Progress towards long lifetime high current polarized electron sources

Jyoti Biswas

Brookhaven National Laboratory

On behalf of the collaborations

August 9, 2022

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Perspective - Polarized Electron Sources

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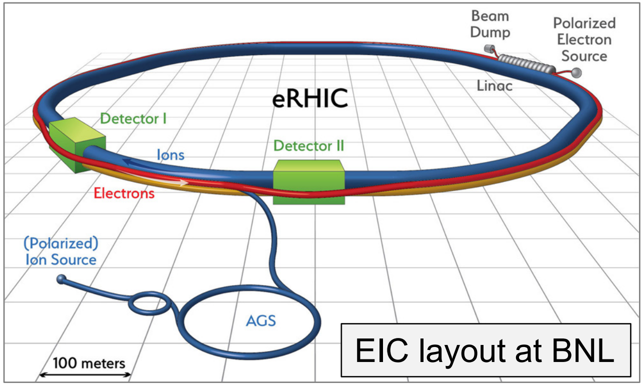

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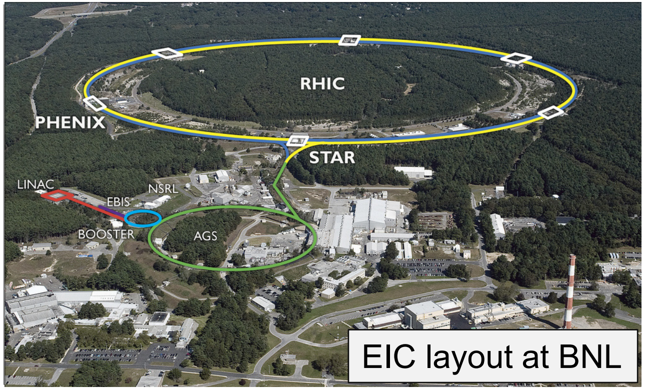
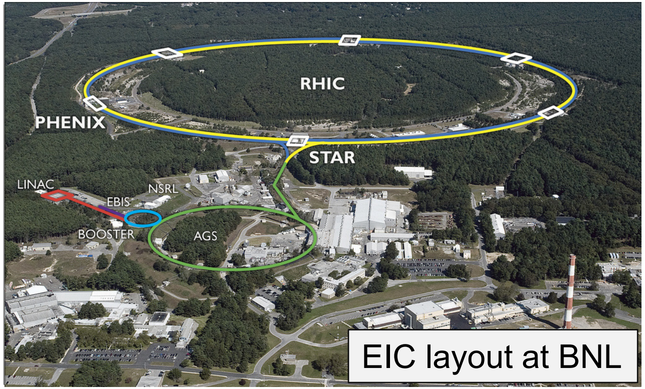
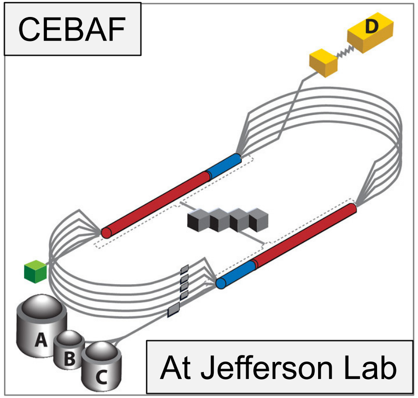


EIC layout at BNL

Perspective - Polarized Electron Sources





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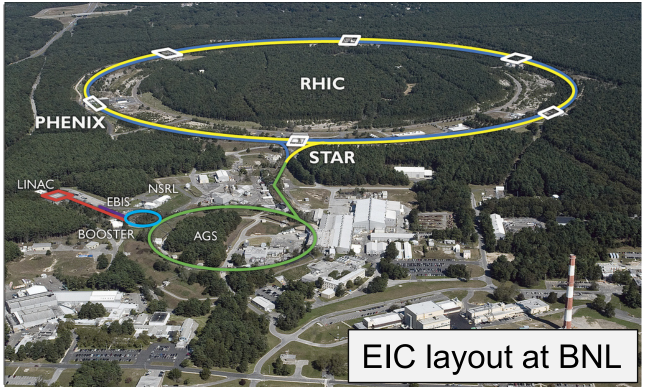

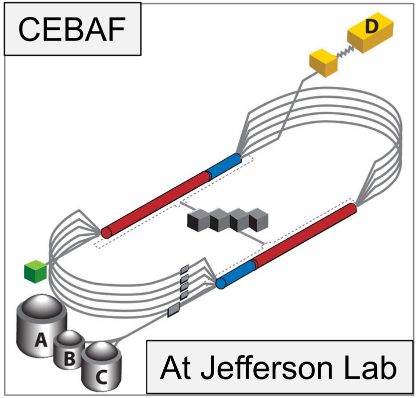

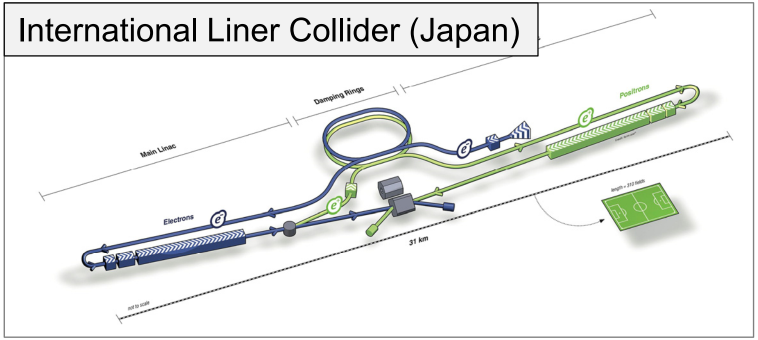

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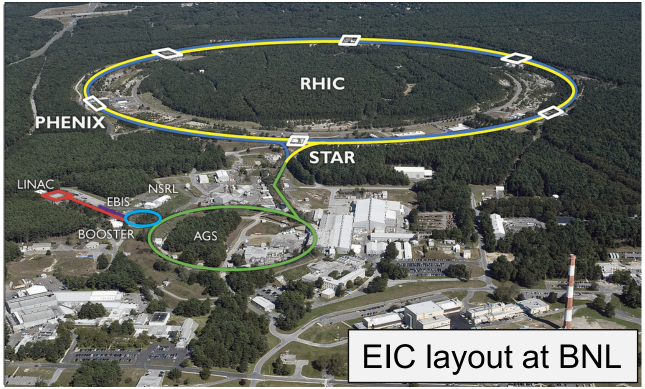

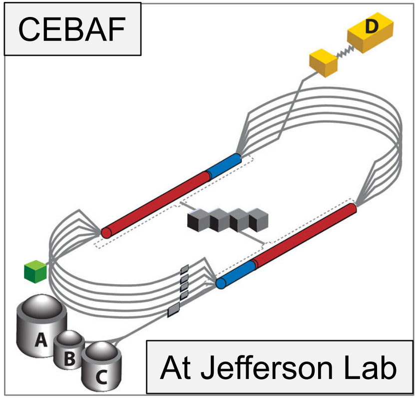

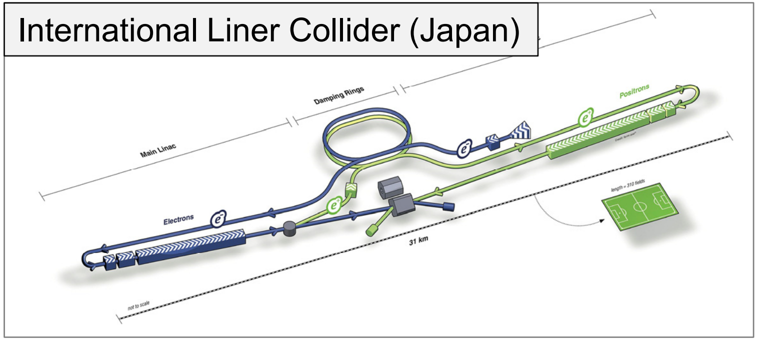

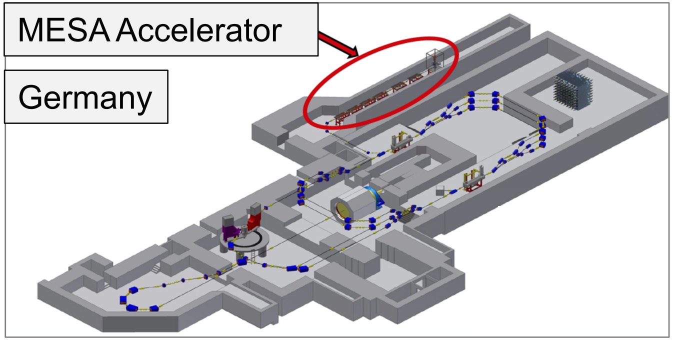

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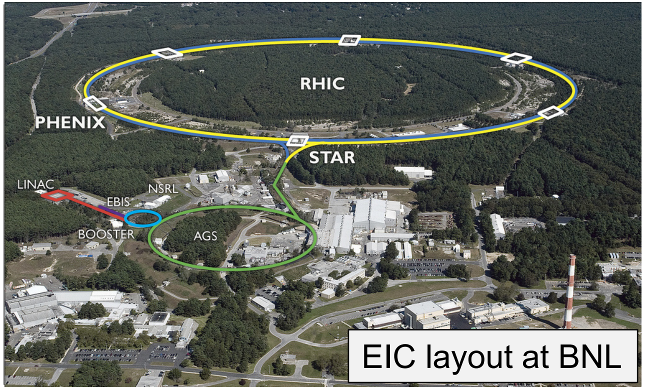

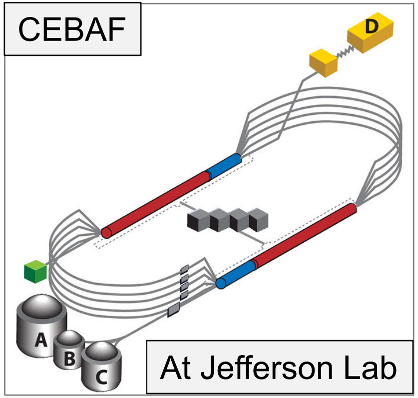

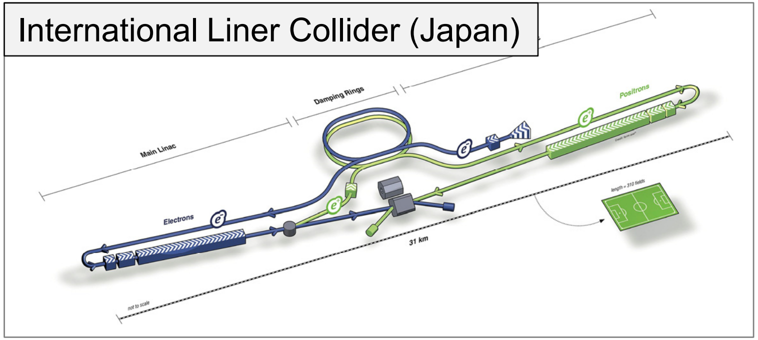

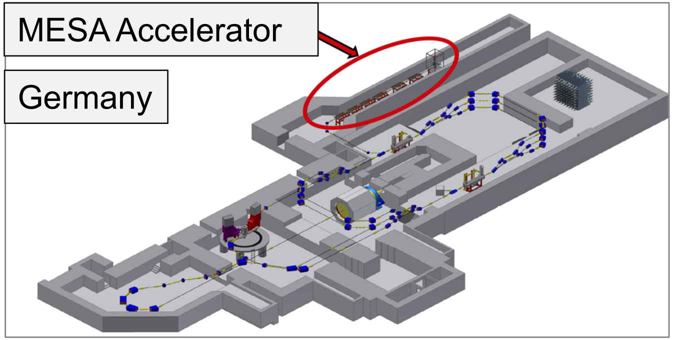

Polarized Electron Sources

GaAs-based photocathodes

Polarized Electron Sources

GaAs-based photocathodes

PHYSICAL REVIEW B VOLUME 13, NUMBER 12 15 JUNE 1976

Photoemission of spin-polarized electrons from GaAs

Daniel T. Pierce* and Felix Meier

Laboratorium für Festkörperphysik, Eidgenössische Technische Hochschule, CH 8049, Zürich, Switzerland

