Photocathodes Characterization Techniques - Basics

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Postdoctoral Associate - Theme 1

CBB Annual Meeting - July 22/2023

1. Intro
2. Quantum Efficiency (QE)
3. RHEED (Reflection high energy electron diffraction)
4. XPS (X-ray photoemission spectroscopy)
5. MTE (Mean Transverse Energy)
6. Summary

Overview

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Photocathodes for Bright Beams

Normalized brightness is defined by:

$$B_n = \frac{2m_e c^2 I}{\sigma_x^2 \, MTE}$$

$\boldsymbol{I} \rightarrow$ Beam Current: Quantum Efficiency, laser fluency, lifetime

$\boldsymbol{MTE} \rightarrow$ Mean Transverse Energy: Intrinsic Momentum spread + roughness + laser heating + ...

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Goal:

Photocathodes with high QE and low MTE

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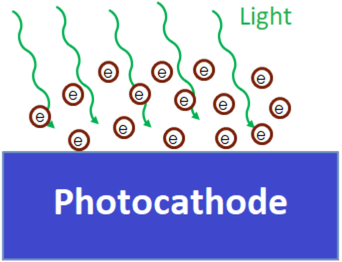
$$EQE = \frac{Average\ e^-}{Incident\ photons}$$



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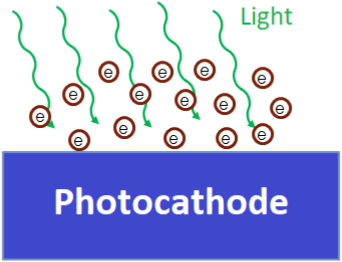
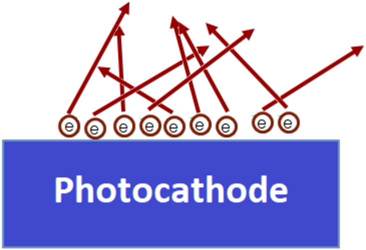


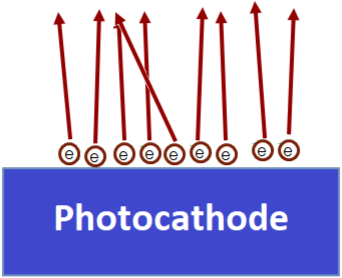
Candidates: (Bi)Alkali antimonides thin films (Cs_3Sb, K_2CsSb, Na_2KSb...)

Photocathodes for Bright Beams

Goal: Photocathodes with high QE and low MTE (Mean Transverse Energy)



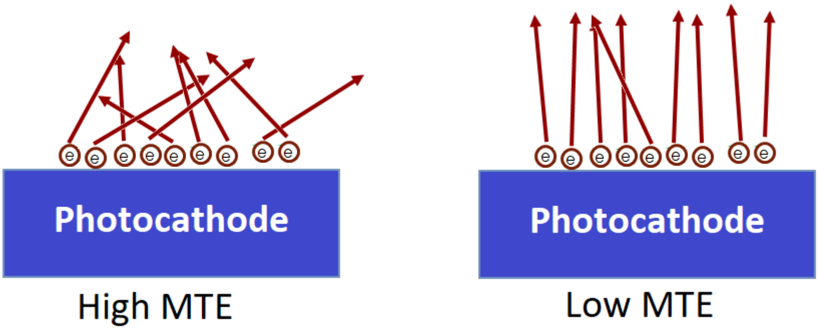
High MTE



Low MTE

Photocathodes for Bright Beams

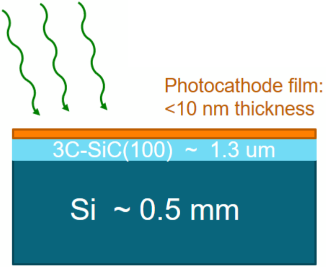
Goal: Photocathodes with high QE and low MTE (Mean Transverse Energy)



