Development of Bi-Alkali Antimonide Photocathode

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LAPPD Collaboration

LAPPD2 Theory-Based Photocathode Godparent Review April 6, 2013

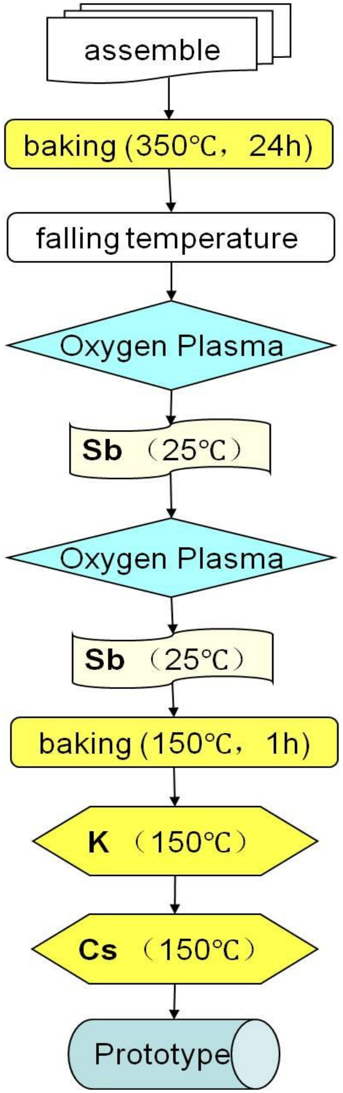
Outline

- **Part I: Application Study**
  - Growth of 1’’ PMT Photocathode Growth with Burle Equipment
  - Growth of Large Area (7’’) Photocathode with Glass Chalice
  - Growth of Photocathode in Single Tile Facility (3’’ & 8’’)
- **Part II: Theory Study**
  - XRR Study of Photocathode Growth
  - GISAXS Study of Photocathode Growth
- **Part III: Summary & Future Work**

Part I. Application Study

- Growth of 1’’ PMT Photocathode Growth with Burle Equipment
- Growth of Large Area (7’’) Photocathode with Glass Chalice
- Growth of Photocathode in Single Tile Facility (3’’ & 8’’)

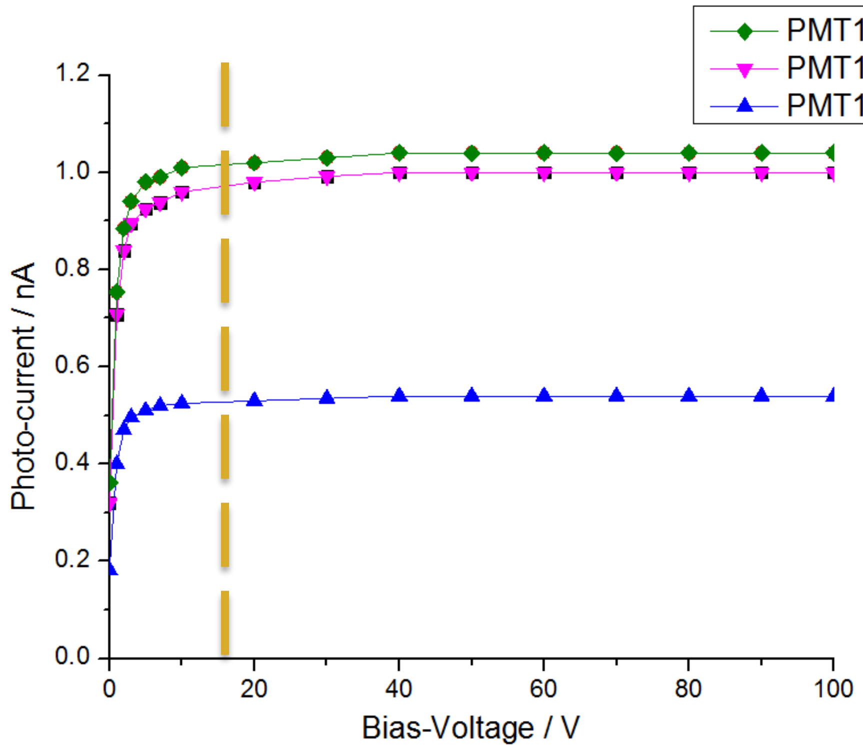
Bi-Alkali Photocathode Deposition Process



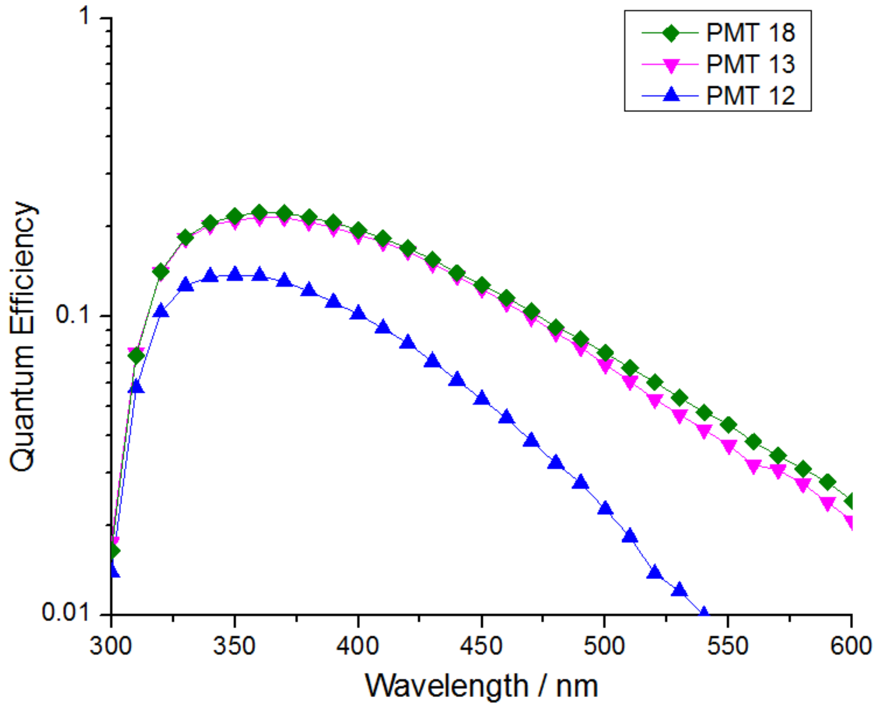
Learn how to deposit photocathode and apply these to the fabrication of large area photocathode.

