National Nuclear Security Administration

Innovative Carbon Nanotube-based Field Emission Electronics for X-ray Generation & Imaging

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Georgia Tech

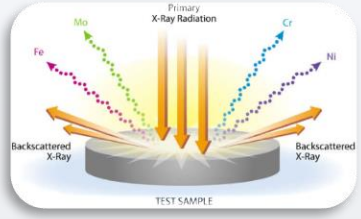
Consortium for Enabling Technologies & Innovation

Introduction and Motivation

X-ray sources have proven important in a wide range of applications since its discovery in 1895.

Bones in the fingers of a living human hand -- "On a new kind of rays" [1].

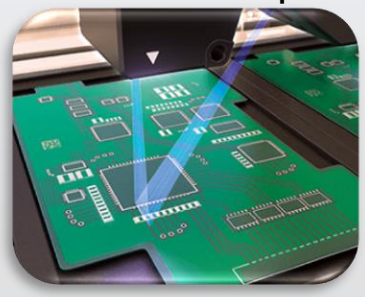
Material Analysis



Security Checkpoint

Pharma Quality

Electronics Inspection



Heavy Industry

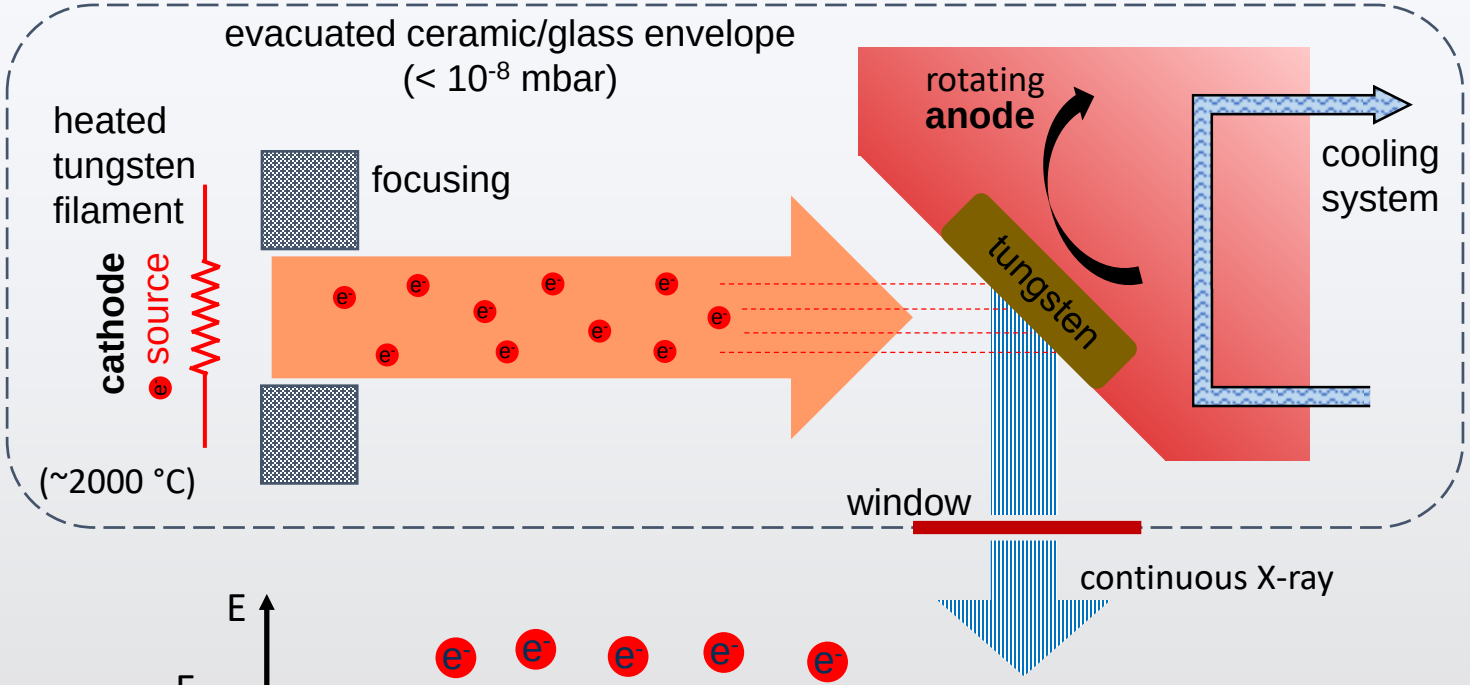
Medical Treatment

Medical Diagnostics

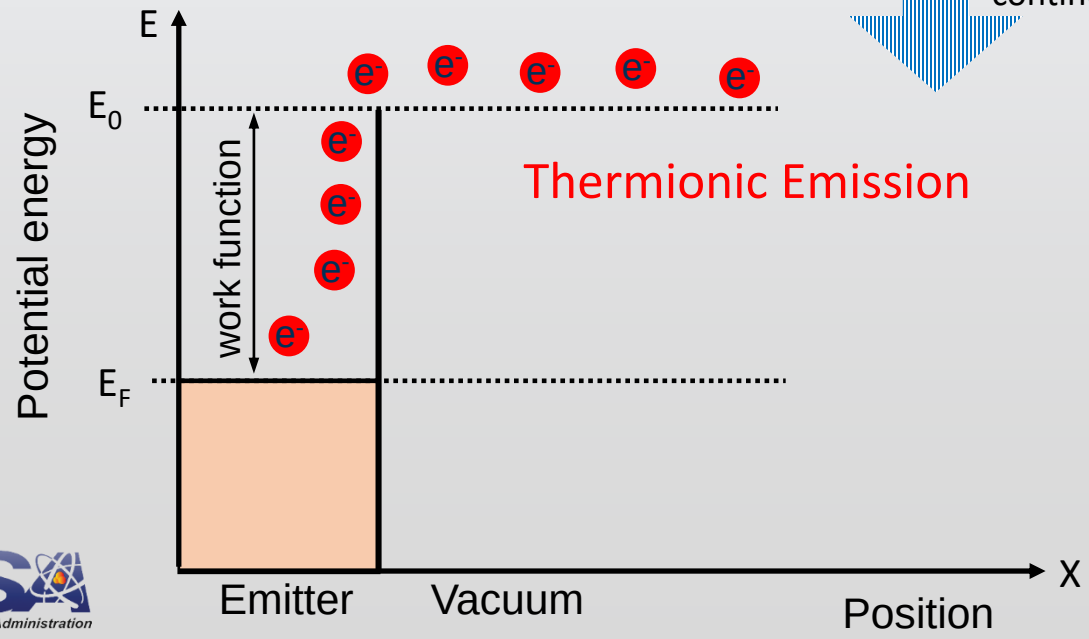
Food Security

