Development of Bi-Alkali Antimonide Photocathode

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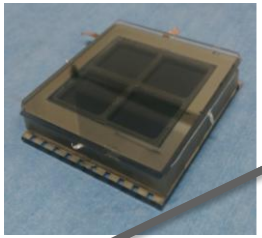
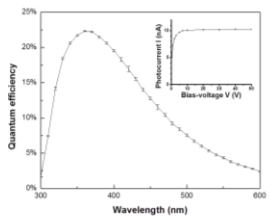
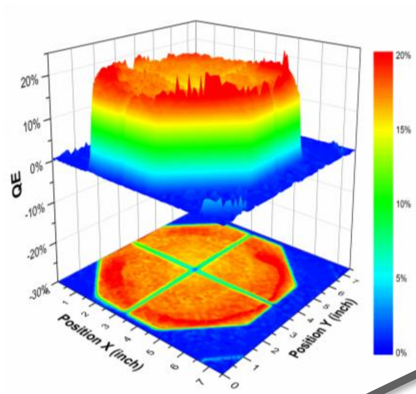
Argonne National Laboratory, Lemont, IL

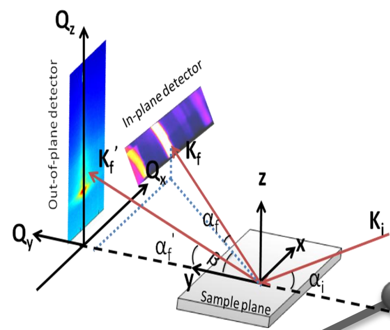
Micro-Channel Plate Based Detectors Workshop
Dec 2nd, 2014

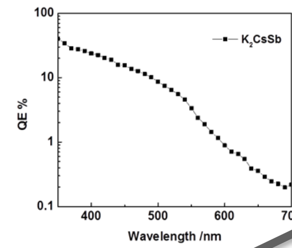
Photocathode work summary at ANL









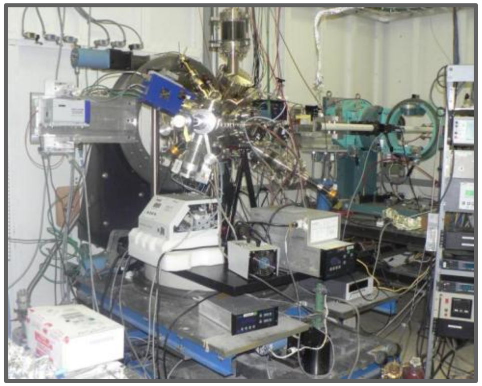


2014. 5

2014. 1

This talk

2013. 1



2012. 1

2011. 1

- ✓ Learn, apply & optimize the sequential process to the fabrication of large area photocathode
- ✓ Achieved QE as high as 24% at 380nm and 7’’X7’’ large area uniform photocathode
- ✓ Understand the photocathode growth process, achieve cathode QE over 30%, transferring to ANL sSTF

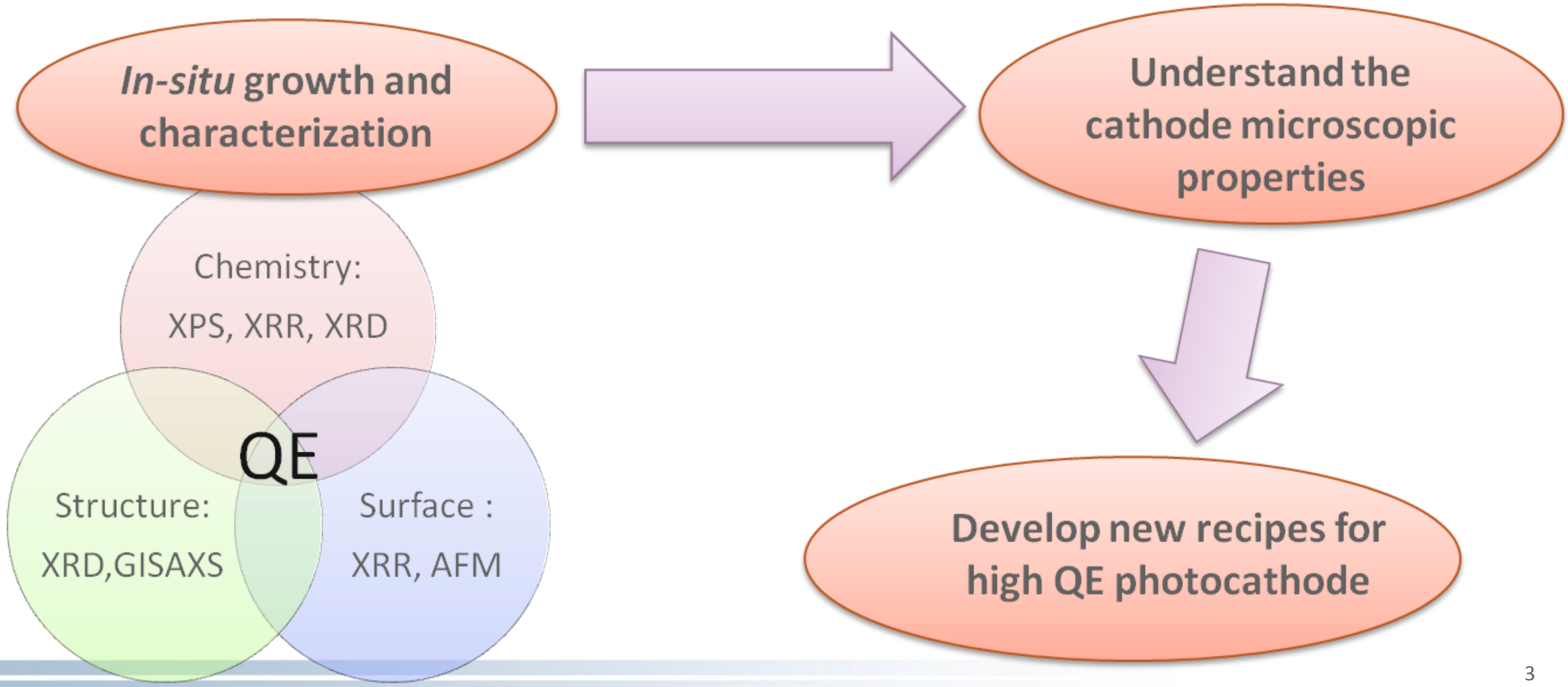
Strategy for high QE photocathode

Alkali antimonide photocathodes are extremely sensitive to air and water, analysis of these materials is very difficult.