Small PMT Photocathode Characterization

I-V Characteristic

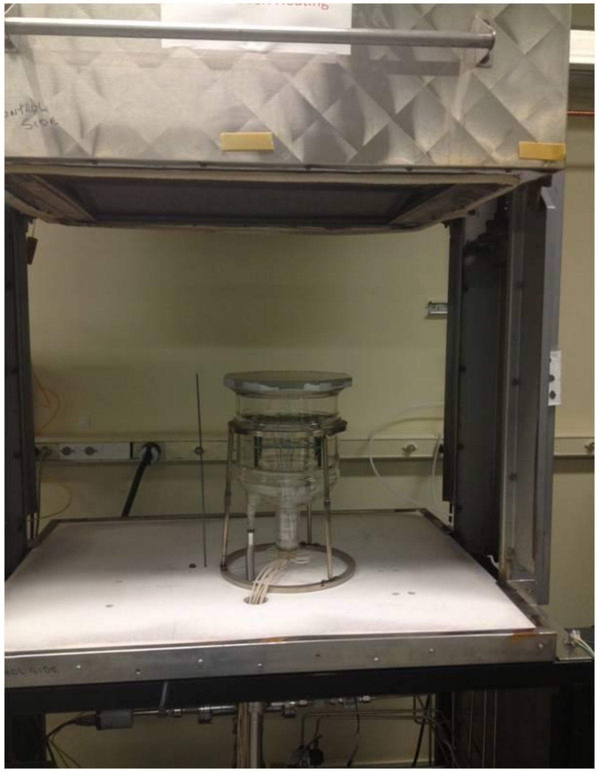


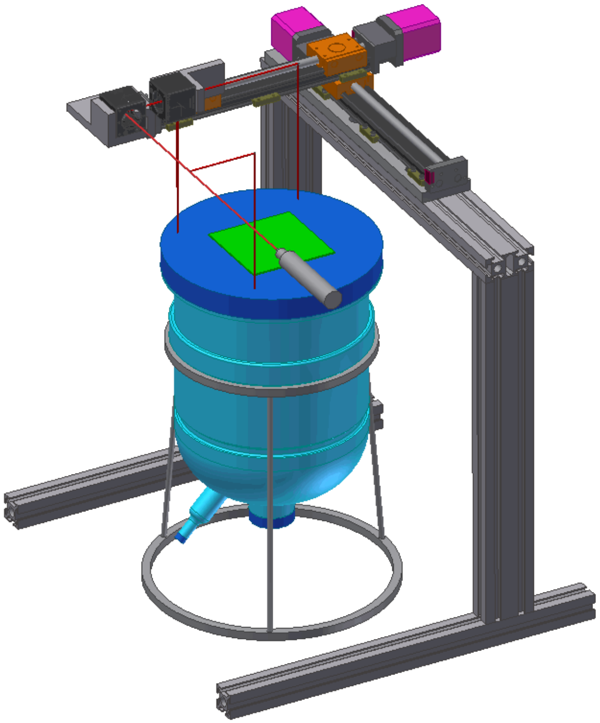
QE Measurement



- Cathodes exhibit characteristic I-V behavior, with QE as high as 24% at 370 nm.
- The quick drop at short wavelength is due to glass absorption.

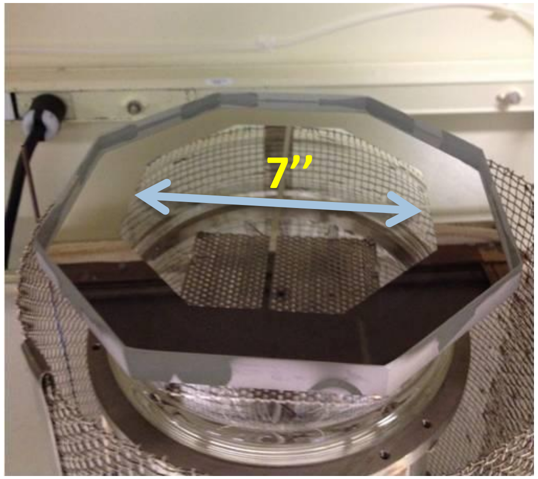
The Chalice Design

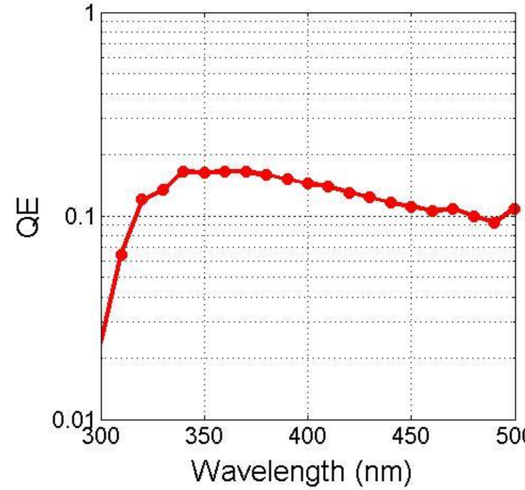




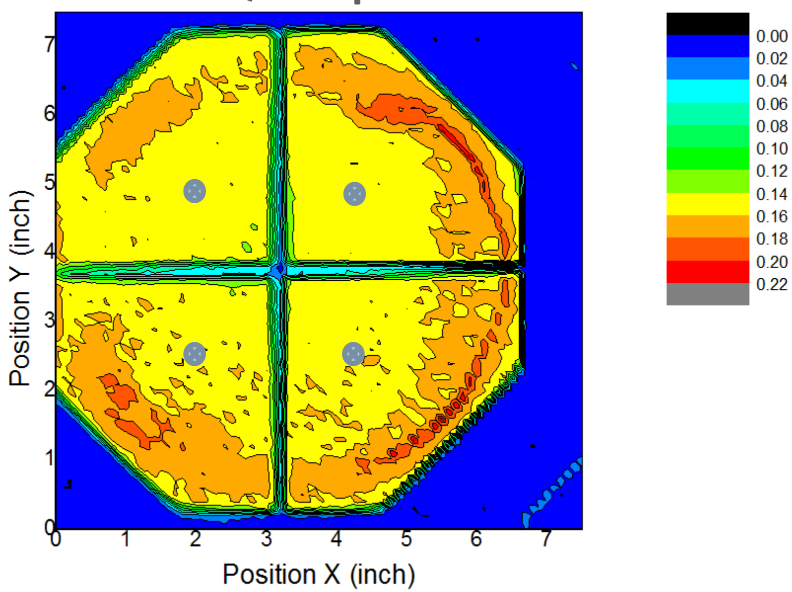
- Design is based on the small PMT tube, the chalice can be seen as a LARGE PMT tube.
- Top glass plate is replaceable for reuse.
- Chalice structure is supported by external legs.
- An X-Y scanner was designed and built for QE scan.

