaging
  - Electronics Imaging
  - Inspections (security)
  - Etc.

Future Work:

- Design/fabricate vacuum environment housing for the device

References

[1] Rajapakse, A. J. (2021, December 14). *Sensing the interactions of ionizing radiation in a semiconductor substrate using carbon nanotubes*. GT Digital Repository. https://repository.gatech.edu/entities/publication/b23e0a6a-f1f6-44b8-9f90-14357240fc4d

[2] Parmee, R.J., Collins, C.M., Milne, W.I. *et al.* X-ray generation using carbon nanotubes. *Nano Convergence* **2**, 1 (2015). https://doi.org/10.1186/s40580-014-0034-2

[3] 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

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[5] *2022 year in Review*. Introduction to Plasma Enhanced Atomic Layer Deposition. (n.d.). https://www.plasma-ald.com/

Thank you

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