



Polarized Electron Sources for C^3 *(and other potential Cornell Activities)*

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Assistant Professor of Physics
Cornell University

Future Colliders Workshop: Cool Copper Collider R&D
5/17/2022



- Brief intro: GaAs
- Beyond GaAs: New Epitaxial Photocathodes
- Thoughts for testing

- Other Cornell interest overlap: Cryo-RF



From Previous Workshop

- GaAs remains the go-to source of polarized electrons for all next-gen collider designs: EIC, ILC, CLIC, more.
- But there have been several advancements since its inception.

PHYSICAL REVIEW B

VOLUME 13, NUMBER 12

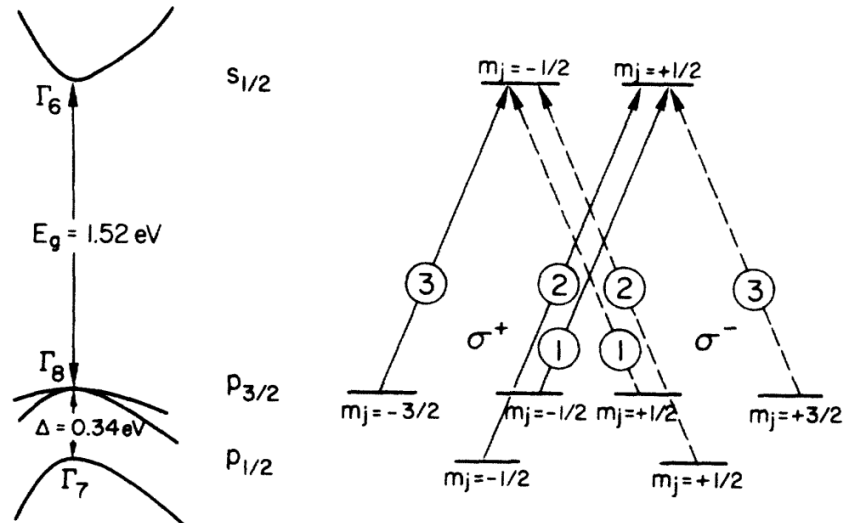
15 JUNE 1976

Photoemission of spin-polarized electrons from GaAs

Daniel T. Pierce* and Felix Meier

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

(Received 10 February 1976)



Band degeneracy:
Maximum polarization of 50%.

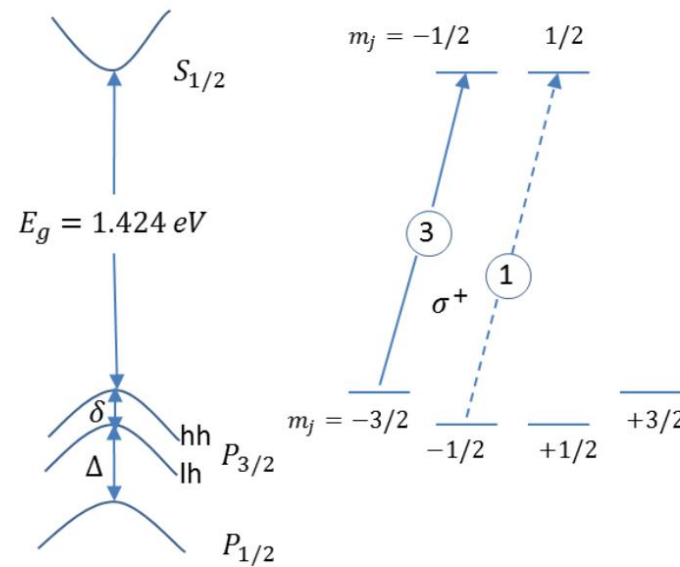
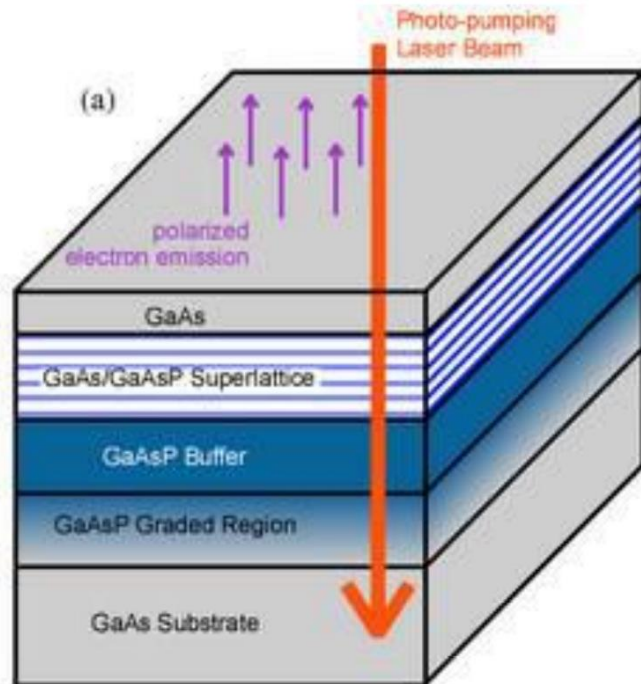
**With activation with Cs, O, bulk GaAs
to yield negative electron affinity, can
give multiple percent QE for bandgap
excitation ($\sim 800 \text{ nm}$).**



From Previous Workshop

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Insight 1: Lift the band degeneracy with strain, ideally via a superlattice.



Very high polarization, >90% measured.

