GaAs Truncated Nanocone Array Photocathode Electron Source

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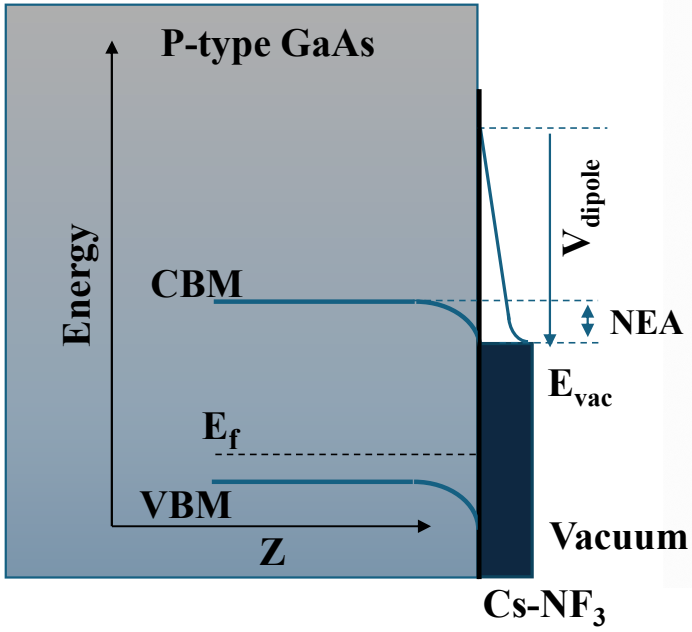
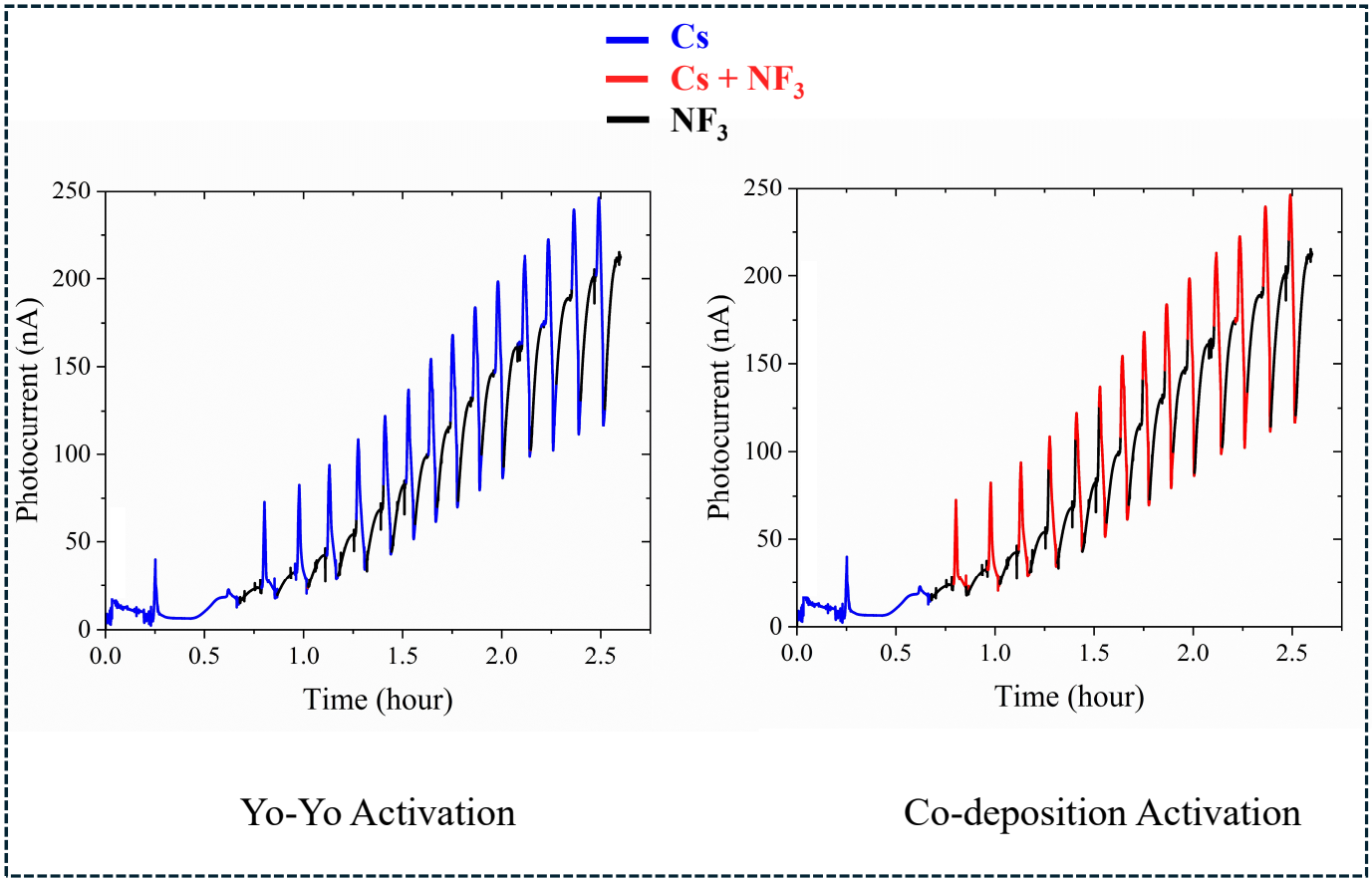
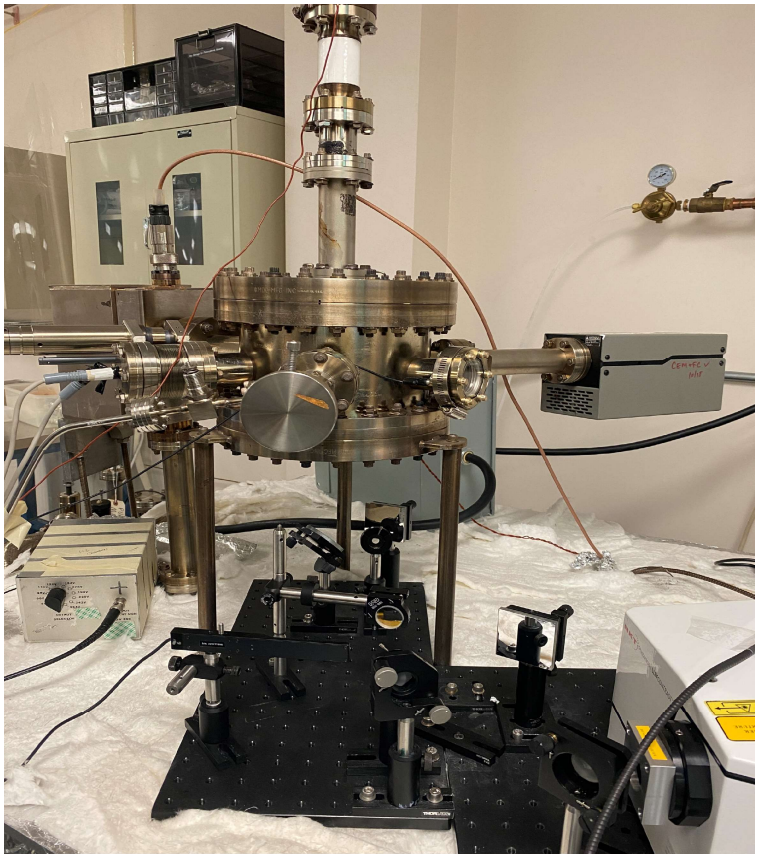
Introduction:



Negative Electron Affinity



H1 Chamber:



MicroMott Polarimeter:

Quantum Efficiency: # of electrons emitted / # of photon

$$\mathbf{QE} = \frac{hc}{\lambda}\frac{I}{P}$$

$$\mathbf{Asymmetry,\ A} = \frac{N_{\uparrow} - N_{\downarrow}}{N_{\uparrow} + N_{\downarrow}}$$

$$\mathbf{Polarization,\ P = A\ /\ S(\theta)}$$

Why GaAs Nanostructure?

Mie Resonance:

- **Optical field enhancement within the subwavelength sized nanostructure due to dipole / higher order mode excitations.**
- $\frac{nD}{\lambda} = 1\ (dipole), 2\ (quadrupole), \ldots$
- **Results in enhanced absorption.**

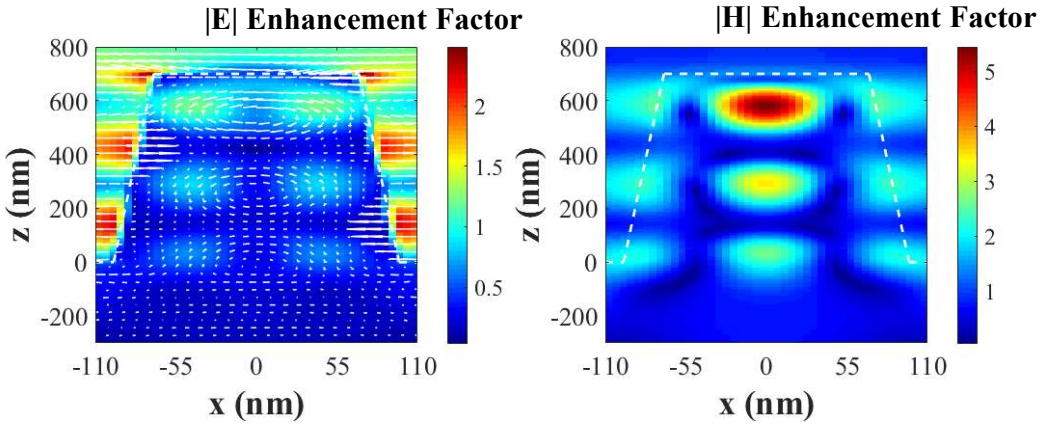
Truncated nanocone has increased surface area.

- **Increased surface area can contribute to over-all enhancement in QE.**

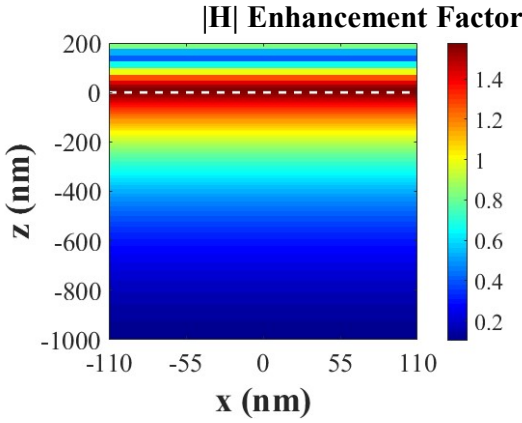
Shorter travelling path of electron towards emission surface.

- **Shorter travelling path helps to reduce the scattering of electrons.**

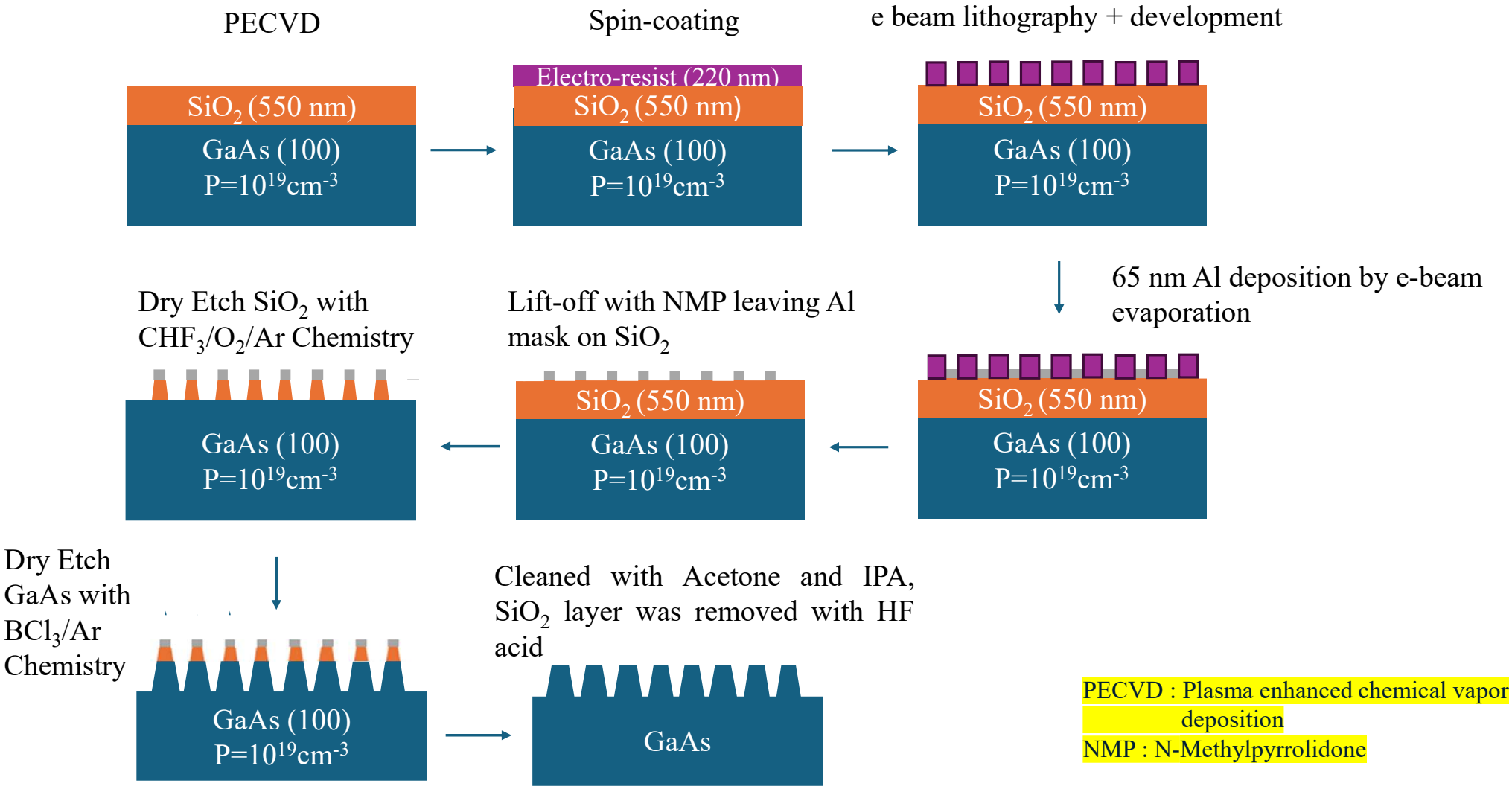
Truncated Nanocone:



Bulk:



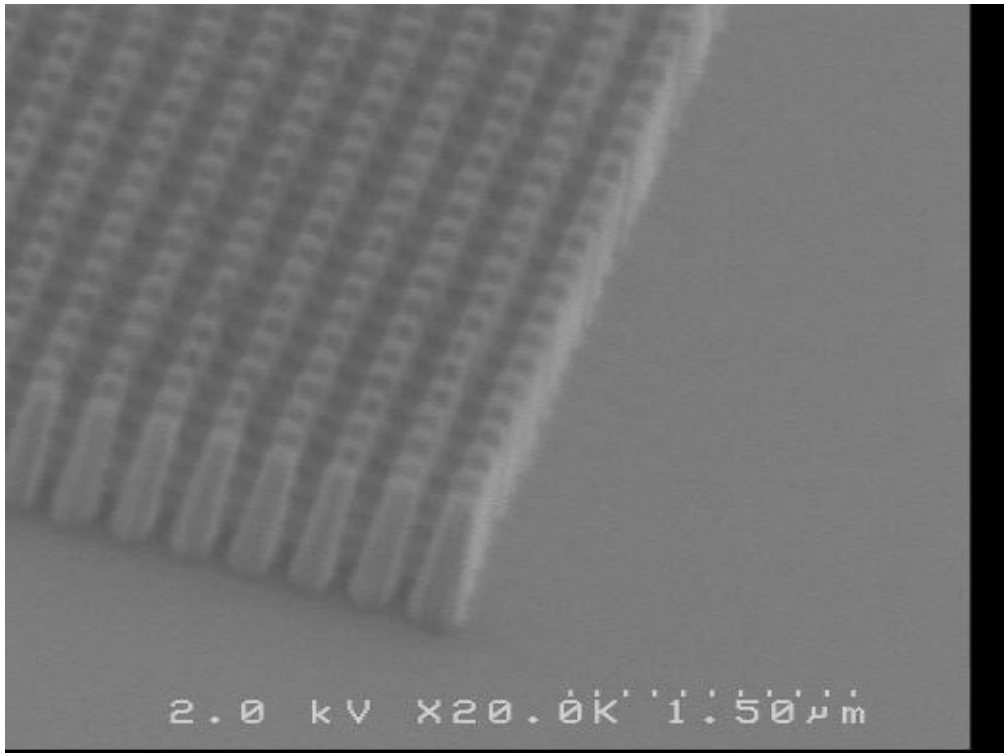
Truncated Nanocone Array Fabrication at SRI:

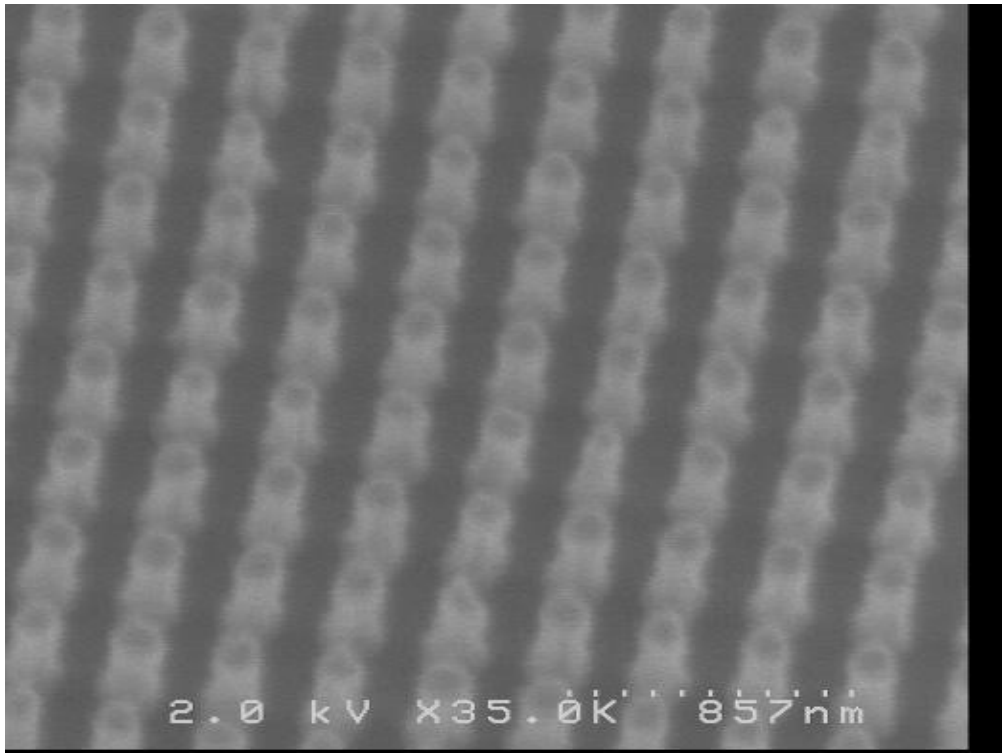


PECVD : Plasma enhanced chemical vapor deposition

NMP : N-Methylpyrrolidone

SEM Image:



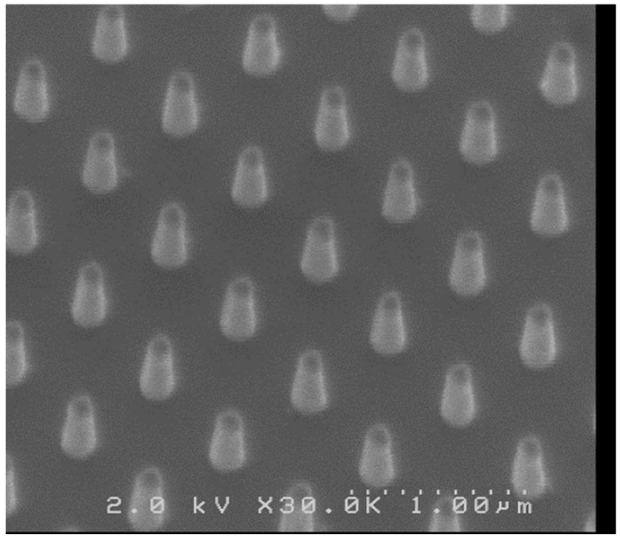


Dimensions:

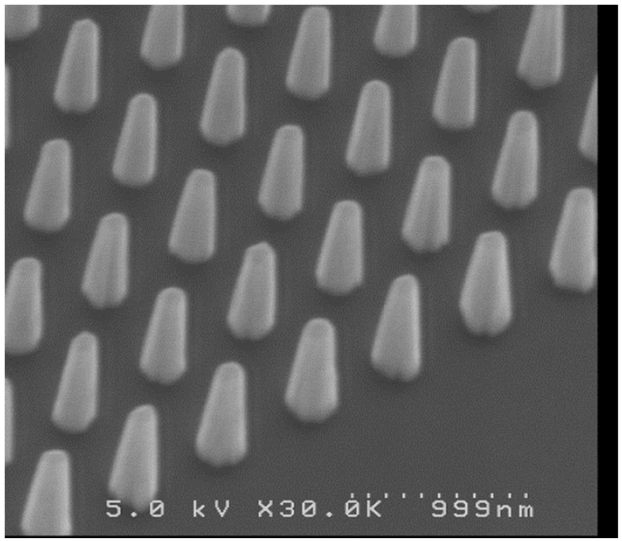
Top Diameter (nm)	Bottom Diameter (nm)	Height (nm)	Pitch (nm)
139	195	700	318

SEM Image: (2nd batch)

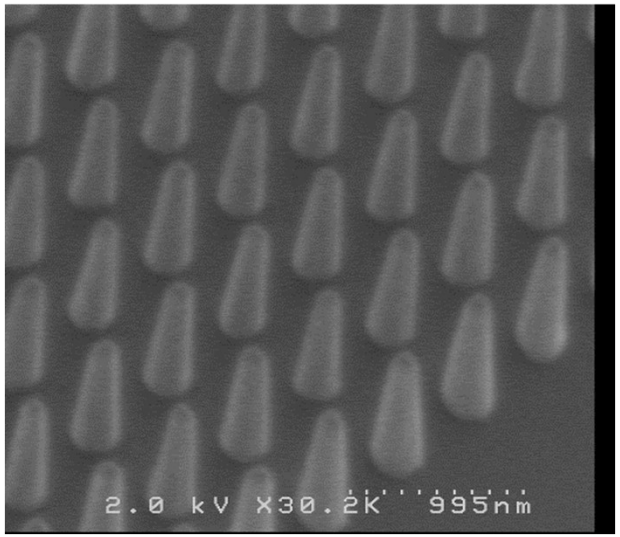
A



B



C



Dimensions:

Sample	Top Diameter (nm)	Bottom Diameter (nm)	Height (nm)	Pitch (nm)
A	125	172	400	586
B	134	211	700	566
C	122	252	1000	555

Available Truncated Nanocone Array Photocathodes:

	Top Diameter (nm)	Bottom Diameter (nm)	Height (nm)	Pitch (nm)	Quantity	Type
GTS	125	172	400	586	1	p-type GaAs(100) Carrier concentration = ~$10^{19}$$cm^{-3}$
GTS	134	211	700	566	1	
GTS	122	252	1000	555	2	
	137	241	400	356	1	
	139	195	700	318	1	
	-	317	1400	378	1	
	120	165	400	590	1	GaAsSb/AlGaAs SSL
	135	198	700	321	1	
	133	235	1000	284	1	

Results:

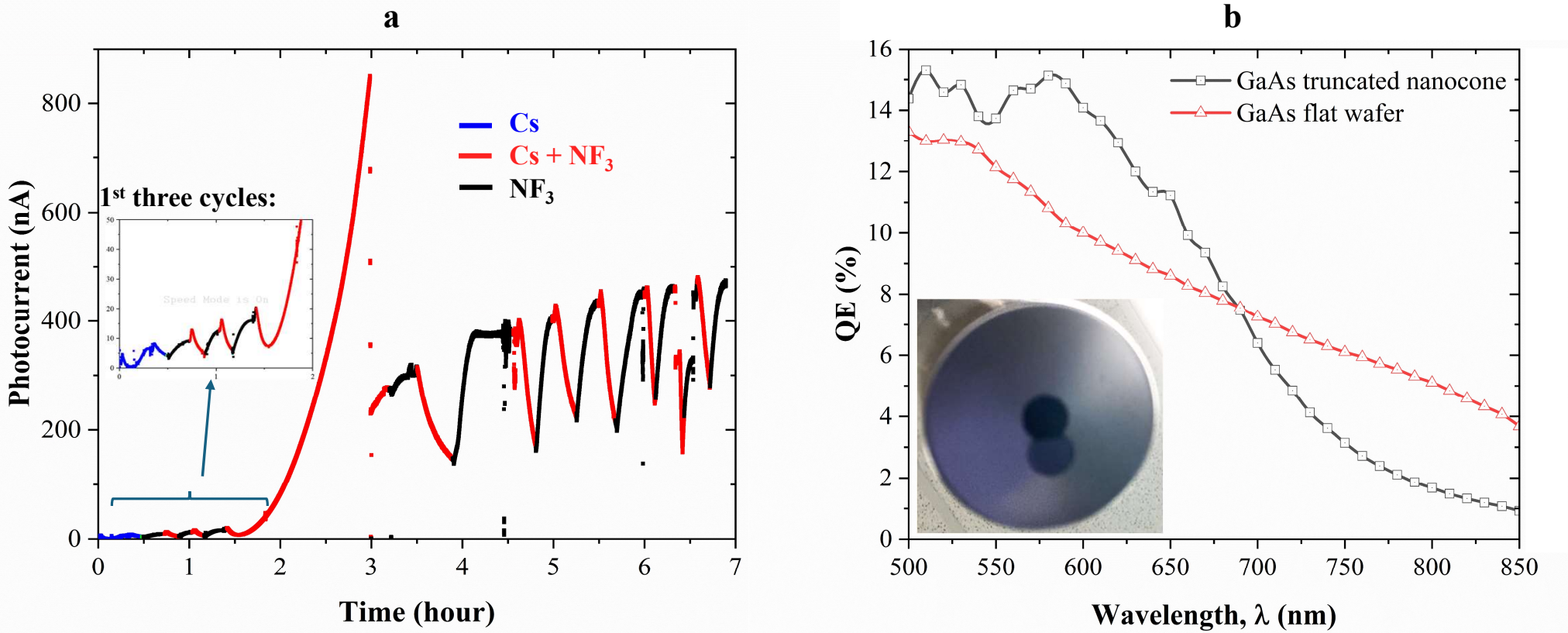


Figure: (a) NEA activation for GaAs truncated nanocone array photocathode with Cs and NF_3, (b) Spectral response comparison between GaAs truncated nanocone and GaAs (100) flat wafer. Resonance peaks are observed at 530 nm and 580 nm wavelengths. The photocathode (nanocone at the center, flat region is off-centered) is shown in the inset image.