[1] Röntgen, W. C., *Science* 3, no. 59 (1896): 227-231
* Photo courtesy of Google Images.

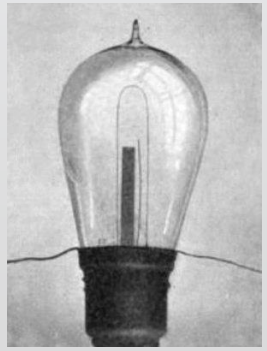
Conventional Thermionic Emission X-ray Source



- bulky physical size
- high power consumption
- slow temporal response (>100ms)
- large focal spot size (mm)
- continuous emission
- cavity sputtering
- single pixel source



Edison effect



One of the bulbs with which Edison discovered thermionic emission in 1880.

www.wikipedia.org

Follow the Evolution of Telephone: Move Forward

Bell's phone

Hard crank wall phone

Craddle phone

Touch tone pad phone

Analog mobile phone

Digital mobile phone

Smart phone

* Photo courtesy of Google Images.

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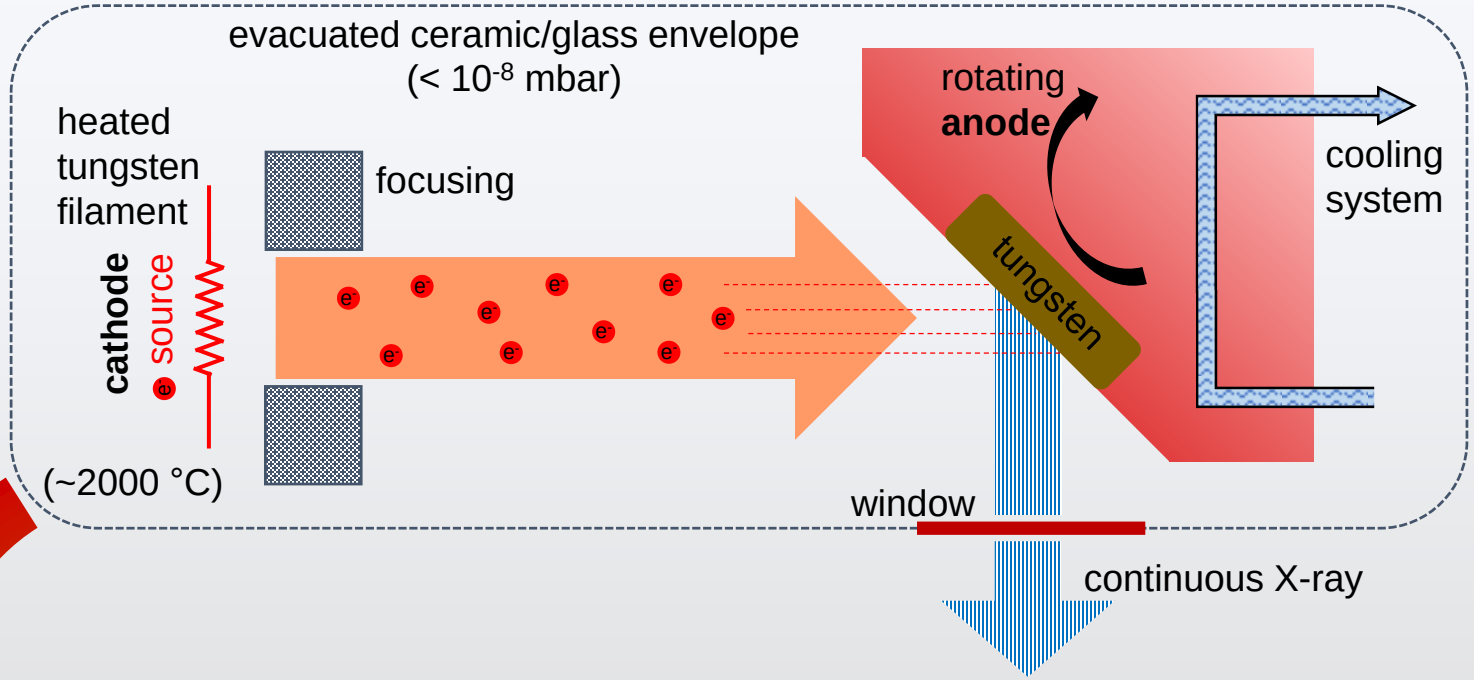
Carbon Nanotube-based Field Emission Source



