Photocathode Physics for Photoinjectors (P3) 2018:

Synthesis and x-ray characterization of Cesium Telluride photocathodes

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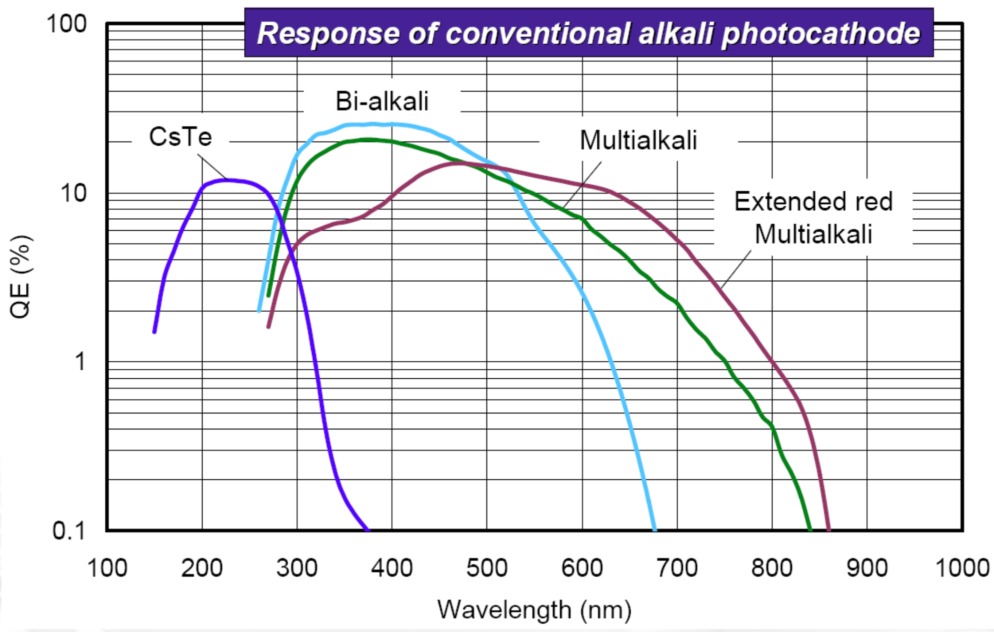
U.S. DEPARTMENT OF ENERGY

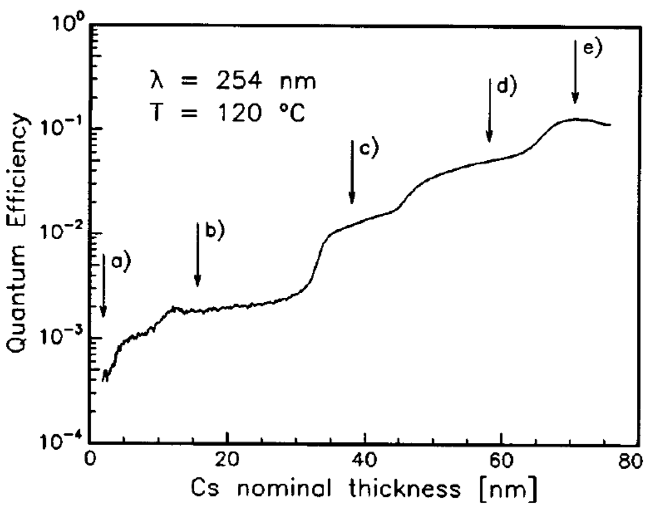
Introduction: CsTe photocathode as electron source

- Cesium telluride (CsTe) photocathodes has been the first hand choice for electron sources by worldwide accelerators, such as LCLSII, AWA, various FELs, etc...
- Perfect balance between lifetime and quantum efficiency
- Less requirement of vacuum level than GaAs and multialkali photocathodes, robust in high gradient environment

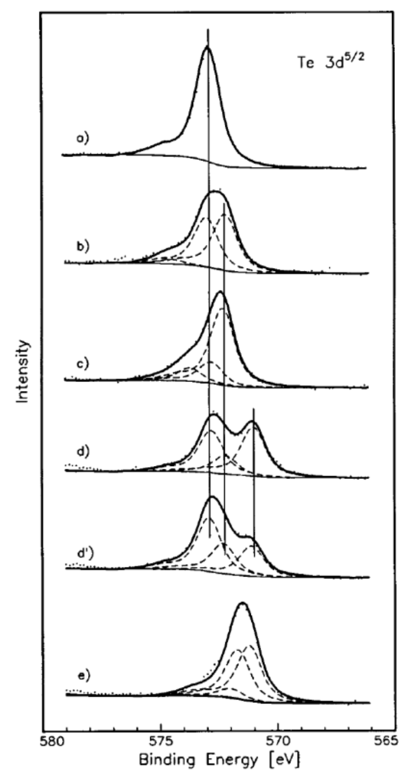


Introduction: Efforts in characterization of CsTe photocathode

- Growth recipe: mostly sequential. 10 ~ 20 nm of Te + 60 ~ 80n nm of Cs @ 120 °C → QE : 15 % ~ 18% @ 250 nm