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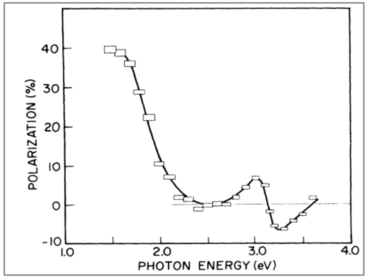

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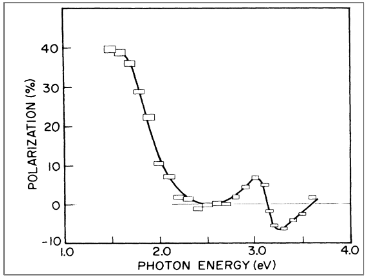

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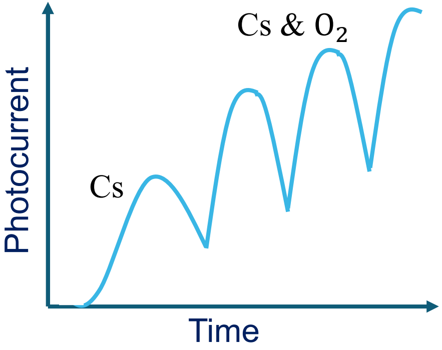

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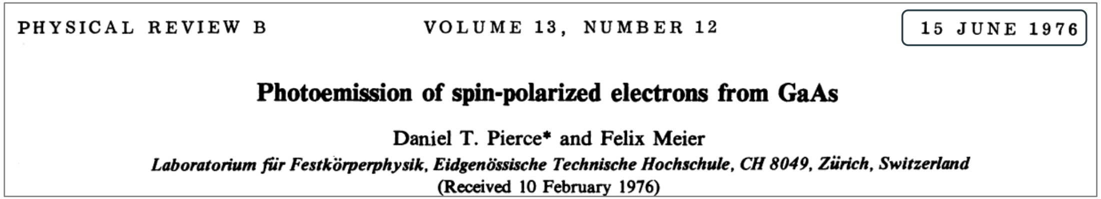
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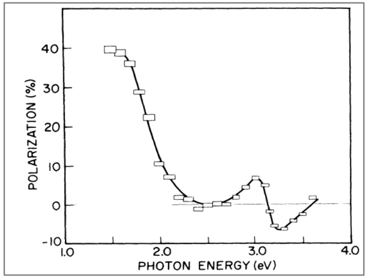

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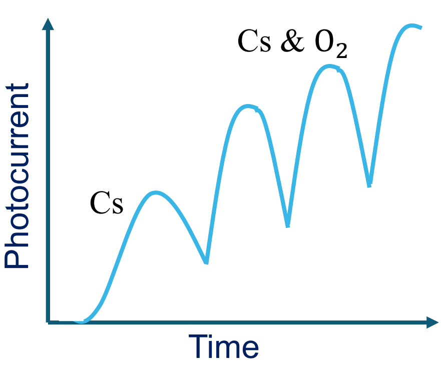

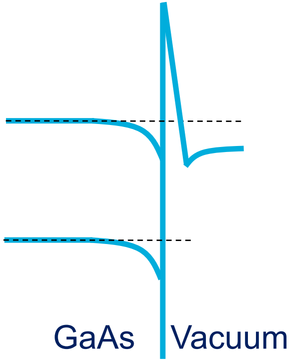

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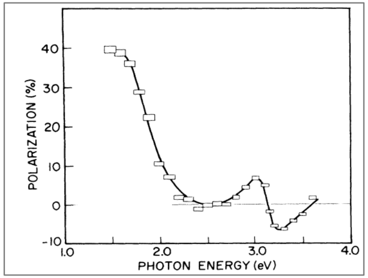

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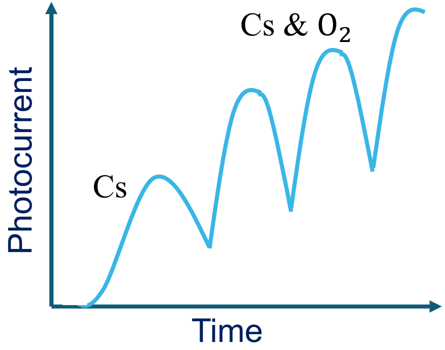

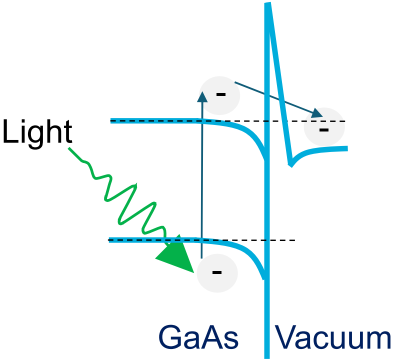

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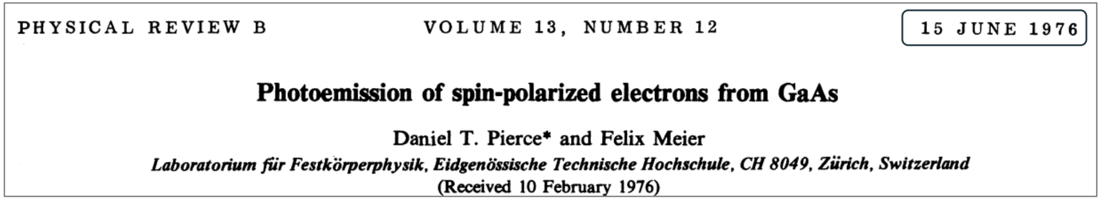
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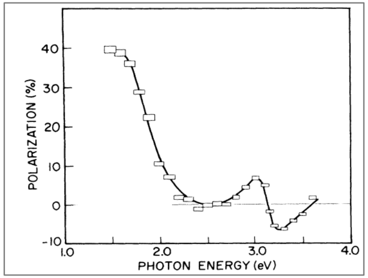

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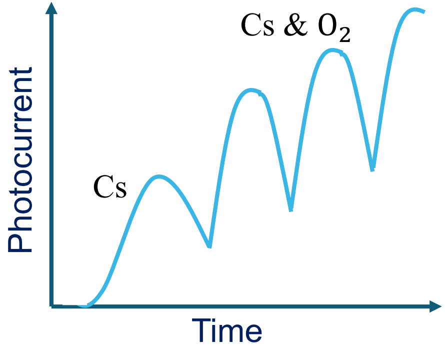

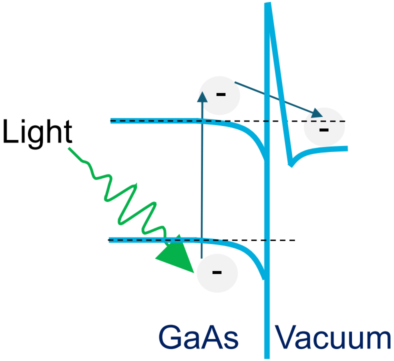

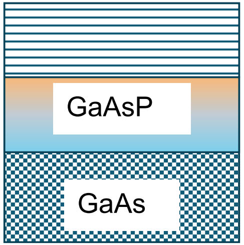

Superlattice GaAs

ESP~92% (@780nm)

QE~1.6% (@780nm)

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Polarized Electron Sources

GaaAs-based photocathodes: Essential Attributes

Polarized Electron Sources

GaAs-based photocathodes: **Essential Attributes**

- ➢ High Quantum Efficiency (QE)
- ➢ Long charge lifetime
- ➢ High Electron Spin Polarization (ESP)

Polarized Electron Sources

GaAs-based photocathodes: **Essential Attributes**

- High Quantum Efficiency (QE)
  - Reducing Surface Contamination
  - Engineering the cathode, SL-DBR
  - Robust activation layer material
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- High Electron Spin Polarization (ESP)

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- **High Electron Spin Polarization (ESP)**
  - SL-GaAs, or SL-DBR

I will present our advances on each of these issues!

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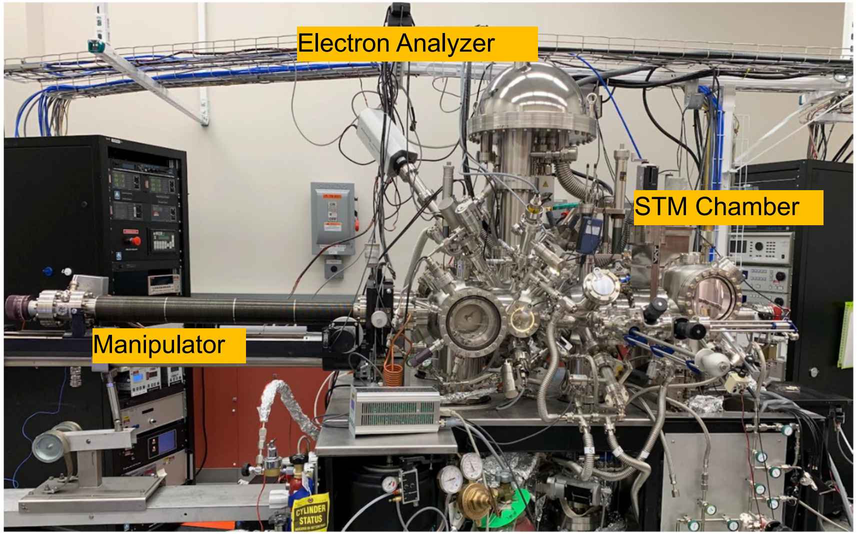
Towards High QE GaAs Photocathode

Motivation:

- ❑ Understanding surface roughness variations due to heat treatment
- ❑ Understanding surface cleaning and its effect on QE
- ❑ Evaluating chemical states of CsO/GaAs

Towards High QE GaAs Photocathode

Substrate Preparation and Characterization



Multiprobe system located in Center for Functional Nanomaterial (CFN) at Brookhaven National Laboratory (BNL).