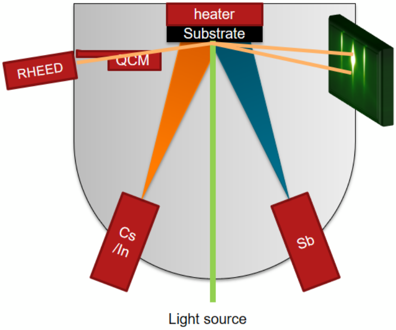
One solution: Flat and ordered films

Deposition System → Molecular Beam Epitaxy (MBE)

Thin films can be obtained in our system



Our growth method:
RHEED monitored
Structure oriented



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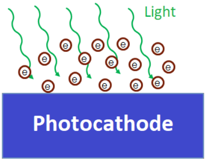
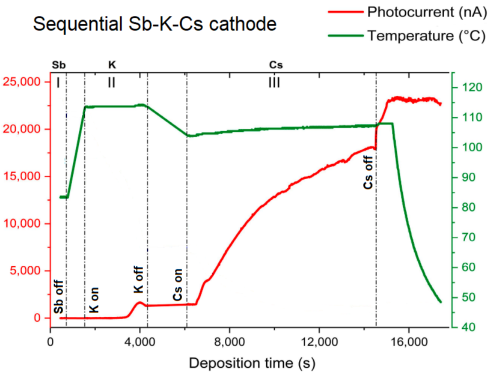
Quantum Efficiency (QE)

in situ most used technique to define the cathode growth

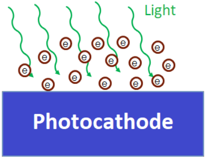


$$EQE = \frac{Average\ e^-}{Incident\ \ photons}$$



Modif. from **Micromachines 2023, 14, 1182**

Spectral Response



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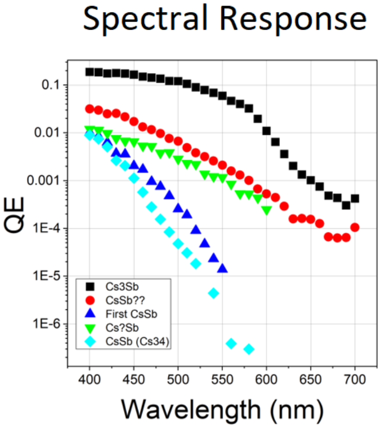
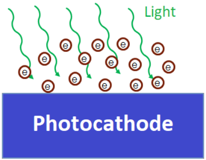


Oxidation Experiments



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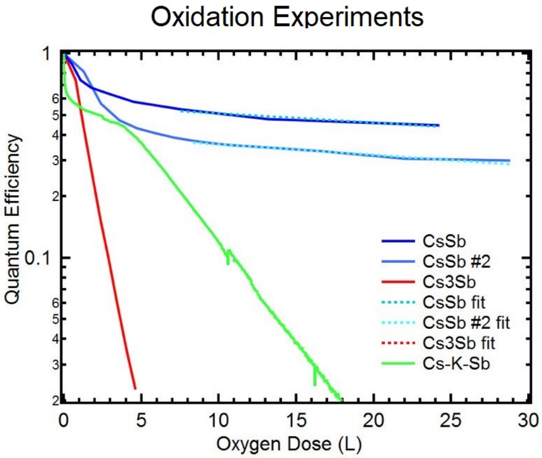

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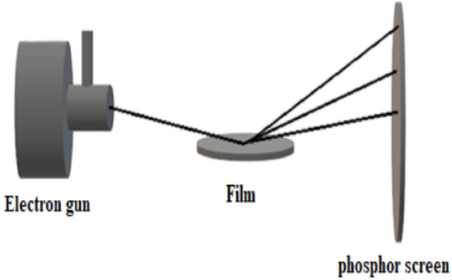
Reflection high energy electron diffraction