A. di Bona *et al*, Auger and x-ray photoemission spectroscopy study on Cs2Te photocathodes, *Journal of Applied Physics* 80 3024 (1996)



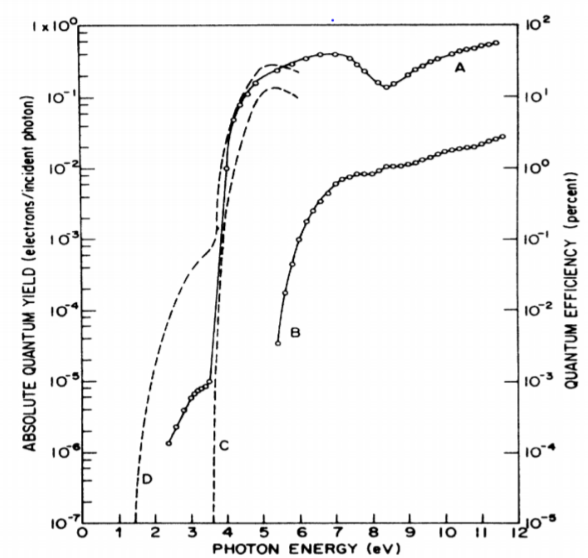


FIG. 1. Spectral distribution of the photoelectric yield from (*A*) Cs_2Te; (*B*) evaporated Te before reaction with Cs. Also shown are the data of Taft and Apker (Ref. 1). In their work, curve *C* was reported to be from a surface containing excess Cs while curve *D* was exposed to less Cs.

Question remained

- Many stable compounds exist besides CsTe and Cs_2Te: Cs_3Te_2, Cs_2Te_3, Cs_2Te_5, $CsTe_4$, Cs_5Te_4……

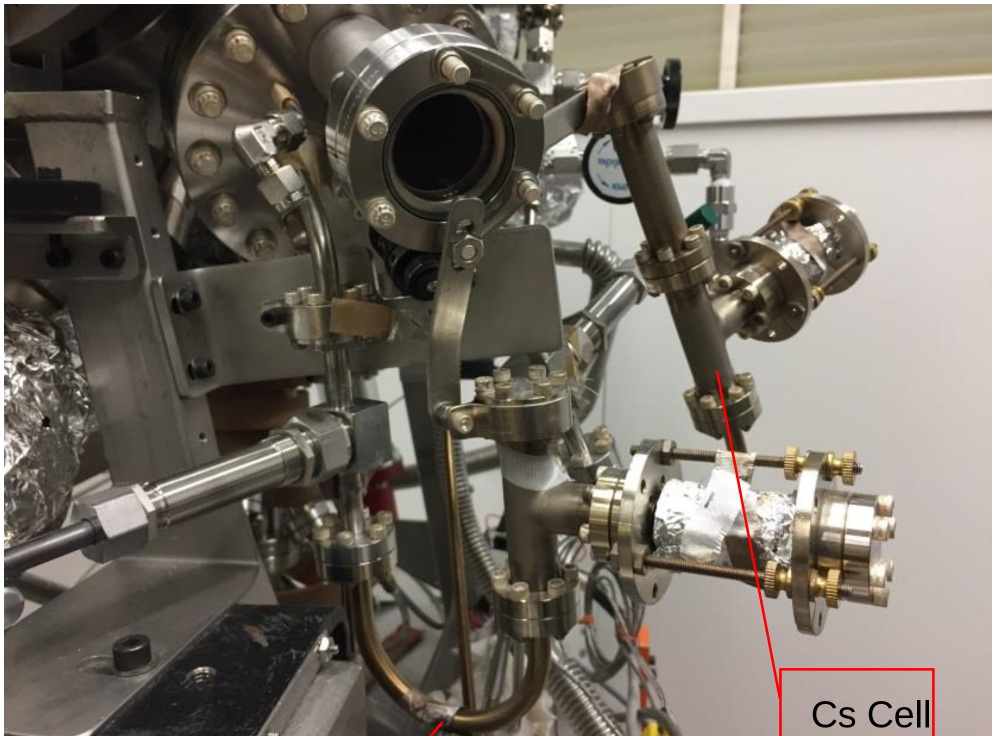
- The form of each stoichemetric compound specifically depends on the growth conditions:
  - substrate temperature,
  - growth rate of each material
  - Te thickness,
  - etc…

