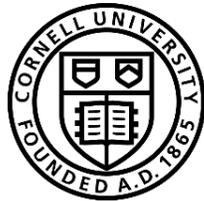


# Improved Lifetime of GaAs Photocathodes Activated with Cs-Sb-O layer



Jai Kwan Bae  
Cornell University

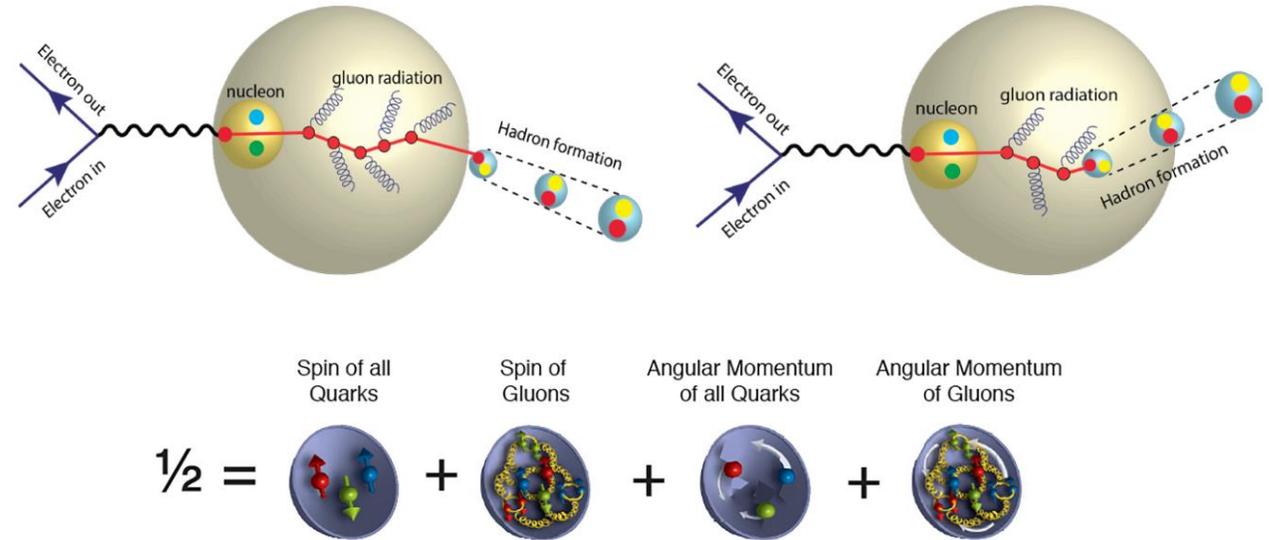
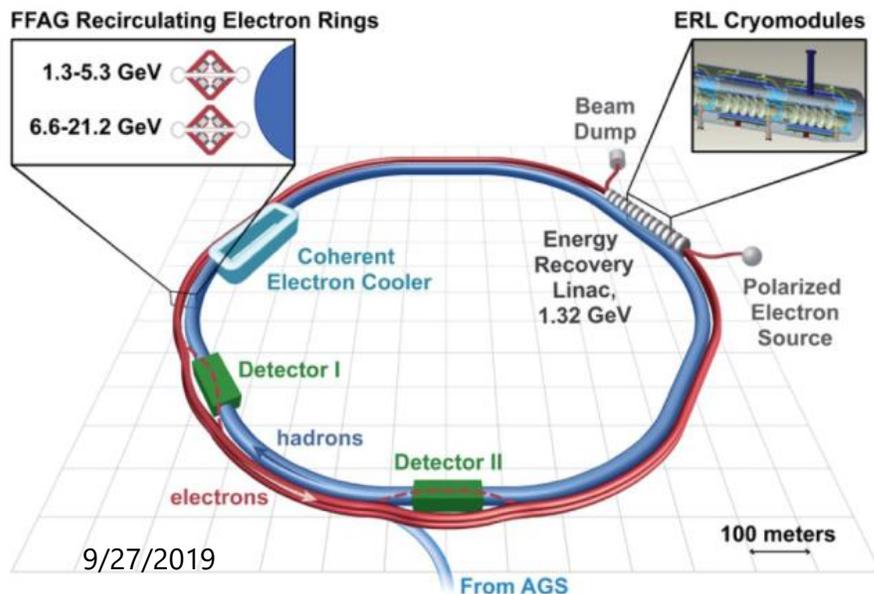


# Outline

- Spin polarized electron source applications
- GaAs photocathode and the standard activation method
- $Cs_2Te$  activation
- $Cs - Sb - O$  activation
- Future works

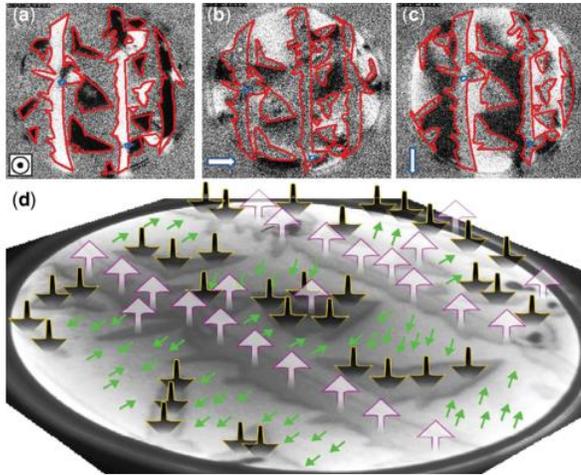
# Spin polarized electron source application (1)

- Electron-Ion collider
  - Deep Inelastic scattering (hadron-lepton scattering)
    - Contribution of gluons to the total spin of a proton
    - Spatial distribution of gluons, quarks in nuclei



# Spin polarized electron source application (2)

- Spin polarized low energy electron diffraction (<30 eV)



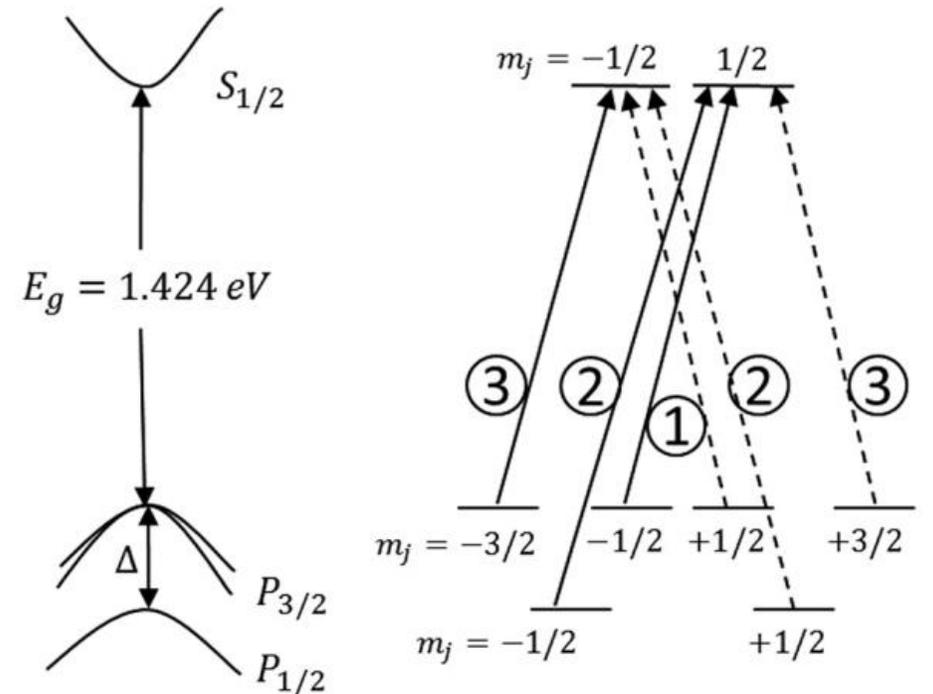
Co/Ru(0001). N'diaye et al. Characterization of Materials (2002): 1-14.