Chalice Photocathode Characterization (7'')

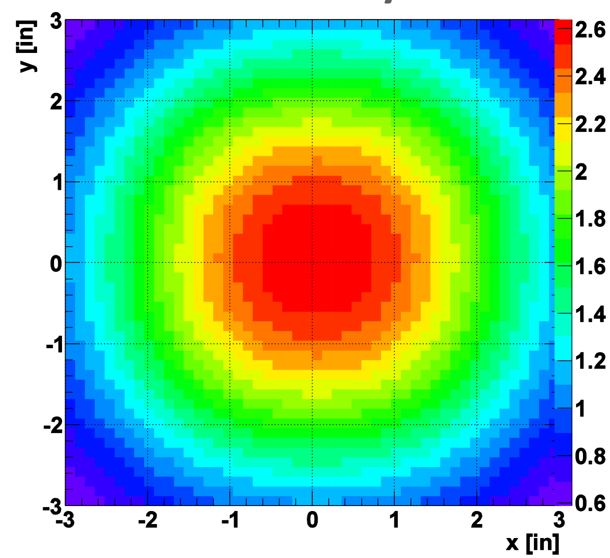




QE Map

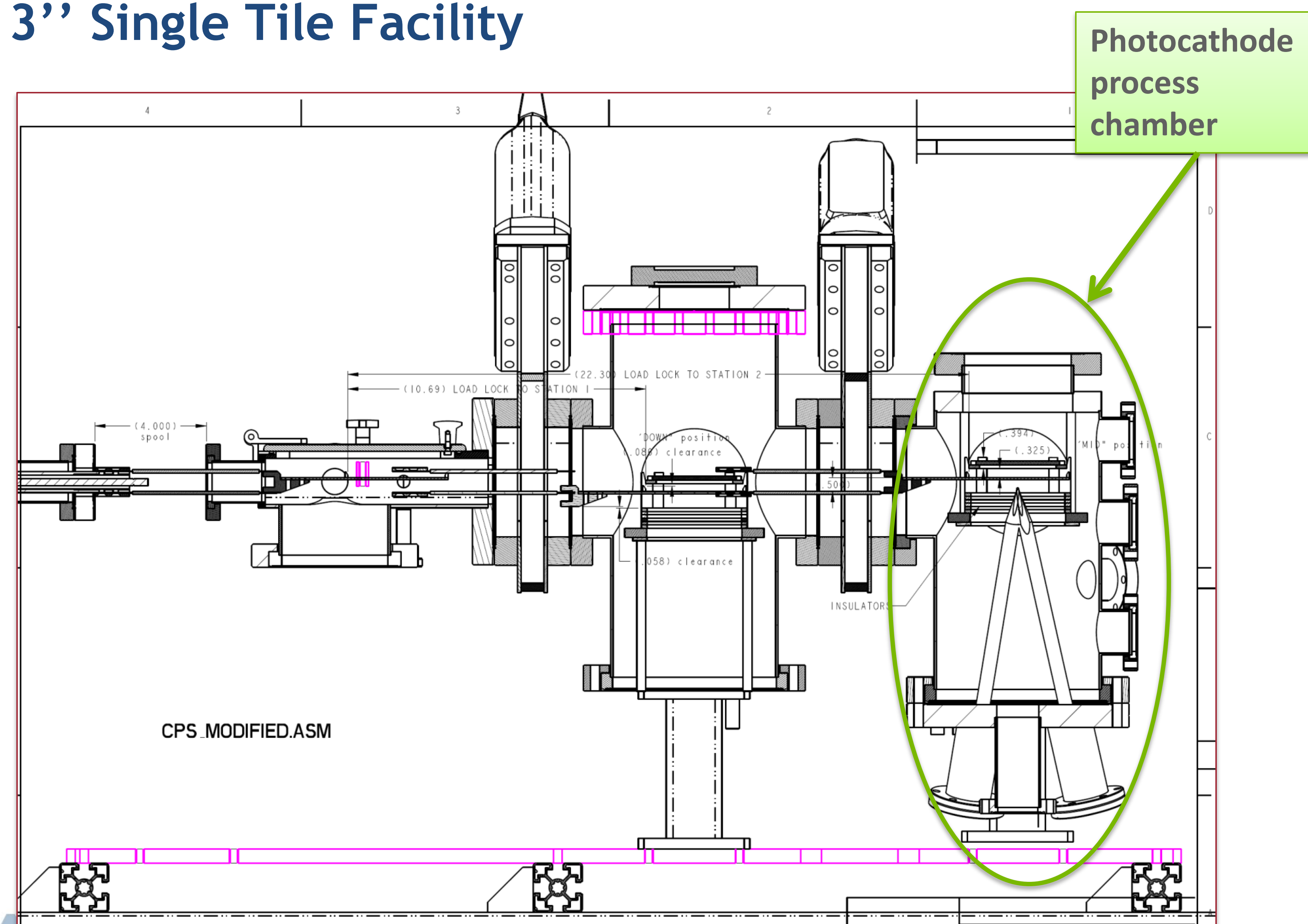


Simulation of Sb layer thickness



- Large area cathode with uniform QE distribution
- The highest QE spot reaches over 22%

3'' Single Tile Facility



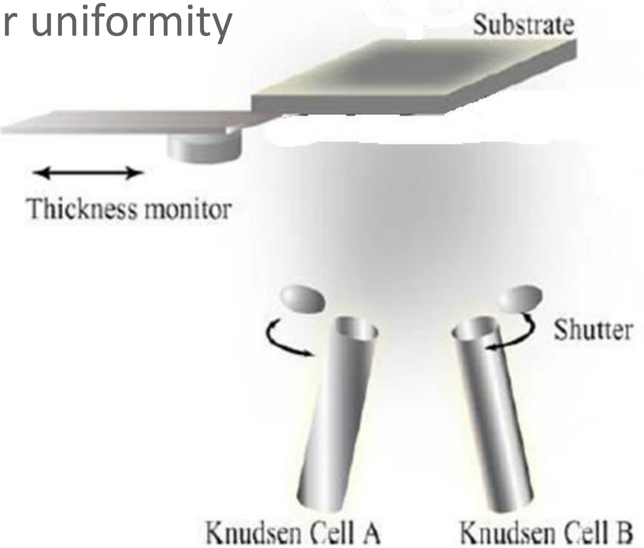
Photocathode Deposition in Tile Facility

- Effusion cells (Knudsen cells) will be used for Sb, K, Cs deposition.
  - Well developed, widely used in molecular beam epitaxy (MBE) technique
  - Pure elements will be used, better purity
  - Far away from substrate, better uniformity

- The tile facility is an ultra high vacuum design with estimated base pressure at 10^{-10} torr
  - Lower base pressure, less contamination, higher QE