Materials Id	Formula	Spacegroup
mp-8361	CsTe	Pbam
mp-505464	Cs_2Te_{13}	Pbcm
mp-573763	Cs_2Te	Pnma
mp-505634	Cs_2Te_3	$Cmc2_1$
mp-620471	Cs_3Te_{22}	P1

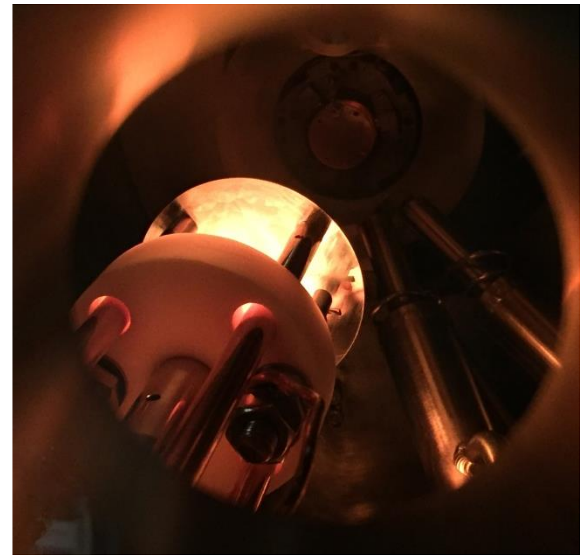
https://materialsproject.org/

Cs-Te cathode growth with effusion cell

Cs effusion cell

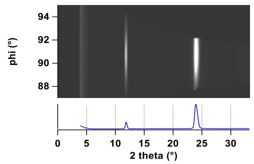


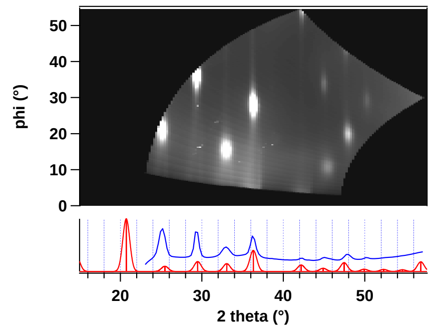
Te evaporator

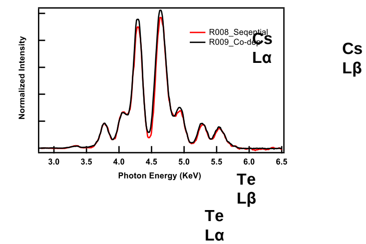


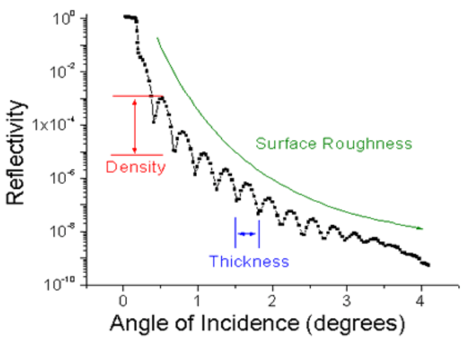
- Growth rate are controlled by J tube temperature, valve and shutter

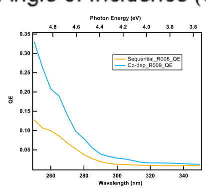
Experimental set-up: Cs-Te cathode growth