- Spin polarized Transmission Electron Microscope (10s - 100s keV)

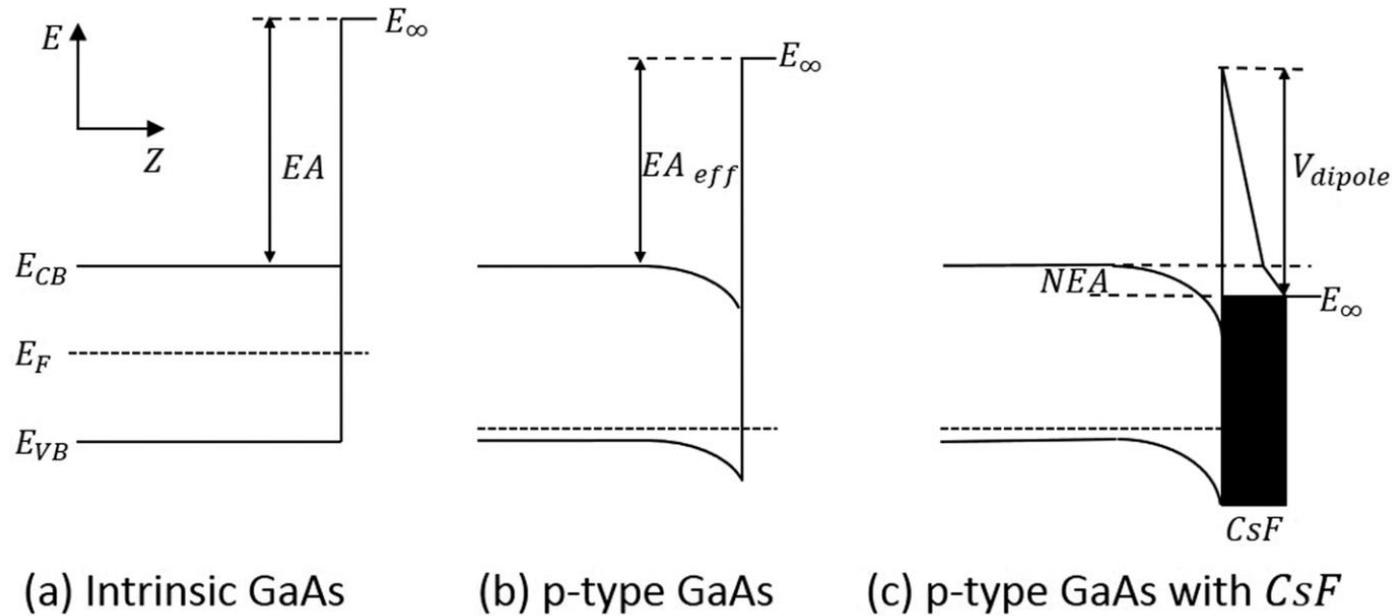
Kuwahara et al. APL 105, 193101 (2014)

# GaAs photocathode

- At  $\Gamma$  valley, circularly polarized light ( $\pm\hbar$  spin angular momentum) is used to extract spin polarized electrons.
- $$P = \frac{N_{\uparrow} - N_{\downarrow}}{N_{\uparrow} + N_{\downarrow}} = \frac{3 - 1}{3 + 1} = 50\%$$
- High Quantum Efficiency (QE)
- $$QE := \frac{\text{\# of electrons emitted}}{\text{\# of incident photons}}$$



# Negative Electron Affinity (NEA)



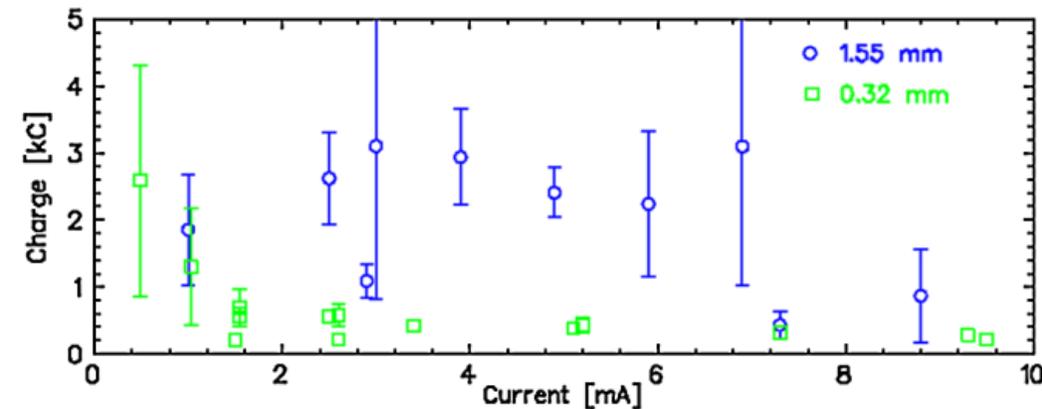
- NEA activation is required for spin-polarized photoemission of GaAs photocathode.
- $Cs + NF_3$ ,  $Cs + O_2$  are commonly used.

Liu et al. J. Appl. Phys. 122, 035703 (2017)

# Relevant Parameters

- Current ( $\sim 50$  mA)
- State-of-art charge extraction lifetime ( $\sim 1000$  C) only allows  $\sim 10$  hours of operational lifetime.
- Spin polarization ( $\sim 80\%$ )
- Fast switching of spin polarization allows removing systematic asymmetries.