OLD TIMES

Experienced workers paying considerable attention to macroscopic properties, Based on empirical experience, lacks of detailed understanding.

NEW STRATEGY



In-situ X-ray studies on photocathode

Sb + K → K_xSb + Cs → K_2CsSb

Perform synchrotron beamline experiment, obtain *in-situ* x-ray characterization data (NSLS, CHESS)

↓

Data analysis

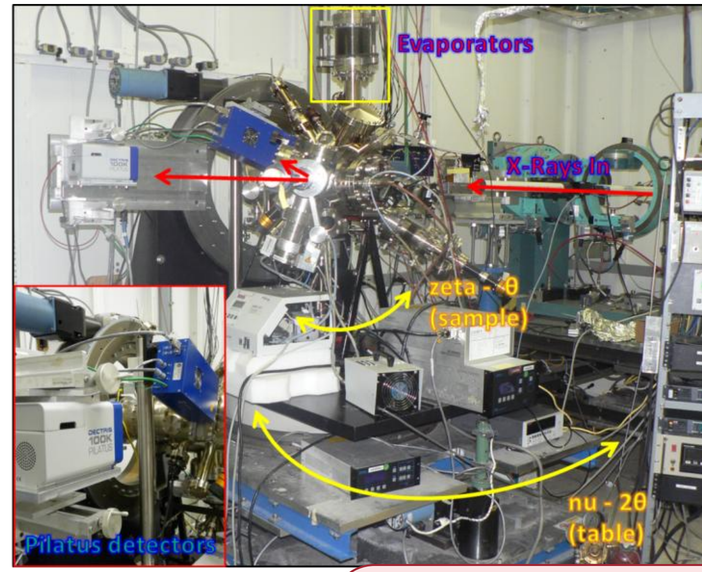
BNL, Stonybrook: XRD	ANL: XRR, GISAXS	LBNL: GISAXS

↓

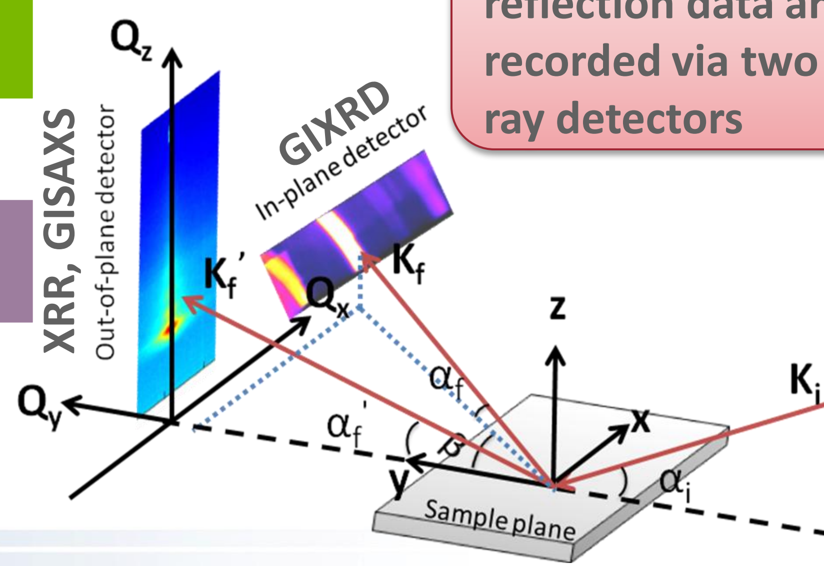
Correlate microscopic properties with macroscopic properties and develop new recipes

↓ ANL **Adapt new recipe to sSTF** → **Photodetector**

↓ BNL, LBNL **Accelerator**



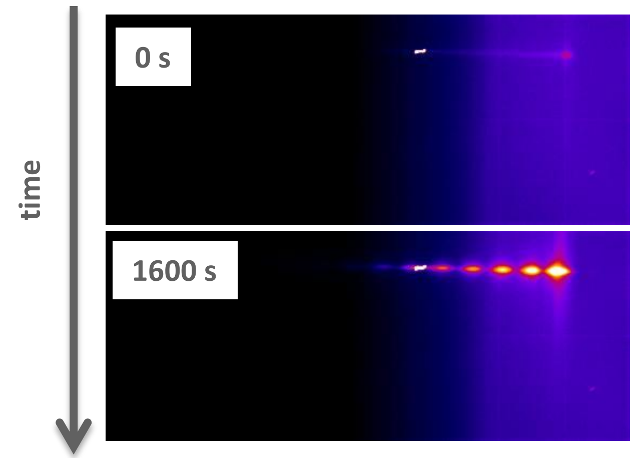
Scatter, diffraction, reflection data are recorded via two x-ray detectors

