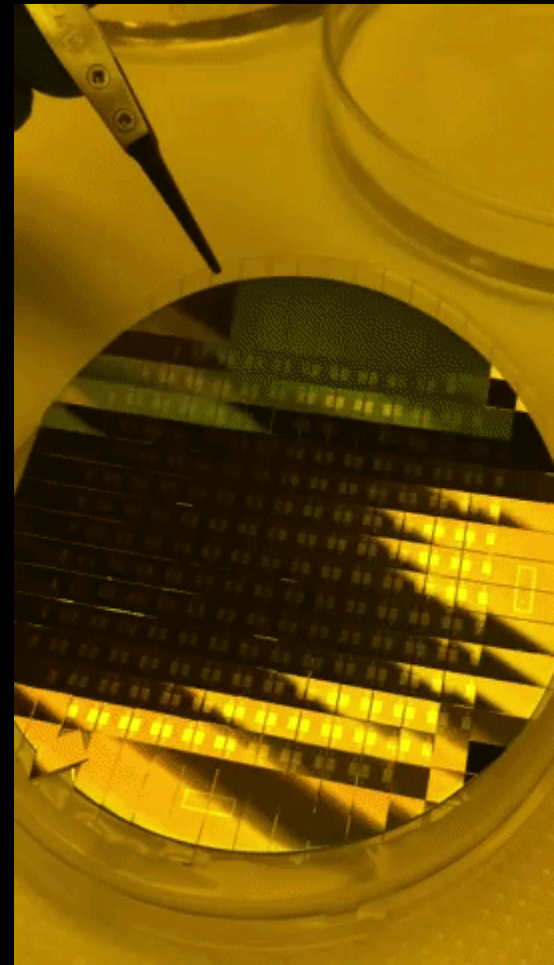
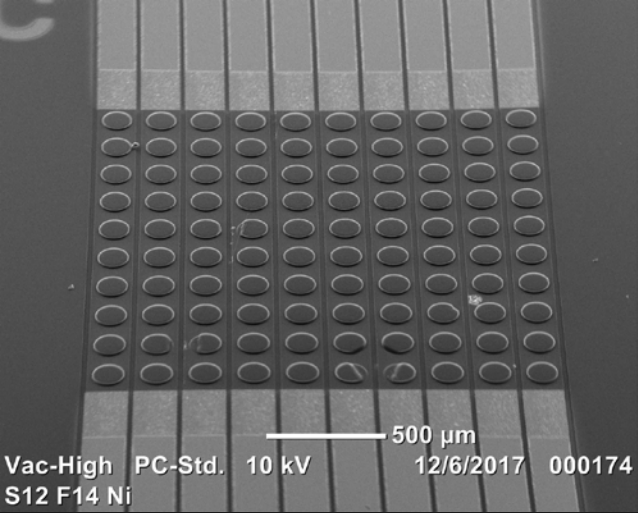


# Effects of Carbon Nanotube Forest Patterning on Field Emission Properties

Nolan Roth  
High Point University  
NASA Goddard Space  
Flight Center



# What is MiniEPMA?



ELECTRON BEAM

A yellow lightning bolt graphic pointing towards the probe holes in the SEM image.

X RAY

A green wavy line graphic representing an X-ray beam.