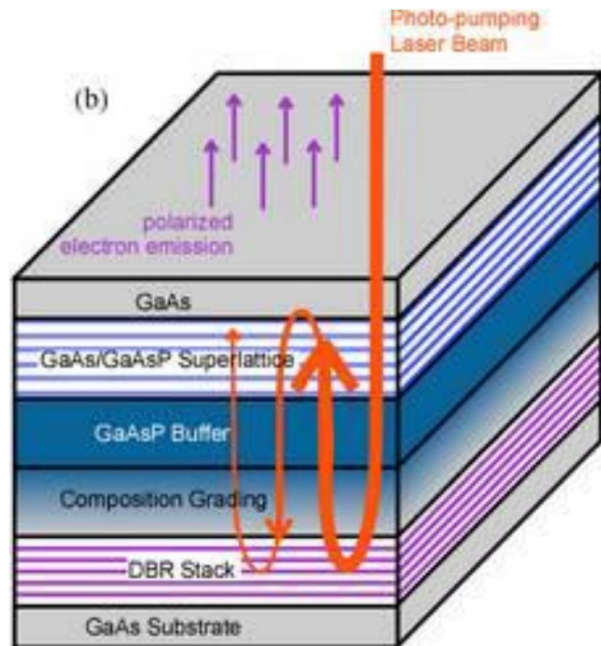
Downside: superlattice is not terribly thick—doesn't absorb much light. QE<1%



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Insight 2: Engineer layer thickness and indices of refraction to engineer absorption via interferometric effects (“Distributed Bragg Reflector”)



DBR photocathode

Record-level quantum efficiency from a high polarization strained GaAs/GaAsP superlattice photocathode with distributed Bragg reflector

Wei Liu,^{1,2,3,a)} Yiqiao Chen,⁴ Wentao Lu,⁴ Aaron Moy,⁴ Matthew Poelker,³ Marcy Stutzman,³ and Shukui Zhang³

QE enhanced to >6%, with polarization of 84%.

Downside? Not really! Will increase temporal response time to on the 10s of picosecond scale, but this is not important for large bunch charges.



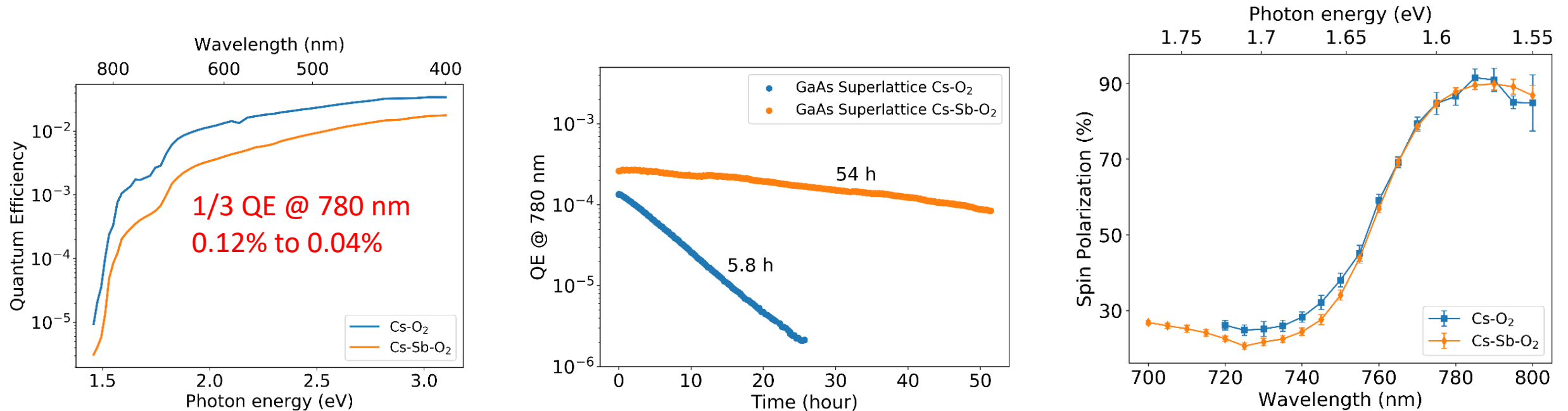
Vacuum Sensitivity

- The main challenge with NEA GaAs photocathodes:
A sub-monolayer of Cs/O activates the surface, and so a small quantity of reactive gas can kill it.
- Can be rejuvenated with heating cycle and recesiation (hours).
- Operating pressures of polarized photoguns to date are typically $<10^{-11}$ torr.
- This explains an important fact: EIC, CLIC, ILC designs intend to use DC photoguns with very pure vacua.



Last time: New activation techniques

- Cs-Sb activating layer: Order of magnitude longer lifetime with small penalty in QE.
- High polarization (90%) preserved from superlattice cathode.



Bae et al, *Journal of Applied Physics*. **127**, 124901 (2020)

- Would be very interesting to try on a DBR sample (high QE)!



What makes GaAs so special?

- Convergence of lots of great properties:
 - **Visible light, direct bandgap**
 - **Cubic symmetry:** VBM and CBM have simple wavefunctions with well defined angular momentum character.
 - **Sizable Spin-orbit band-splitting (0.34 eV)**
 - **Negative Electron Affinity:** VBM- \rightarrow CBM transitions can have high QE.
 - **Epitaxial Control:** Atomically ordered, and engineerable at the atomic level.

Until recently, GaAs was the only high QE single-crystal photocathode. All others (CsTe, Alkali antimonides) were, at best, highly polycrystalline.



- Recent: First epitaxial growth of alkali antimonides

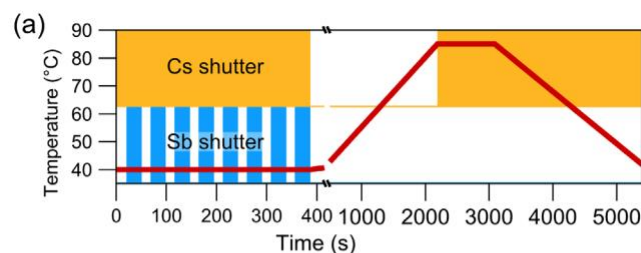
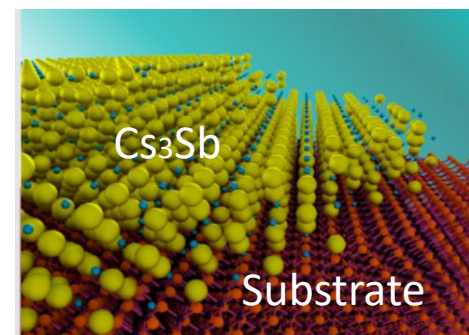
PHYSICAL REVIEW LETTERS **128**, 114801 (2022)