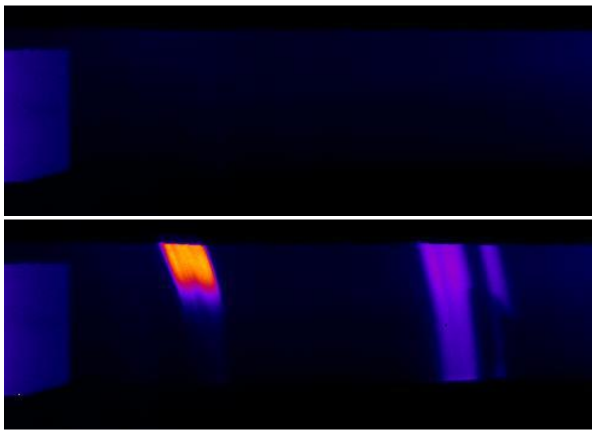


Monitoring of Sb film growth

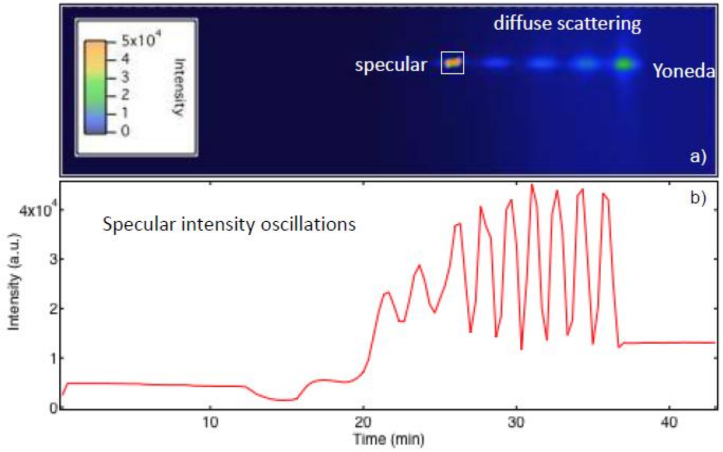
Out-of-plane detector
GISAXS (thickness & morphology)

In-plane detector
GIXRD (structure & composition)

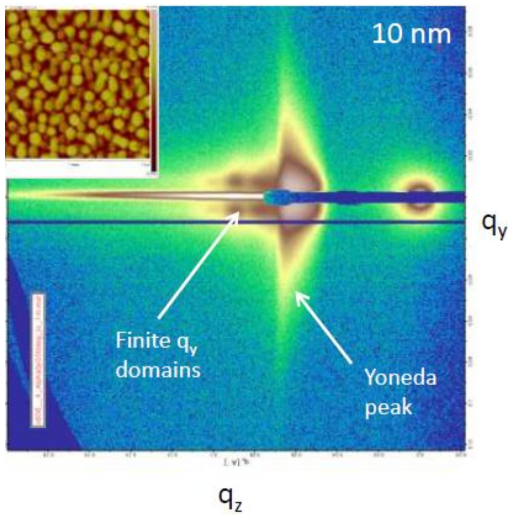




GISAXS images with periodic oscillation can be used to characterize thin film thickness and surface morphology