- No rotor in 3'' deposition, substrate rotation mechanism will be integrated in the 8'' facility
  - 3'' substrate, OK with no rotation mechanism
  - 8'' substrate, integrated rotation mechanism for better uniformity

PMT Assemble	Base Pressure	QE
1'' Tube	2×10^{-8} Torr	24%
7'' Chalice	8×10^{-8} Torr	18%
3'' & 8'' Single Tile	Estimated 10^{-10} Torr	Expect over25%



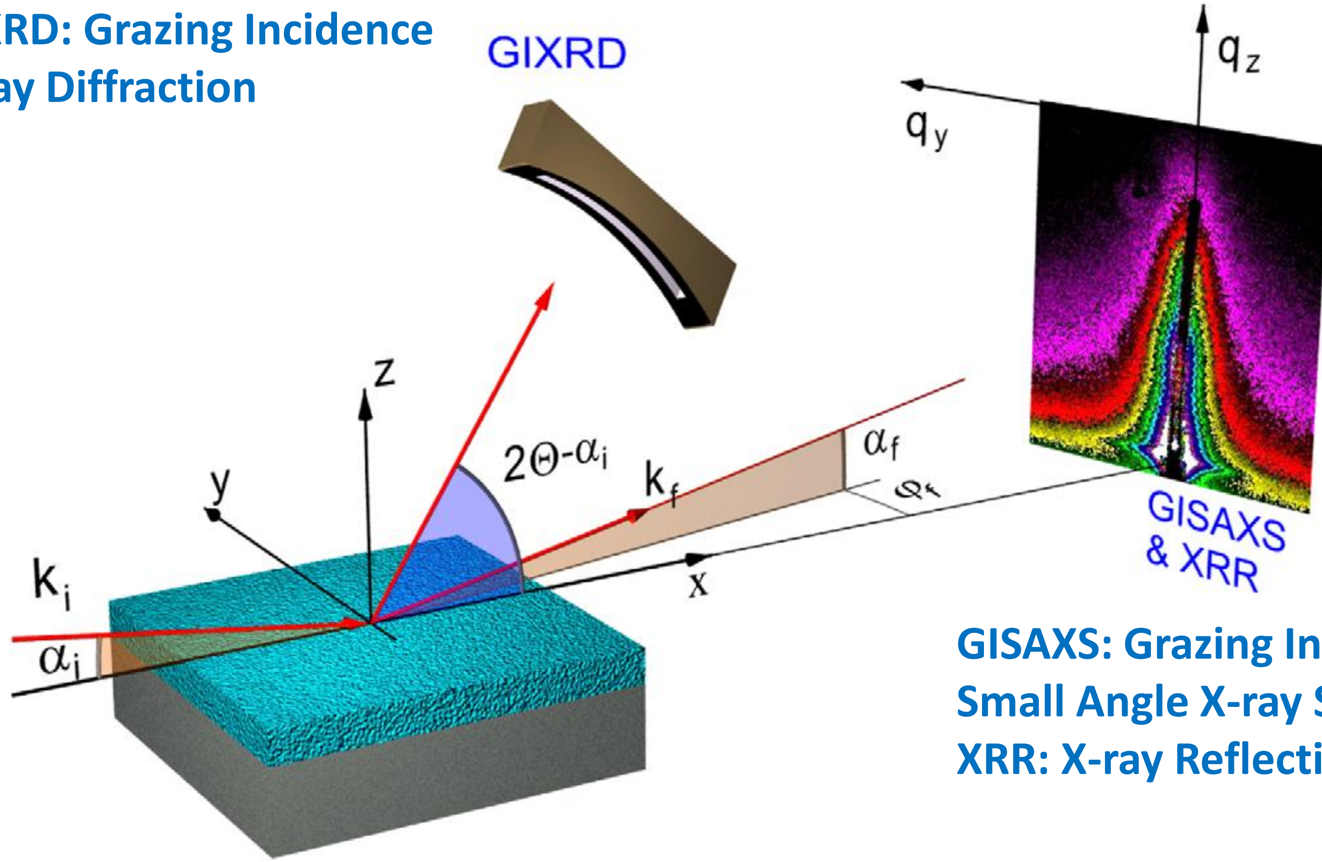
Part II. Theory Study

- XRR Study of Photocathode Growth
- GISAXS Study of Photocathode Growth

X-ray Techniques used for Bi-alkali Photocathode Study

Experiment performed at: NSLS X21 (BNL) & CHESS G3 (Cornell)

GIXRD: Grazing Incidence X-ray Diffraction



GISAXS: Grazing Incidence Small Angle X-ray Scattering
XRR: X-ray Reflectivity

In XRR scan, incidence angle (α_i) = exit angle (α_f), scan range: 0 - 4^o
In GISAXS and GIXRD, α_i =1.8^o, fringes due to x-ray scattering was recorded.

CHESS Cathode Growth Process (Yo-Yo)

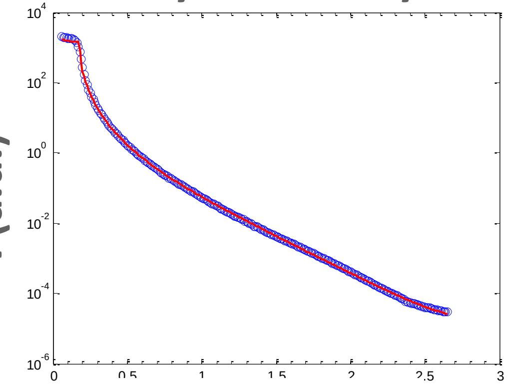
Sb, K, Cs deposited at 150 °C	Sb deposited at Room Temperature, K & Cs at 150 °C	
Cathode 1	**Cathode 2**	**Cathode 3**
* All thicknesses are from QCM estimation, the K, Cs deposition thicknesses are determined by QE	Cs (26 nm) (150 °C)	Cs (26 nm) (150 °C)
	Sb (3 nm) (25 °C)	Sb (3 nm) (25 °C)
Cs (100 nm) (150 °C)	Cs (6 nm) (150 °C)	Cs (6 nm) (150 °C)
K (50 nm) (150 °C)	K (53 nm) (150 °C)	K (53 nm) (150 °C)
Sb (5 nm) (150 °C)	Sb (6 nm) (25 °C)	Sb (6 nm) (25 °C)
K (15 nm) (150 °C)	K (16 nm) (150 °C)	K (16 nm) (150 °C)
Sb (5 nm) (150 °C)	Sb (5 nm) (25 °C)	Sb (5 nm) (25 °C)
Silicon Substrate (p-type)	Silicon Substrate (p-type)	B33 Glass Substrate