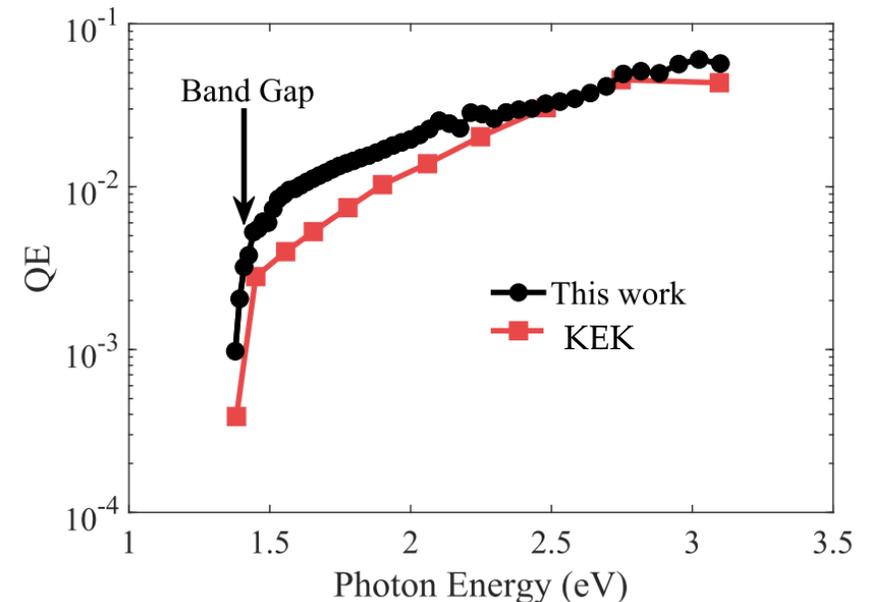
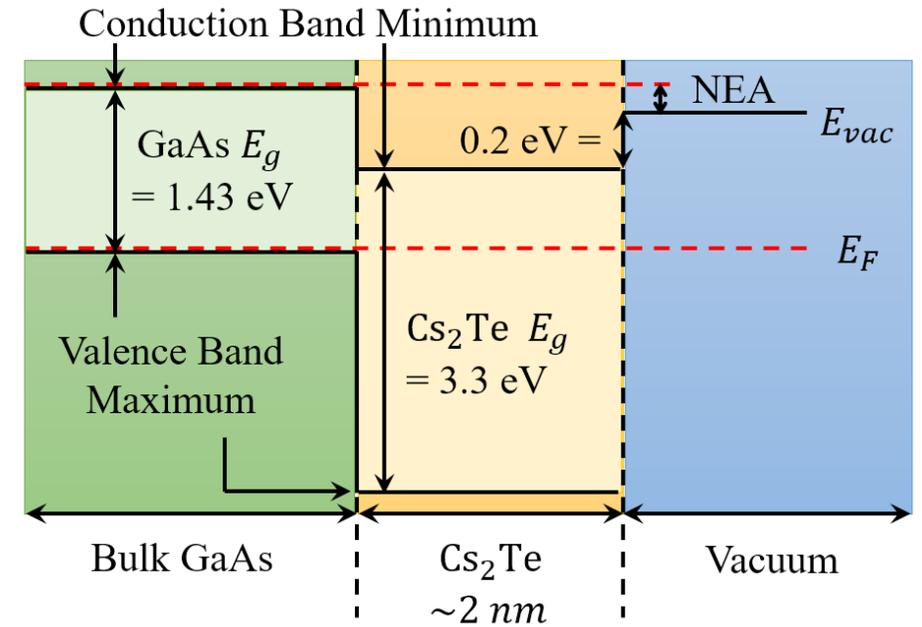
$$QE(q) \sim e^{-q/\tau_c}$$



Grames et al. Phys. Rev. ST Accel. Beams 14, 043501 (2011)

# $Cs_2Te$ activation layer

- $Cs_2Te$  is popular solar blind photocathode material known for high chemical resistance.
- Successful NEA activations were reported with  $Cs_2Te$  semiconductor layer.



# $Cs_2Te$ activation layer (2)

O. Rahman et al., IPAC 2019, TUPTS102

**5X LIFETIME!**

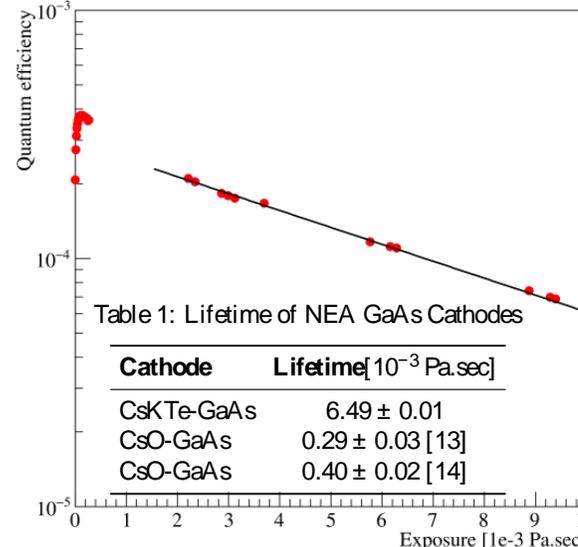
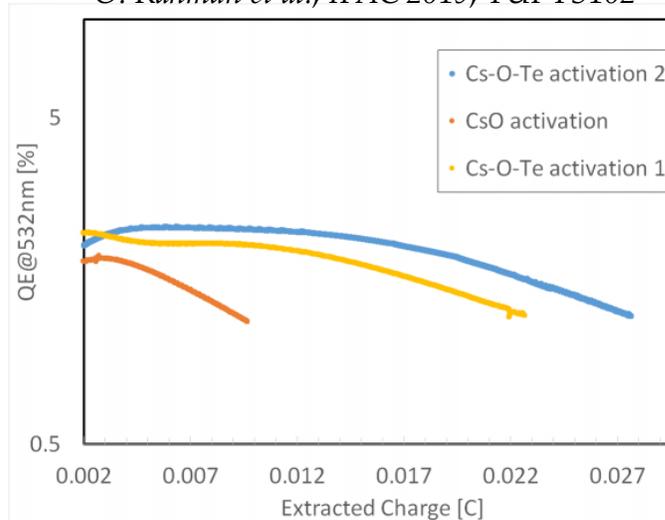
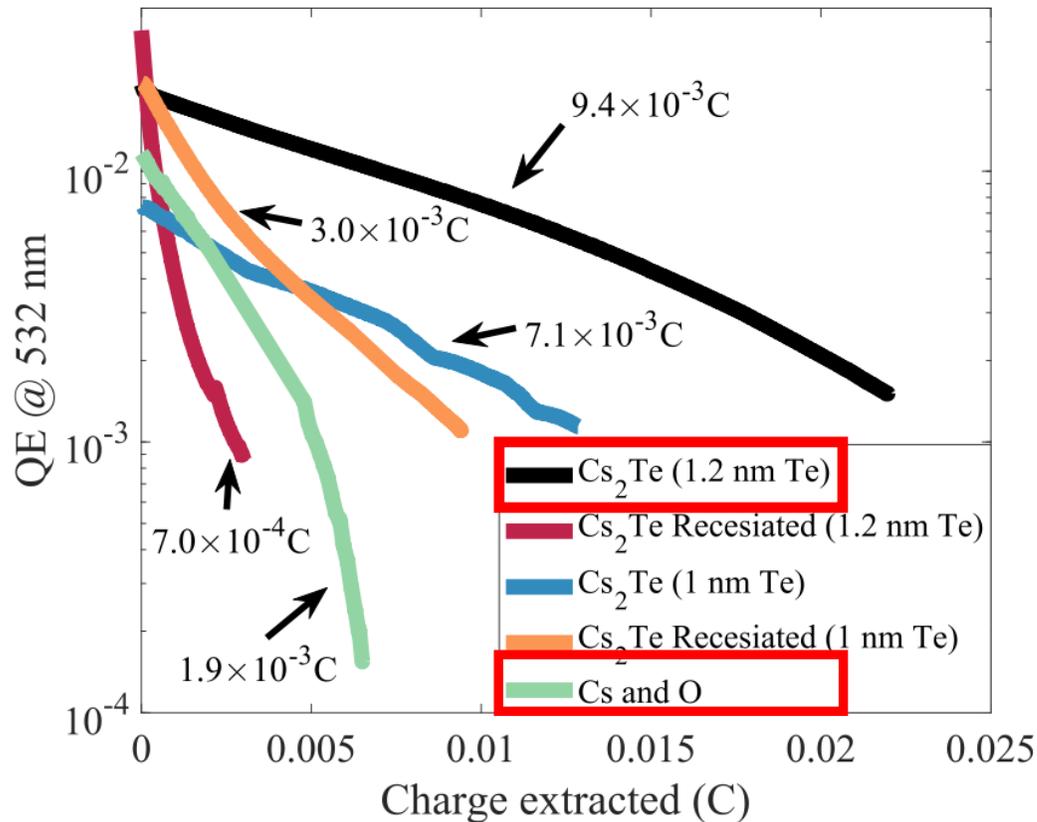
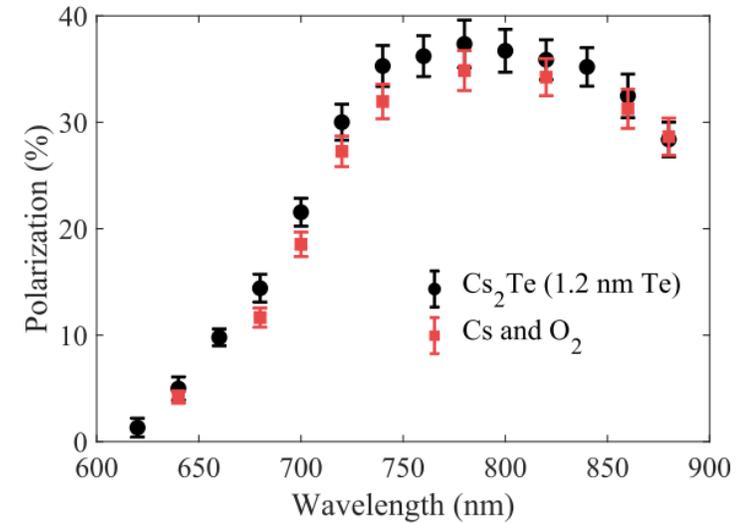