Incident angle = 1.8^0



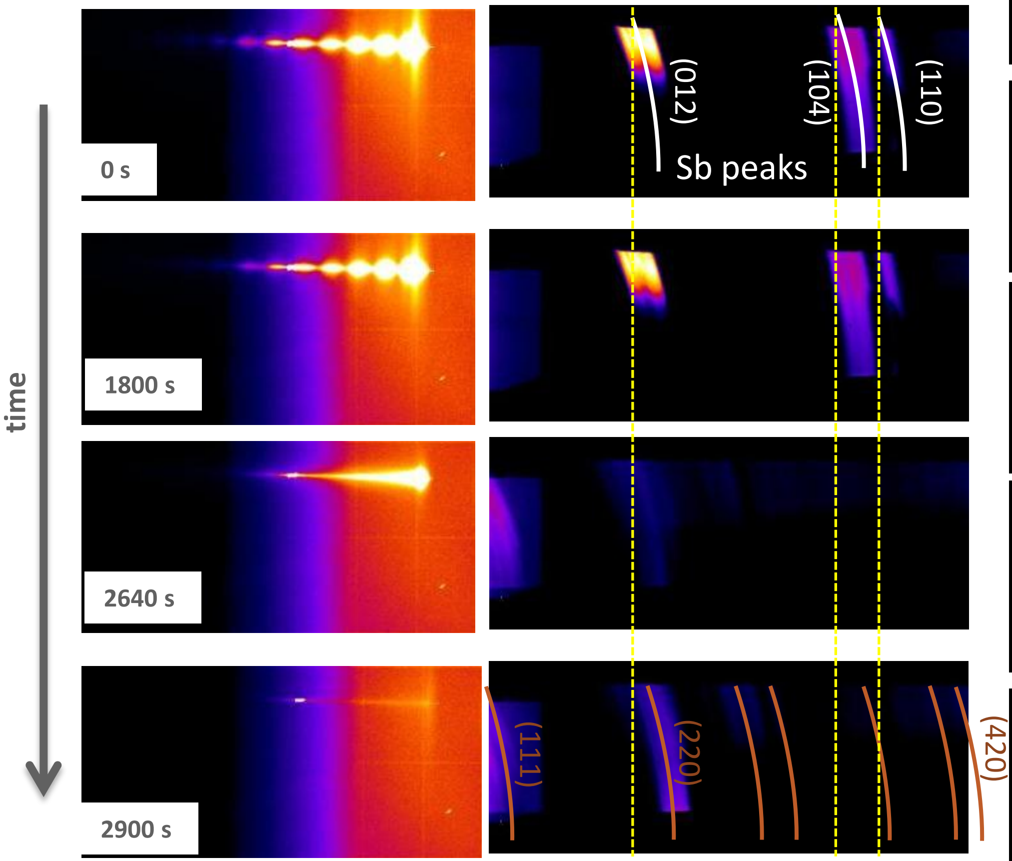
Incident angle= 0.3^0

Diffusion process of K and Cs

Diffusion of K

Out-of-plane detector
GISAXS

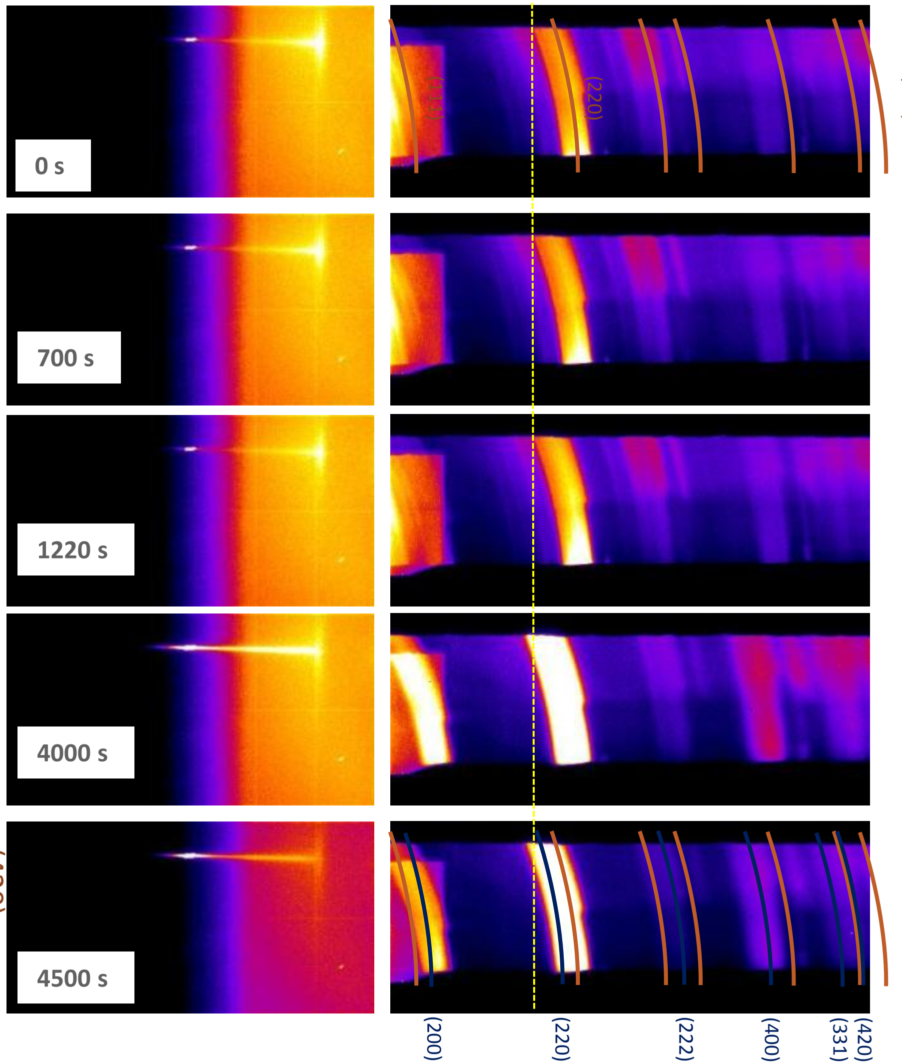
In-plane detector
GIXRD



Diffusion of Cs

Out-of-plane detector

In-plane detector

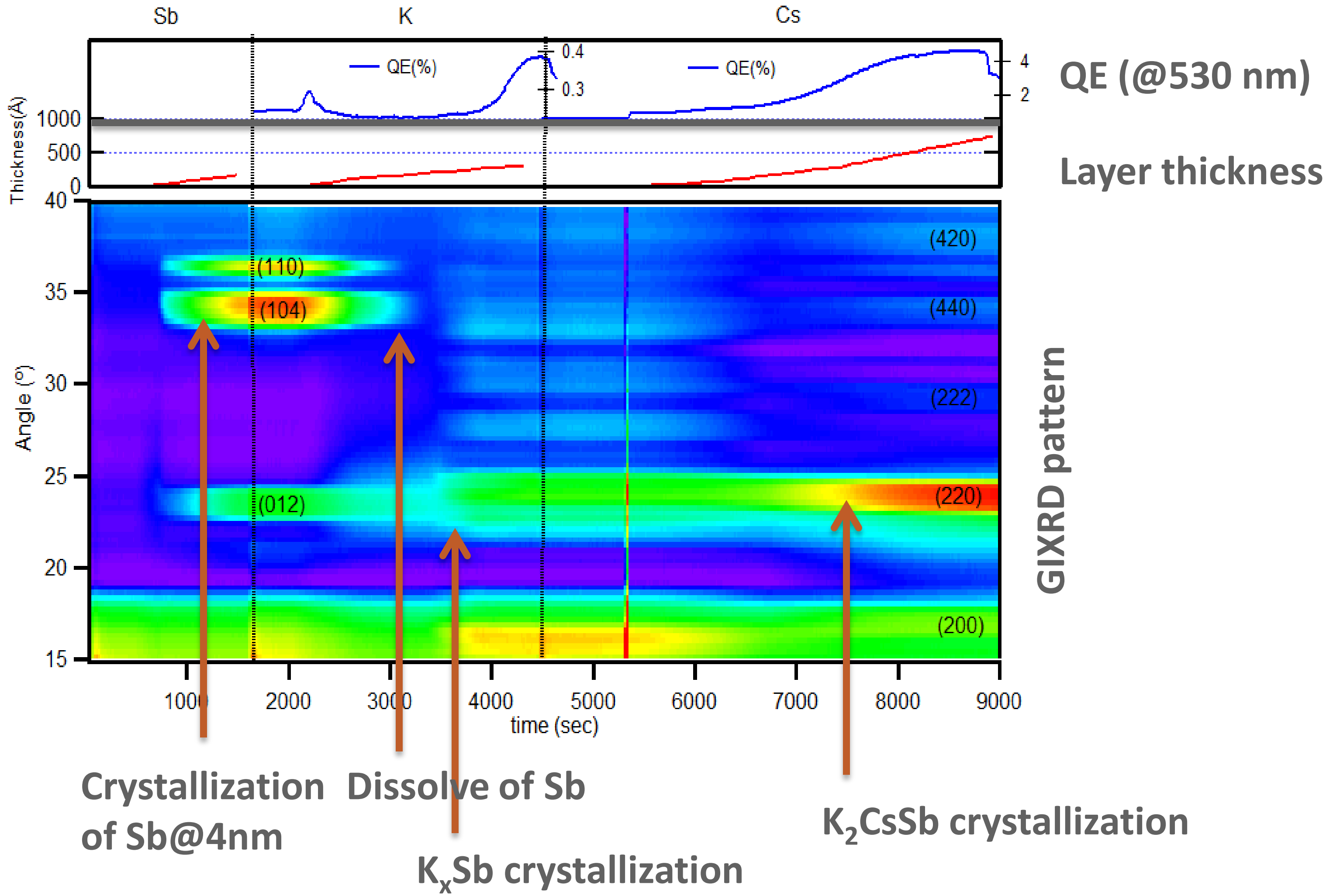


With the diffusion of K and Cs, GISAXS image fades out, indicating cathode surface getting rougher and rougher. XRD pattern indicates different compounds.