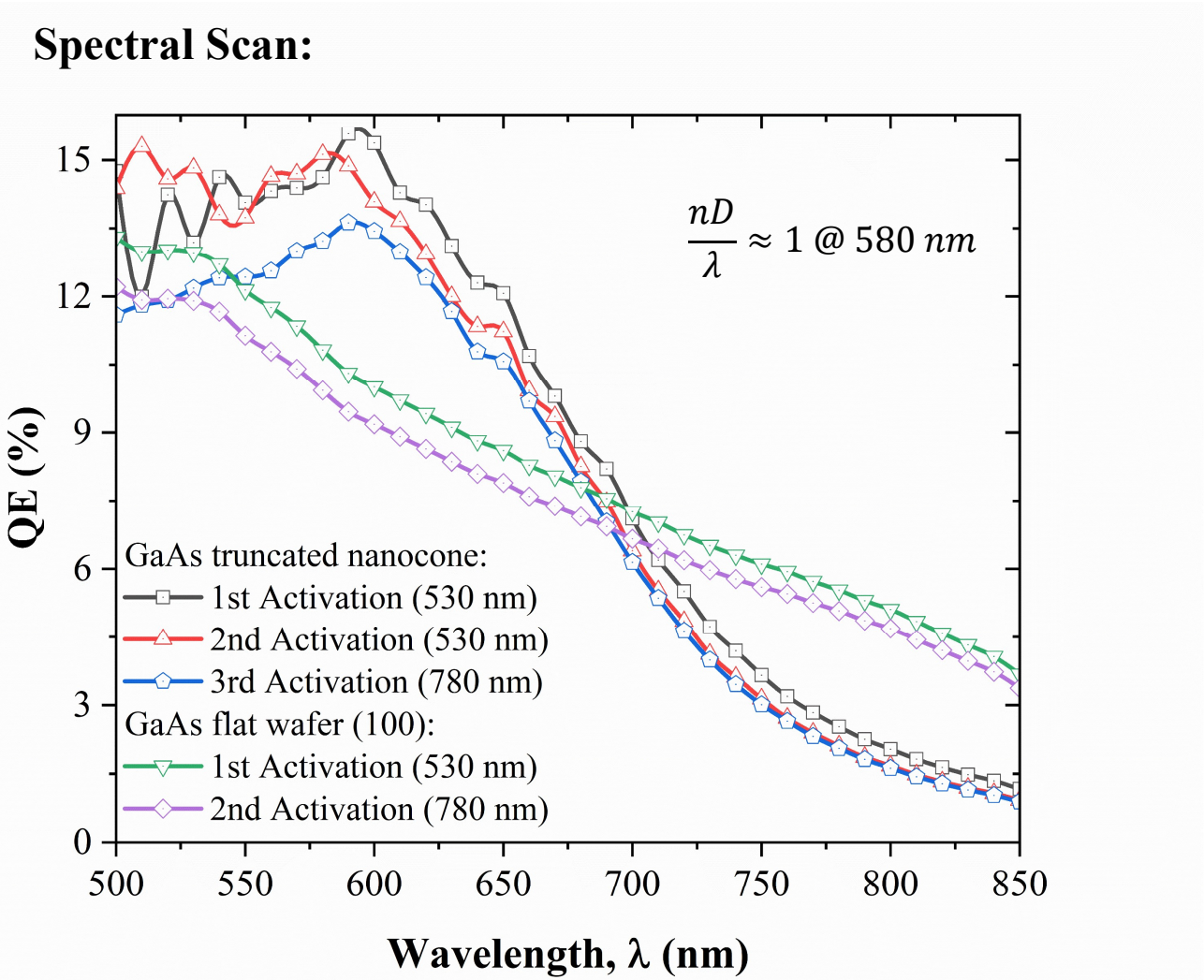


Figure: Spectral response: the nanocone 3rd activation and flat wafer 2nd activation were done using 780 nm light, all other activations are done using 530 nm light.

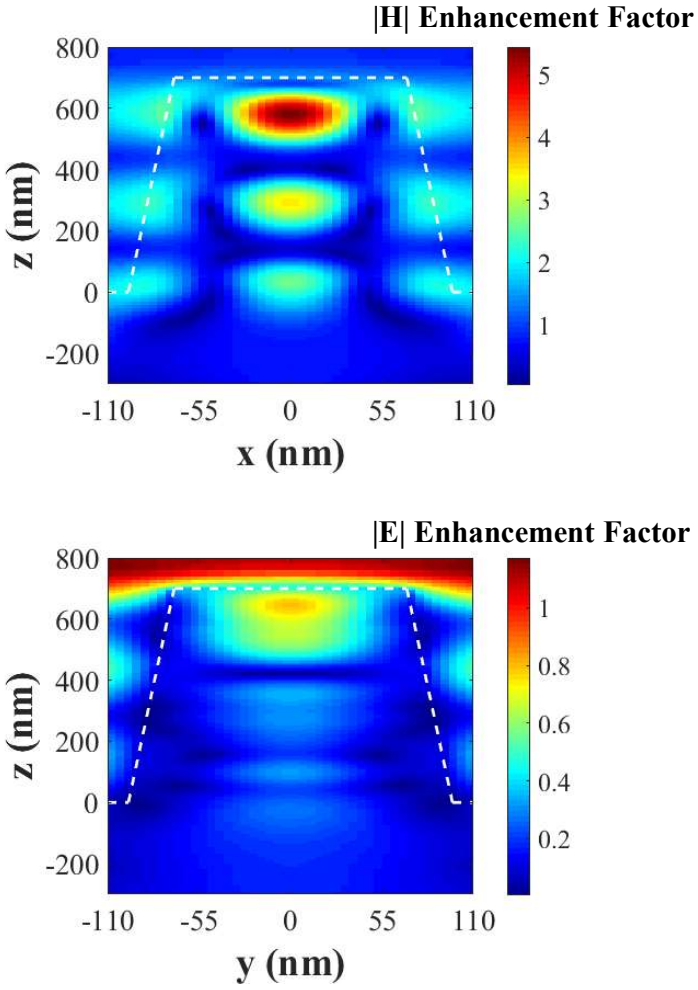


Figure: Optical field enhancement at 580 nm.