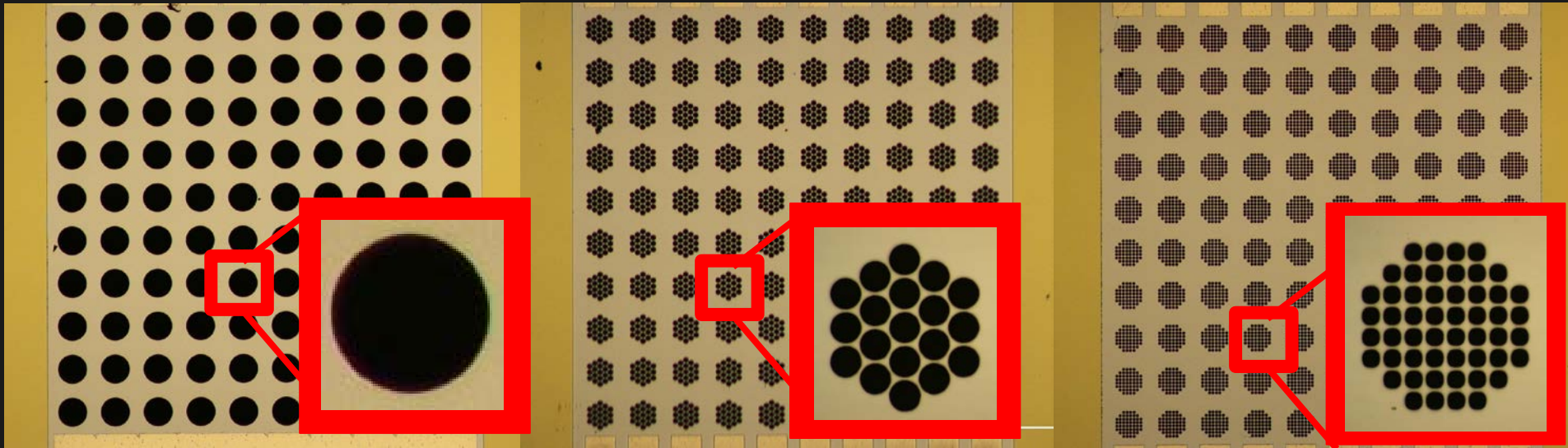


# Common Issues

***Efficiency = Turn-on Field***

***Performance = Amount of Emission***

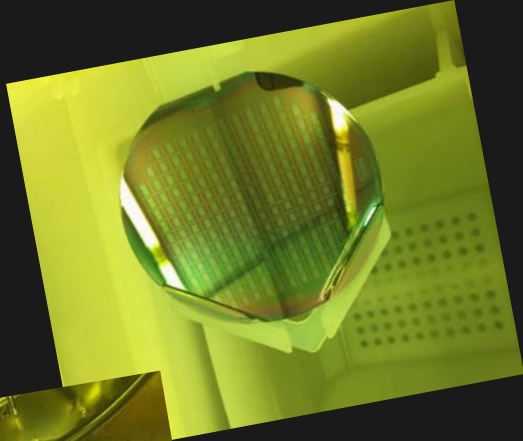
# Forest Geometries



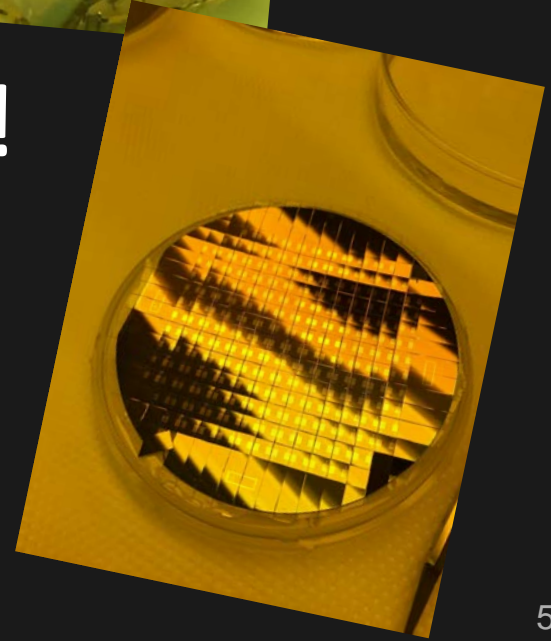
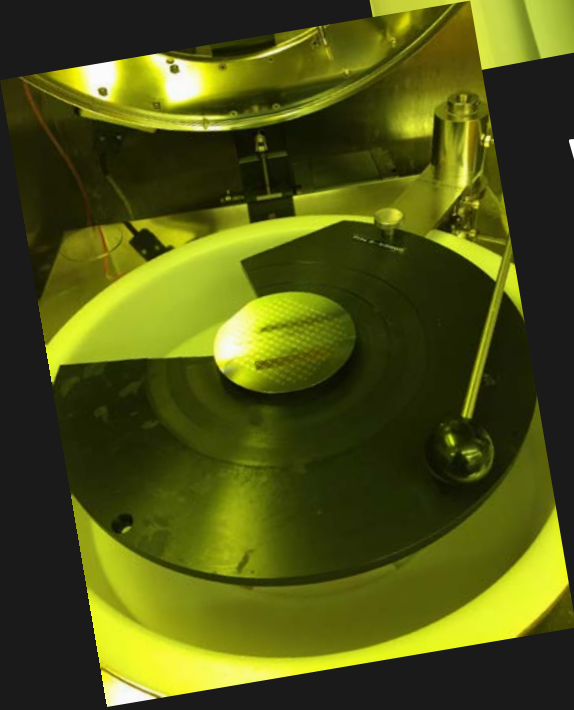
Control  
Geometry

