The Quest for the Perfect Cathode

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What makes a useful cathode for a photoinjector?

Growth Parameters

material, substrate, temperature, methods, recipes

Materials Properties

roughness, crystallinity, band structure, affinity

System Properties

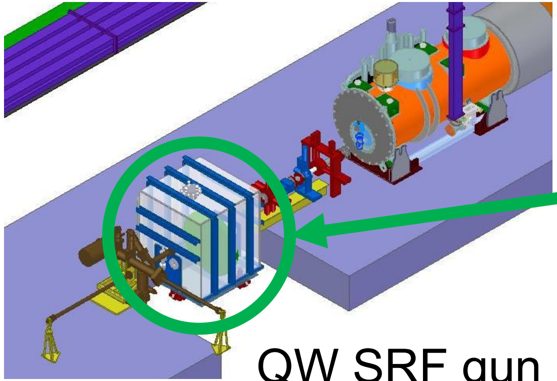
MTE/emittance, lifetime, QE, current density, total current, dark current, time response, cavity contamination

Goal: use things we can control (Growth Parameters) to optimize those relevant to accelerator operation (System Properties), by understanding the underlying physics (Material Properties)

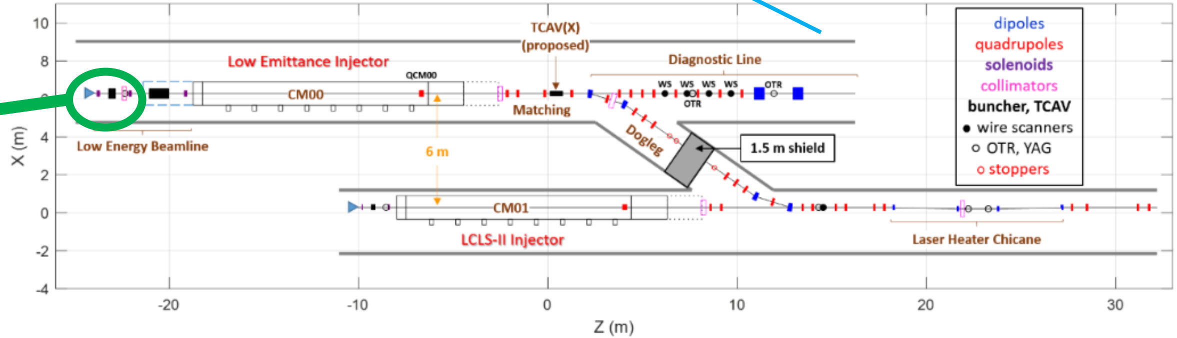
Customer: Low-Emittance Injector w/ SRF Gun

LCLS-II-HE will install a new, low-emittance injector in a new tunnel at the west end of the SLAC linac. Goal: $\varepsilon_{n,rms,95\%} < 0.1\ \mu m$ @ 100 pC

- 30 MV/m on cathode
- MTE < 184 meV
- Lifetime > 1 week
- “green” illumination



QW SRF gun



Project Structure

Low-gradient characterization at multiple laboratories

- Cornell and ASU both have in-house materials science facilities
- SLAC, Cornell and ASU collaborate on BNL synchrotron effort

Goal: Investigate the trade space of MTE vs wavelength, growth method, temperature, substrate/crystal structure. Demonstrate Reproducibility!

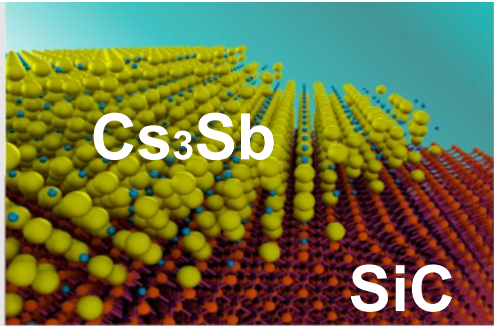
High Gradient tests

- DC high gradient tests w/ proximal probe (LEEM and STM/nanoprobe)
- Transfer of cathodes into UCLA and LBNL photoinjectors
- Investigate commercial cathode production

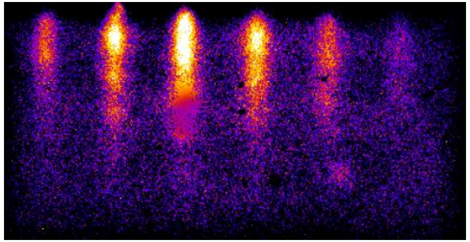
Goal: Develop operational experience at high gradient, and investigate dark current. Possibly qualify commercial vendor.