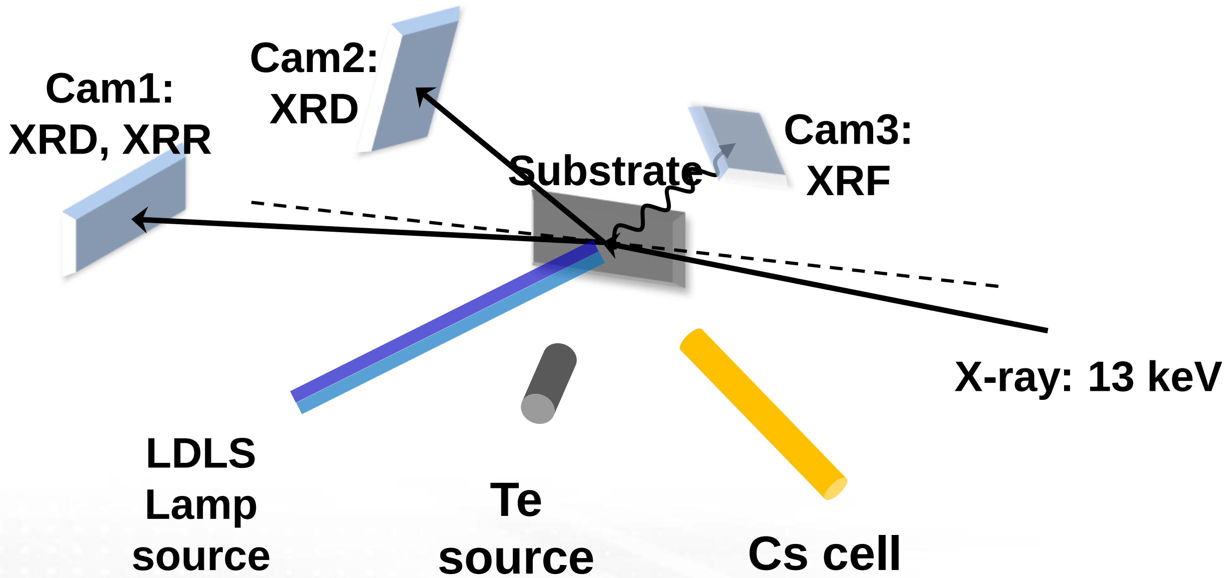










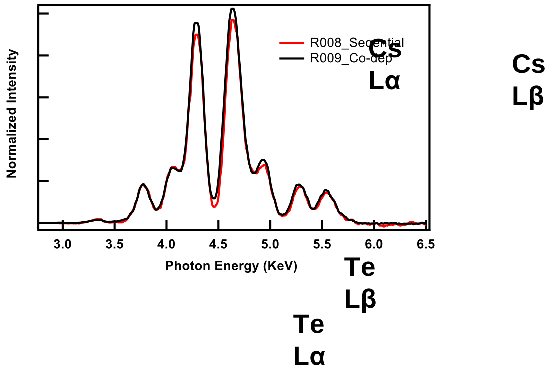


Sequential vs Co-dep CsTe -- XRF

Si substrate

↓ Te deposition @ 120 °C → ↓ Cs deposition @ 120 °C

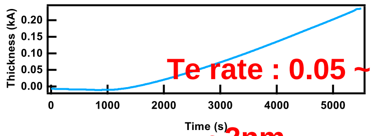
↓ Cs Te Co-deposition @ 120 °C → ↓ Leave Cs on for a while @ 120 °C



Sample	Te	Cs (+/-0.05)
R008 Sequential	1.00	1.15
R009 Co-dep	1.00	1.3

- At same substrate temperature; co-dep method incorporates more Cs.