Editors' Suggestion

Featured in Physics

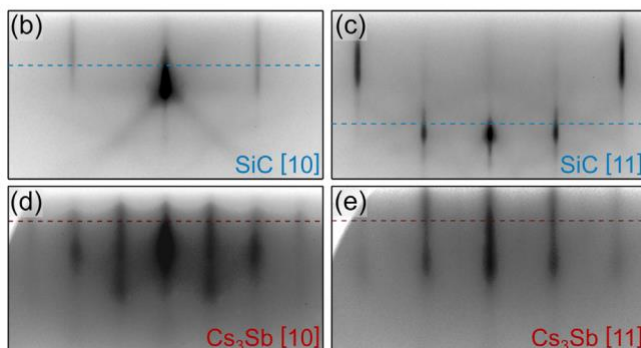
Single-Crystal Alkali Antimonide Photocathodes: High Efficiency in the Ultrathin Limit

C. T. Parzyck^{1,*}, A. Galdi^{2,*}, J. K. Nangoi³, W. J. I. DeBenedetti³, J. Balajka³, B. D. Faeth⁴,
H. Paik⁴, C. Hu¹, T. A. Arias³, M. A. Hines³, D. G. Schlom^{5,6,7}, K. M. Shen^{1,6} and J. M. Maxson^{2,†}

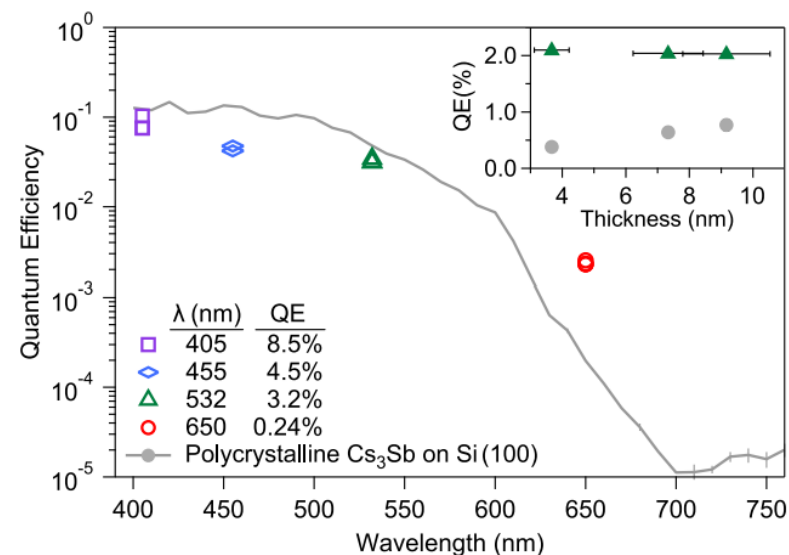


RHEED Images:

Substrate: 3C-SiC →



Photocathode →
Cs₃Sb





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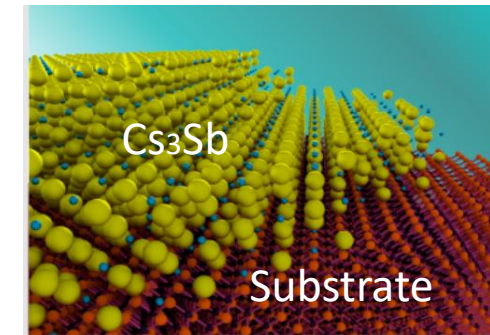
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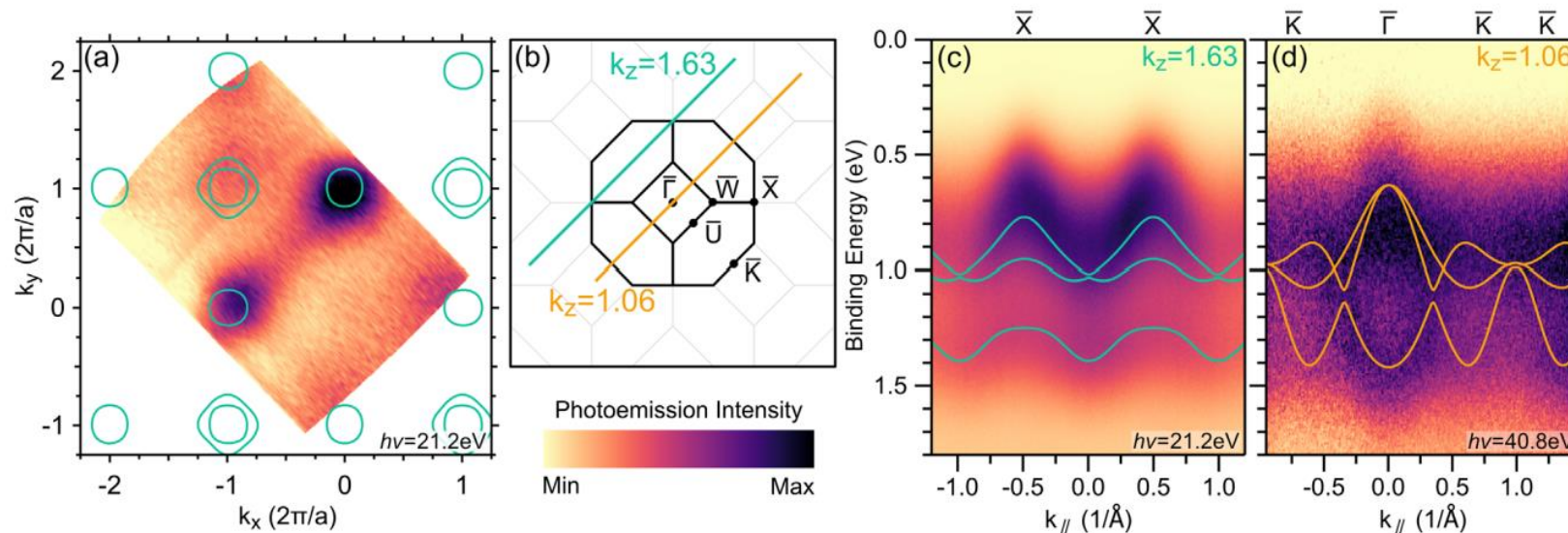
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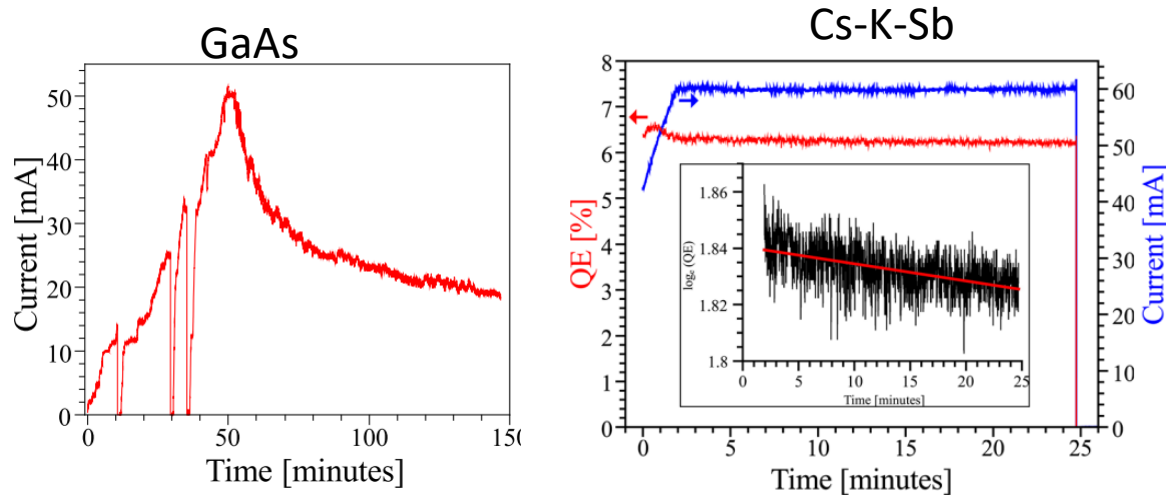
Valence band structure measured via ARPES agrees with DFT:





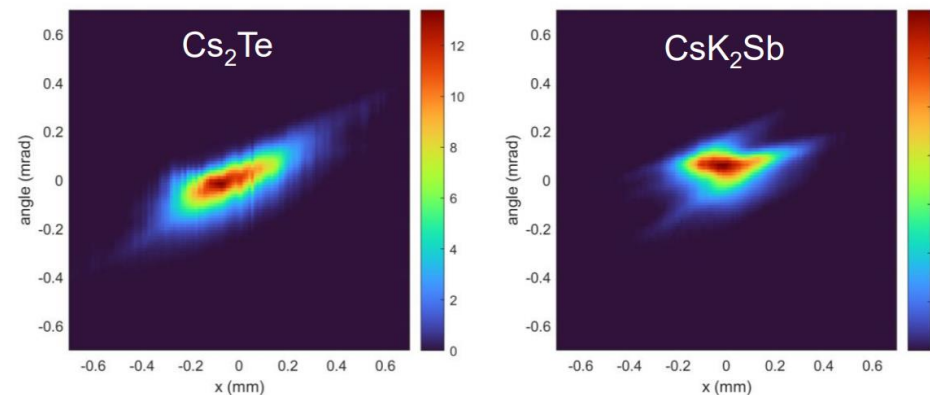
- Probably.
 - Visible light, direct bandgap
 - Cubic symmetry
 - Sizable Spin-orbit band-splitting (0.1 eV for Rb_3Sb)
 - Epitaxial Control
 - Negative (or small) Electron Affinity: probably
 - Na-K-Sb/Cs-Sb heterojunction has been suspected to be NEA
- Why care? **Not reliant on one monolayer**, many many orders of magnitude more robust than GaAs (even compared to the newly robust activation layers)

- High Current operation in DC gun: Appl. Phys. Lett. **102**, 034105 (2013)



- Tested up to ~ 50 MV/m @ Pitz L-band gun: (H. Qian et al, P3 workshop @ SLAC, 2021)