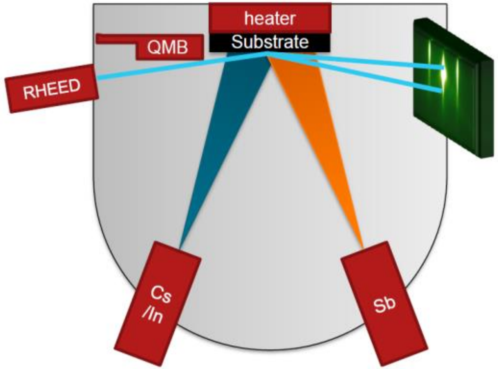
Low Gradient Tests at Cornell: Growth

Meet **PHOEBE**: **PHO**tocathode **E**pitaxy and **B**eam **E**xperiments laboratory

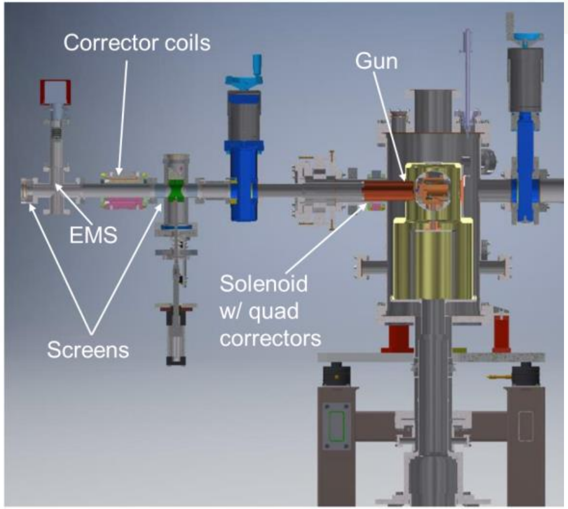


RHEED image of epitaxial Cs_3Sb on SiC at PHOBE





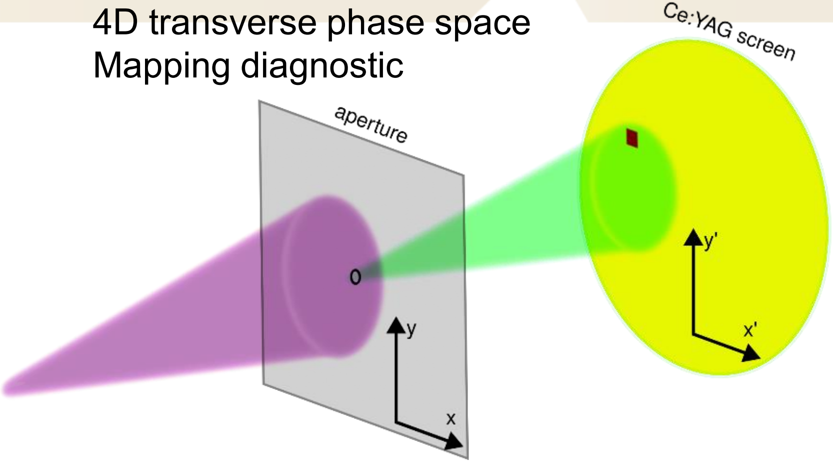
Low Gradient Tests at Cornell: MTE



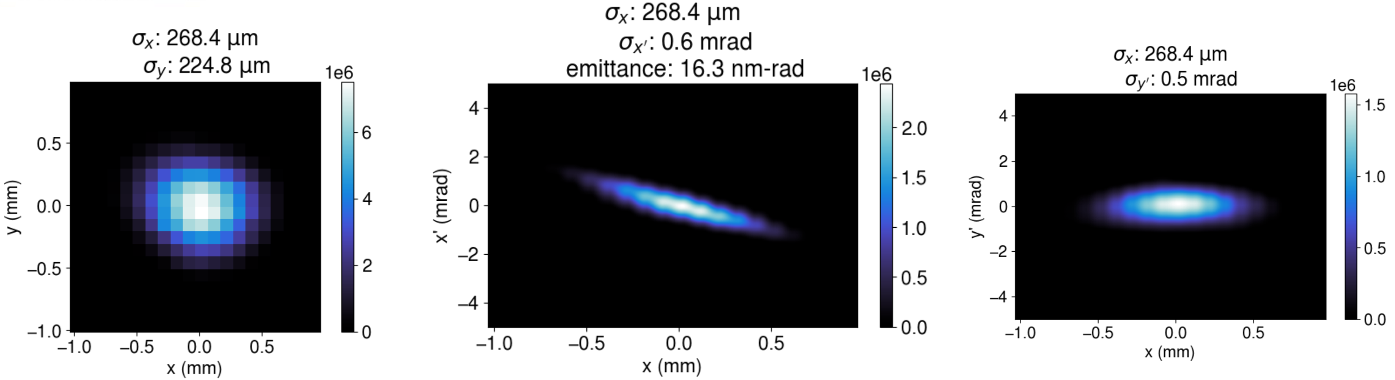
Cryo-TE meter:
A 10 keV gun cyrocooled to 18 K with diagnostic beamline.

Accepts cathodes from MBE via vacuum suitcase.