Geometry 1

Geometry 2



# Wafer Processing!





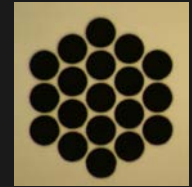
# Emission Testing!



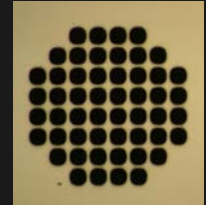
- 27 controls



- 3 Geometry 1



- 3 Geometry 2

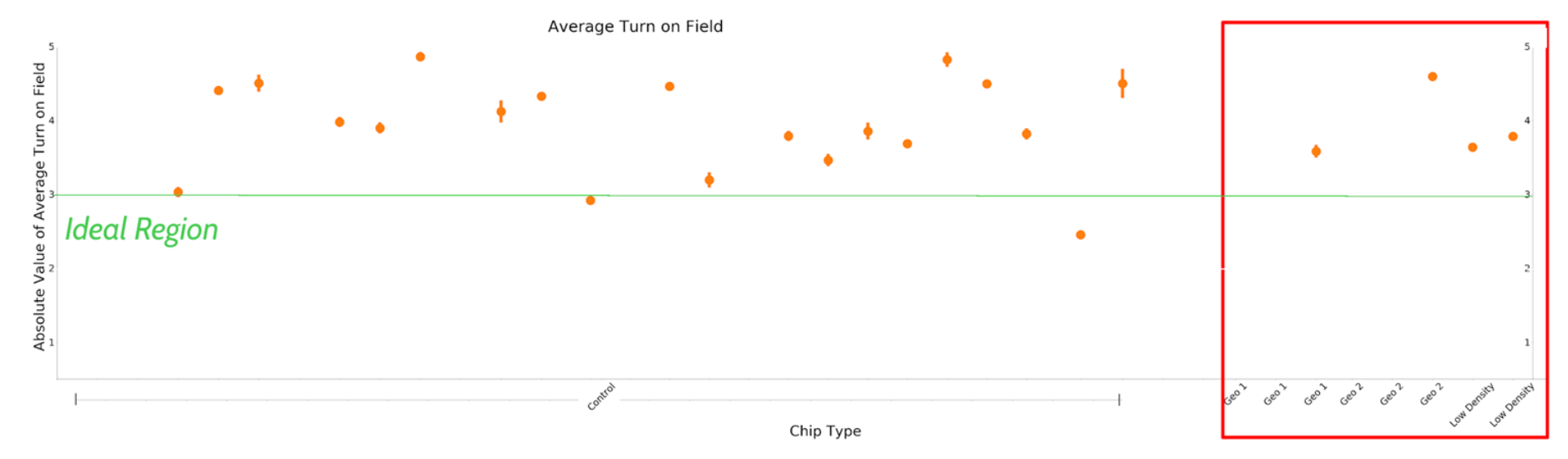


- 2 Low Density



# Efficiency

Significant:  $< 3 \text{ V}/\mu\text{m}$



# Performance

Significant: 10  $\mu$ A

Control Set 1	Avg Emission at 5 V/ $\mu$ m ( $\mu$ A)	Control Set 2	Avg Emission at 5 V/ $\mu$ m ( $\mu$ A)	Variable Set	Avg Emission at 5 V/ $\mu$ m ( $\mu$ A)
Control Chip		Control Chip		Spacer Chip	
Control Chip	<b>0.4</b>	Control Chip	<b>0.3</b>	Geo 1	<b>0.2</b>
Control Chip	<b>9</b>	Control Chip	<b>0.2</b>	Geo 1	<b>0.5</b>
Control Chip	<b>3.4</b>	Control Chip	<b>29.8</b>	Geo 1	<b>3.7</b>
Control Chip	<b>1.3</b>	Control Chip	<b>0.3</b>	Control	<b>1.7</b>
Control Chip		Control Chip		Control	<b>0.7</b>
Control Chip	<b>18</b>	Control Chip	<b>144.7</b>	Control	<b>0.4</b>
Control Chip	<b>2.6</b>	Control Chip	<b>1.9</b>	Geo 2	<b>0.5</b>