Towards High QE GaAs Photocathode

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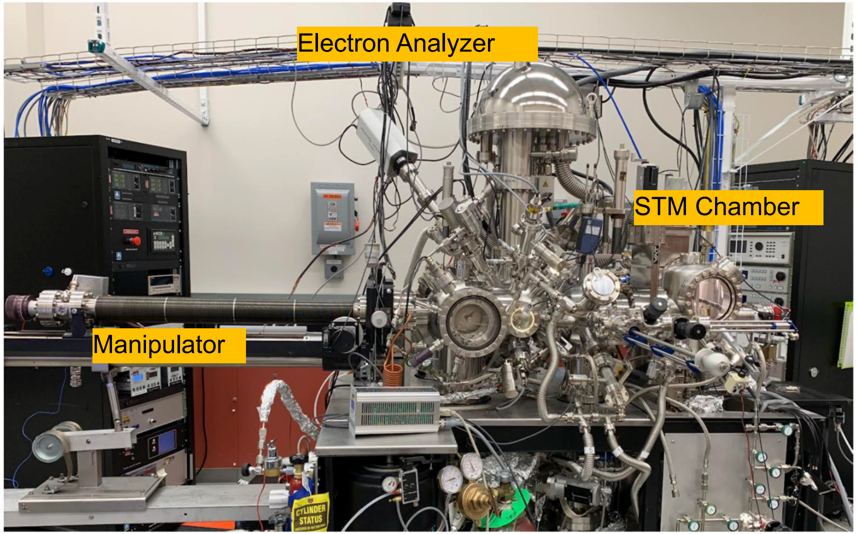

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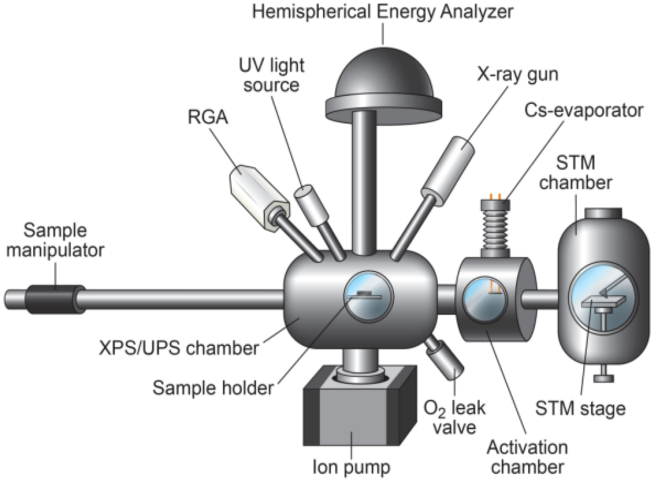

Schematic drawing of the multiprobe system at CFN, BNL

Towards High QE GaAs Photocathode

Substrate Preparation and Characterization - Surface Roughness

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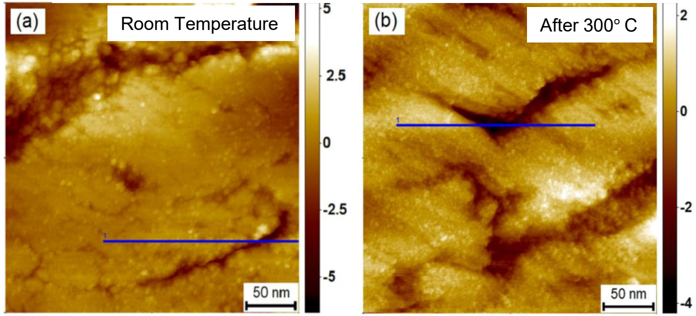
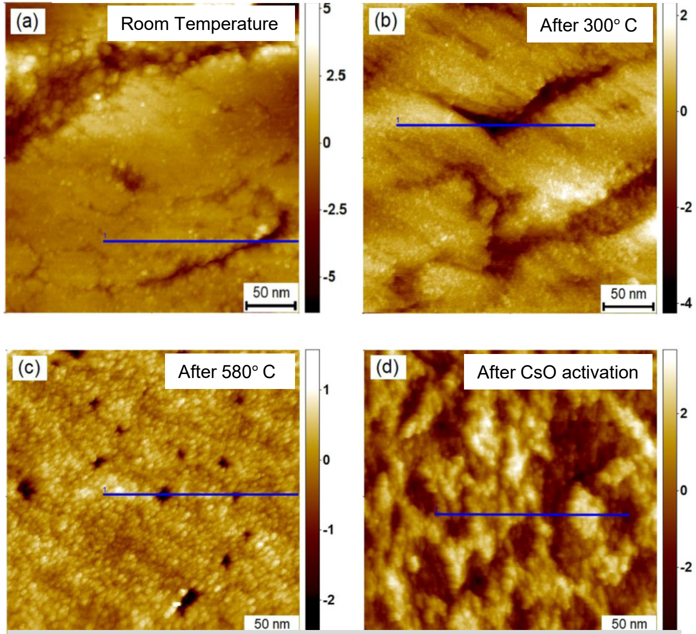


STM - GaAs at different temperature, & after activation

Towards High QE GaAs Photocathode

Substrate Preparation and Characterization - Surface Roughness



STM - GaAs at different temperature, & after activation

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J. Biswas *et al.* J. Appl. Phys. 128, 045308 (2020); https://doi.org/10.1063/5.0008969

Towards High QE GaAs Photocathode

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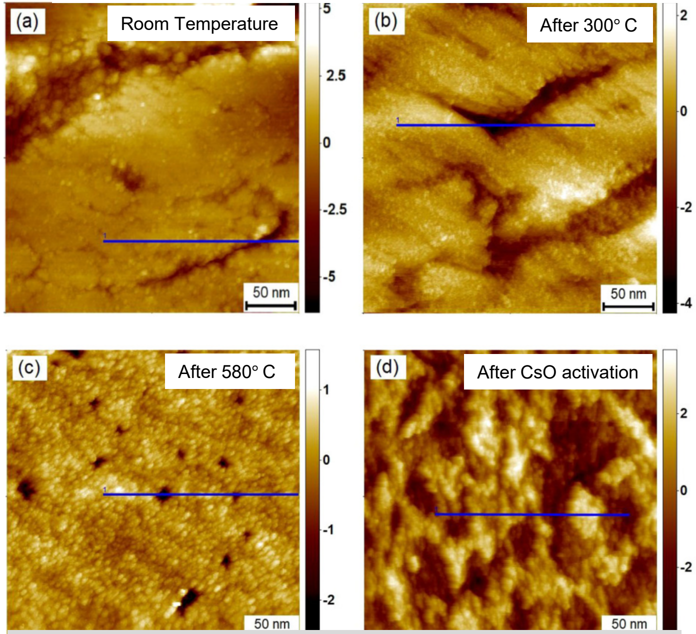

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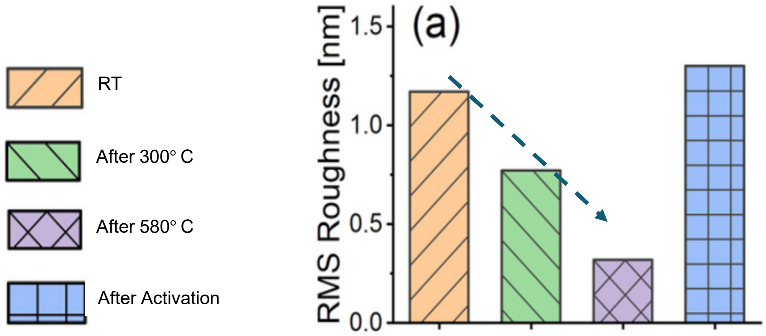

RMS roughness at different stage of the activation

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Conclusion from Substrate Preparation and Characterization

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- ❑ This preparation is optimal for the subsequent growth of thin activation material on it.

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Conclusion from Substrate Preparation and Characterization

- ❑ Contrary to common assumption, we found that right amount of heat treatment at UHV decreases the surface RMS roughness.

- ❑ This preparation is optimal for the subsequent growth of thin activation material on it.

- ❑ Reduced field emission and emittance growth.

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Pre-growth contamination analysis using XPS

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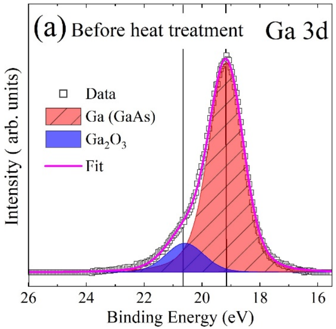

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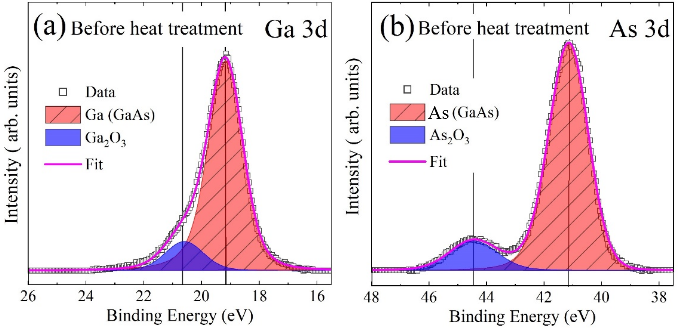

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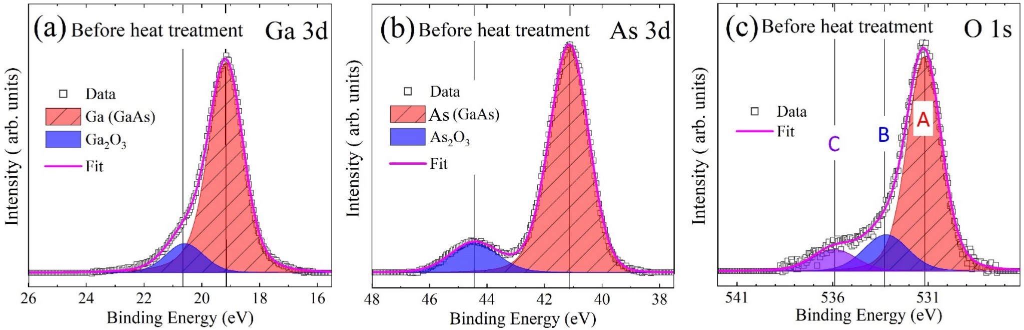

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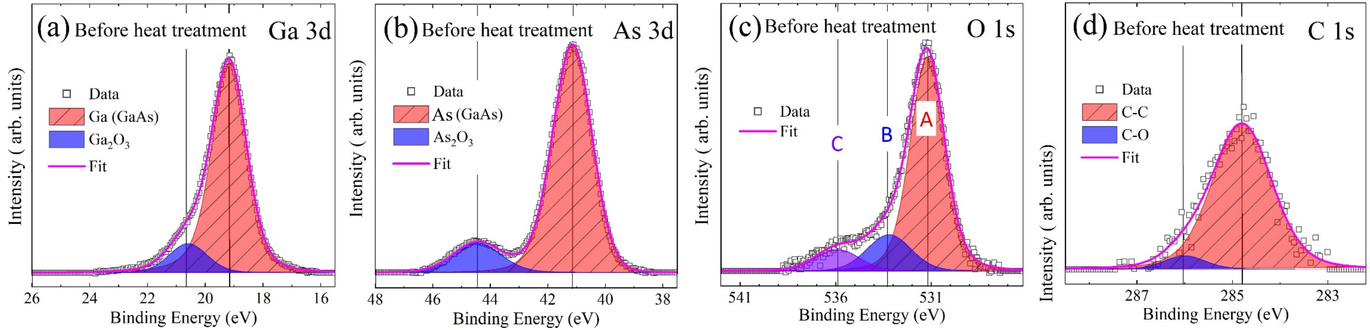