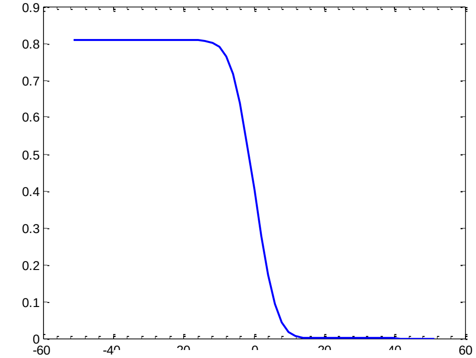
K-Sb deposition on B33 glass substrate

X-ray reflectivity

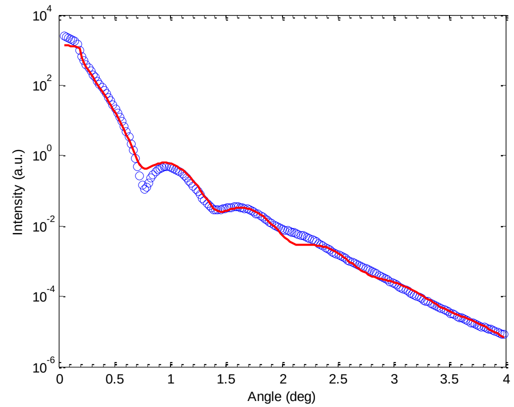
Electron density profile

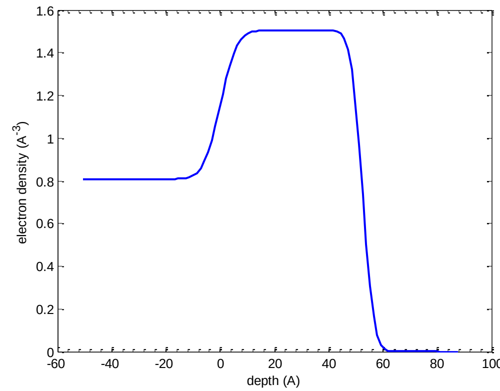
B33 glass substrate





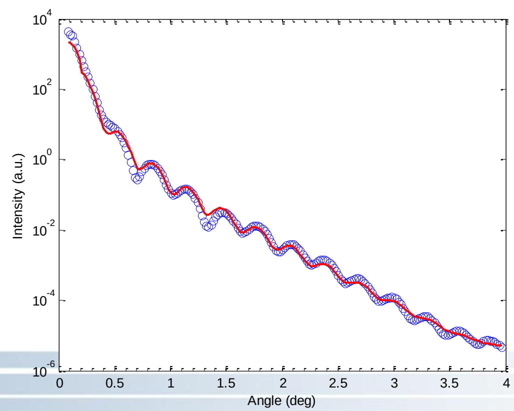
5nm Sb/glass

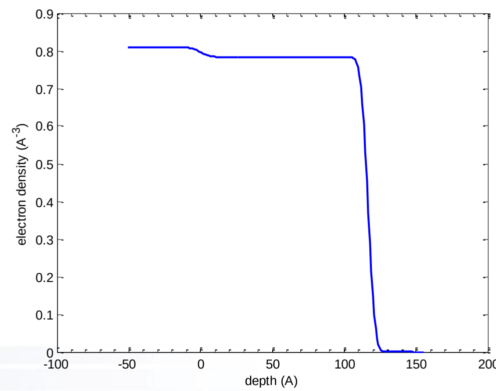




16nm K on Sb/glass

K-Sb/glass



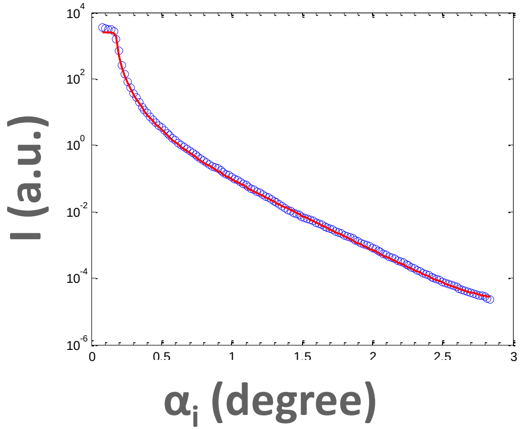


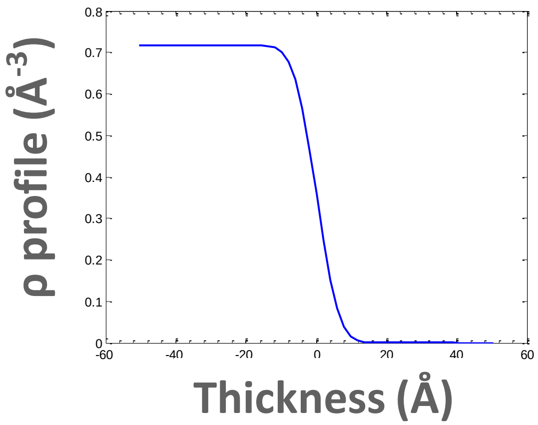
Uniform K_xSb compound on glass

K-Sb deposition on Si substrate

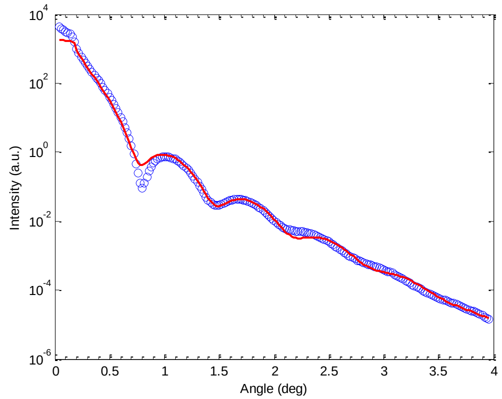
X-ray reflectivity | Electron density profile