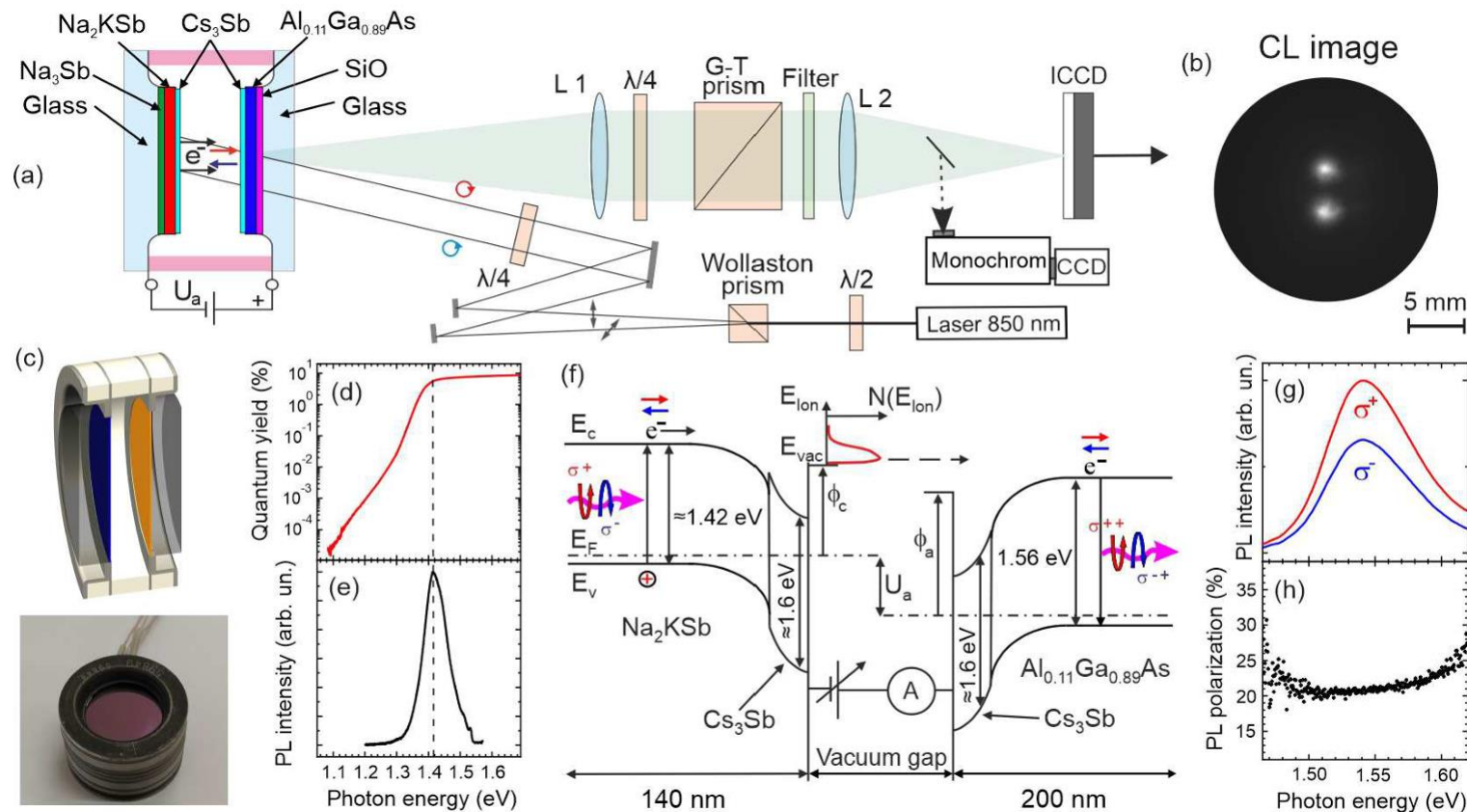
- Multiple day lifetime at high gradient
- Notably increased dark current as compared to Cs-Te (this makes sense).



100 pC beam phase space



- Recent Arxiv paper: claim of observation of spin polarized electrons from Na-K-Sb/Cs-Sb, V.S. Rusetsky et al., arXiv:2205.03693v1, 2022.

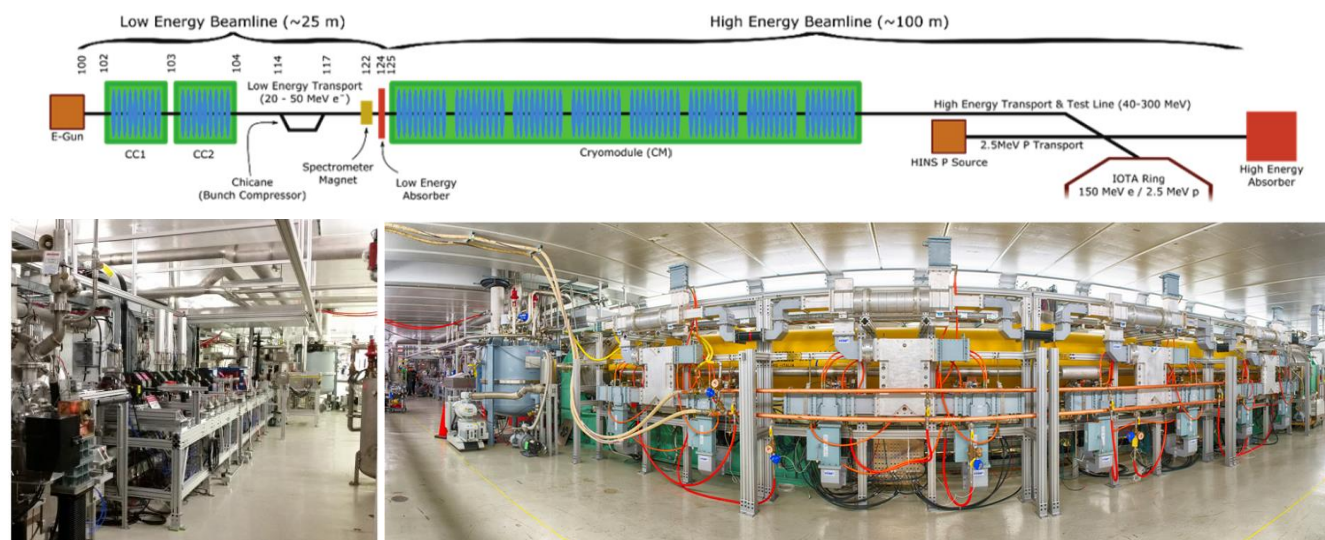


- Not epitaxial, but this does not necessarily exclude the measurement of some polarization.
- Looks to be well-demonstrated NEA
- “Indirect” measurement: they measure the circular polarization of cathodoluminescence.
- Claim is of 40-50% electron polarization.
- Very interesting result!
- Would be very good to do this with a Mott polarimeter
- Epitaxy would enable strain engineering.



Cathode testing

- High RF gradient and high QE cathode tests are few and far between—more are needed!
- Would be remiss to not point out that the FAST injector is a potentially very interesting place to test photocathodes: **high gradient gun with INFN-style load lock.**



Images
courtesy FAST

- Cornell has an alkali antimonide growth chamber compatible with INFN style plugs. We would be interested to provide alkali antimonides to FAST, if such tests would be of interest. Potential brightness enhancements from lower emittance photocathodes.



Thanks!