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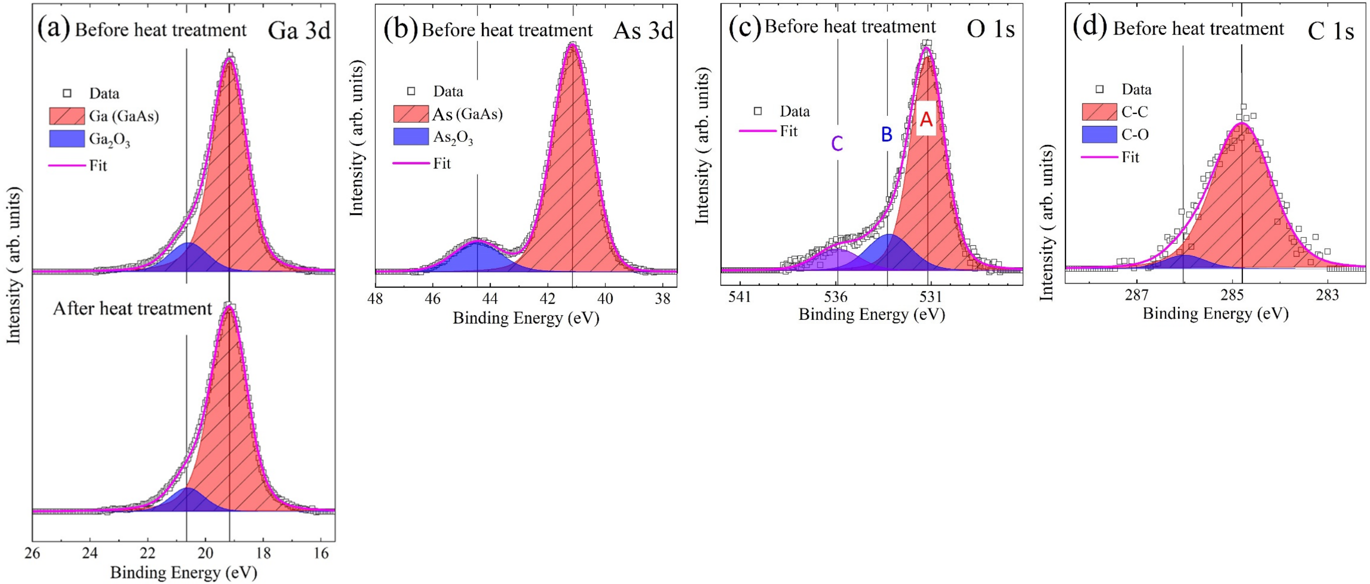

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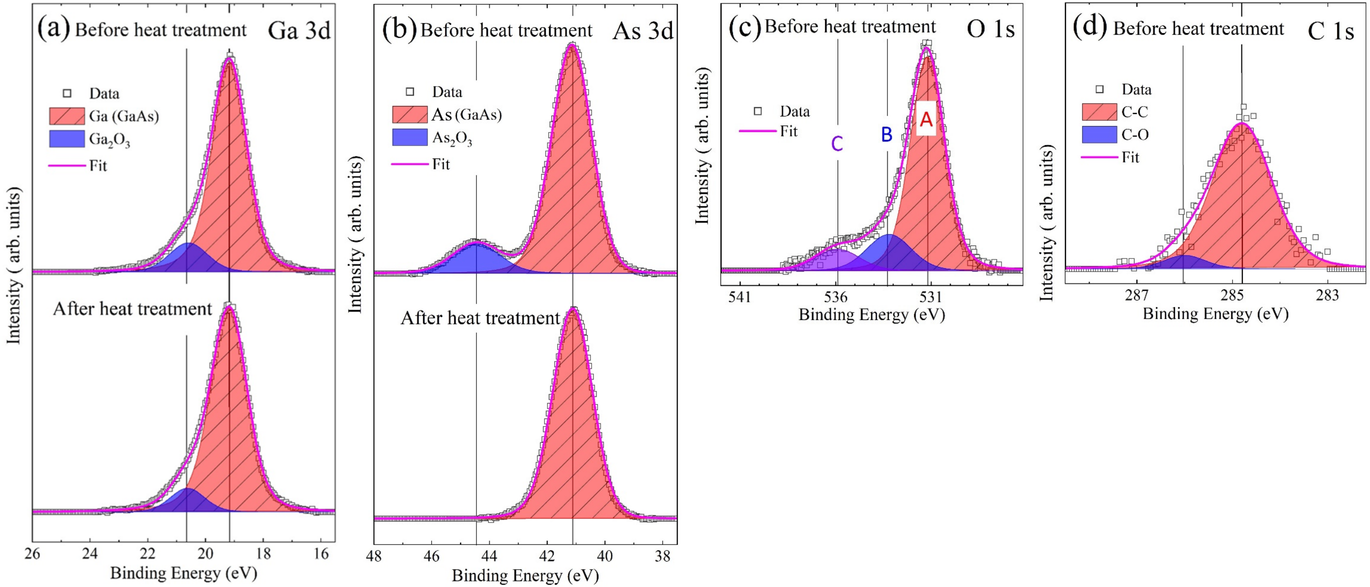

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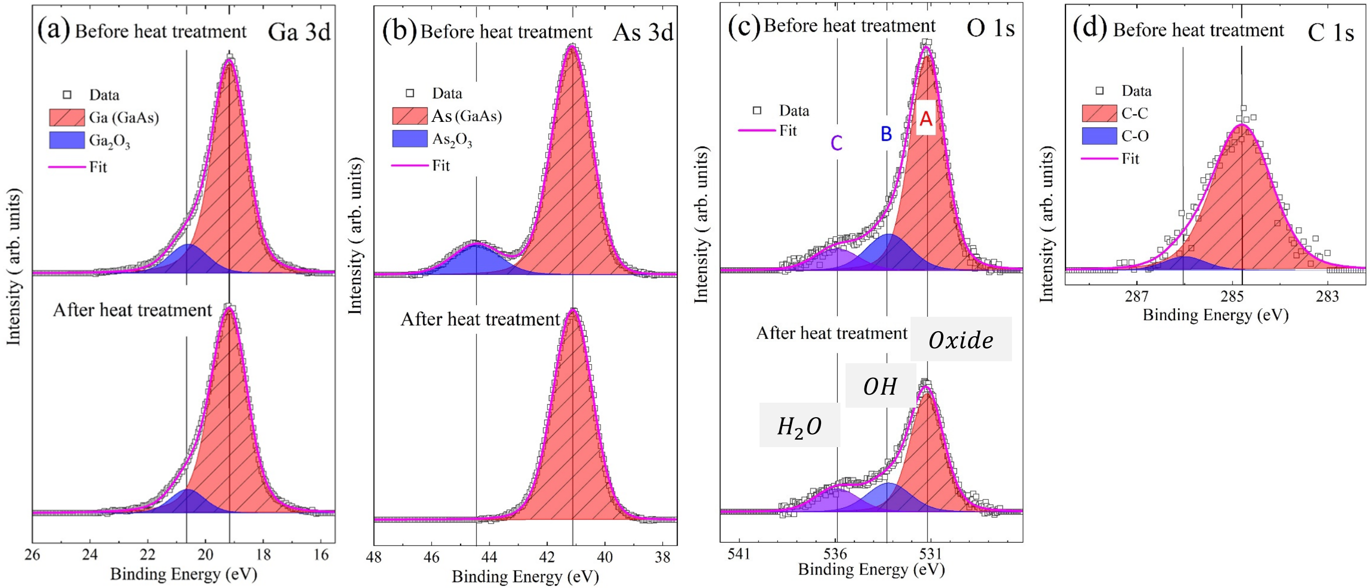

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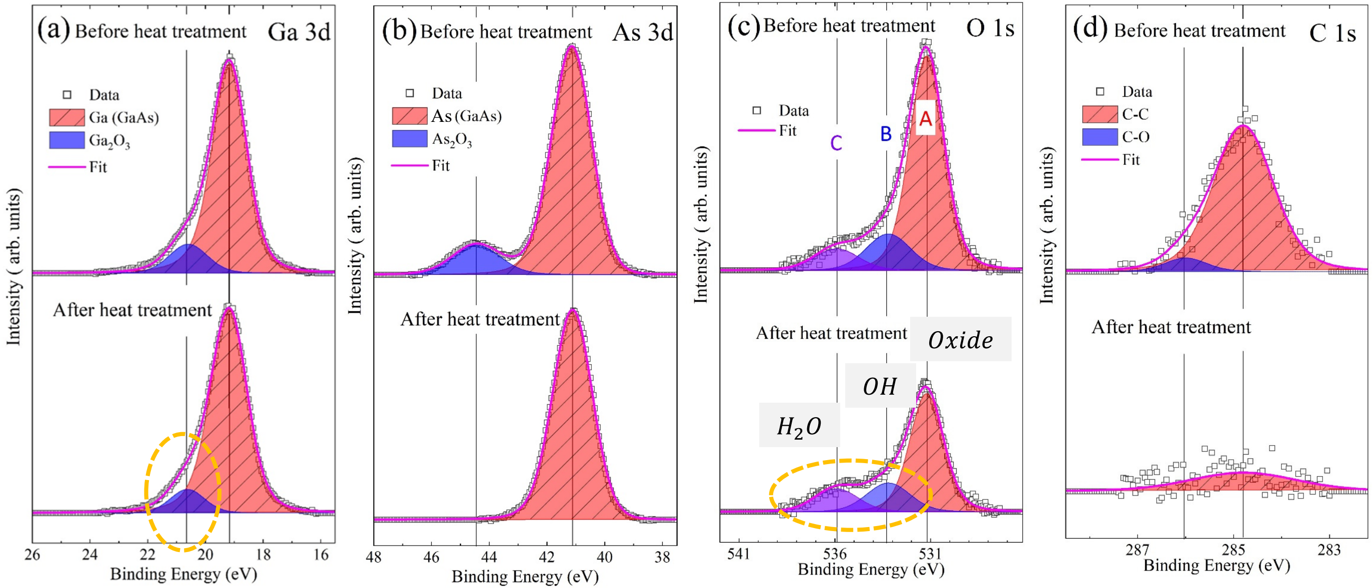

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Towards High QE GaAs Photocathode

Conclusion from pre-growth contamination analysis

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Although others have confirmed that presence of H_2O leads to lower QE, we have shown presence of H_2O causes other types of contamination to appear on the surface.

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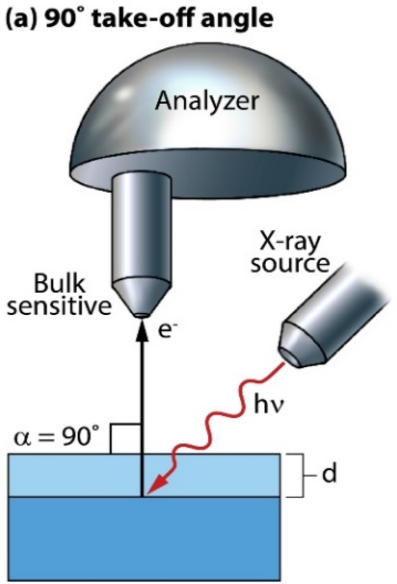
Towards High QE GaAs Photocathode

Chemical analysis of CsO/GaAs cathode using AR-XPS/UPS



$\alpha = electron\ take\ off\ angle$

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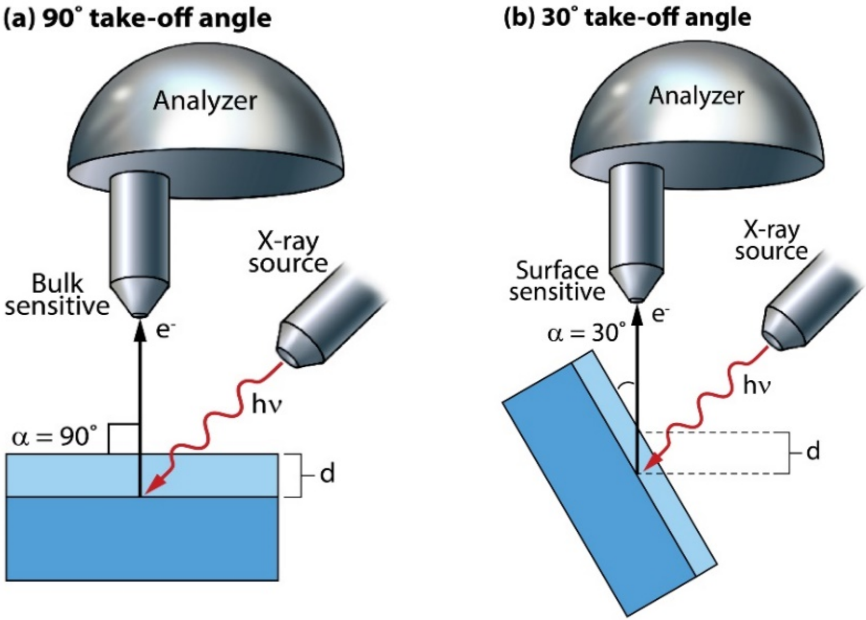