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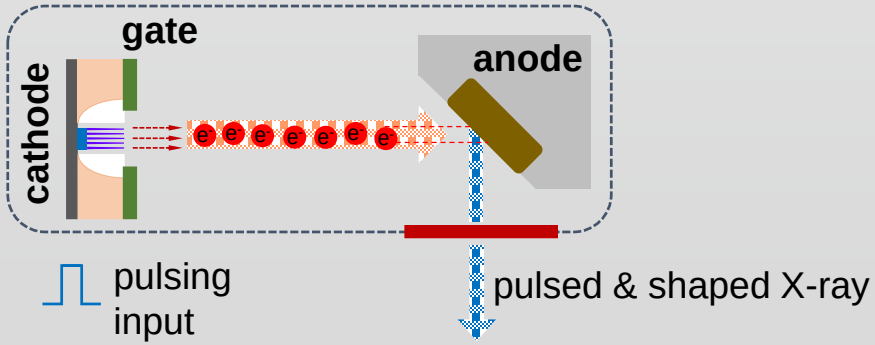
CNT-based field emission source



- miniaturized
- pulsed emission
- fast temporal response (µs, **1000x**)
- micro focal spot size (µm, **1000x**)
- controlled beam shaping
- low turn-on voltage
- multi-pixel source

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Mission Relevance

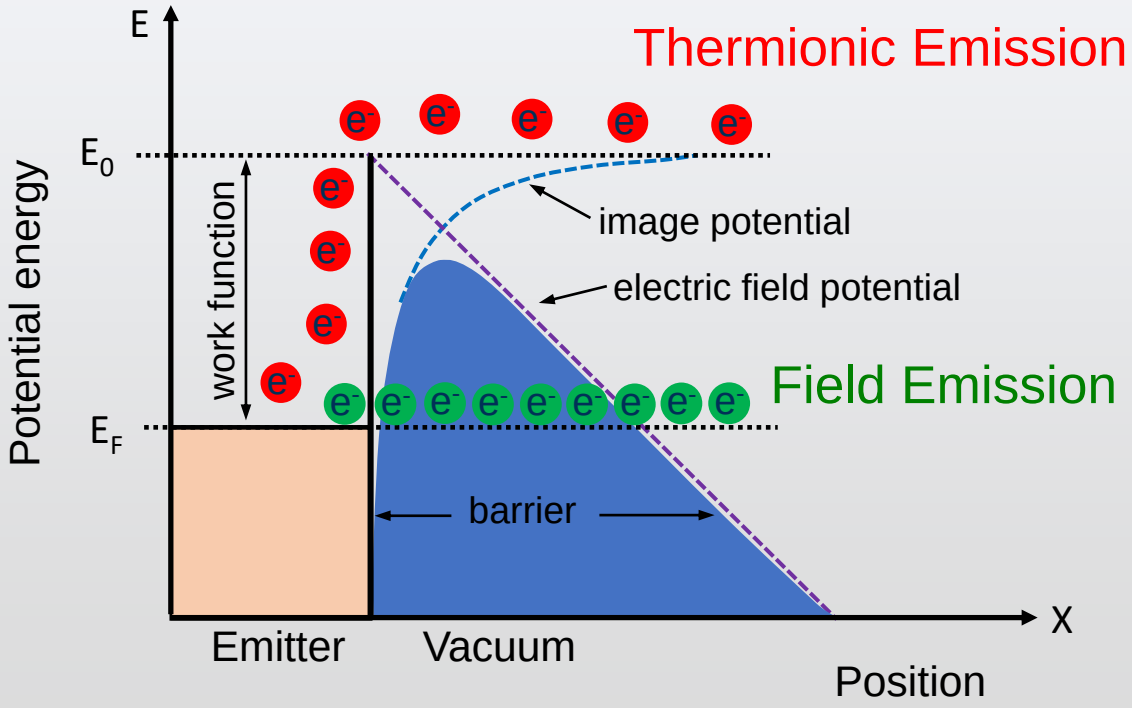
Aligned with the NNSA mission -- nuclear nonproliferation