4D transverse phase space Mapping diagnostic

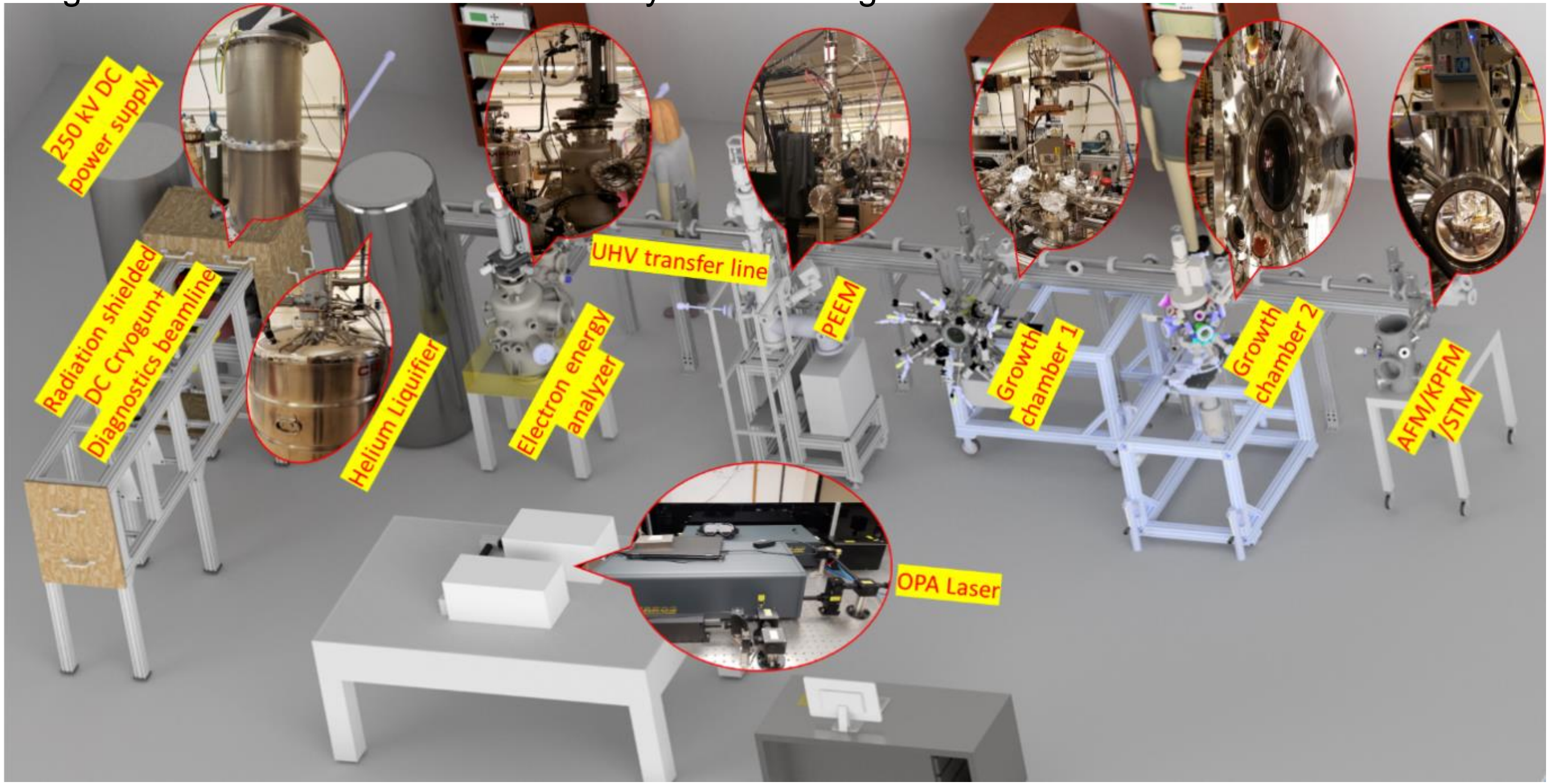


Example Data:

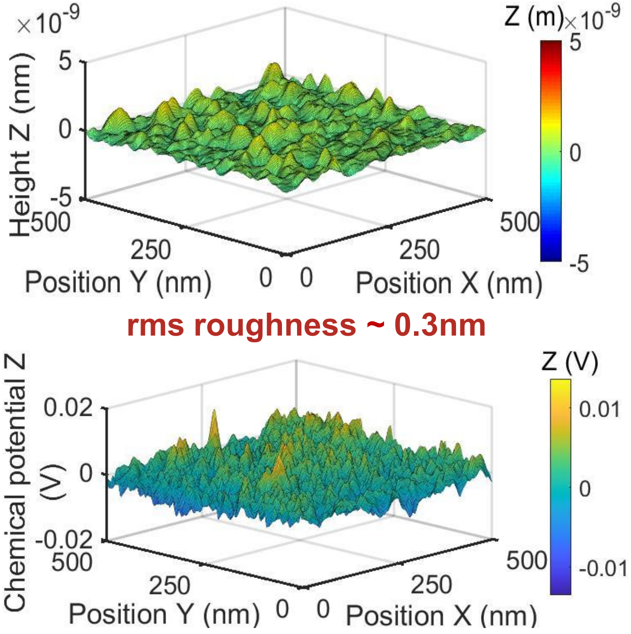


ASU Cathode research facility

- Atomic scale surface characterization
- detailed photoemission characterization
- Bright beam demonstration in 200 kV cryocooled DC gun