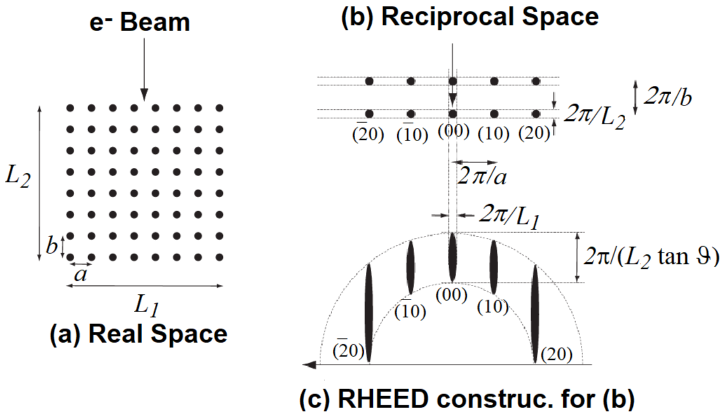
RHEED → Crystal Structure



Source	Electron Gun
Energy	1 keV<E<30 keV
Depth	surface
Angle	$< 5^\circ$

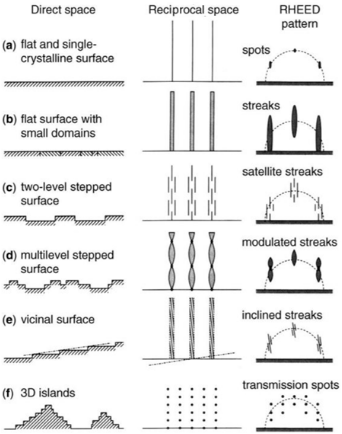
https://doi.org/10.1117/12.2585204

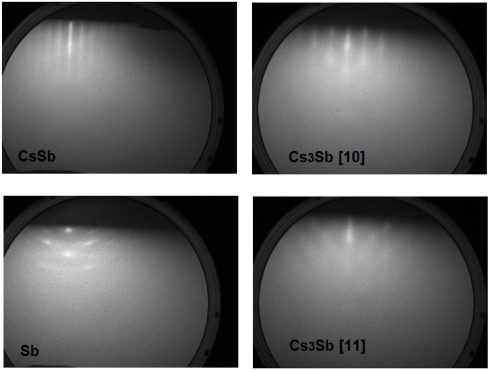
RHEED → Diffraction Patterns



Ichimiya & Cohen (2004) Reflection High-Energy Electron Diffraction
doi:10.1017/CBO9780511735097

RHEED → More Diffraction Patterns





https://phas.ubc.ca/~berciu/TEACHING/PHYS502/PROJECTS/RHEED.pdf

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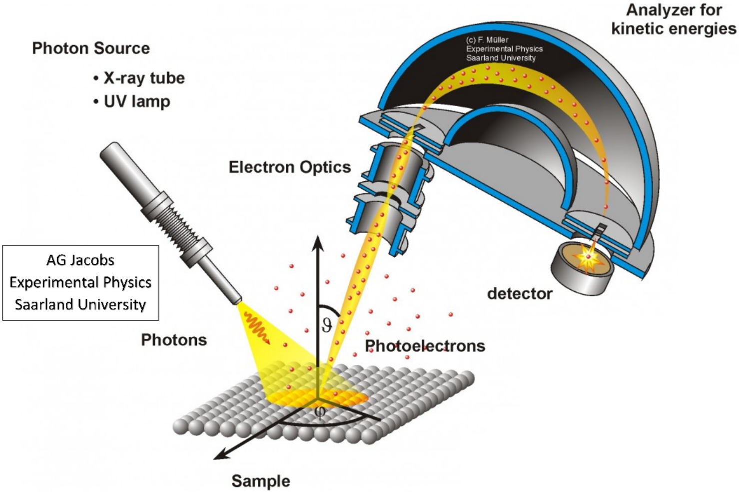
XPS → Elemental composition/chemical state of elements