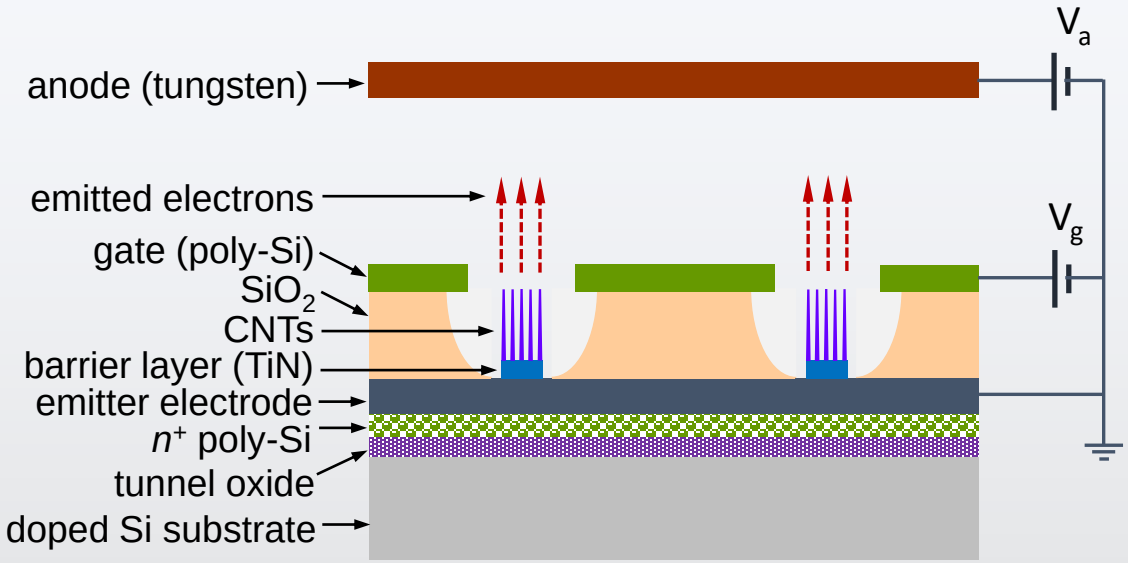
Developing the CNT-based radiation detectors and the CNT-based field emission electronics for X-ray generation & imaging system to:

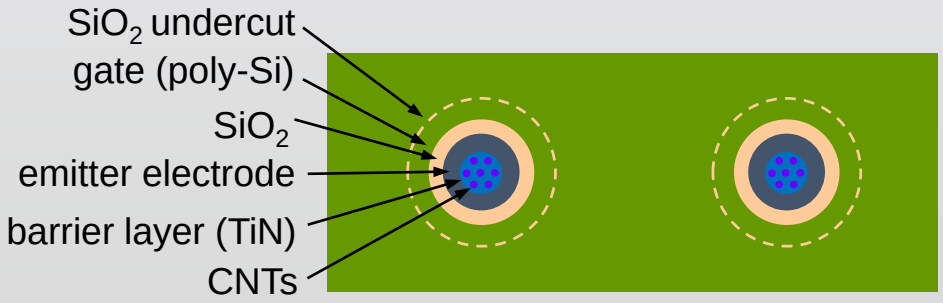
- Reduce temporal response
- Minimize physical dimensions
- Shrink focal spot sizes
- Lower power consumption
- Enable fast-switching pulsed X-ray sources (digitally controlled electron beams)

Operation Mechanism of CNT-based Field Emission Source, and Device Structure

- ✓ Emission process occurs at room temperature.
- ✓ Tunneling process, near-instantaneous emission.