The Cornell Polarized Photocathode Team: Jai Kwan Bae, Alice Galdi, Luca Cultrera (now at BNL), Matthew Andorf, Jared Maxson, Ivan Bazarov



Thanks to The Center For Bright Beams, NSF, DOE HEP, and DOE NP for funding!





- Cornell SRF (Group leader Matthias Liepe) also has interest in C3.
- Several possible areas of overlapping interest and possible collaboration.
- What follows is a brief “advertisement” for Cornell SRF.

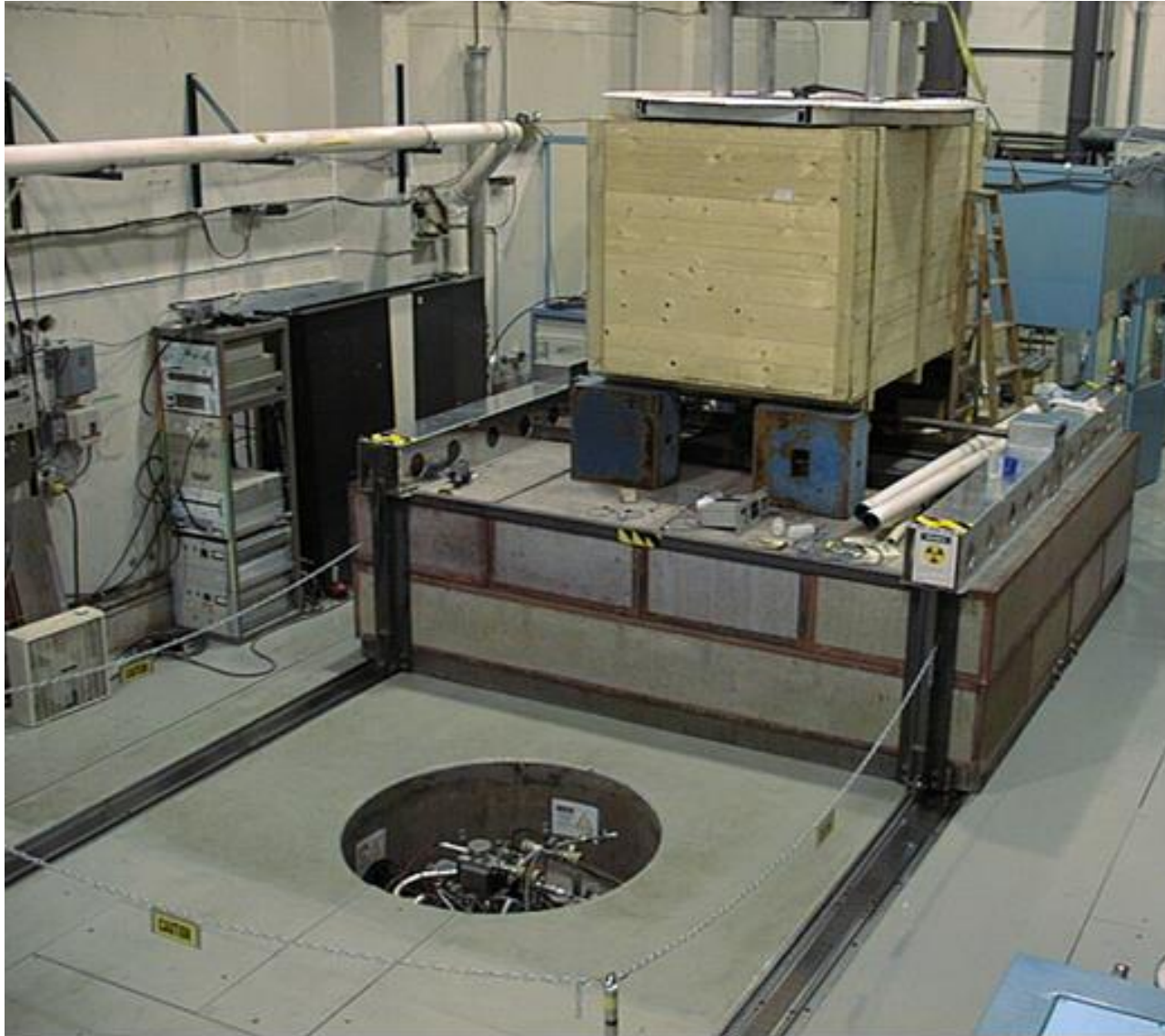


Cornell SRF Facilities: Cavity Test Inserts





Cornell SRF Facilities: RF Test Pits





SRF Cryomodules

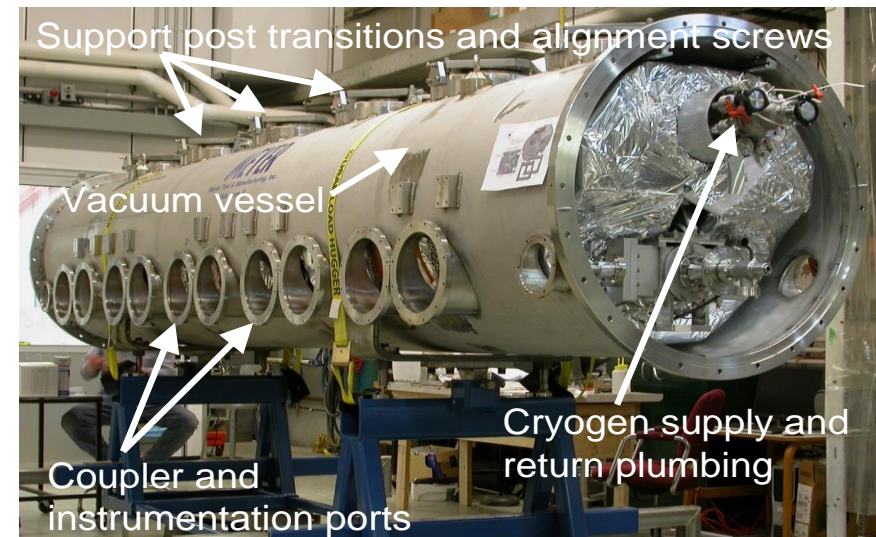
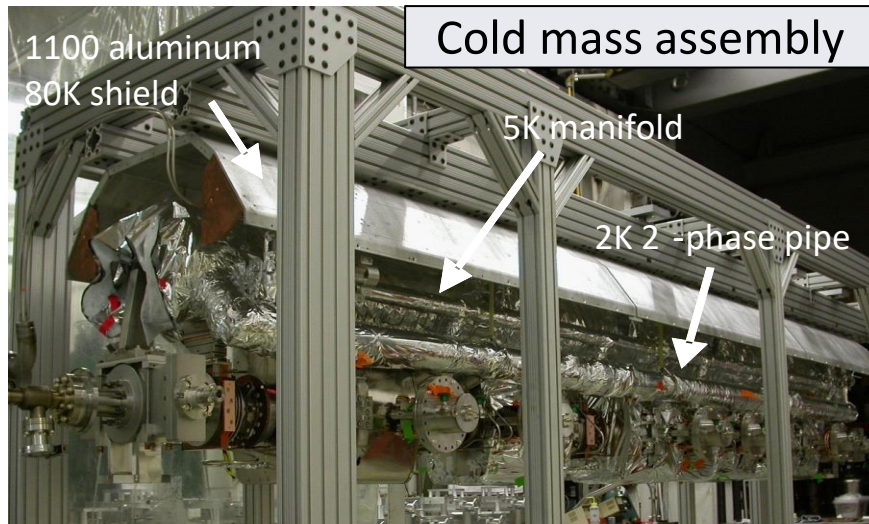


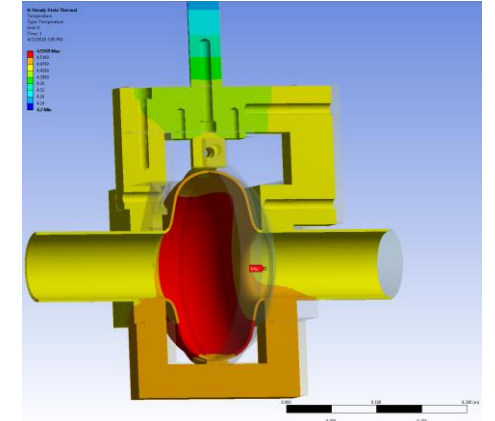
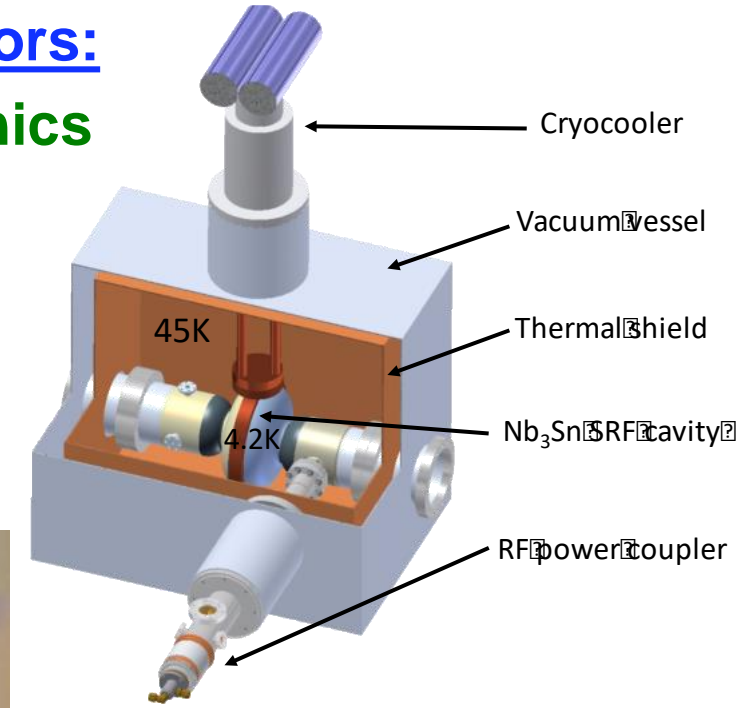
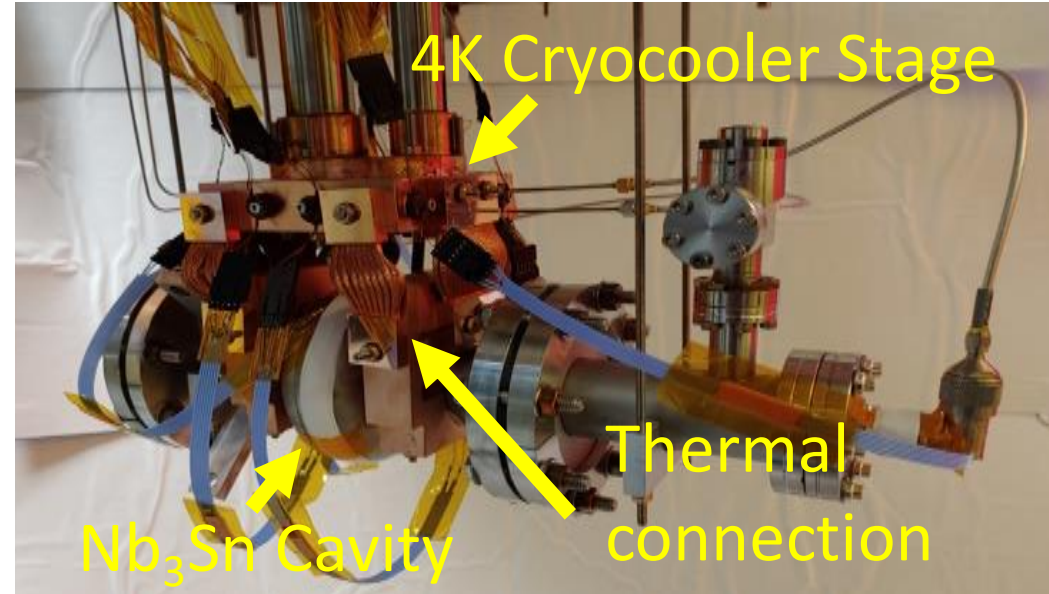
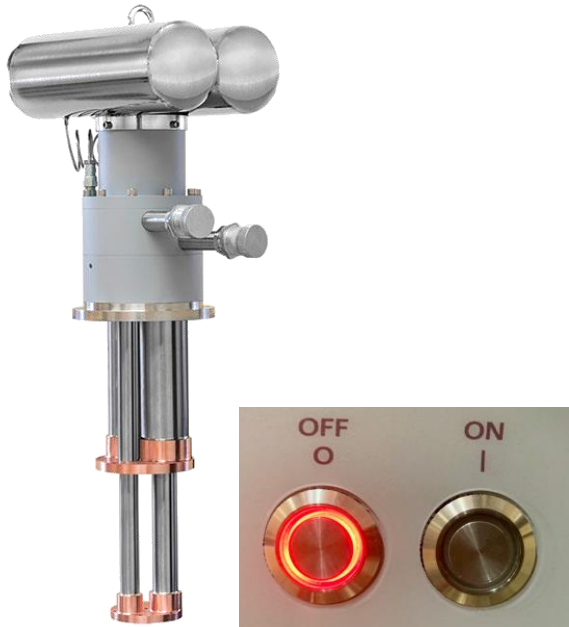