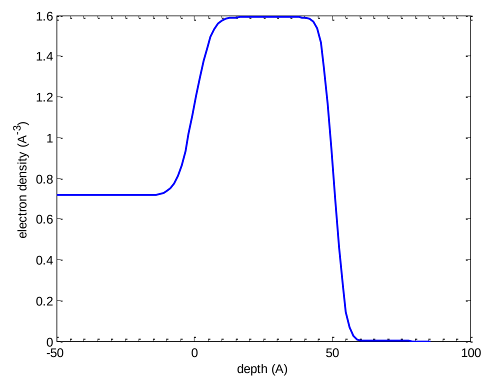
Si (100) substrate



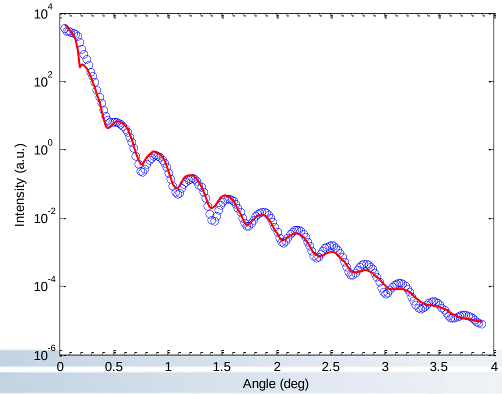


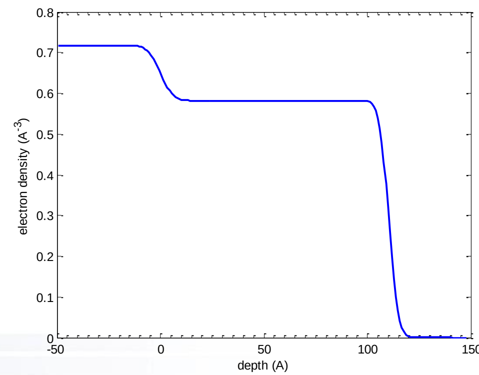
5nm Sb/Si





16nm K on Sb/Si
K-Sb/Si





Uniform K_xSb compound on Si

XRR Preliminary Summary (continue updating)

	Glass		Silicon	
	Thickness (Å)	Roughness (Å)	Thickness (Å)	Roughness (Å)
Substrate	-	4.94±0.02	-	4.84±0.02
Sb on Substrate	52. 39±0.28	3.40±0.03	50.53±0.21	3.37±0.03
K-Sb on Substrate	116.55±0.56	3.80±0.03	110.41±0.41	3.67±0.04

- Similar thickness and roughness indicates the growth of bi-alkali (until step K-Sb/substrate) photocathode on glass and Si follow the same growth mechanism.

- Uniform electron density profile indicates the formation of pure alkali antimonide (K_xSb) compound.

NSLS Cathode Growth Process

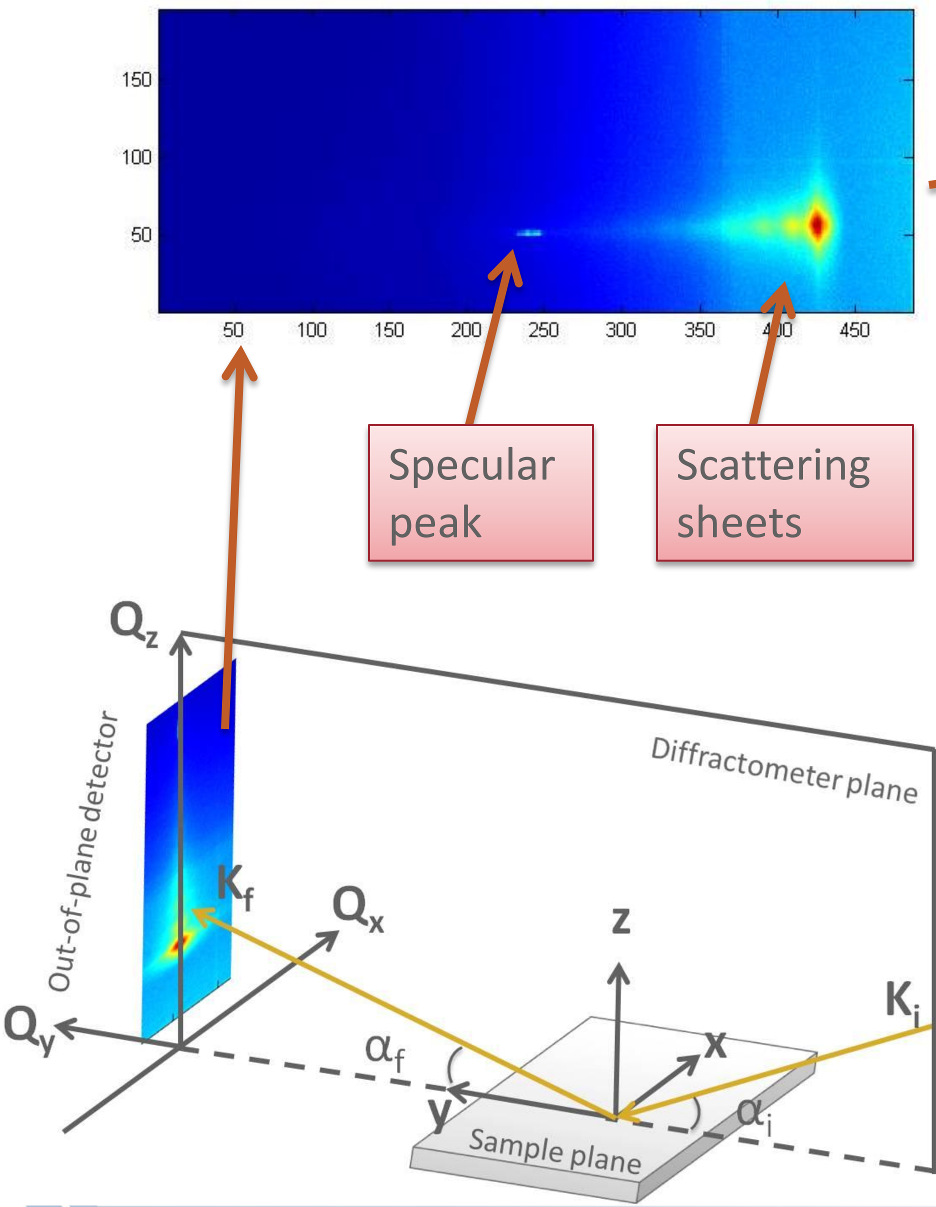
* All thicknesses are from QCM estimation, the K, Cs deposition thicknesses are determined by QE

Sb, K, Cs deposited at 150 ºC

Bialkali Cathode

Cs (78 nm) (150 ºC)	Weak GISAXS Fringes
K (88 nm) (150 ºC)	Weak GISAXS Fringes
Sb (23 nm) (150 ºC)	Detectable GISAXS Fringes
Silicon Substrate (p-type)	