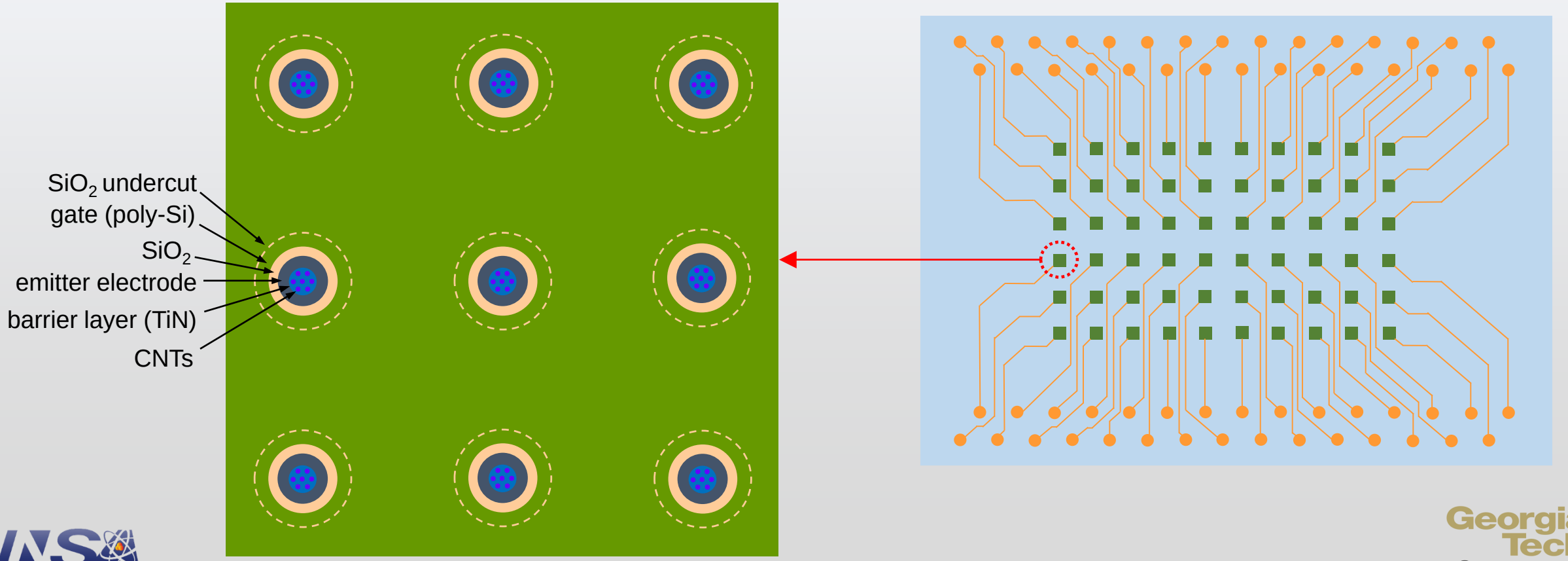




Triode instead of **diode:** more accurately control the emission current.

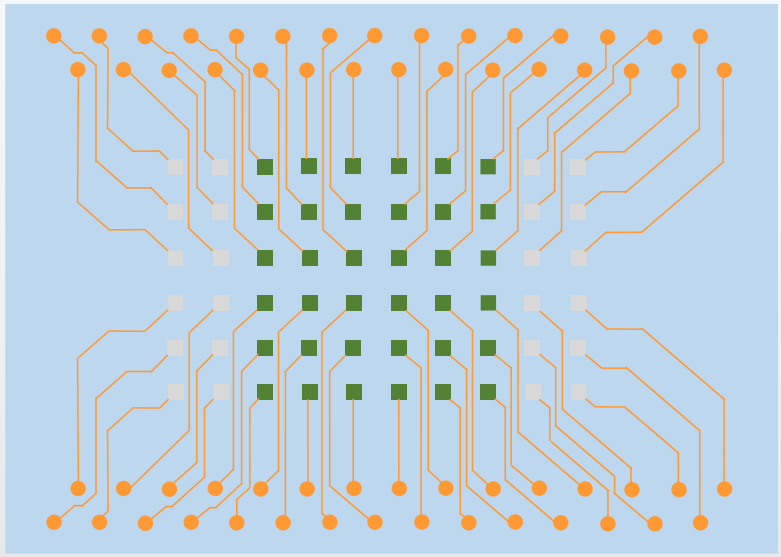
Multi-pixel Source by Micro-integrated Two Dimensional CNT-based Field Emission

- Higher spatial resolution
- X-ray beam shaping (digitally controlled electron stream under low turn-on voltage)