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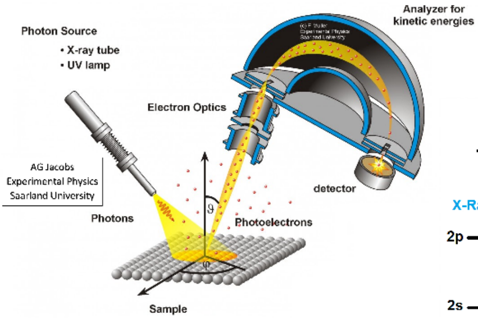
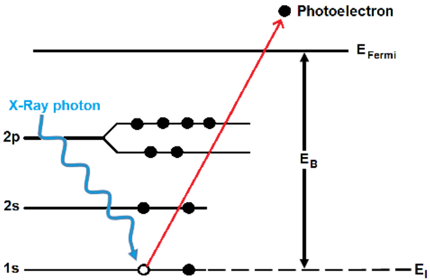
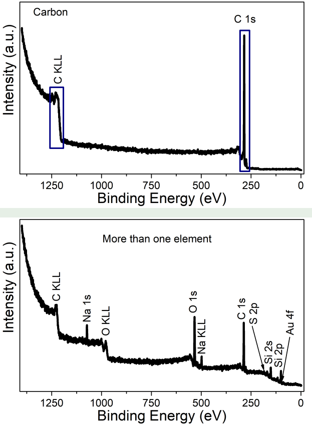




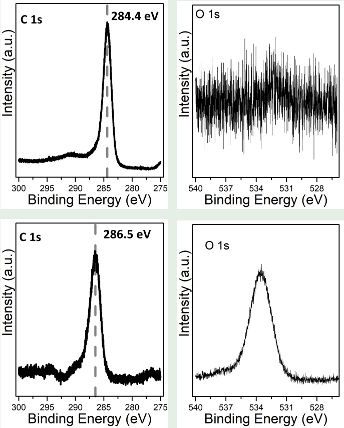
$$h\nu = E_B + \Phi_{sys} + KE$$

Two types of spectra are collected

Surveys or Wide Scans

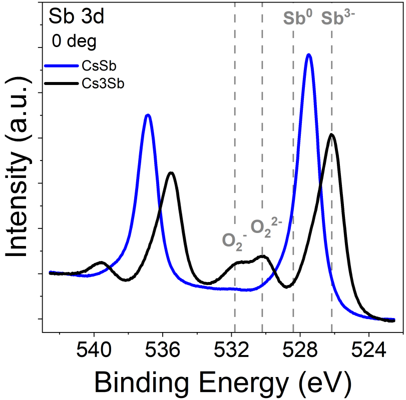


Zooms

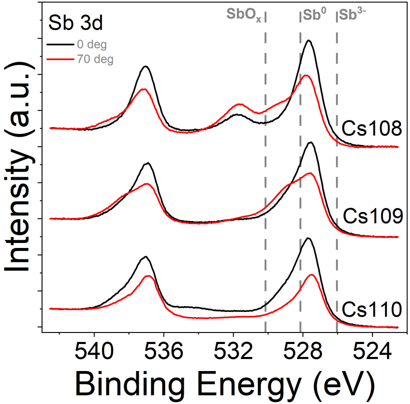


In the case of Cesium Antimonide

CsSb vs Cs_3Sb



"Bulk" vs Surface (Cs_xSb_y)



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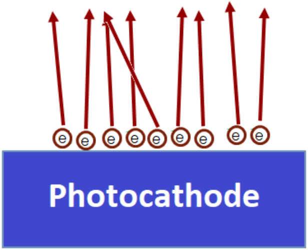
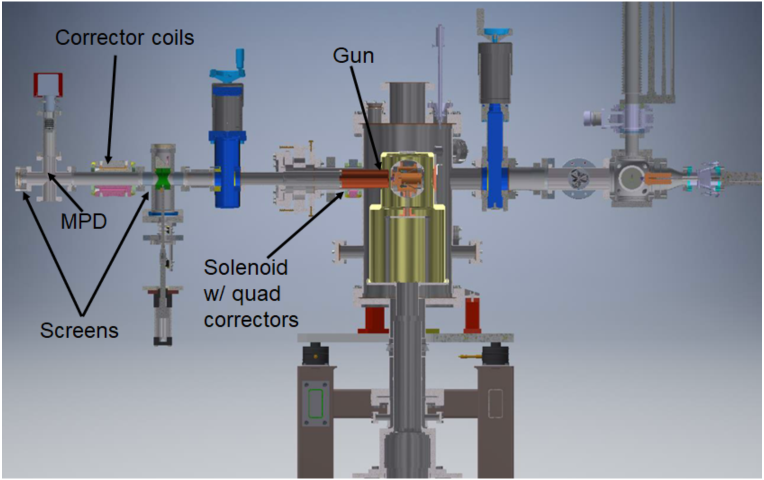
MTE (Mean Transverse Energy)