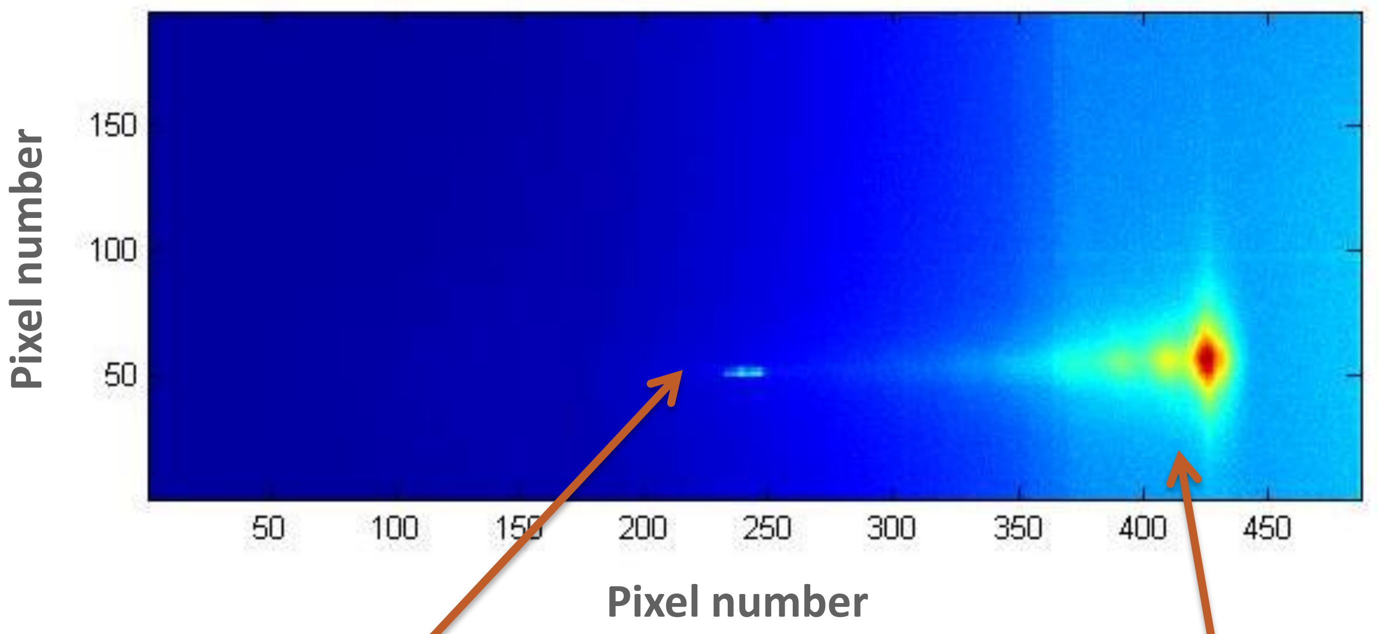
Schematic of GISAXS Experiment Geometry



Pilatus 100K Detector System	
Pixel size	172 x 172 μm^2
Format	487 x 195 = 94 965 pixels
Active area	83.8 x 33.5 mm^2
Counting rate	> $2x10^6$ counts/s/pixel
Energy range	3 – 30 keV
Readout time	< 2.7 ms
Framing rate	> 200 Hz

K_i is the direction of incident X-ray, pointing to sample.
The recorded image is the reflected beam intensity image

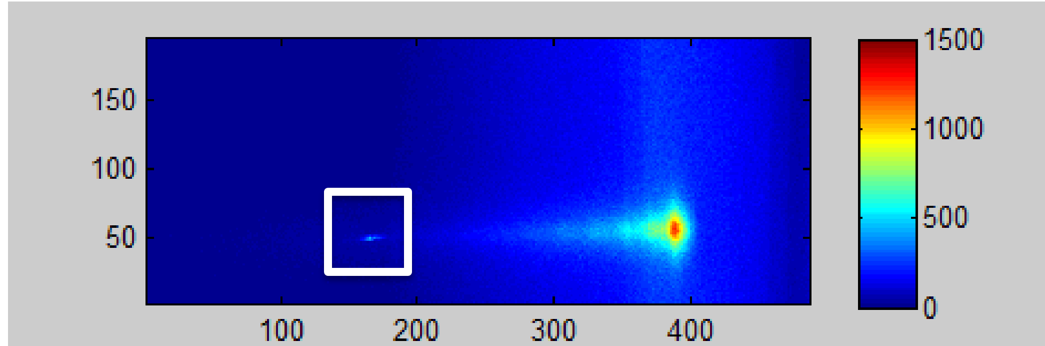
GISAXS Movie (see attachment)

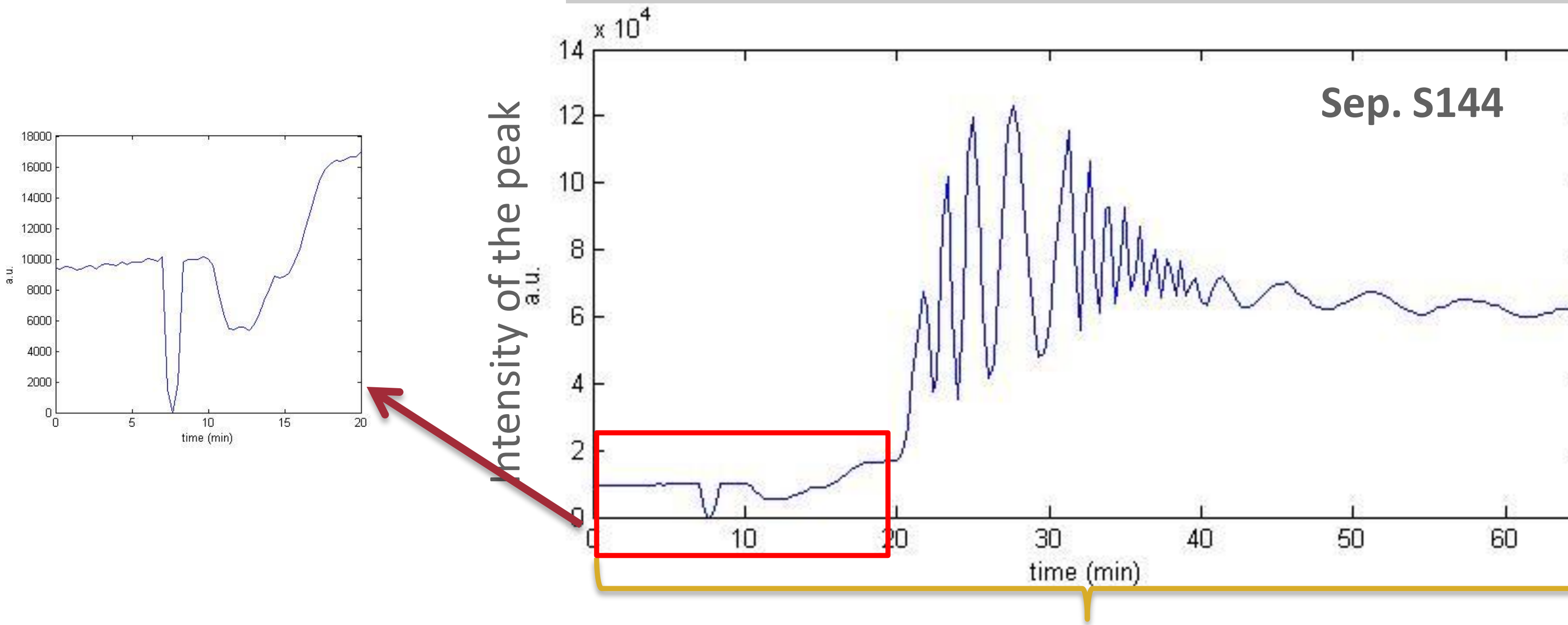


1. **Specular peak**
   Notice the blink as movie goes

2. **Scattering sheets**
   Notice the number of the fringes increases as movie goes.