Monitoring of film structure during growth

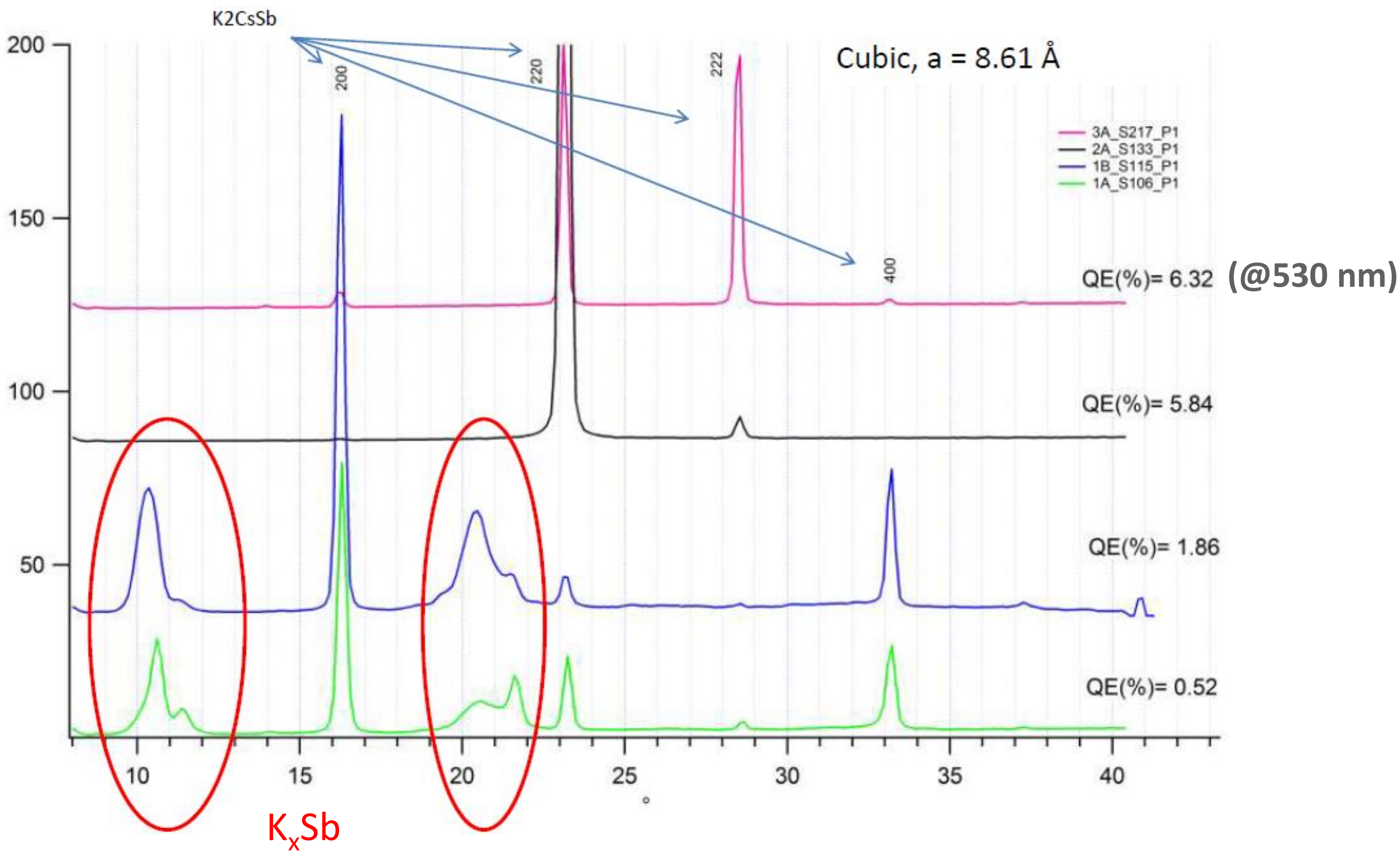
Sb + K → K_xSb + Cs → K_2CsSb

In-plane detector



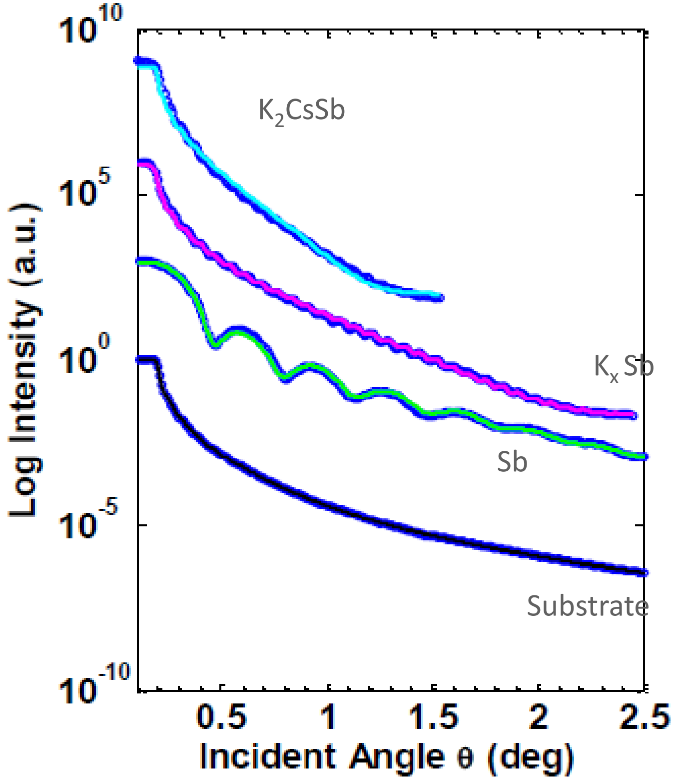
Sb film was completely dissolved into K, with continuing growth of K, polycrystalline K_xSb mixture was formed. With the diffusion of Cs, polycrystalline K_2CsSb starts to form.