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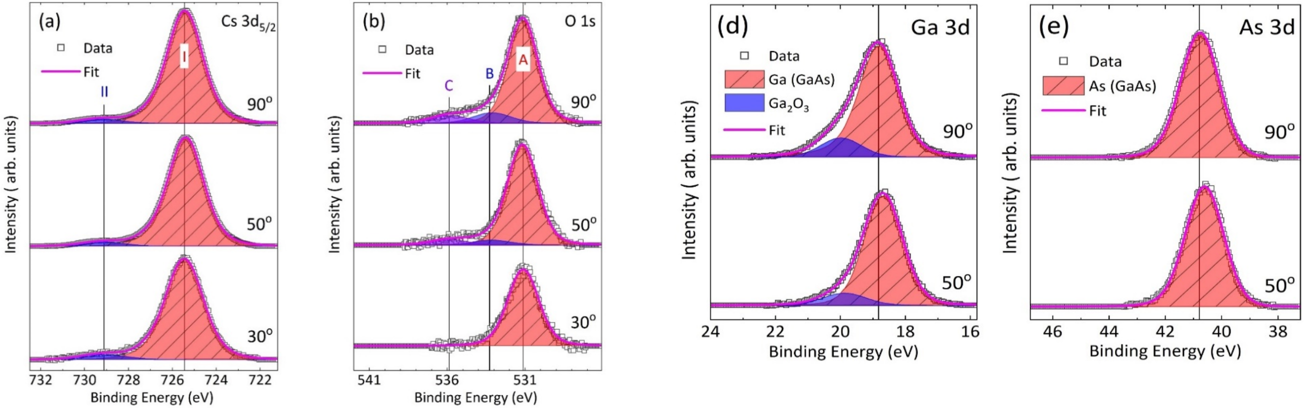

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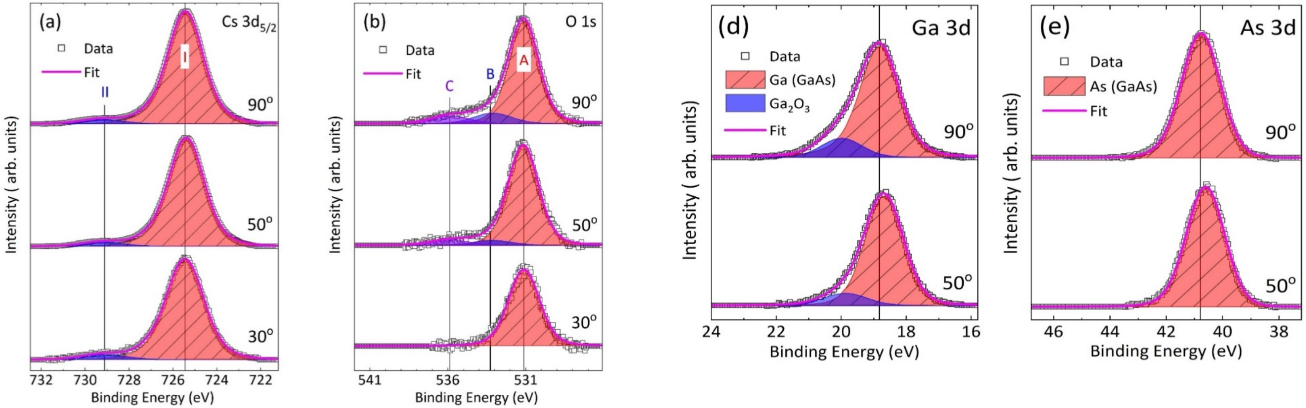
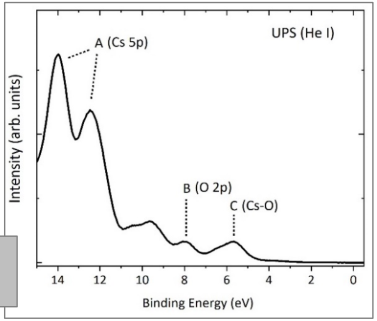


UPS after Cs-O Activation



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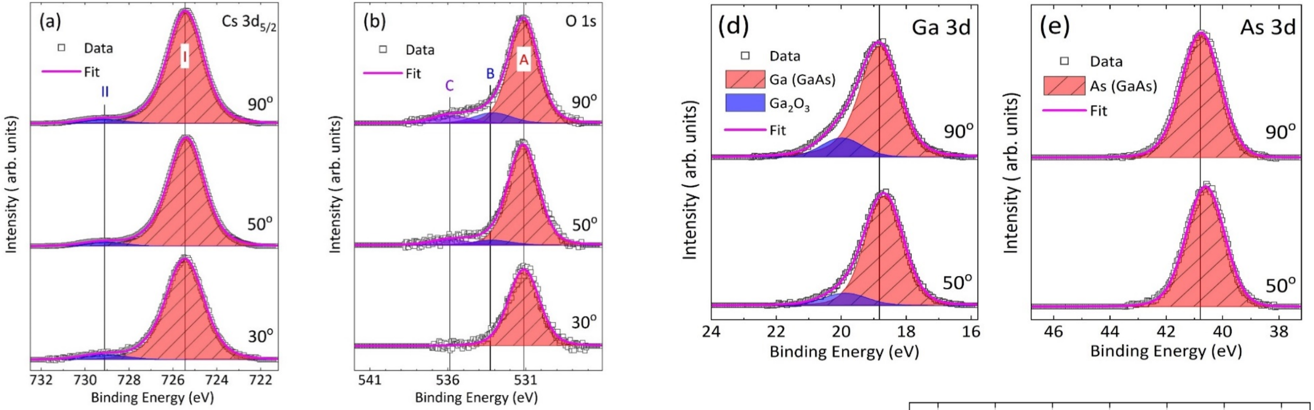

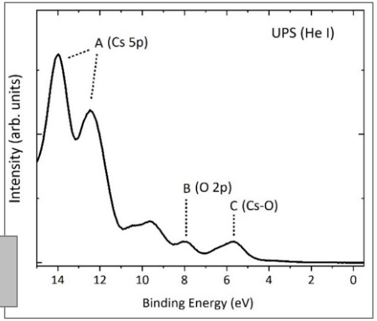

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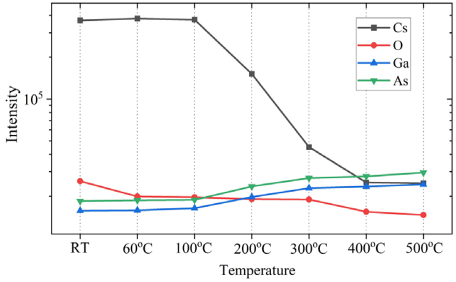

XPS - Temperature Programmed Reduction

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J. Biswas *et al.* J. Appl. Phys. 128, 045308 (2020); https://doi.org/10.1063/5.0008969

Towards High QE GaAs Photocathode

Conclusion from the chemical analysis of CsO/GaAs

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- ❑ XPS confirms that, surface start to lose Cs significantly at ~100°C, whereas **oxygen loss is significant even at 60°C**.
  - ➢ Laser illumination induced heating could destroy the cathode if temperature of the sample exceeds 60°C.

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Towards Long Charge lifetime GaAs Photocathode

New Activation Technique using Te, Cs, and O

We developed a new technique of activation employing a combination of cesium, tellurium, and oxygen that shows longer charge lifetime.

New Cs-Te and Cs-Te-O based Activation on GaAs

Towards Long Charge lifetime GaAs Photocathode

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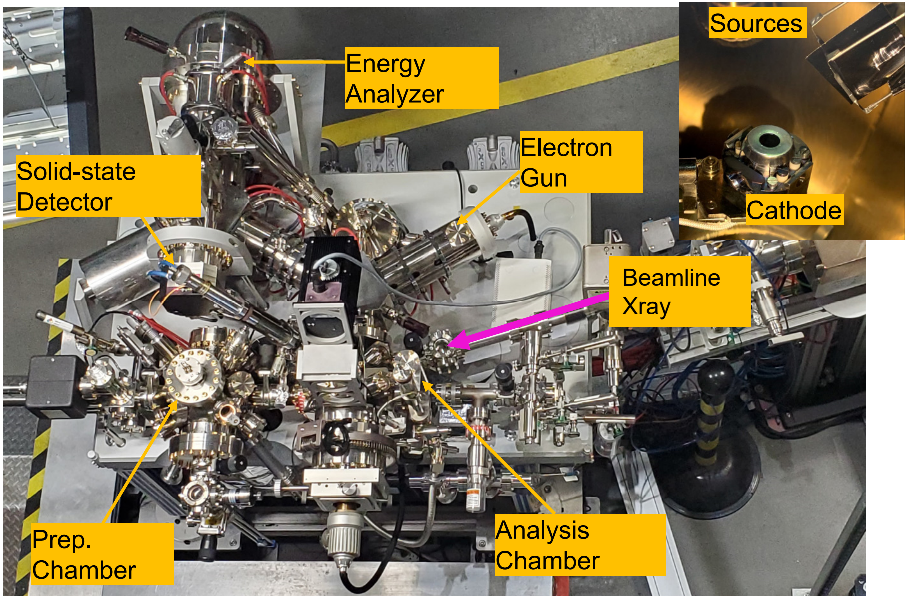

LEEM/XPEEM beamline located at NSLS II, BNL

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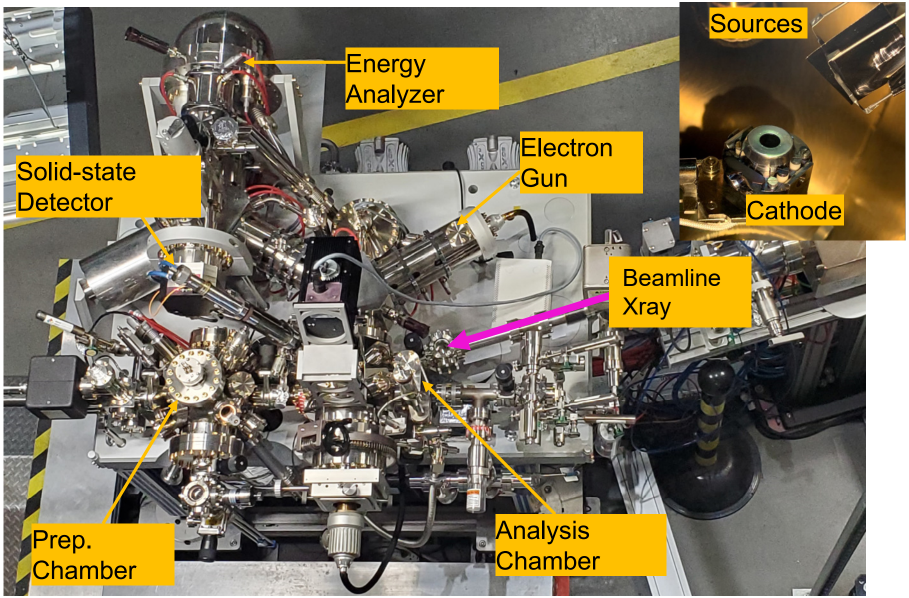