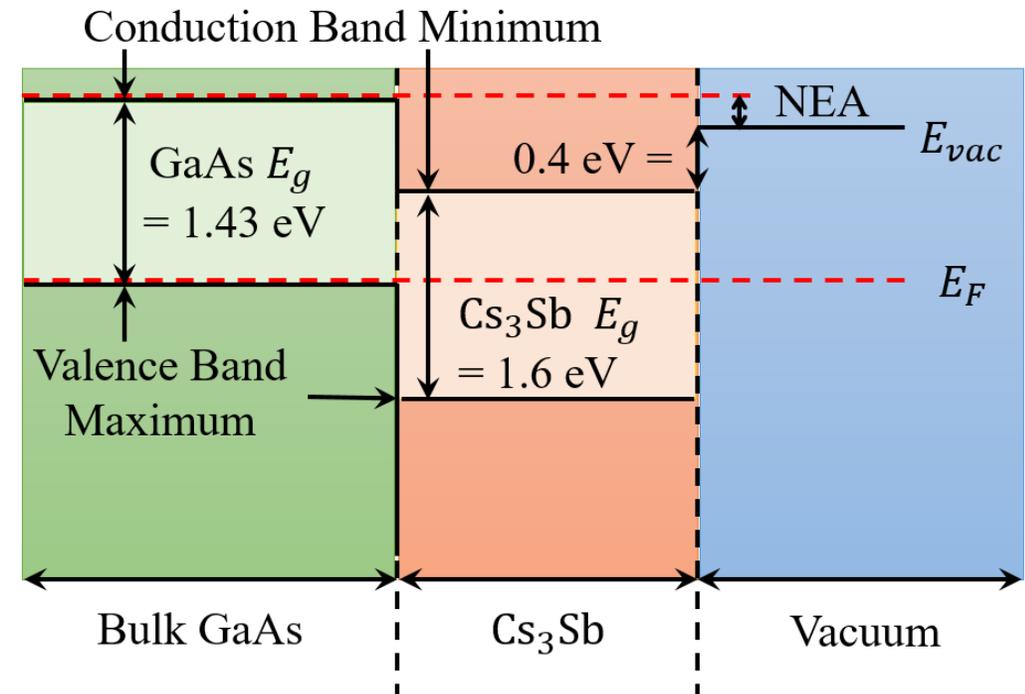
Table 1: Lifetime of NEA GaAs Cathodes

Cathode	Lifetime [10 <sup>-3</sup> Pa.sec]
CsKTe-GaAs	6.49 ± 0.01
CsO-GaAs	0.29 ± 0.03 [13]
CsO-GaAs	0.40 ± 0.02 [14]



# $Cs_3Sb$ activation layer

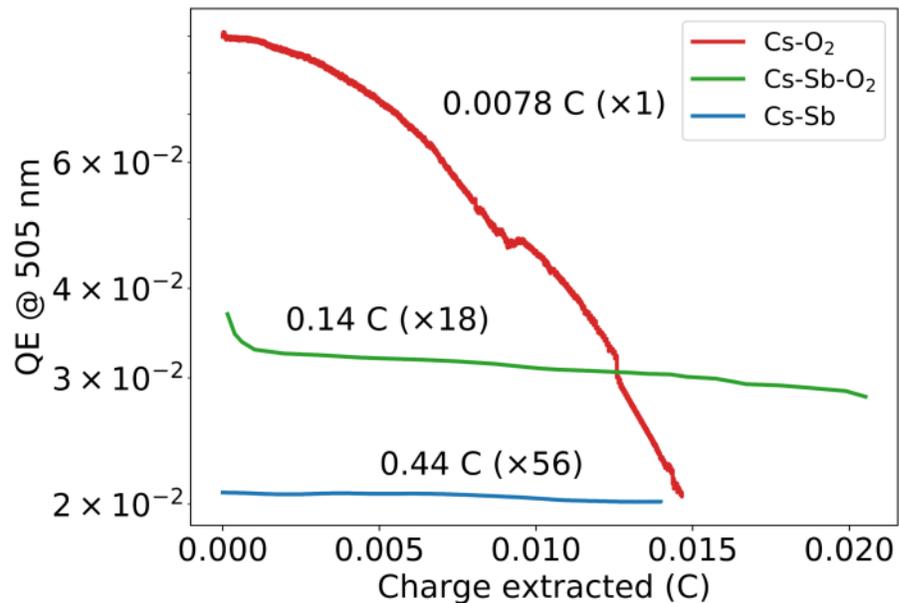
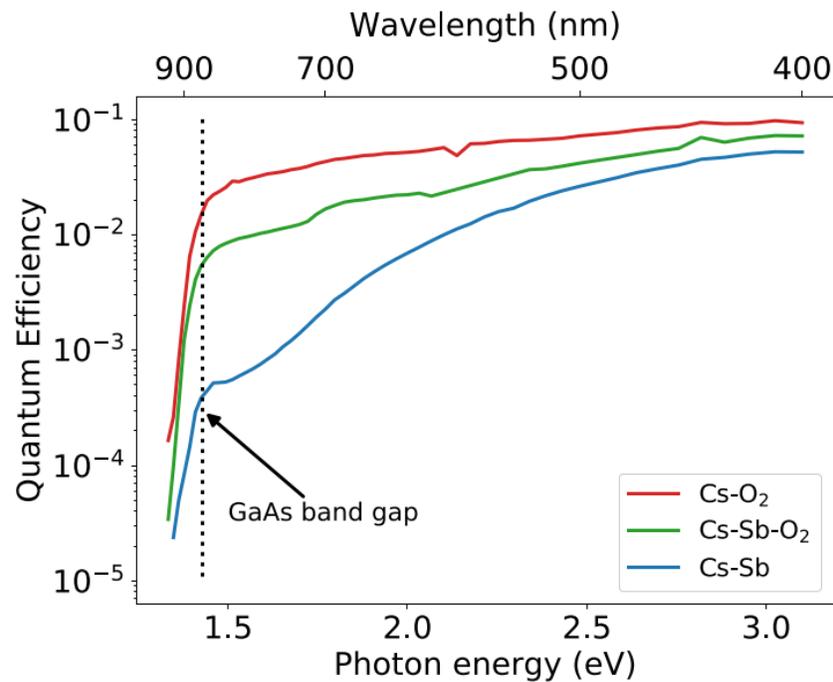
- $E_{vac} - E_F < GaAs E_g$
- Band gap of activation layer  $>$  GaAs band gap
- Doping control is not needed to achieve NEA.