Comparison of cathode XRD pattern with different QE

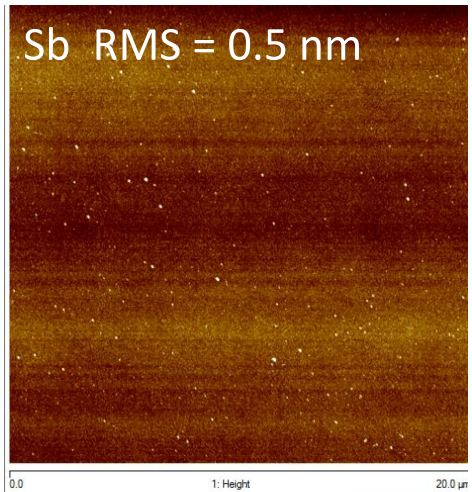


High QE cathode exhibits single K_2CsSb composition, shows cubic structure with preferred texture at (220)(222) directions.
Low QE cathodes exhibit mixture of different compositions.

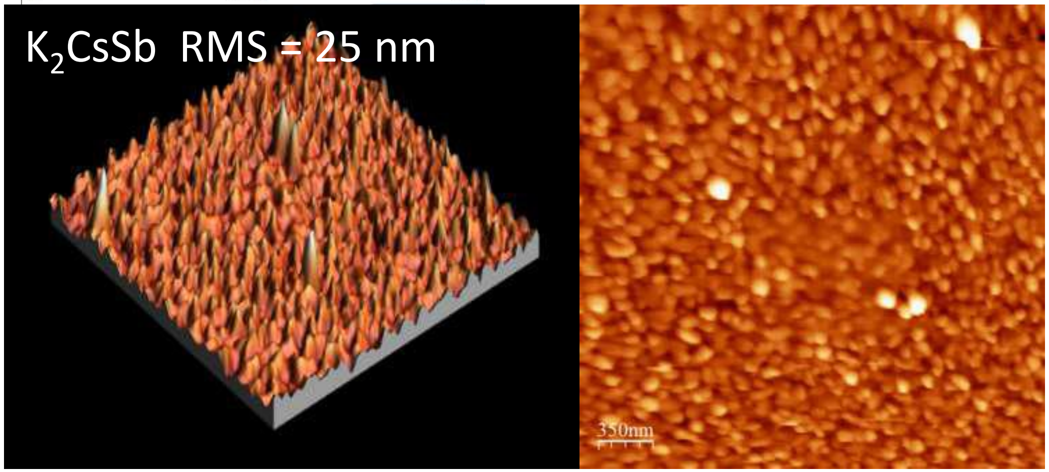
Evolution of film thickness and surface morphology



	Thickness (Å)	Roughness (Å)
K_2CsSb	530	11.5
K_xSb	468	6.3
Sb	100	3.4
Substrate	-	3.4



- Sb layer shows flat surface, the diffusion of K and Cs breaks the surface along lattice, increase surface roughness.



- The diffusion of K increases film thickness by a factor of 4.5, the diffusion of Cs does not increase film thickness a lot, indicating a replacement of K atom with Cs atom.

Growth recipe development

- Co-evaporation to achieve high QE photocathode

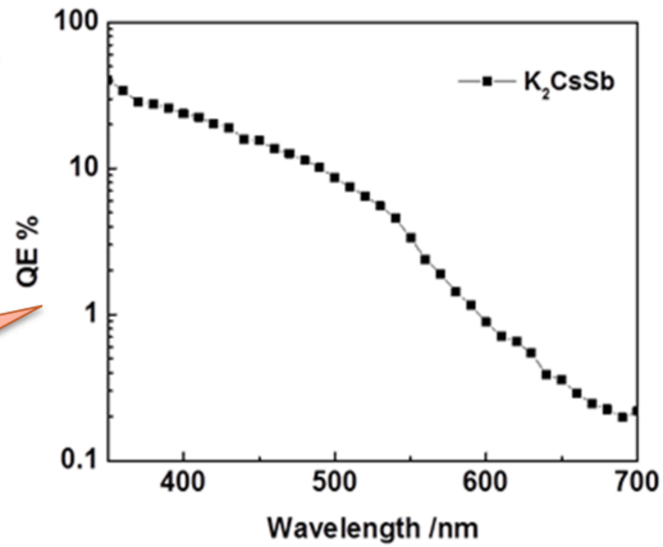
What gives a high QE photocathode?

- Right stoichiometry, slow growth rate
  -> better crystallinity, smoother surface
  -> reduce defect scattering & improve electron mean free path
  -> higher QE

K_2CsSb via new recipe

How to grow a high QE photocathode?

- Control the source deposition rate to the chemical stoichiometry to form single compound;
- Control the growth rate to be slow to form smooth crystalline film.