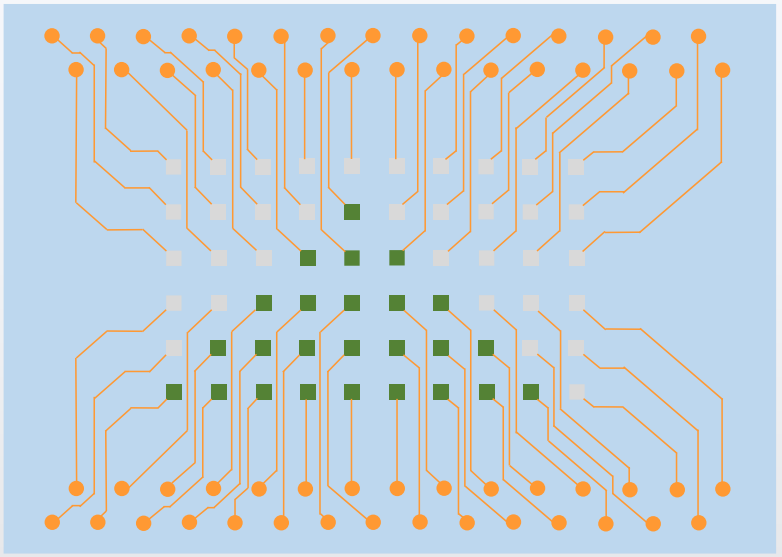


X-ray Beam Shaping by Digitally Controlled Electron Stream

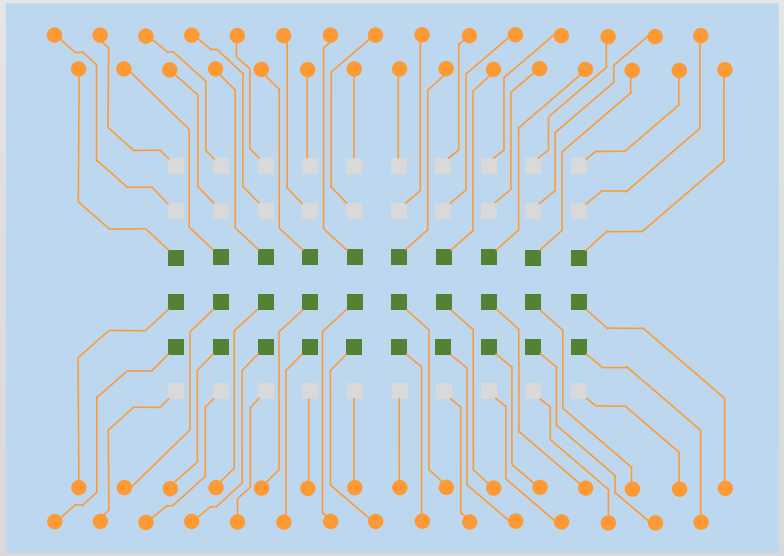
Square



Triangle



Rectangle



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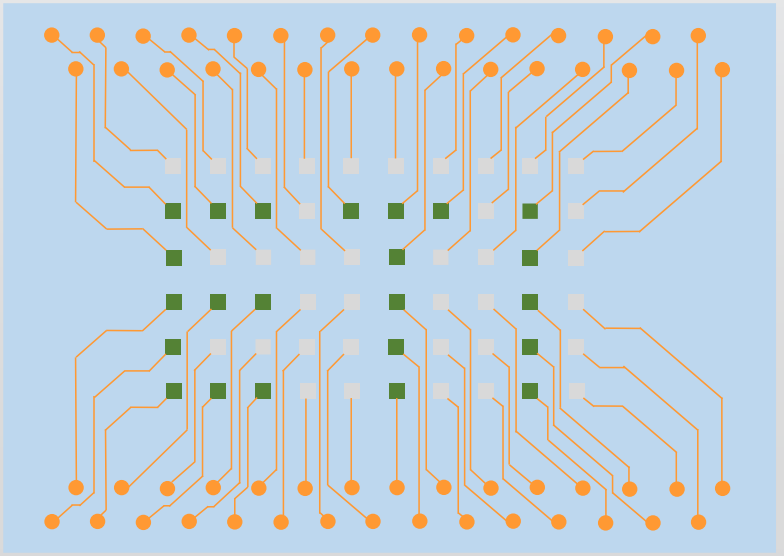