Spicer et al. J. Appl. Phys. 31, 2077 (1960)

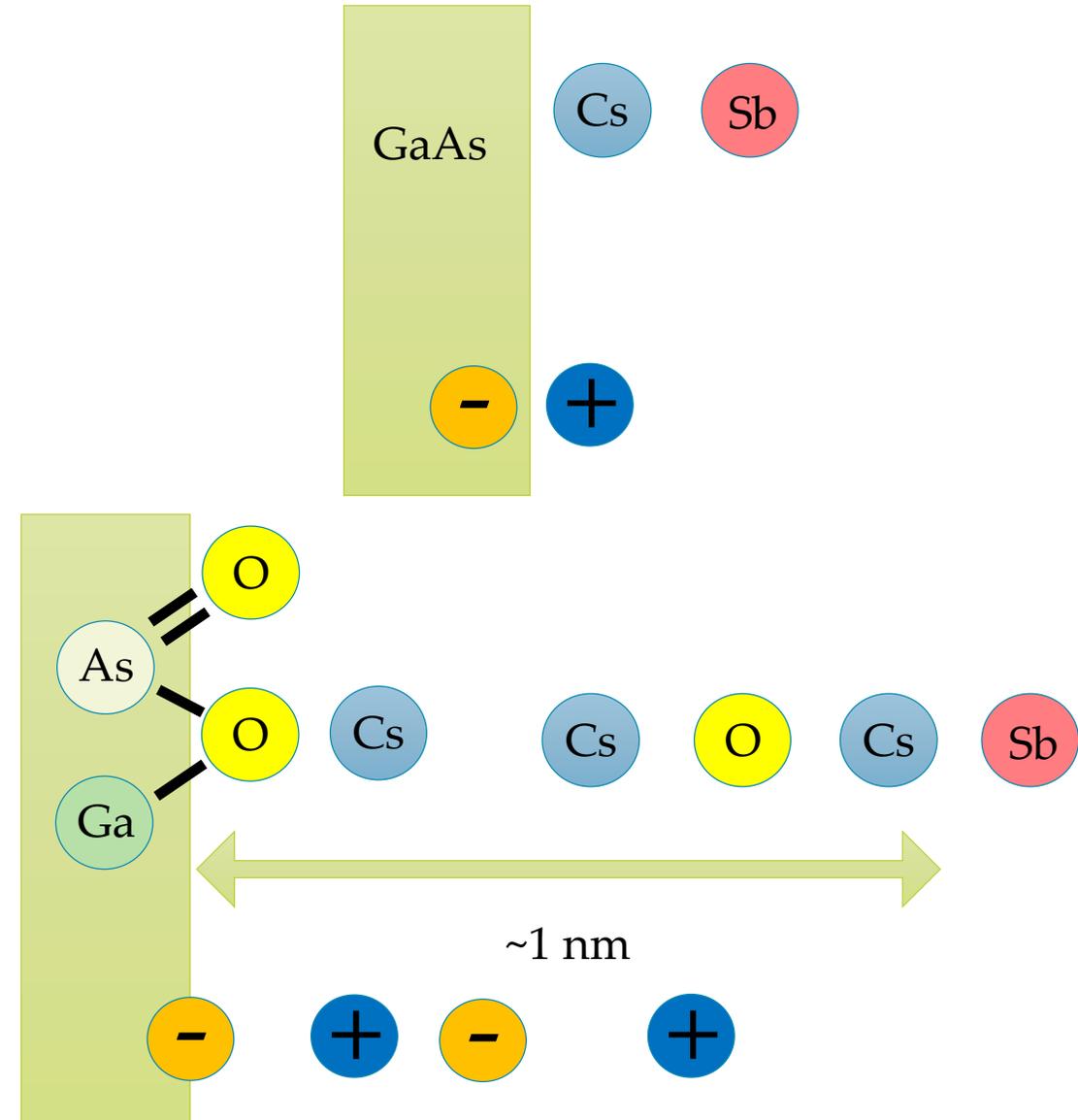
# Cs-Sb-O activation

- Steep drop of QE at 1.43 eV implies NEA achieved.
- Lifetimes are improved by orders of magnitude.



# Double dipole layer

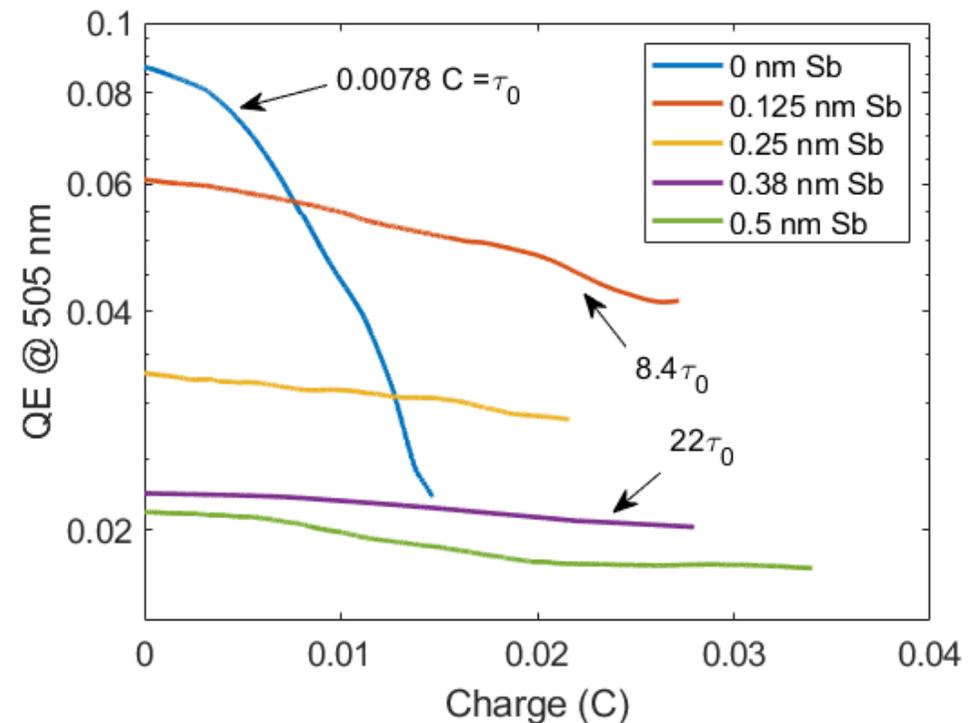
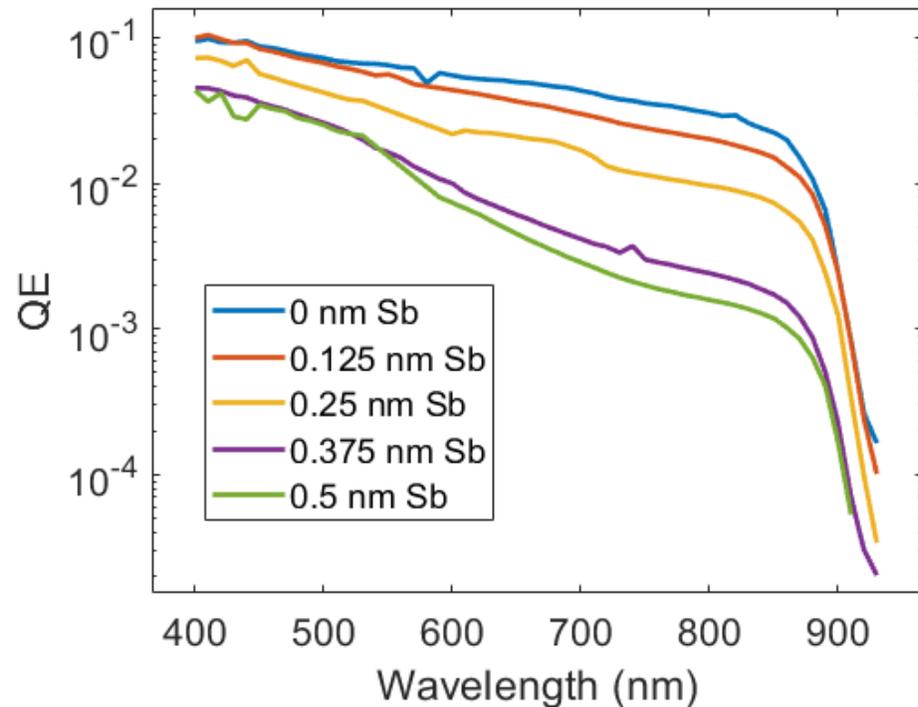
- Cs-O forms wider dipole layer.
- Sb atoms interacts directly with dipole layer on the surface in case of Cs only activation.
- The second dipole layer might help isolating dipole layer at GaAs surface from  $Cs_3Sb$ .