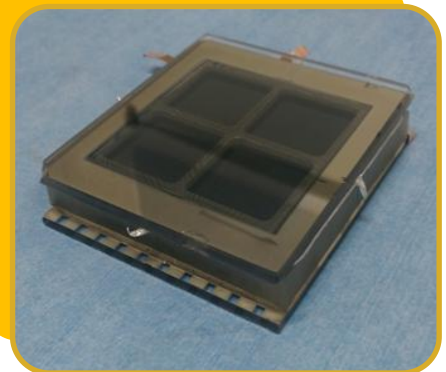


6 cm X 6 cm Photocathode overall goal

Product
- 6cm x 6 cm Picosecond photodetector

Requirement
- High performance

Final goals



- **Good uniformity**
  - **< ± 10% non-uniformity**
- **High QE**
  - **QE ~20 % before process optimization**
  - **QE > 30% after process optimization**

➢ *In-situ* X-ray studies reveal that achieving a **stoichiometric** photocathode with better **crystallinity** is the major point to achieve high QE.

➢ **Over 30% QE** photocathode was achieved recently via **co-evaporation** recipe.

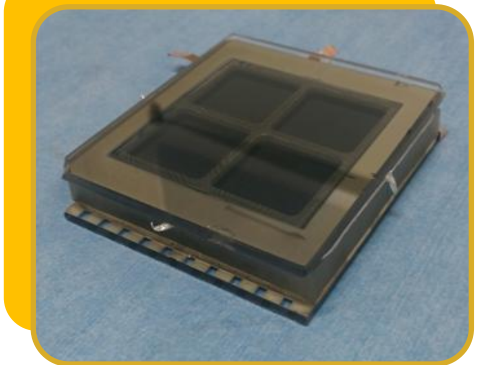
6 cm X 6 cm Photocathode strategy

Product
- 6cm x 6 cm Picosecond photodetector

Requirement
- High performance

Equipment
- Well developed thin film growth technique

Advantages
- Good uniformity
- Easy industrialization
- High QE



Good uniformity

High QE

Knudsen effusion cells

Uniformity
Far source to sample distance

Industrialization
Scalable large mass production

High QE
Feasible new recipe adaption

6cm x 6cm Small single tile facility

- Production line of photodetector

- An integrated facility dedicated for air sensitive photodetector production
- Transfer photocathode for flat panel MCP photodetector production

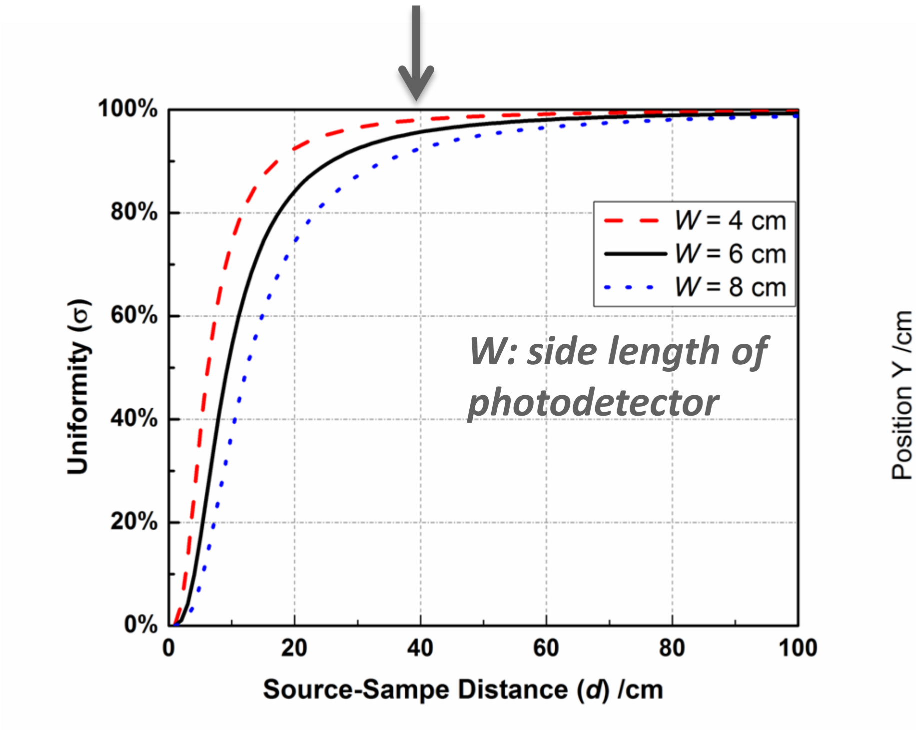
Current photocathode growth chamber status

- **Cathode growth:**
  - ✓ Chamber base pressure 10^{-10} Torr
  - ✓ Three full range temperature control effusion cells (room temperature to 900 ^{o}C)
- **Cathode growth monitoring:**
  - ✓ Quartz crystal microbalance (QCM
  - ✓ Transmission (400 nm)
  - ✓ Photocurrent response
- **Issues:**
  - X Plasma generator (under repair)
  - X MCP outgas and getter activation are done in photocathode growth chamber, may contaminate the chamber (Lei's talk)

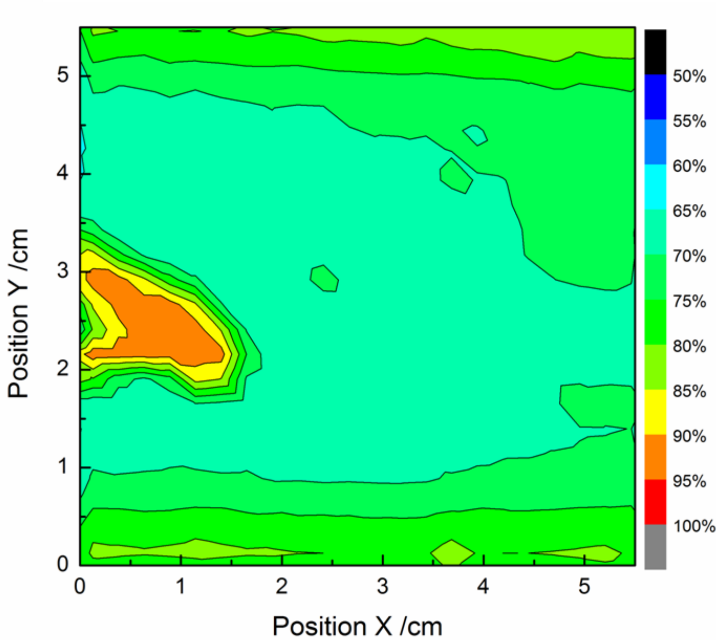
X **Other possible monitoring equipment?**