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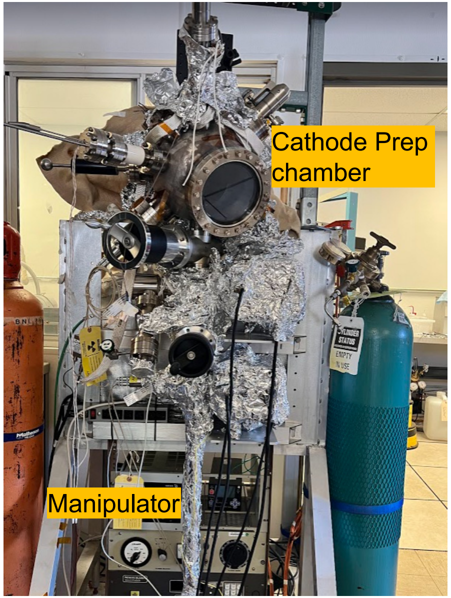

Cathode chamber at CAD, BNL

Towards Long Charge lifetime GaAs Photocathode

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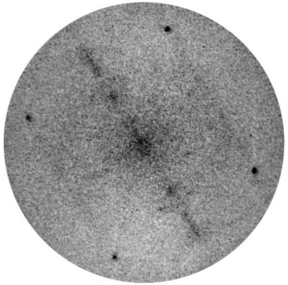

Oxide desorption – LEED

J. Biswas *et al.* AIP Advances 11, 025321 (2021); https://doi.org/10.1063/5.0026839

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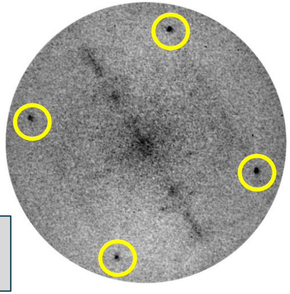
(1x1), & defused (4x6) reconstruction



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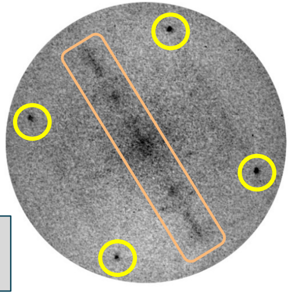

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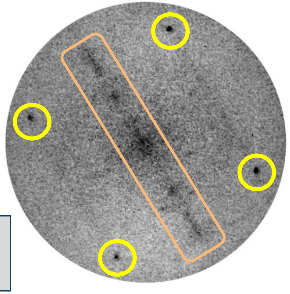

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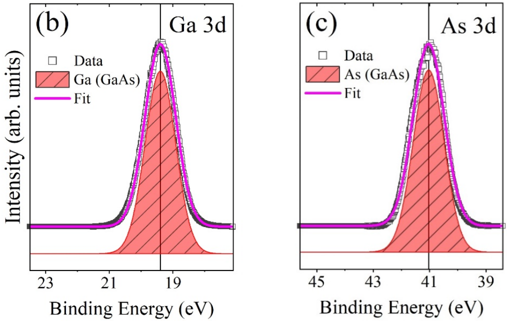

Oxide desorption – SR-XPS

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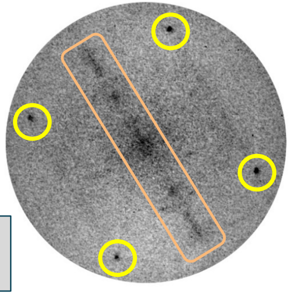

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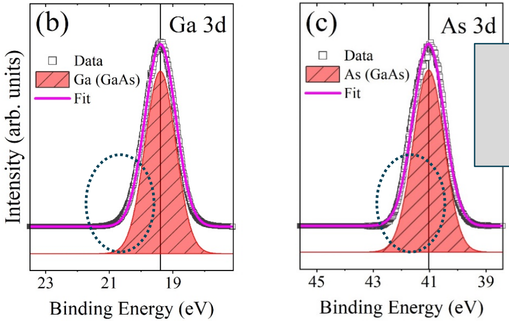

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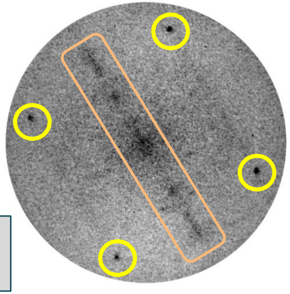

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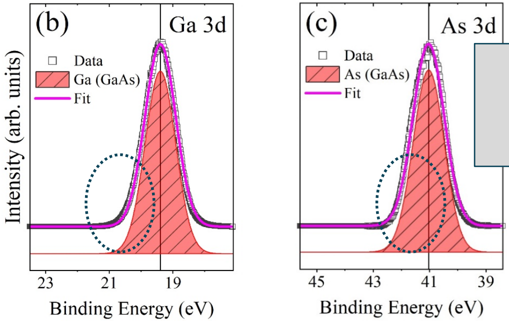

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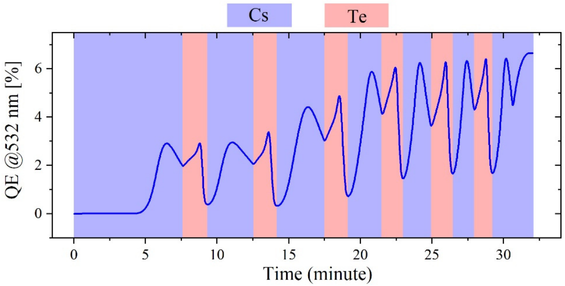

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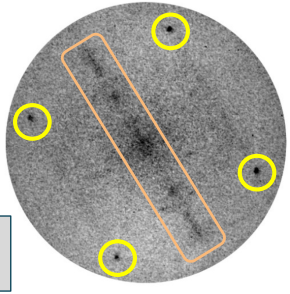

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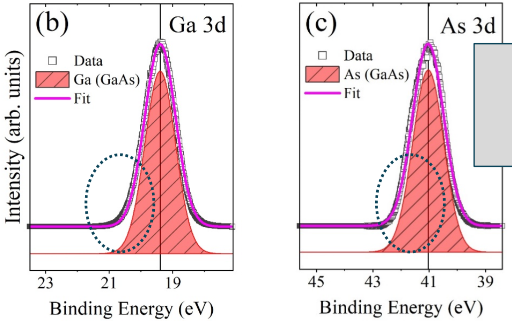

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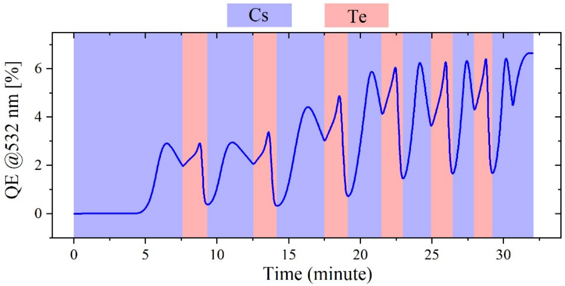

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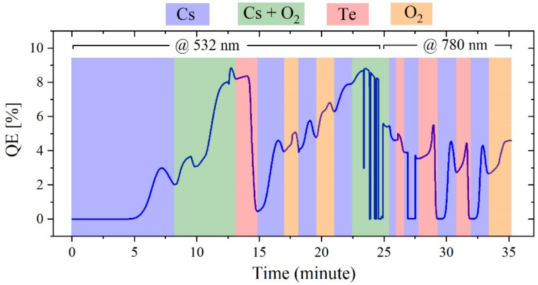

Cs-Te-O activation on GaAs

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Conclusion from the Cs-Te and Cs-Te-O based Activation

- ❑ In Cs-Te activation QE **at 532 nm: 6.6%**
- ❑ In Cs-Te-O activation QE **at 532 nm: 8.8%;** at **780 nm: 4.5%**

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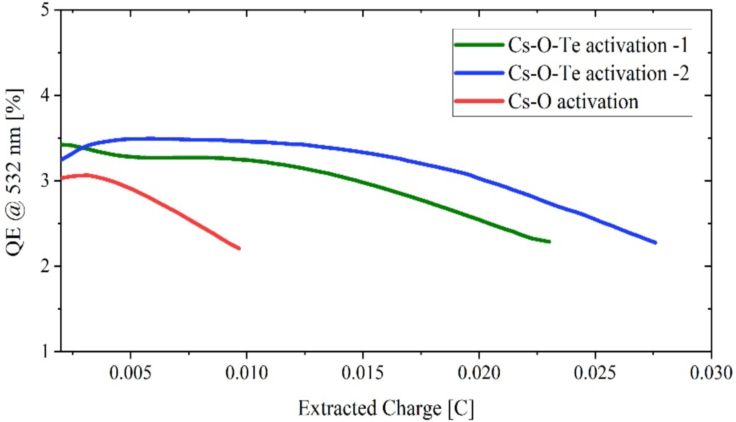
Towards Long Charge lifetime GaAs Photocathode

Comparing Charge lifetime of Cs-Te-O based Activation



We demonstrated 5-6 times longer charge lifetime in a test chamber as compared to Cs-O/GaAs

O. Rahman *et al.* , Int. Particle Accelerator Conf. IPAC2019, Melbourne, Australia

Evaluating Surface Chemical States Cs-Te/GaAs

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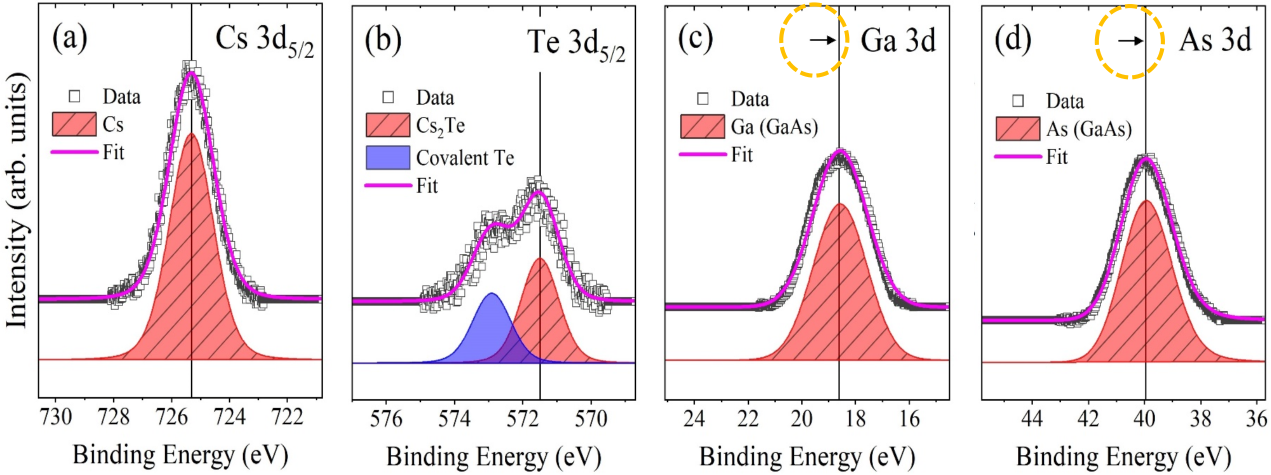

SR-XPS spectra after GaAs photocathode **activation with Cs-Te**

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Evaluating Surface Chemical States Cs-Te-O/GaAs