Control Chip	<b>2</b>	Control Chip	<b>9.6</b>	Geo 2	<b>0.4</b>
Control Chip	<b>0.3</b>	Control Chip	<b>3.4</b>	Geo 2	<b>1.1</b>
Control Chip		Control Chip	<b>11.6</b>	Standard Geo, RTP	<b>28.2</b>
Control Chip	<b>2.1</b>	Control Chip	<b>0.2</b>	Standard Geo, RTP	<b>10.2</b>



# Acknowledgments

Both of my NASA advisors: Adrian Southard and Larry Hess

Society of Physics Students for this amazing summer!

Eric from The Big Board

# References

Nilsson, L., O. Groening, C. Emmenegger, O. Kuettel, E. Schaller, L. Schlapbach, H. Kind, J-M. Bonard, and K. Kern. 2000. "Scanning Field Emission from Patterned Carbon Nanotube Films." *Applied Physics Letters* 76 (15): 2071–73.

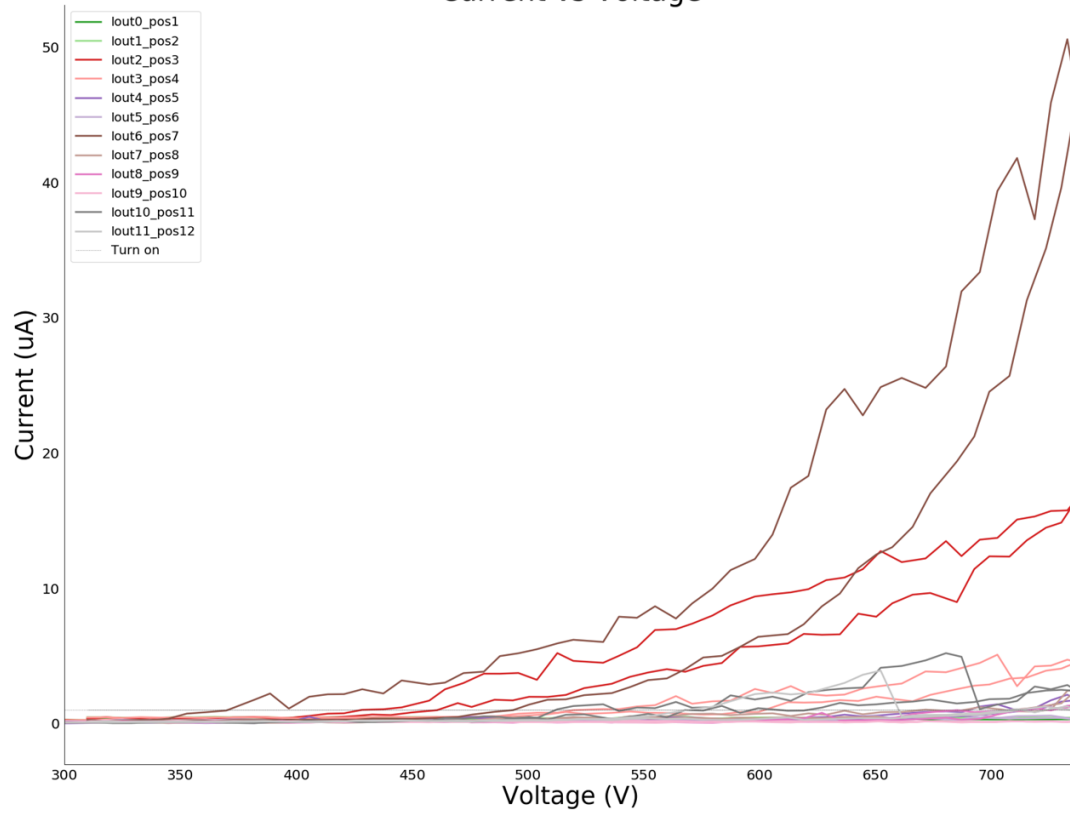
Sato, Hideki, Kazuo Haruki, Masaaki Watanabe, Koichi Hata, and Yahachi Saito. 2012. "Effect of Geometry of a Vertically Aligned Carbon Nanotube Pillar Array on Its Field-Emission Properties." *Surface and Interface Analysis* 44 (6): 776–79.