Su, C. Y., W. En Spicer, and I. Lindau. *Journal of Applied Physics* 54.3 (1983): 1413-1422.

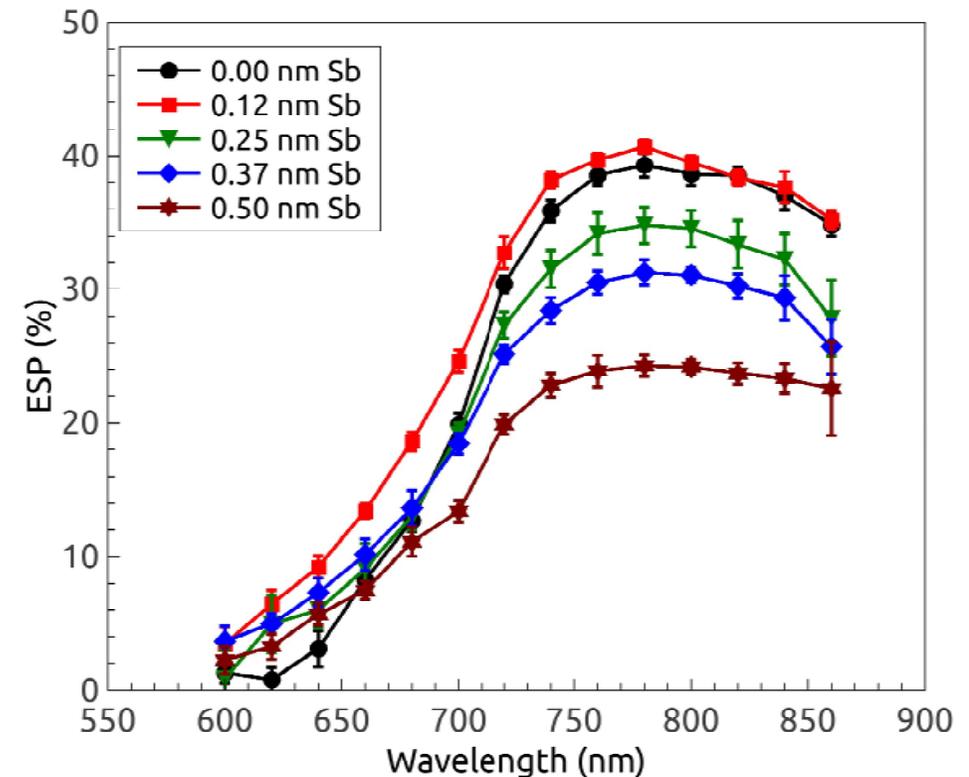
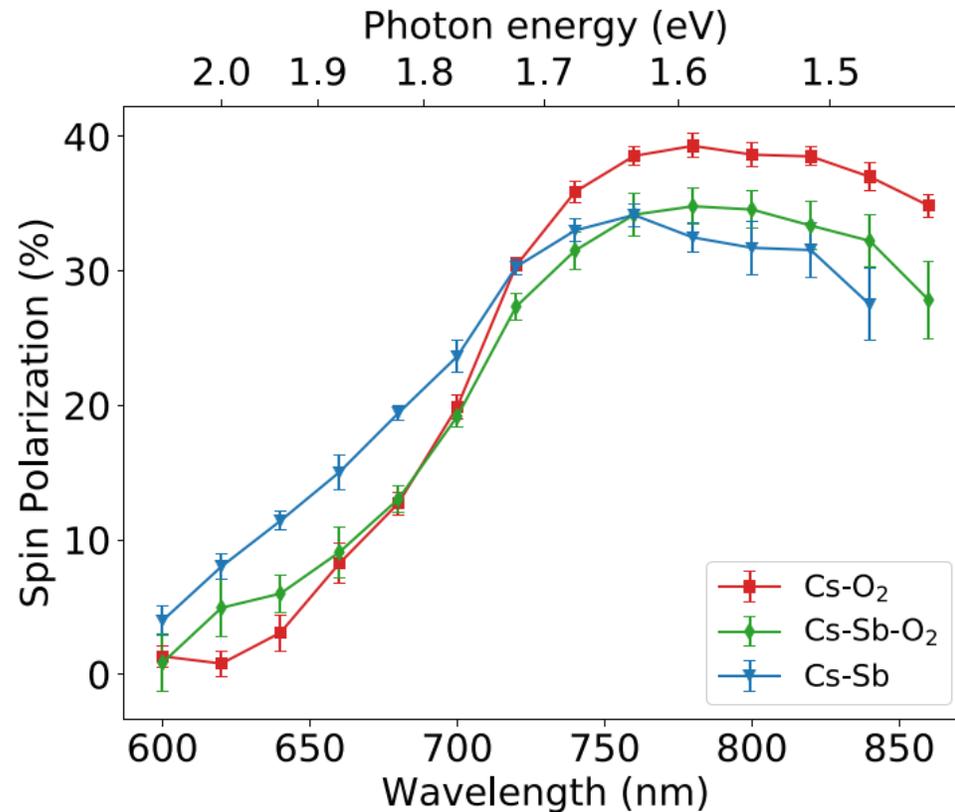
# Thickness variation

- QE and lifetime tend to decrease and increase as the activation layer gets thicker, respectively.