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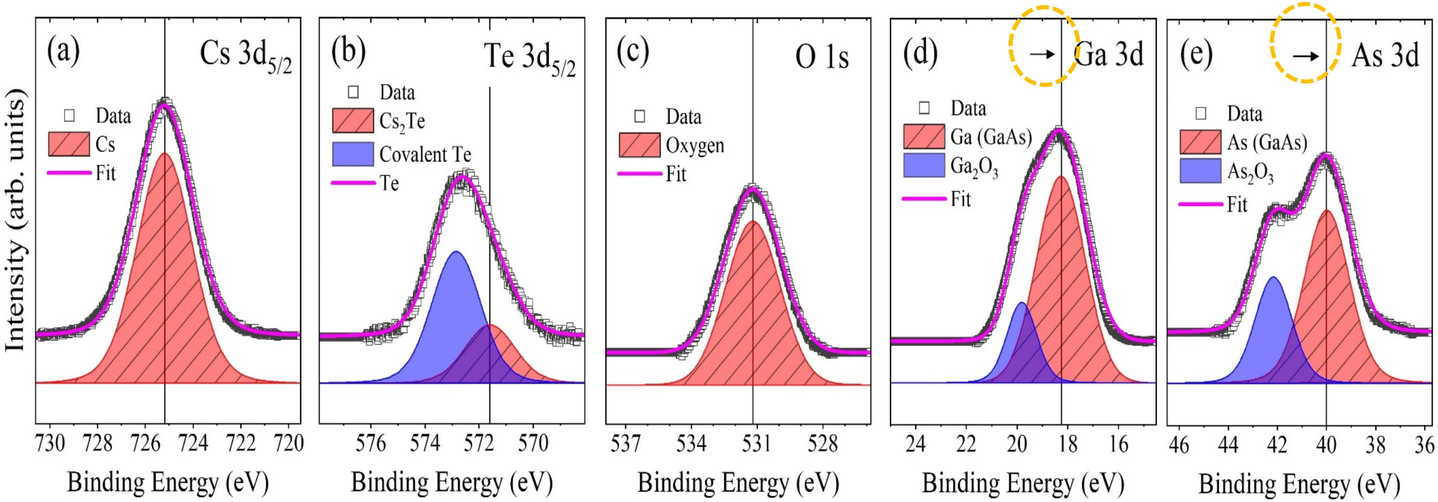

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Evaluating the Negative Electron Affinity (NEA)

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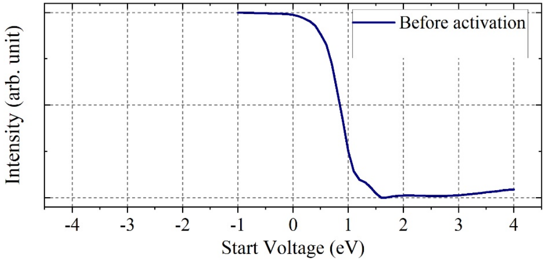

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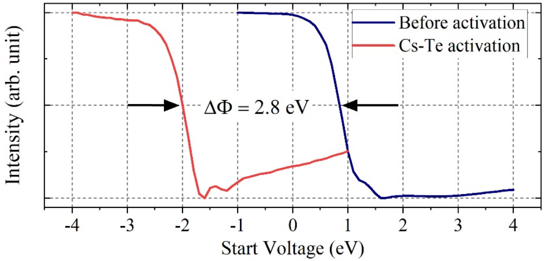

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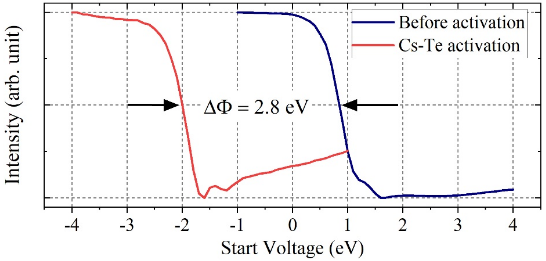

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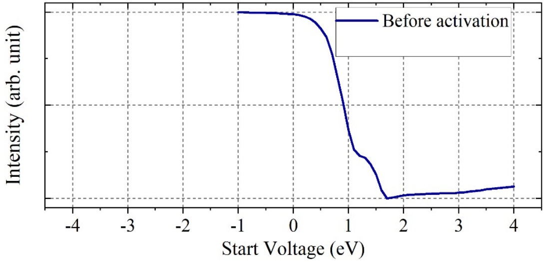

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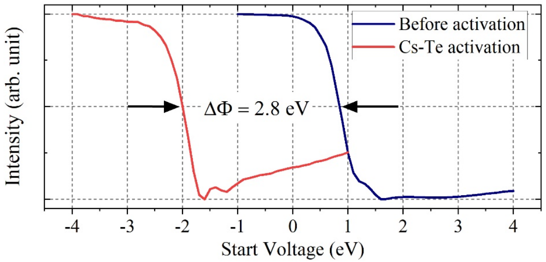

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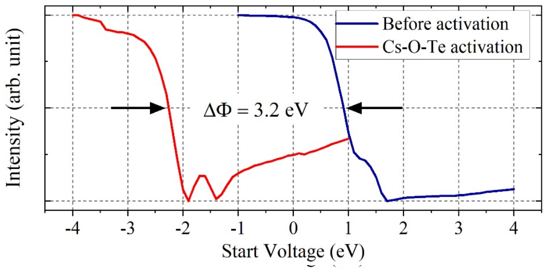

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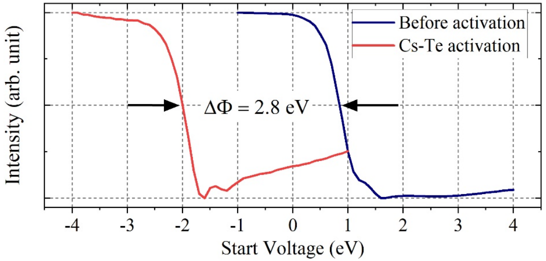

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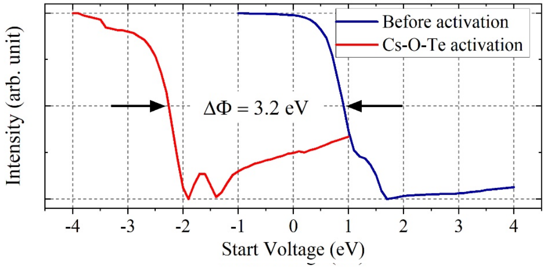

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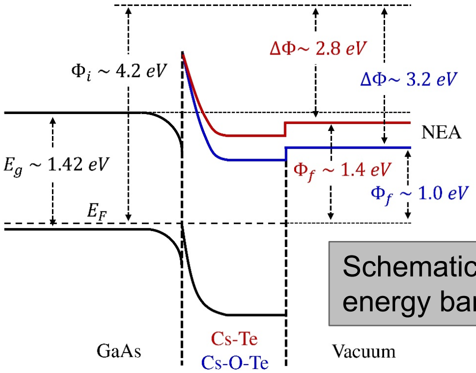

Schematic drawing of energy band diagram

Towards Long Charge lifetime GaAs Photocathode

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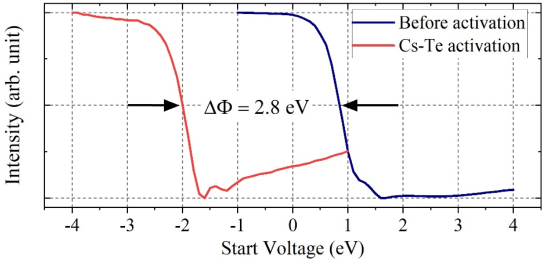

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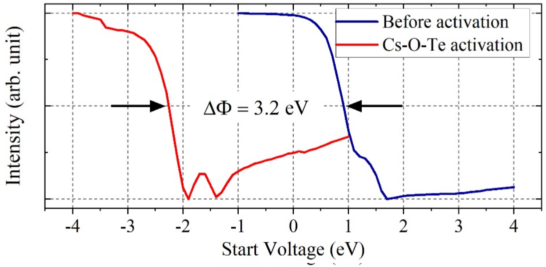
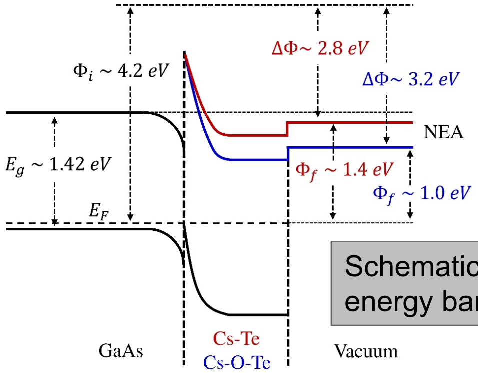


LEEM I/V of Cs-Te-O activated GaAs

Cs-Te/GaAs
Final work function, $\Phi_f = 1.4$ eV
Effective NEA, $\chi_{eff} = -0.02$ eV



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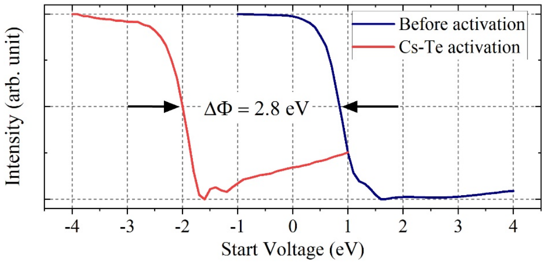

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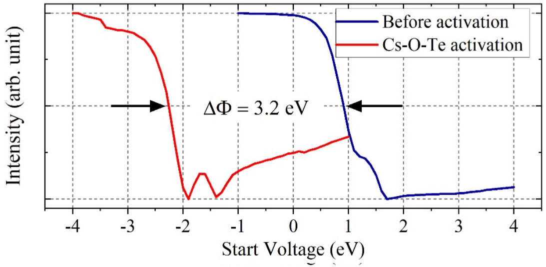

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Cs-Te-O/GaAs
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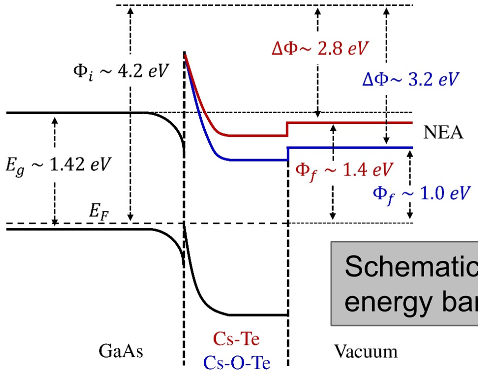
Effective NEA, $\chi_{eff} = -0.42$ eV



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NEA is important because the thermalized electrons at the bottom of the conduction band can escape into the vacuum. Thus, QE increases the when larger NEA is achieved.