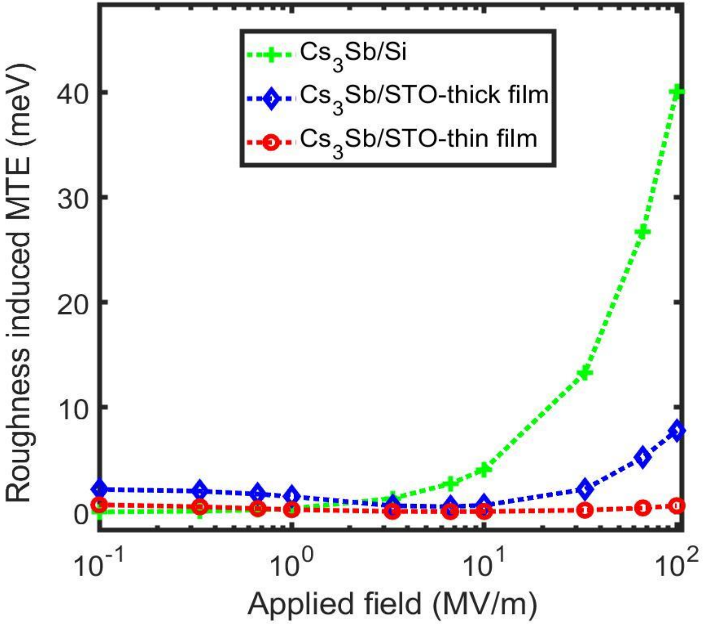


Effects on Physical and Chemical Roughness on MTE



rms roughness ~ 0.3nm

rms roughness ~ 2.65 mV



P. Saha et al., Appl. Phys. Lett. 120, 194102 (2022)

Cathode fabrication and high gradient tests

Both the UCLA and LBNL guns can accept INFN style plugs

SLAC $CsTe_2$ system for LCLS-II: can easily grow antimonides

RMD, BNL and Cornell: sealed capsule option for INFN plugs

ASU: modified INFN plug with removable tip

DC high gradient tests – keep electron energy under 300eV to avoid electron stimulated desorption and bremsstrahlung.

Want 30 MV/m => tip to surface of <10μm

Easily achievable in proximal probe systems (STM, nanoprobes)

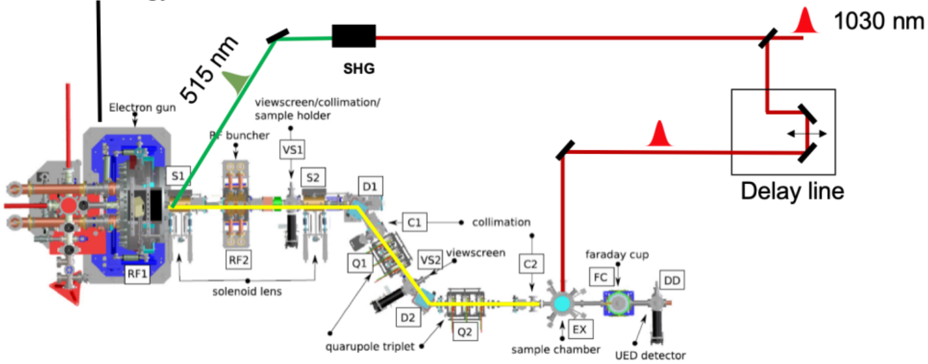
Alternative is to use LEEM, but only to 15 MV/m

HiRES at LBNL: High Rep rate test bed

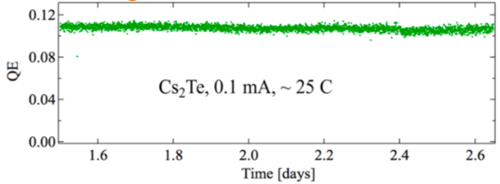
Unique capabilities

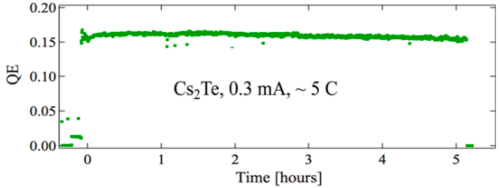
- CW operations at High gradient, similar to LCLS-II HE operations
- Cathode exchange system, a prototype of LCLS-II
- Full 6D characterization of photoemitted electron beam

Electron energy = 750 keV

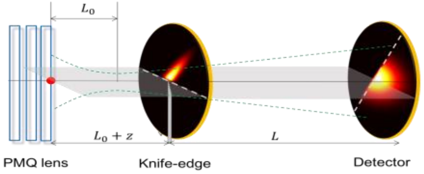


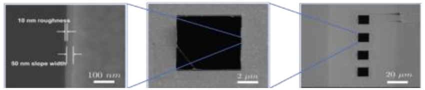
High current measurements



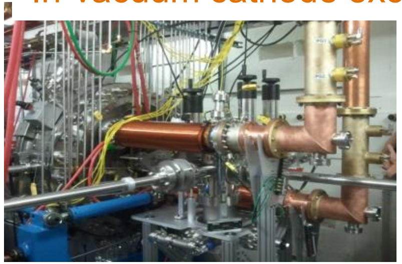


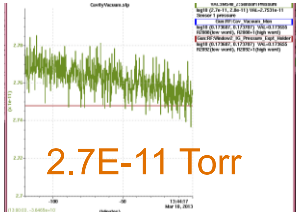
Advanced measurement tools





In-vacuum cathode exchange system (LCLS-II compatible)