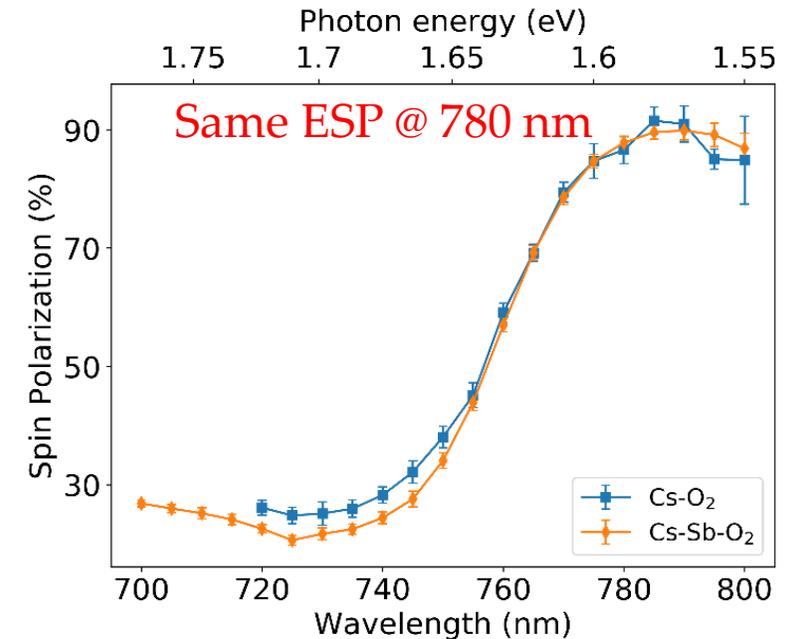
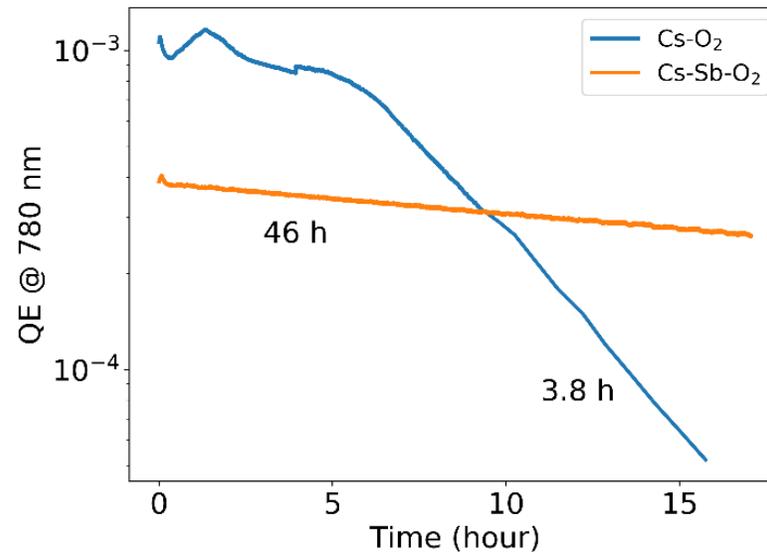
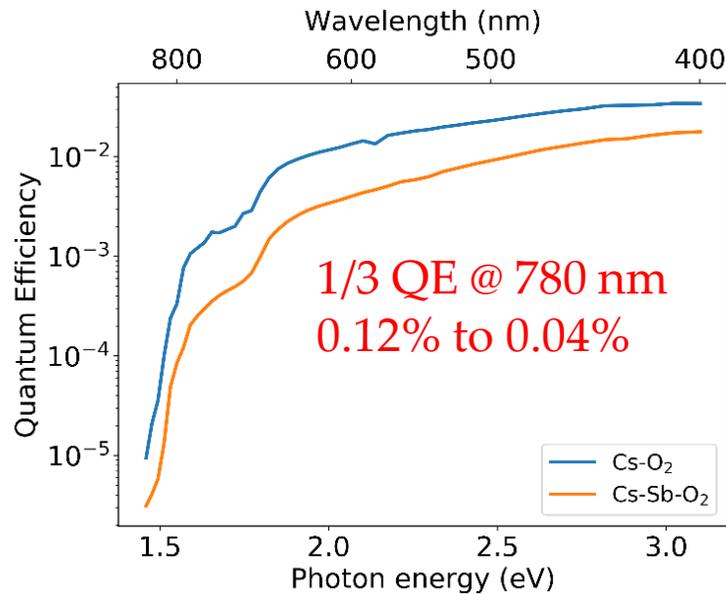
# Depolarization

- Ultrafast femtosecond scale spin relaxation ( $\sim 10$  fs) was observed.



# Superlattice GaAs

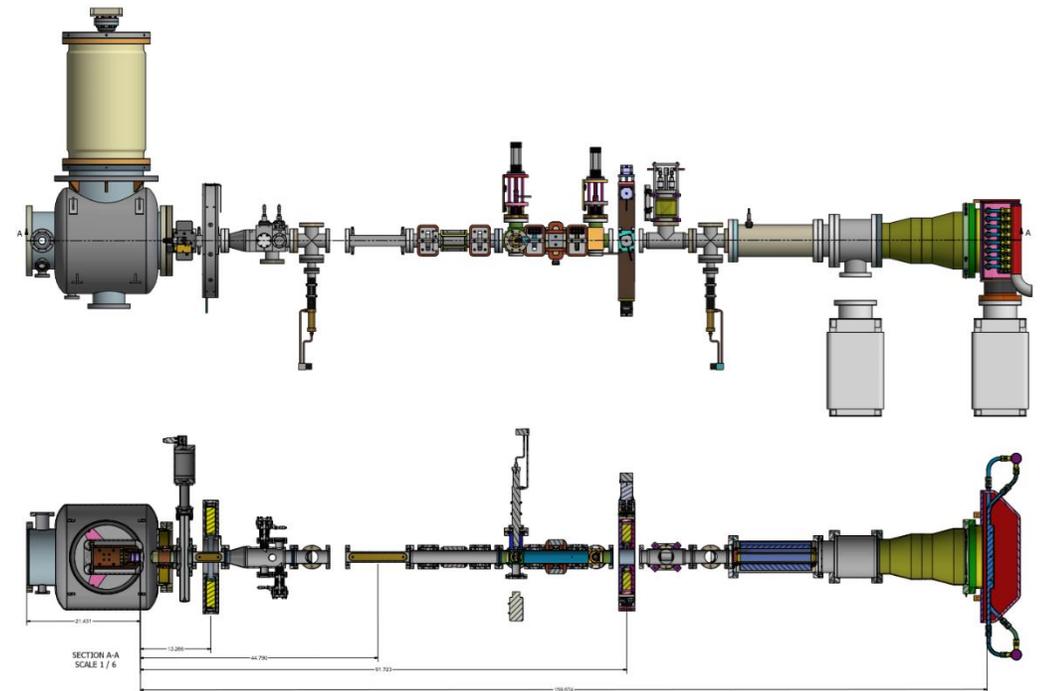
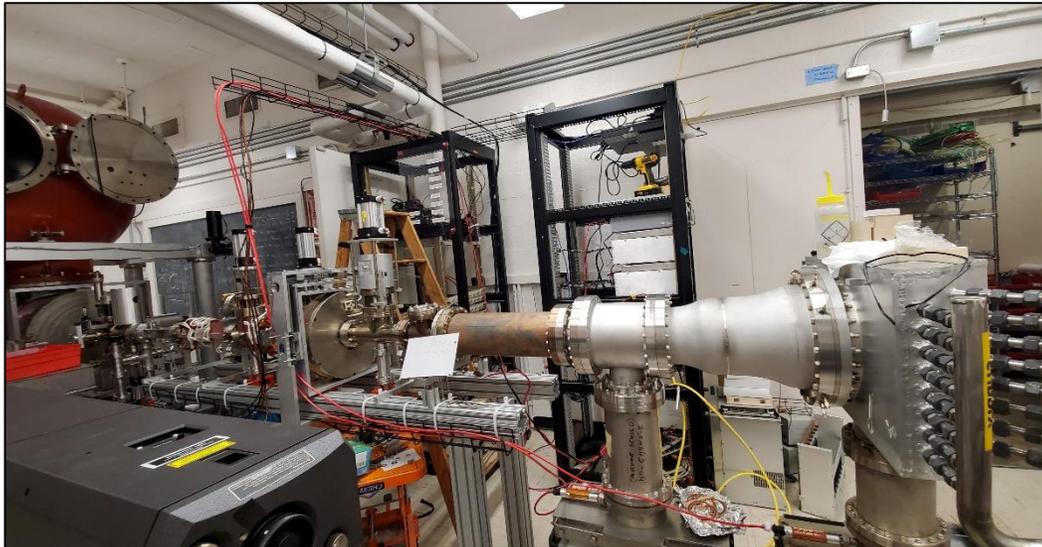
- Superlattice GaAs are used to produce highly spin polarized ( $\sim 90\%$ ) electrons.
- We attempted to activate superlattice sample with our method.