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Towards High Electron Spin Polarization (ESP)

Superlattice (SL) GaAs

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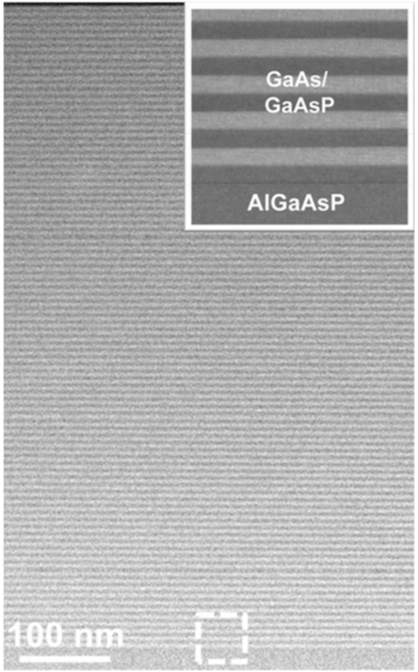

Jin *et el.* Appl. Phys. Lett. **105**, 203509 (2014)

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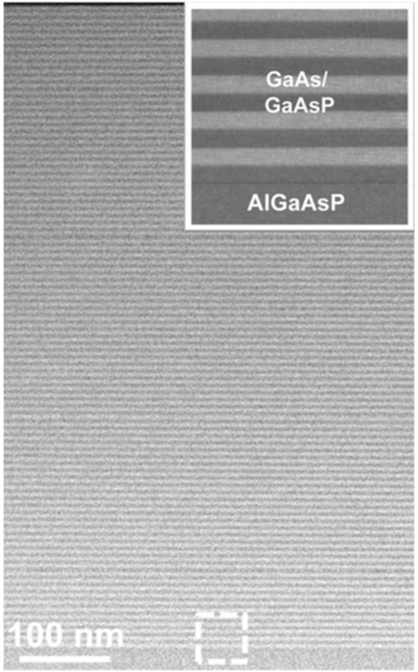

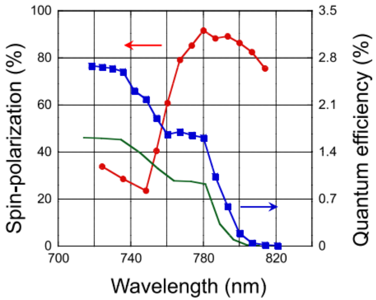

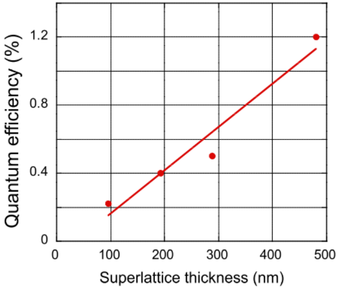

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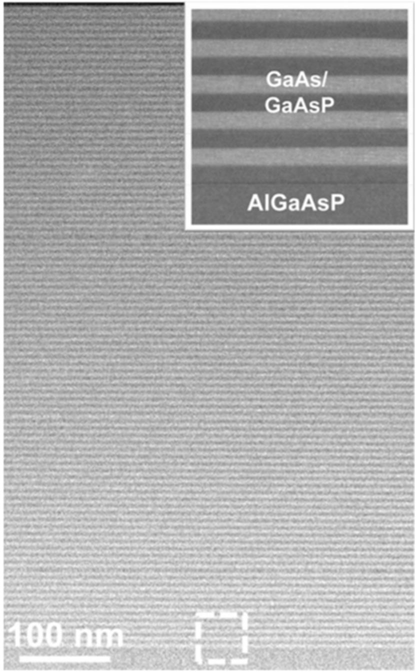

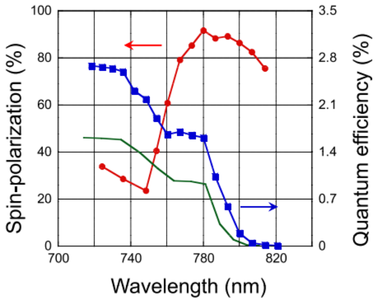

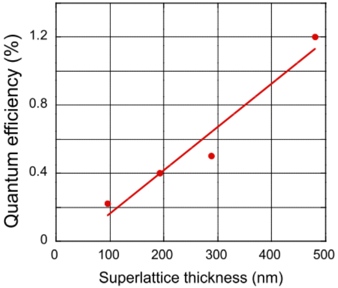

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SL – GaAs with Bragg Reflector

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Towards High Electron Spin Polarization (ESP)

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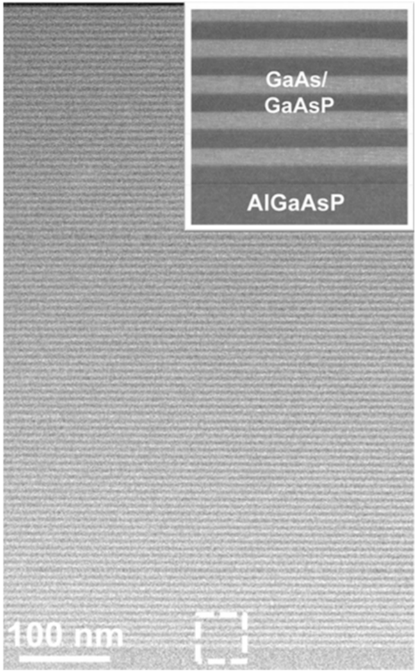
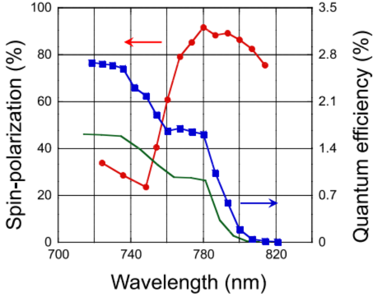
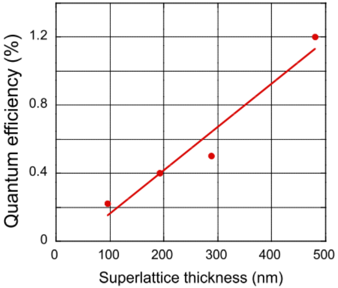
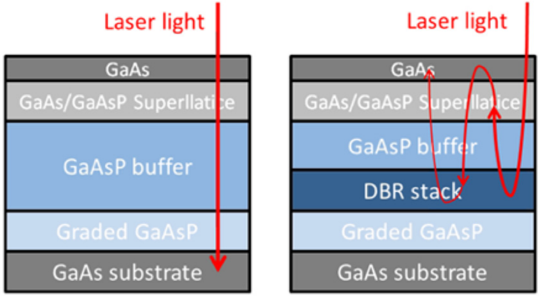






Jin *et el.* Appl. Phys. Lett. **105**, 203509 (2014)

SL – GaAs with Bragg Reflector



Standard photocathode **DBR photocathode**

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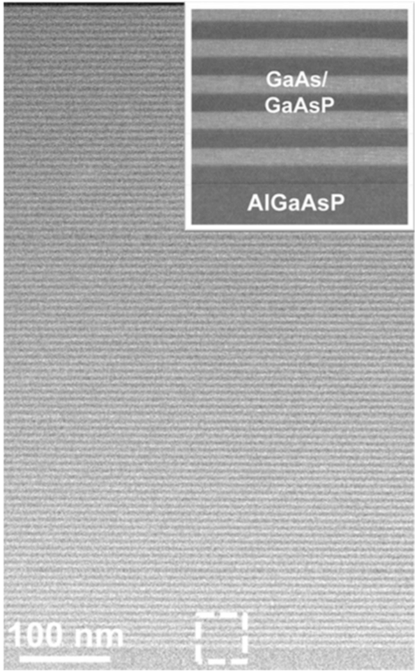
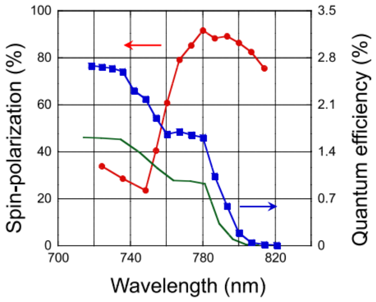
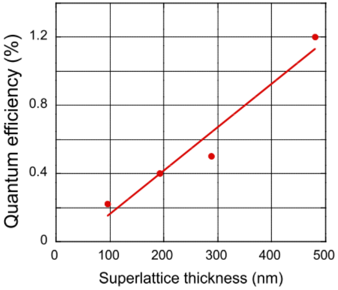
Towards High Electron Spin Polarization (ESP)

Superlattice (SL) GaAs







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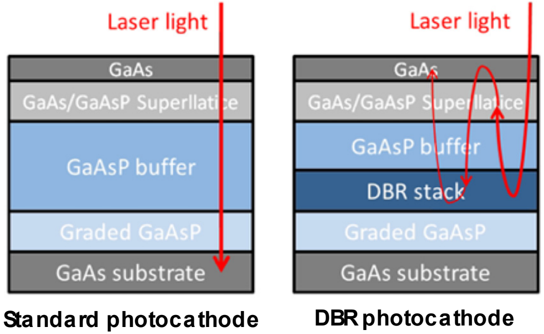

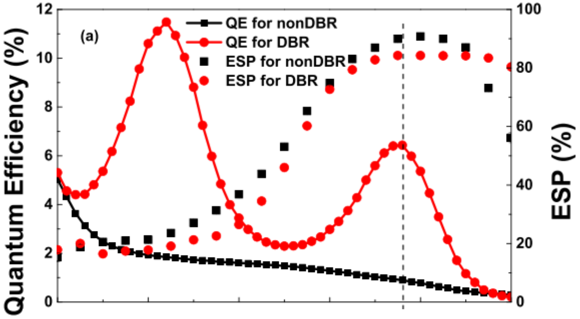

Liu *et el.* Appl. Phys. Lett. **109**, 252104 (2016)

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Towards High Electron Spin Polarization (ESP)

Motivation:

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- ❑ Achieving both high QE and ESP at near bandgap energy is challenging.

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- ❑ We need stable vendors.

Towards High QE and ESP using SL-DBR

We have been growing SL-DBR and characterizing them

- ➢ Details will follow in the Poster session: **WEPA68**

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GaAs	4 nm	p = 5×10^{17} cm^{-3}	
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$AlAs_{0.78}P_{0.22}$	65 nm	p = 5×10^{18} cm^{-3}	10 pairs
$GaAs_{0.81}P_{0.19}$	55 nm	p = 5×10^{18} cm^{-3}	
$GaAs_{0.81}P_{0.19}$	2000 nm	p = 5×10^{18} cm^{-3}	
GaAs->$GaAs_{0.81}P_{0.19}$	2750 nm	p = 5×10^{18} cm^{-3}	
GaAs buffer	200 nm	p = 5×10^{18} cm^{-3}	
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85 layers!!!

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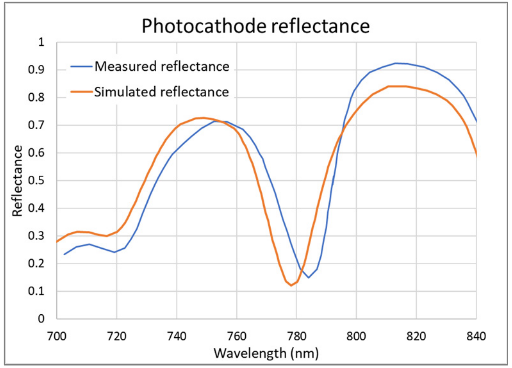

Good agreement between the design reflectance and the measured one.

The sample **photoemission efficiecny** and the **photoelectron spin polarization** are currently being evaluated at BNL

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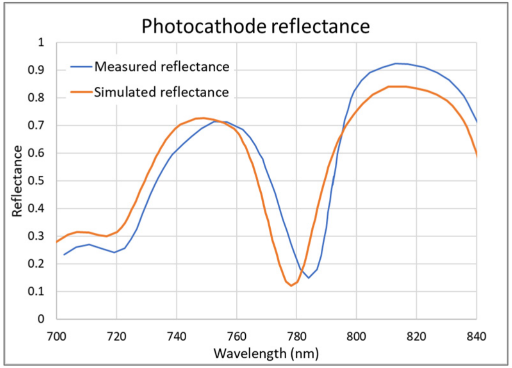

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Achieved over 15% QE and ESP around 75% at near band gap photon energies.

J. Biswas *et el. NAPAC 2022, Paper WEPA68*

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Summary - 1

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- Let's evaluate the robustness & charge lifetime of Cs-Te-O/GaAs in a gun
- SL / SL-DBR with Cs-Te-O based activation

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- Further tuning of SL layer, and growth method are ongoing, and activation with Cs-Te-O could lead to even higher QE.

Thanks for your attentions!

Acknowledge:
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