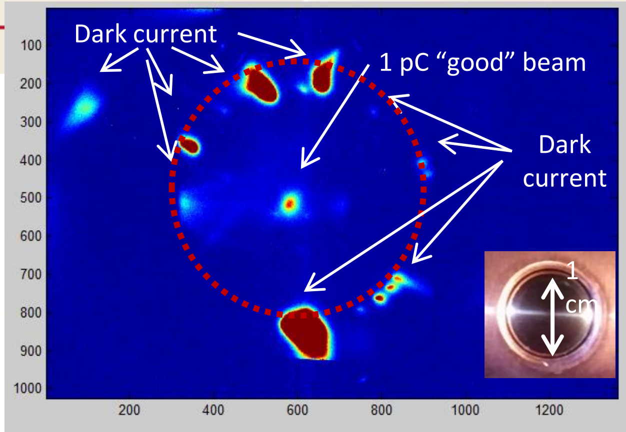


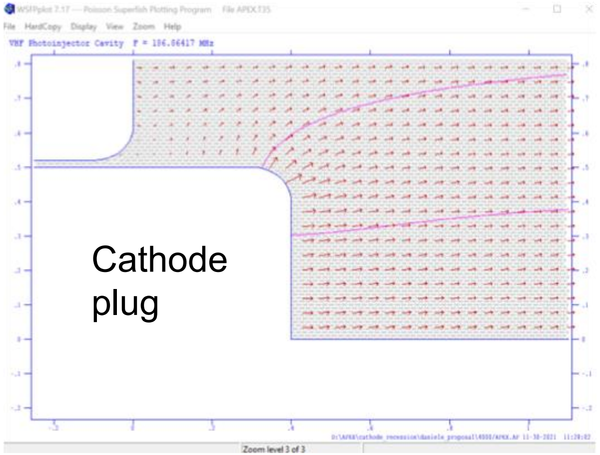


Photocathode tests at LBNL

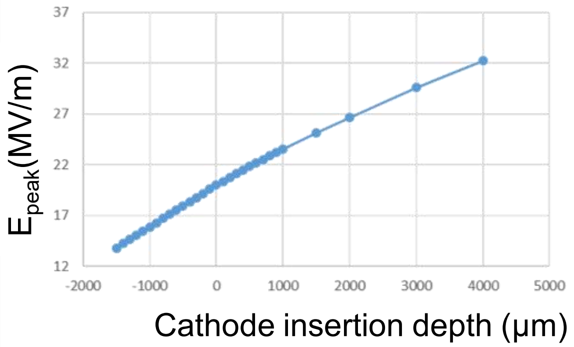
- Fabricate and test different plug geometries:
  - Minimize dark current from cathode and cavity wall corners
  - Increase accelerating field at cathode above 25 MV/m
- Design advanced plugs allowing tests of photocathode materials on wafers
- Measure emittance and lifetime of different cathodes produced by partner labs
- Characterization of dark current: source imaging and average current transmitted

Example of dark current imaging on old cathode





Peak Field at cathode center
for a constant energy gain of 750 KeV



High field S-band gun with load-lock chamber (UCLA)

Enable study of high field (40-100 MV/m) effects on photoemission from alkali-antimonides cathodes

Operating vacuum < 1e-9 (@ 10 Hz) with additional NEG pumping

Simple cathode transfer setup (copy from LBNL) + INFN-style plug

Platform for testing novel photoemission concepts with well-characterized beamline

- Systematic study of roughness in metals
- Nanoscale emission area
- Alternative cathode materials

Tunable/shapeable laser for photocathode optimization

INFN/DESY/LBNL cathode plug

Conclusions

We hope to pick up where most cathode materials efforts have ended

Demonstrate practical aspects of advanced cathodes in real guns

We expect to demonstrate reproducibility across growth systems and methods

We hope to validate cathode delivery of Alkali antimonides on INFN plugs

Advice welcome!

THANK YOU!