- Quantifies the angular spread of the electron beam coming off from the cathode
- Along with the spot size of the photoemitting laser, limits the beam brightness



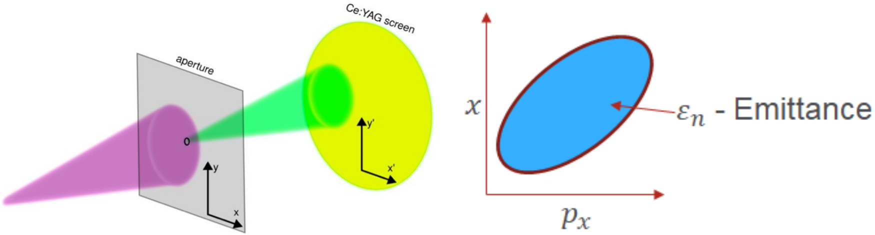
Low MTE

Beamline → MTE meter setup at Cornell



x-y components of the momentum

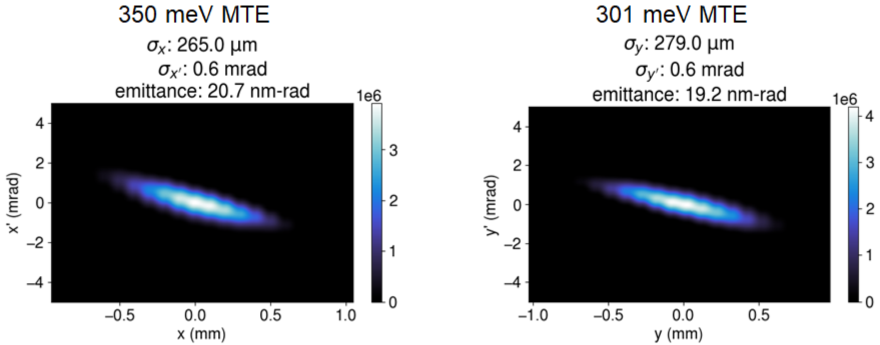
An aperture scan is used to record the beam image on a screen to subsequently recover the transverse phase space of the emitted beam



From here, the emittance is measured and therefore the MTE is calculated

$$\epsilon_n = \sigma_x \sqrt{\frac{MTE}{m_e c^2}}$$

Phase Space Images



Taken from William Li, Theme 1 meeting, April 4th 2022

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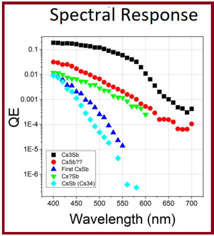
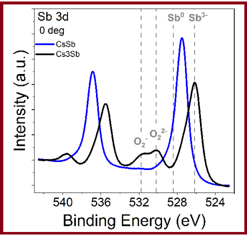
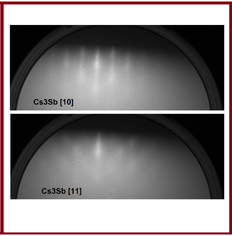
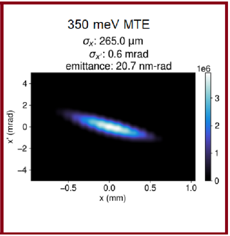

Spectral Response
QE
0.1
0.01
0.001
1E-4
1E-5
1E-6
400 450 500 550 600 650 700
Wavelength (nm)
Cs3Sb
CsSb??
First CsSb
Cs?Sb
CsSb (Cs34)


Sb 3d
0 deg
CsSb
Cs3Sb
Sb0 Sb3-
O2- O22-
Intensity (a.u.)
540 536 532 528 524
Binding Energy (eV)


Cs3Sb [10]
Cs3Sb [11]


350 meV MTE
σ_x: 265.0 µm
$\sigma_{x'}$: 0.6 mrad
emittance: 20.7 nm-rad
1e6
x' (mrad)
x (mm)
−0.5 0.0 0.5 1.0

Thanks! Questions?