PMT Assemble	Base Pressure	QE
1" Tube	2×10^{-8} Torr	24%
7" Chalice	8×10^{-8} Torr	18%
6cm x 6cm Single Tile	5×10^{-10} Torr	Expect over 30% with new recipe

Photocathode growth chamber commissioning
- Sb film uniformity via effusion cells



Sb film uniformity simulation



Sb film transmission uniformity map

- ➢ Simulation indicates source-substrate distance needs to be at least 40 cm for ±5% non-uniformity over 6cm x 6cm substrate;
- ➢ Sb film transmission uniformity map confirms the uniformity as-expected

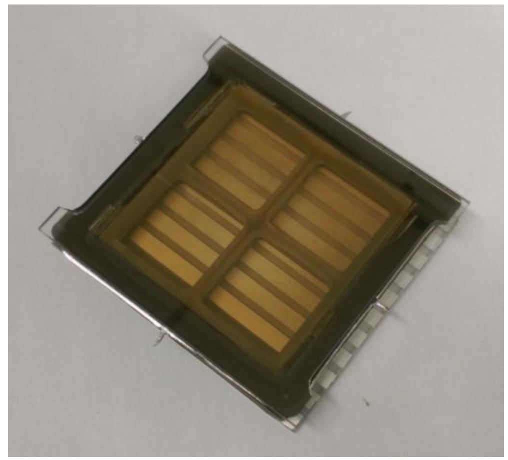
Bialkali Photocathode for LAPPD small Photodetector

Currently, sequential diffusion process is followed to grow cathode for easy process control.

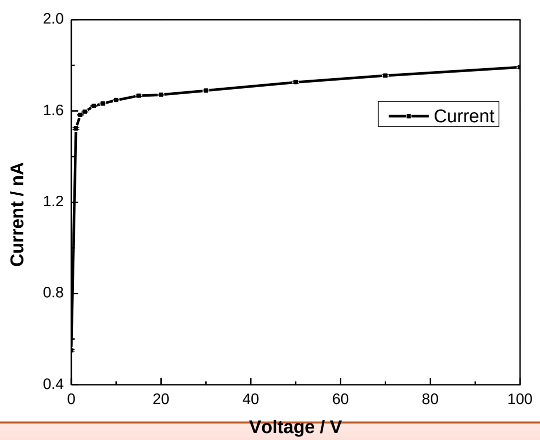
$Sb + K \rightarrow K_3Sb + Cs \rightarrow K_2CsSb$

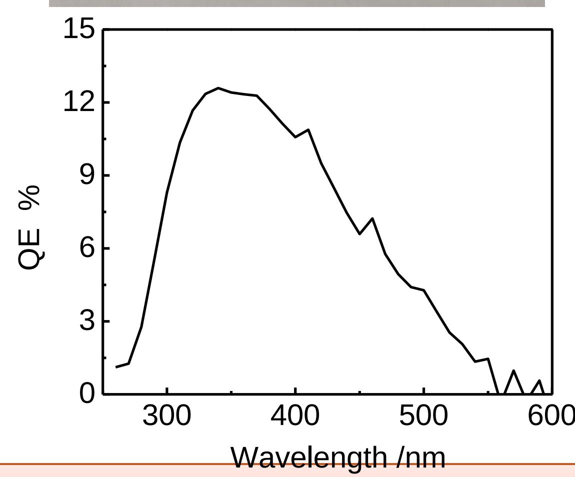
Photocathode only tile

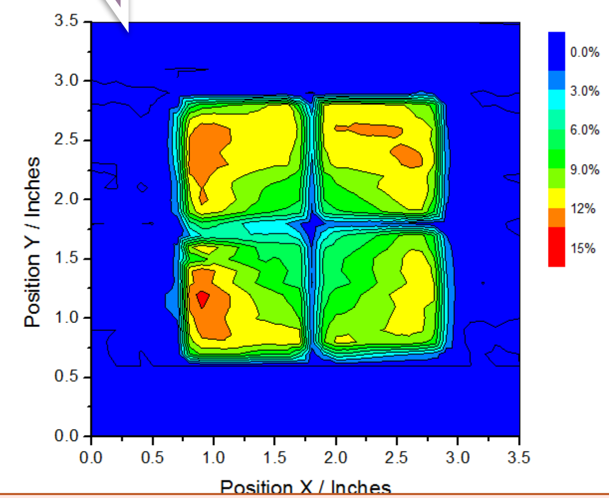
Evaluate photocathode grown via effusion cells



Calibrate in-situ QE monitoring system







- Initial photocathode growth shows 13% QE via effusion cell technique
- Non-uniformity is possibly due to halogen lamp heater temperature difference at center and edges

Summary

- **Previous photocathode work has been summarized.**
- **X-ray techniques including XRD, XRR and GISAXS were used to *in-situ* characterize the K-Cs-Sb bialkali photocathode growth process.**
- **High QE cathode exhibits cubic structure with preferred texture at (220)(222) directions.**
- **QE over 30% at 400 nm was achieved with new recipe.**
- **6cm x 6cm facility integrated with effusion cells was designed and built.**
- **Good film growth uniformity using effusion cell as expected.**
- **Initial photocathode growth shows QE ~13%, QE improvement is undergoing.**

Future works

- Demonstrate photocathode with uniform QE ~20% in the 6cm x 6cm facility.
- Transfer the developed new recipe to the 6cm x 6cm facility.
- Demonstrate prototype photodetector with over 30% QE photocathode.
- Other possible photocathode materials based on different applications.

Acknowledgement

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Thanks for your attention!