Monitor Oscillation of Specular Reflection Peak during Sb Growth





Sb thickness: t = (# of intensity peaks* Sb film lattice) =21*1.1273 nm = 23.7 nm

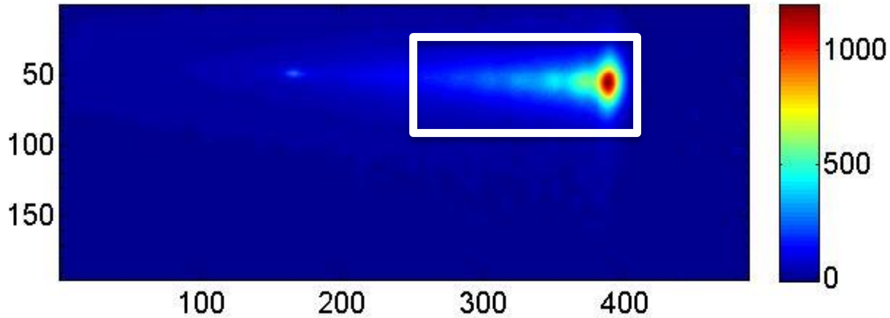
Specular peak oscillation is due to the relative surface coverage (0%-100%) of the growing thin film, similar to that of RHEED. By counting the oscillation, film thickness is calculated.

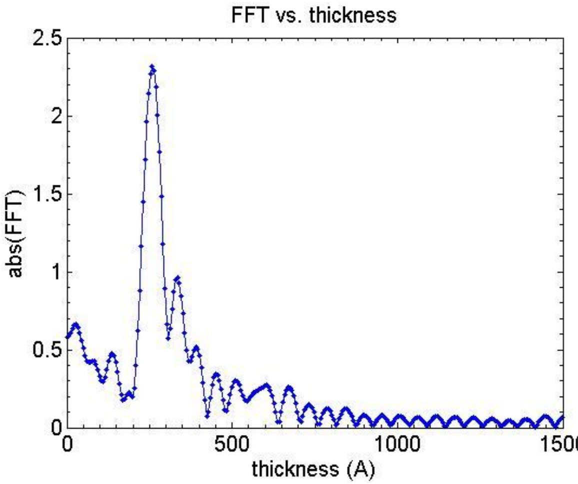
GISAXS Fringes Analysis

Thickness

One Frame

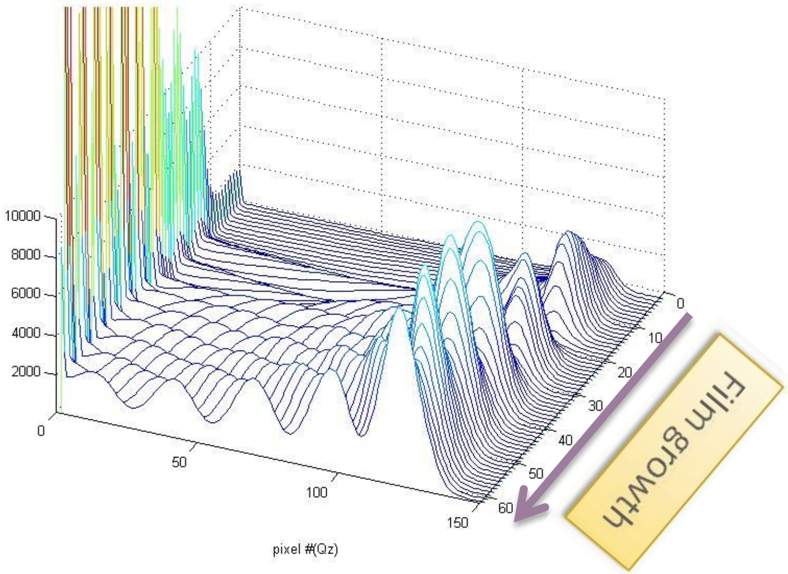
FFT

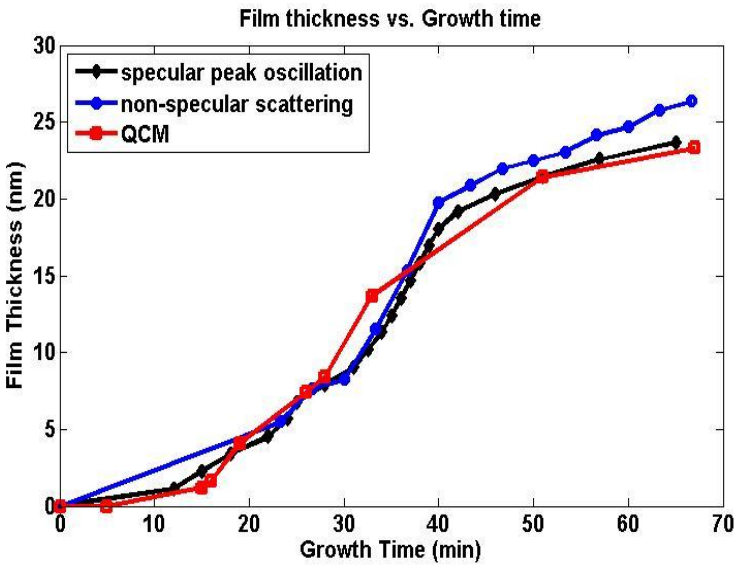




Whole Movie: All Frames

Thickness vs. Time





Three methods (Specular peak analysis, Scattering fringes analysis, QCM monitor) get the similar growth result for Sb deposition

Part III. Summary

1. High QE photocathode has been achieved in small PMT tube
2. Uniform photocathode at large area has been achieved in chalice
3. 3’’ and 8’’ single tile facility has been designed and under construction
4. XRR preliminary data indicates flat surface for thin layers and uniform electron density profile, possibly single compound formed
5. GISAX data shows the real time movie of Sb deposition

Future Work

1. Complete 3’’ and 8’’ single tile facility
2. Deposit bialkali photocathode in 3’’ & 8’’ single tile facility for assembled LAPPD photodetector, which can be really provided for detector testing
3. Finish XRR data analysis
4. Improve GISAXS data analysis method