Table-top, Turn-key SRF Accelerators

Enabling new class of compact, turn-key SRF driven accelerators:

Key: Reduced cryogenic cooling power and simplified cryogenics

- **Widespread use of SRF**
- **Small-scale science accelerators**
 - High-intensity, high-brightness MeV scale beams
- **Industrial and medical applications...**
 - E.g. in wastewater and flue-gas treatment





New Compound and Multilayer Superconductors

Multi-layer laminates (S'S, S'IS)



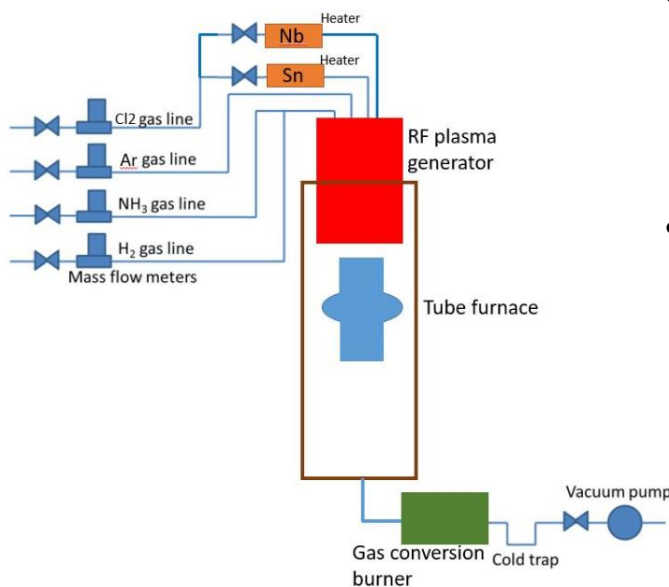
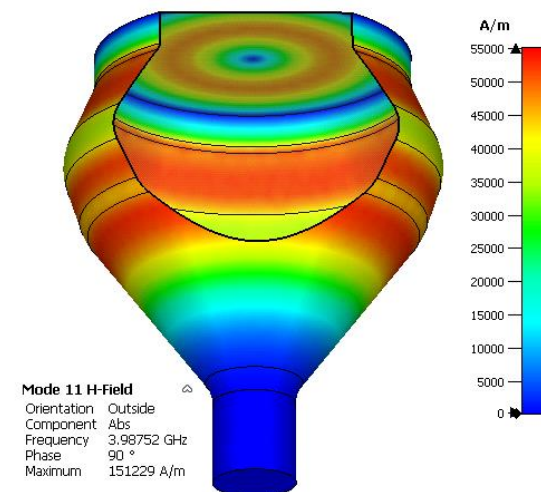
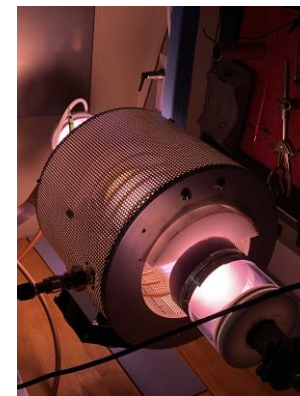
Few nm over-layers



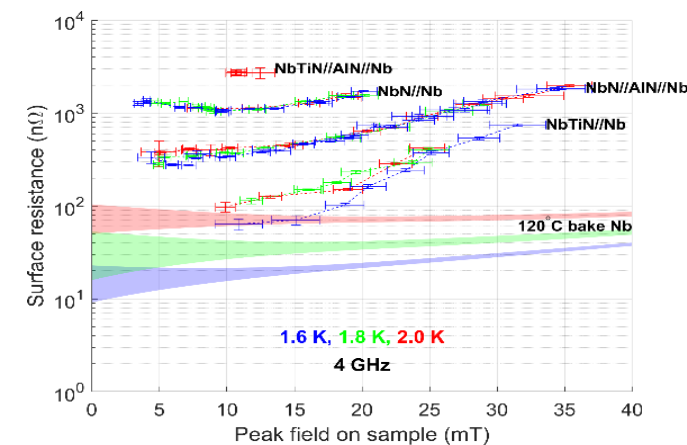
100 nm ALD NbTiN/Nb



~400 nm MgB₂/Nb



- Developing CVD and ALD system for thin-film superconductor growth
- Understand the impact and potential of nm-scale structuring of the RF penetration layer on RF performance





Cornell Laboratory for
Accelerator-based Sciences and
Education (CLASSE)



Thanks!