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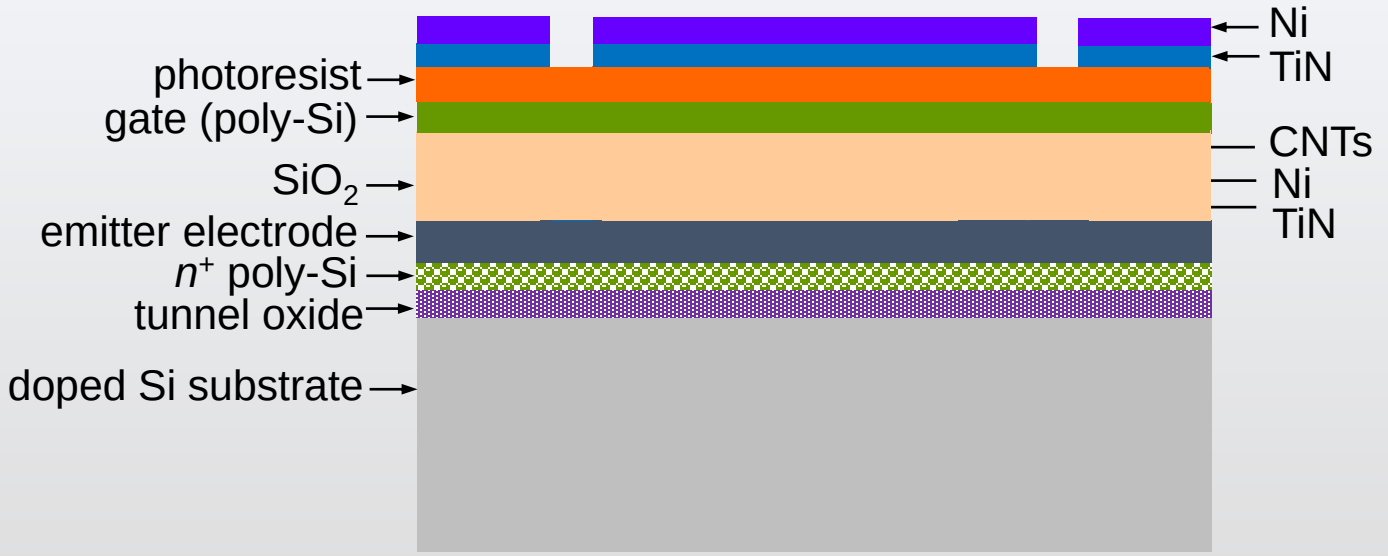
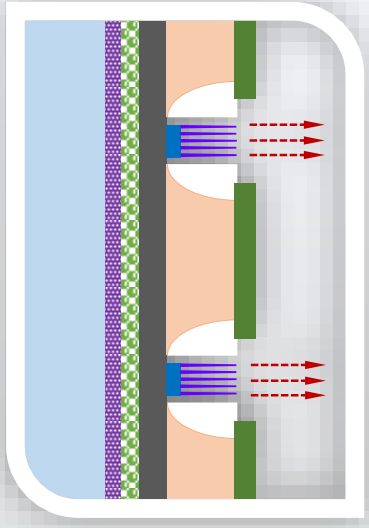
Device Fabrication: Vertically Self-aligned and Gated CNTs

1. Grow thin-film layers
2. Photolithography patterning
3. Reactive ion etching: undercut
4. Wet chemical etching: undercut
5. Deposit barrier layer & catalyst
6. Lift-off
7. Grow vertically self-aligned & gated CNTs

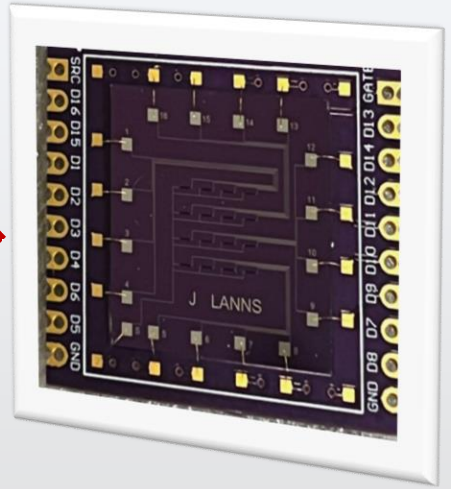


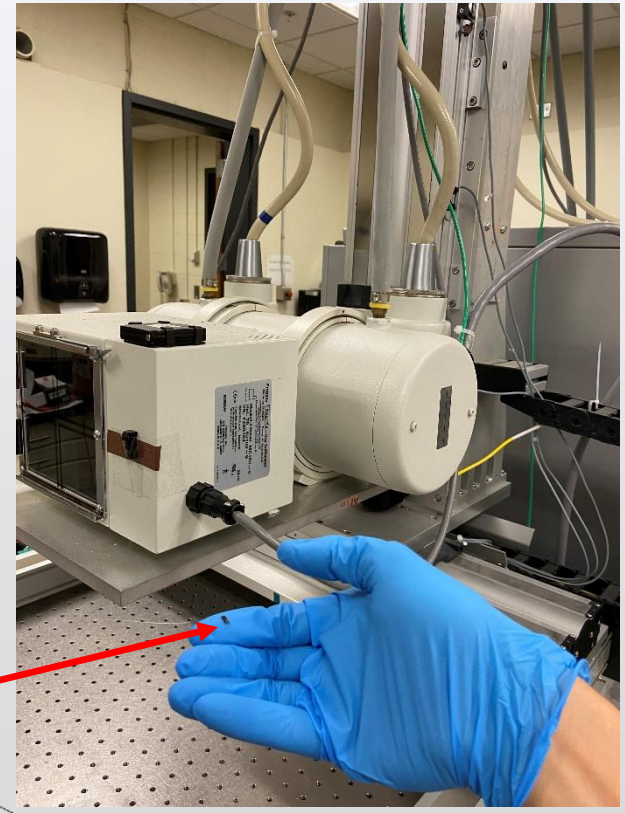
Innovative X-ray Generation and Imaging System with CNTs