Lifetime:

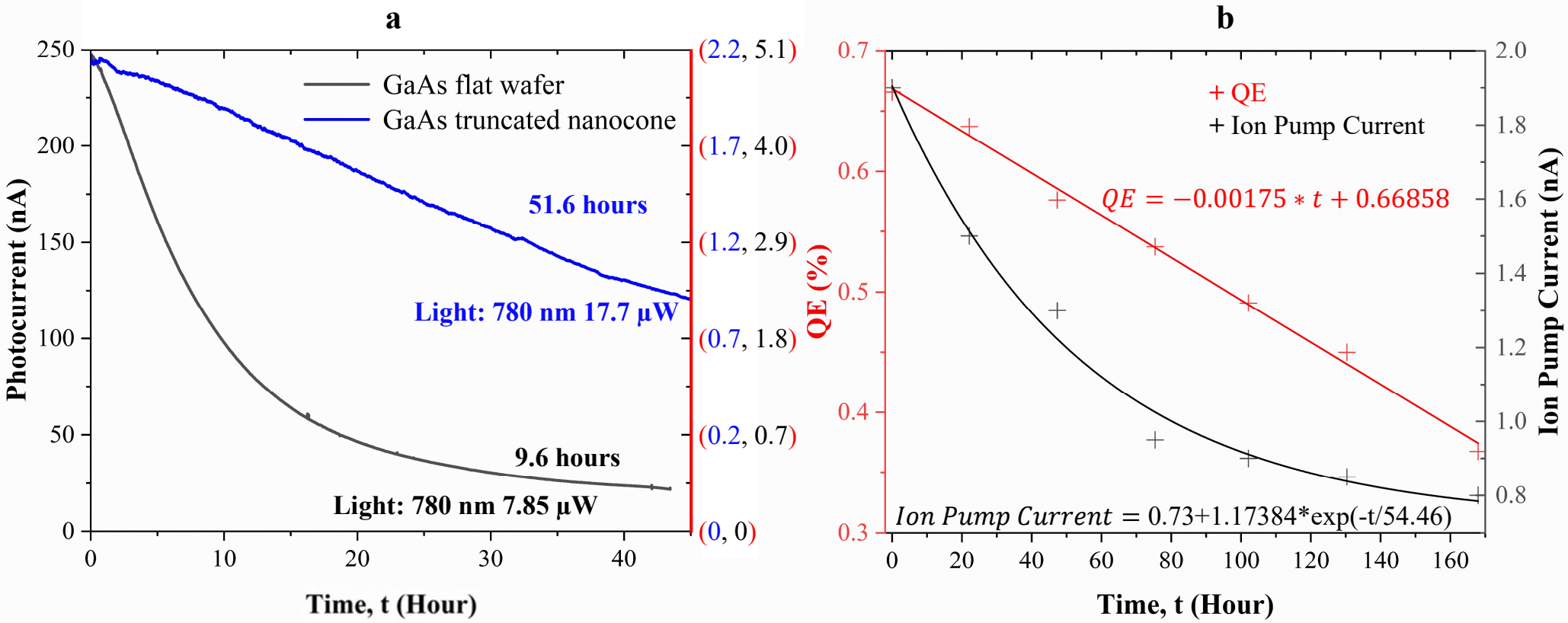


Figure: (a) Operating lifetime (1/e lifetime) is found to be improved by ~5.4 times in truncated nanocones compared to the flat wafers. Initial chamber pressure was 12 nA for both the measurements. (b) Dark lifetime and chamber pressure (in terms of ion pump current) vs. time for truncated nanocone.

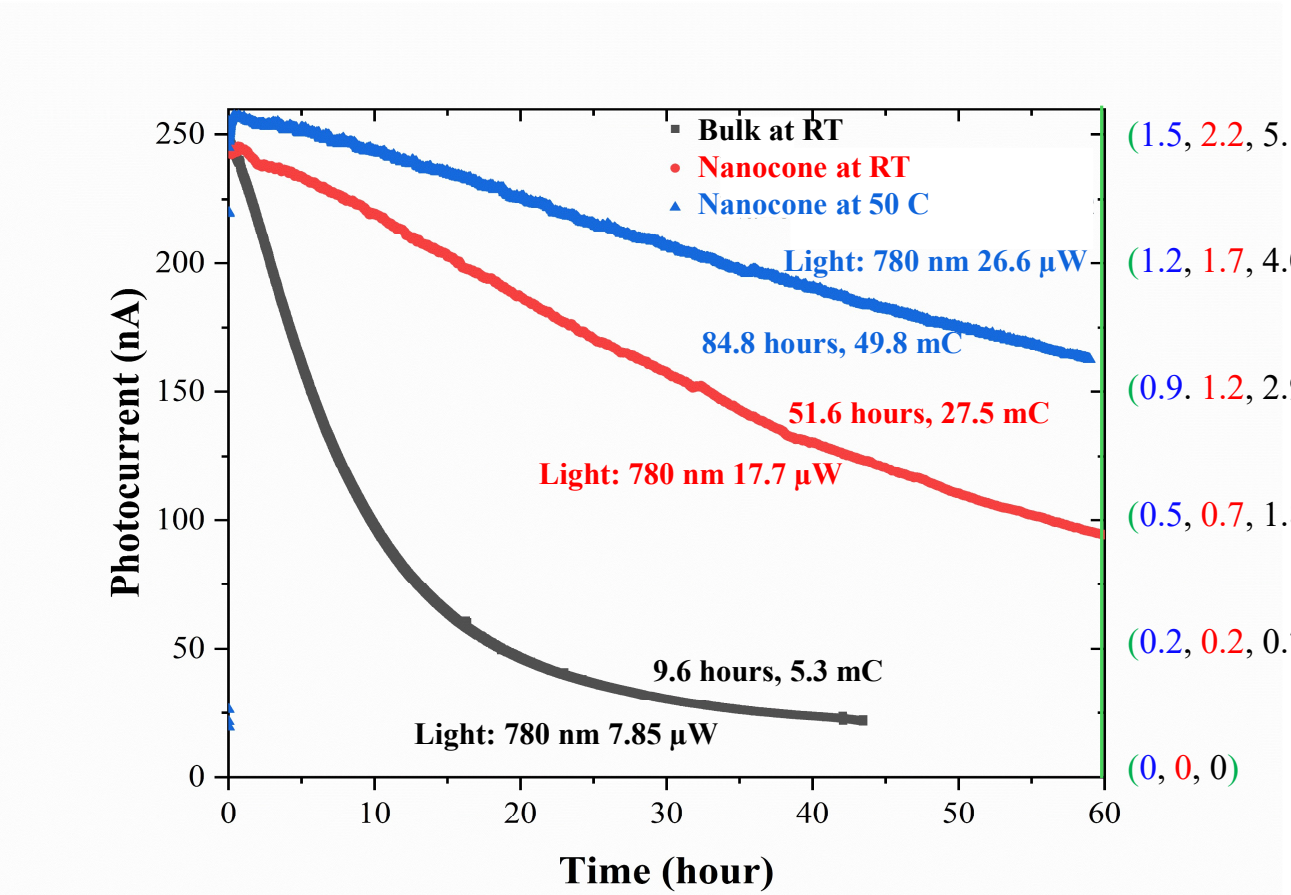
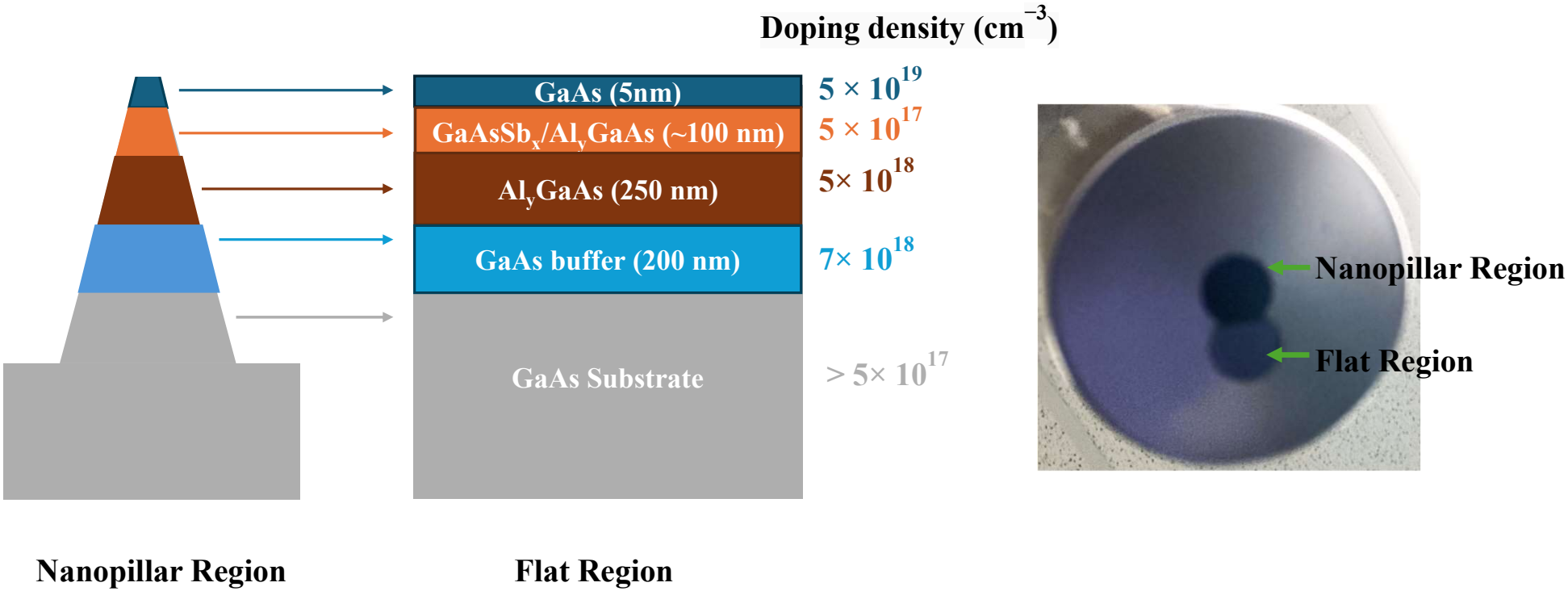