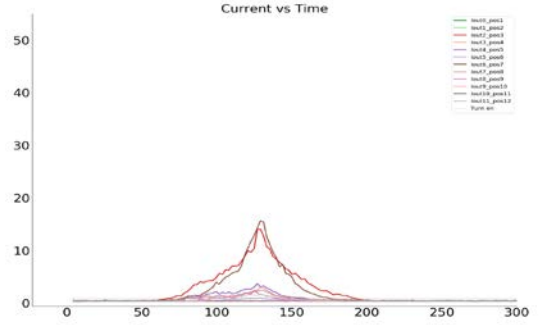
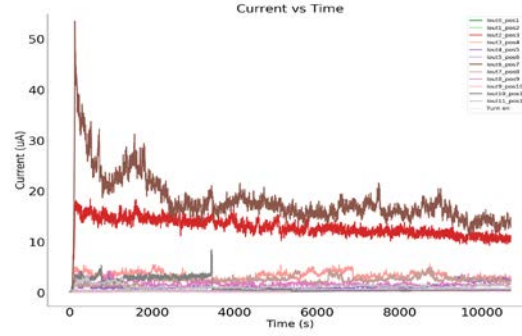
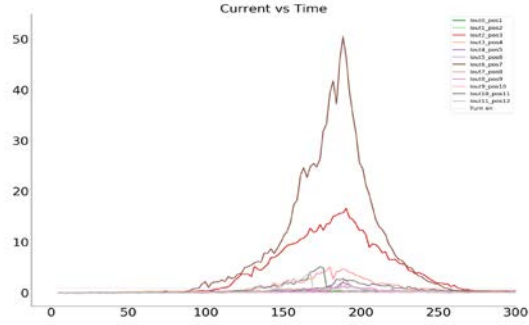
Silan, Jeremy L., Darrell L. Niemann, Bryan P. Ribaya, Mahmud Rahman, M. Meyyappan, and Cattien V. Nguyen. 2009a. "Novel Geometry of Carbon Nanotube Field Emitter to Achieve High Current Densities." In 2009 International Semiconductor Device Research Symposium, 1–2. IEEE.

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Wow! Bonus slides!

## Current vs Voltage





All\_-750\_stp4\_18\_06182019\_114341.csv Fowler-Nordheim Compilation Plot