# Future works (1)

We are completing the installation of a dedicated beamline:

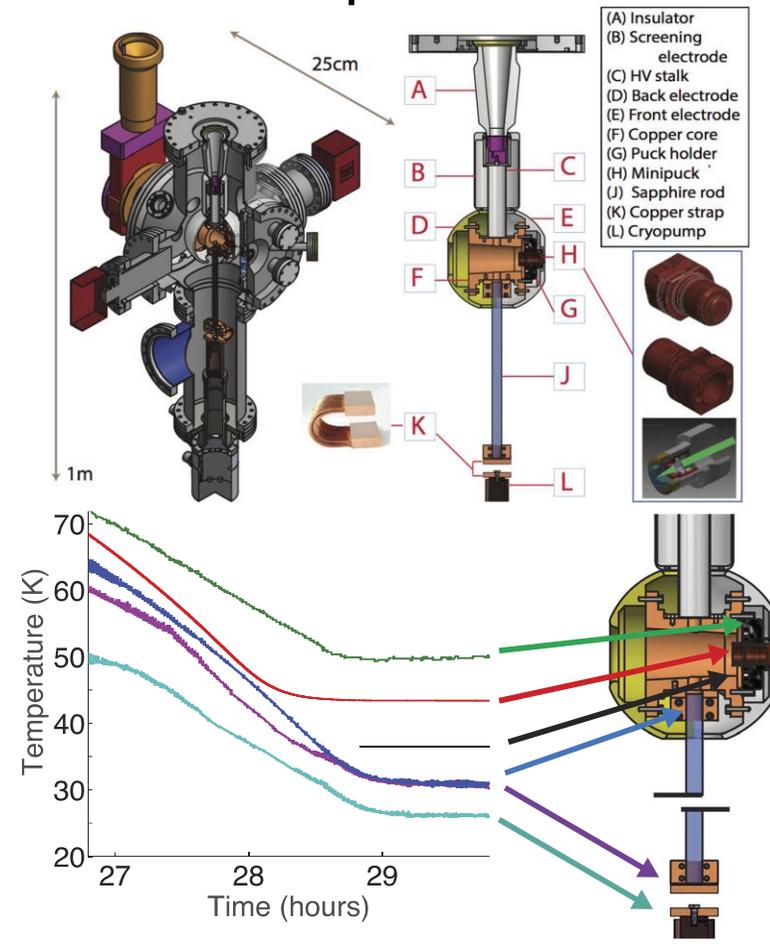
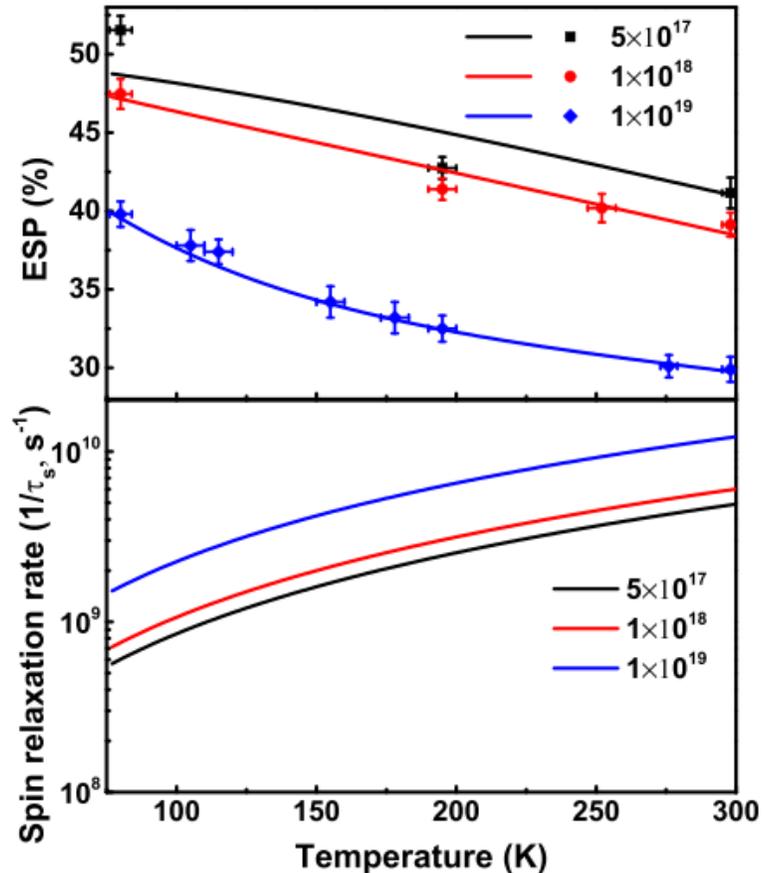
- Old CU-ERL gun 400kV @ 100 mA;
- Ion clearing electrodes;
- High power lasers;
- 75 kW beam dump;



# Future works (2)

Liu et al. *J. Appl. Phys.* 122, 035703 (2017)

- Spin polarization can be improved at low temperature



# Acknowledgment

- This work was supported by the Department of Energy and National Science Foundation.
- In collaboration with
  - Alice Galdi
  - Luca Cultrera
  - Frank Ikponmwen
  - Jared Maxson
  - Ivan Bazarov



# Next steps

- Surface studies (**XPS, STM, Auger** ...) are needed for Cs-Sb-O layer.
  - Vacuum suit case allows transferring samples to Hines lab.
- MTE of cesiated GaAs is determined by thermal limit near the photoemission threshold. **MTE measurement** of coated GaAs is important for high brightness photoinjector applications.
- NEA allows electrons to escape after relaxation down to the bottom of the conduction band, and it results in long **response time**. Coating layer might help filtering out the long tail.