Figure: (a) Operating lifetime (1/e lifetime) and charge lifetime comparison between Bulk and truncated nanocone array photocathodes.

GaAsSb/AlGaAs SSL:



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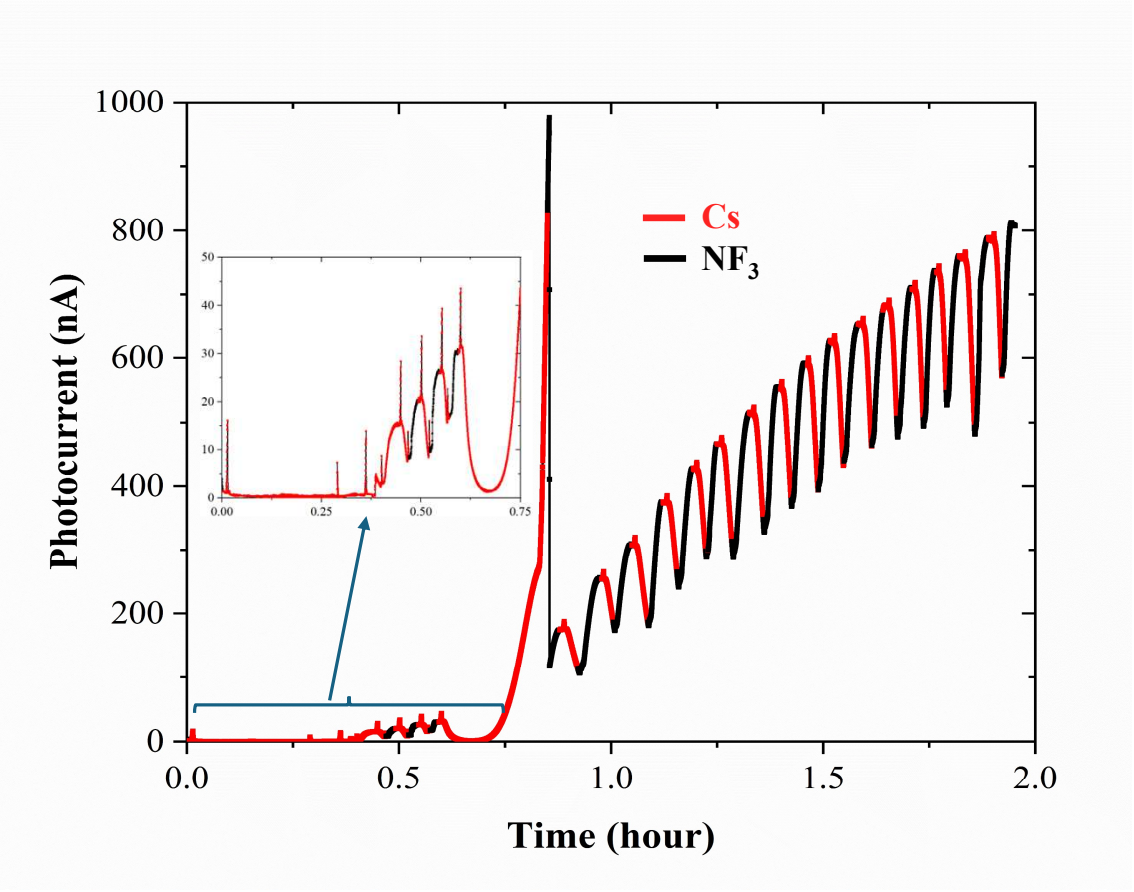
GaAs/GaAsSb SSL:



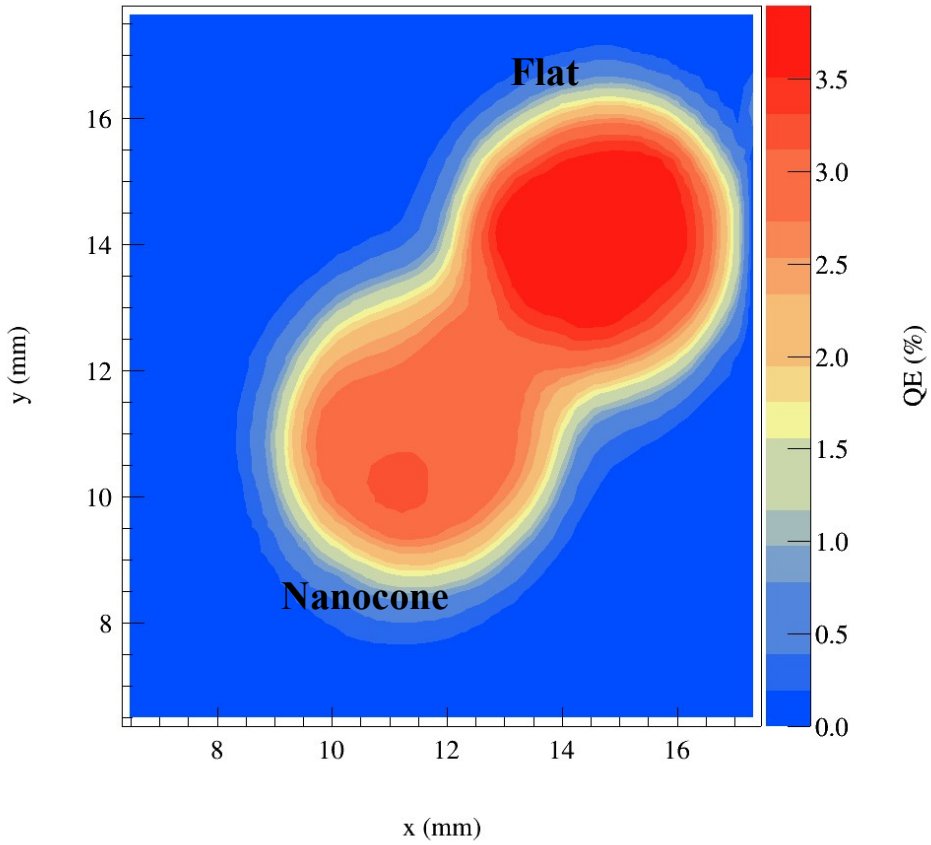


Figure: (a) NEA activation and (b) QE map using 660 nm laser light.

Acknowledgement: We would like to thank Greg Blume for polarization measurement.

GaAs/GaAsSb SSL:

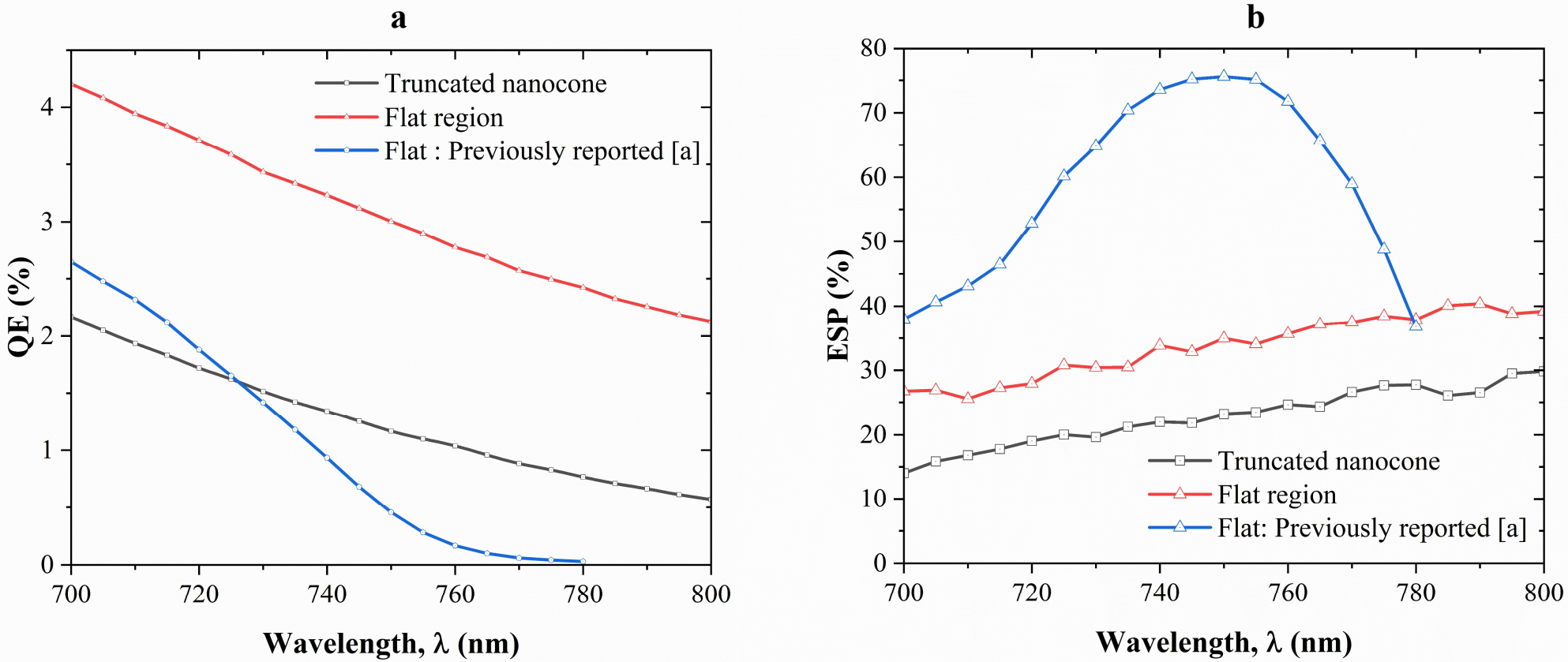


Figure: (a) QE and (b) Electron Spin Polarization (ESP) comparison between truncated nanocone and flat GaAsSb/AlGaAs SSL photocathodes.

Acknowledgement: We would like to thank Greg Blume for polarization measurement.

[a] *AIP Advances* 8, 075308 (2018)

Summary:

- **We observed enhancement in QE in 500-680 nm waveband.**
- **Peak QE was found at 580 nm wavelength due to magnetic dipole (MD) excitation mode.**
- **1/e lifetime was enhanced by a factor of 5.4 compared to the bulk.**
- **The electron spin polarization decreased by ~30% in longer wavelength region.**

Future Outlooks:

- **Optimization of the QE simulation model by incorporating experimental limitations.**
  - ❑ **Contribution from different emission area configuration.**
  - ❑ **Different doping profile.**
  - ❑ **Nanospike**
- **Testing the lifetime performance in high voltage gun at GTS.**
- **Polarization test at UITF for 1 bulk and 1 SSL.**