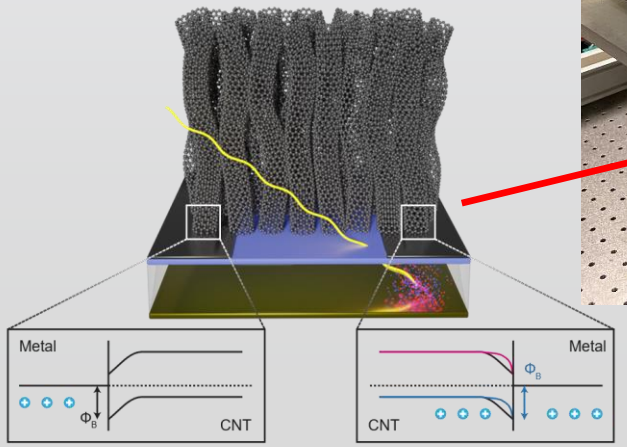
X-ray Source



X-ray Detector







CNT-based radiation detector

- ✓ Advance industries
- ✓ Improve people's lives
- ✓ Strengthen homeland security
- ✓ Enhance nuclear nonproliferation

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[1] A. Rajapakse, PhD dissertation, Georgia Institute of Technology, December 2021.

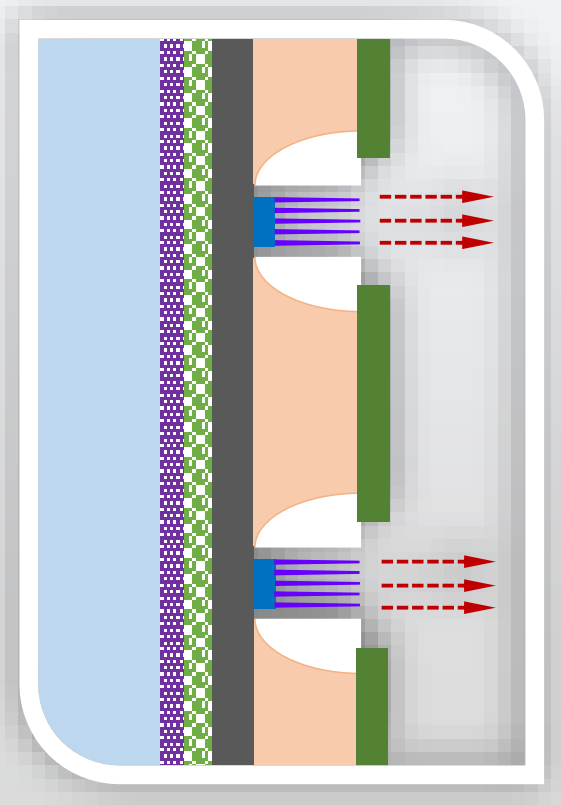
ETI Impact

- **Impact of the ETI on this development**
  Workshop participation: ETI Annual Workshop, UPR, IEEE NSSMIC.
  Networking, connections: ORNL, BNL, OSU, …
  Peer-reviewed journal paper publication.

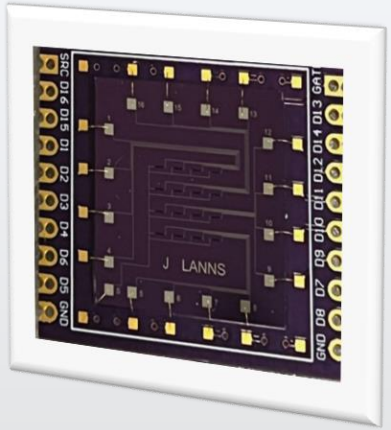
- **Plans for future relationship with national labs**
  BNL, ORNL, SNL, INL, …

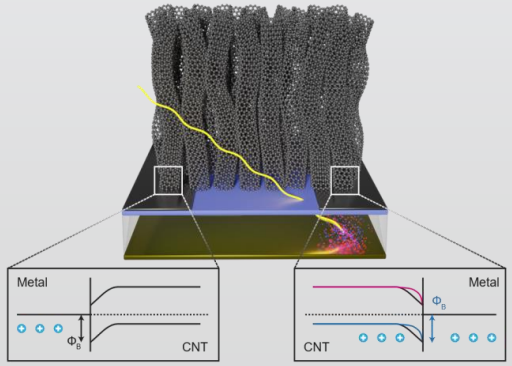
Conclusion

CNT-based field emission electronics X-ray Source



CNT-based radiation Detector





- ✓ **Advance industries**
- ✓ **Improve people's lives**
- ✓ **Strengthen homeland security**
- ✓ **Enhance nuclear nonproliferation**

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Thank you!

LANNS

LABORATORY FOR ADVANCED NUCLEAR NONPROLIFERATION AND SAFETY

Scan me

https://lanns.gatech.edu

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ACKNOWLEDGEMENTS

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