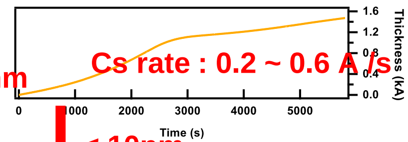
Realtime analysis : Sequential growth



Te rate : 0.05 ~ 0.07 A/s

~2nm

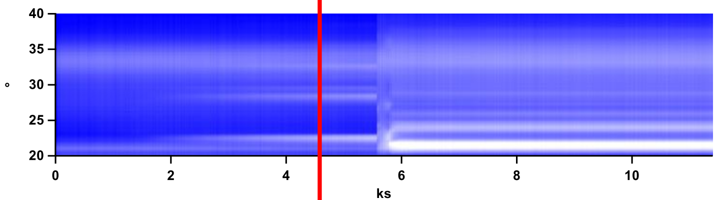
23.5nm

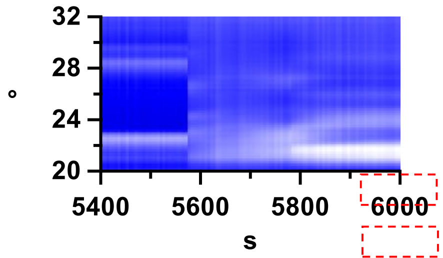


Cs rate : 0.2 ~ 0.6 A /s

< 10nm

~150 nm

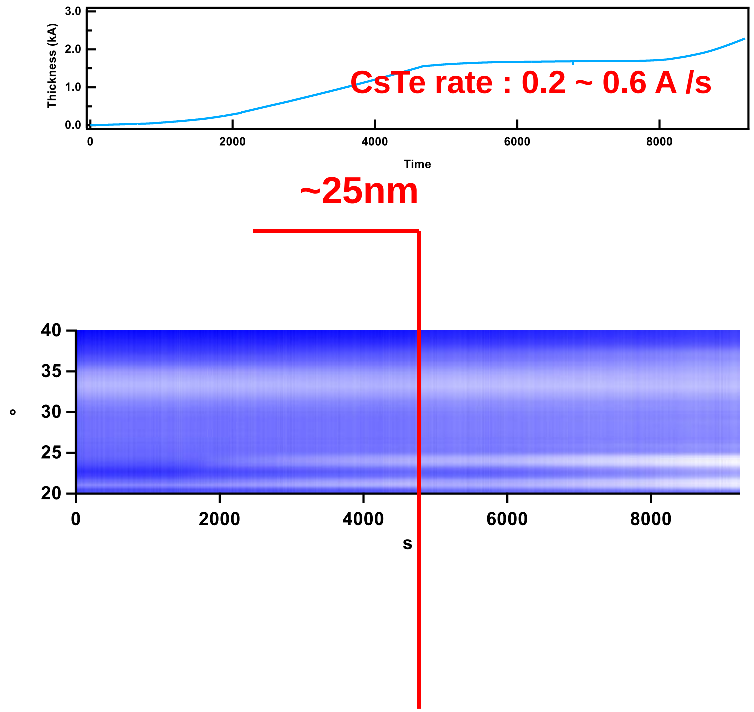




In less than 10 nm of Cs deposition, at least 2 intermediate phases appeared and disappeared, then a stable product of CsTe forms.

Realtime analysis : Co-deposition

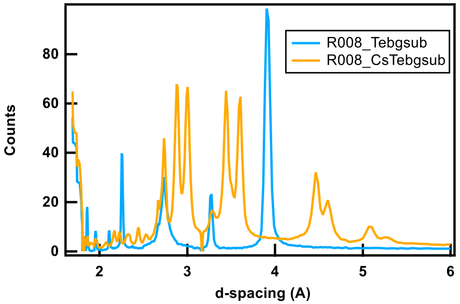
~230nm



- Starts to crystalize ~ 25 nm of total thickness.
- Same phase throughout the growth.

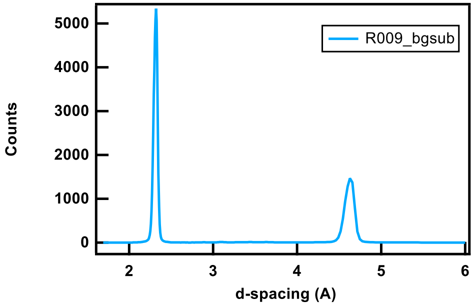
CsTe cathode structure: XRD analysis

Sequential growth



- Nearly all of the crystalized Te are dissolved.
- Low counts in diffraction peaks
- Multiple phase of Cs-Te compound co-exist

Co- deposition



- Well crystalized.
- Single phase

Sequential growth

Te: 23.5 nm

HKL	Theory_d spacing (Trigonal)	Exp_d spacing
2-1-10	2.256	2.259
10-11	3.268	3.27
10-10	3.908	3.91

Cs : > 150 nm

HKL	Theory_d spacing	Exp_d spacing
132 (Cs_2Te_3)	2.85	2.87
203 (Cs_2Te)	3.005	3.005
131 (Cs_2Te_3)	3.45	3.44
103 (Cs_2Te)	3.59	3.60
201 (Cs_2Te)	4.41	4.46
111 (Cs_2Te)	4.61	4.60
021(Cs_2Te_3)	5.08	5.08
011 (Cs_2Te)	5.27	5.28

Co- deposition

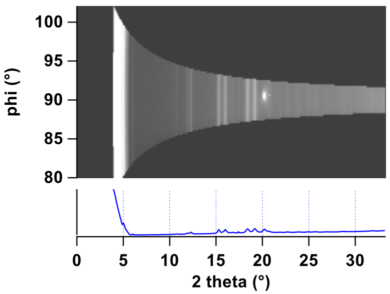
~ 100 nm

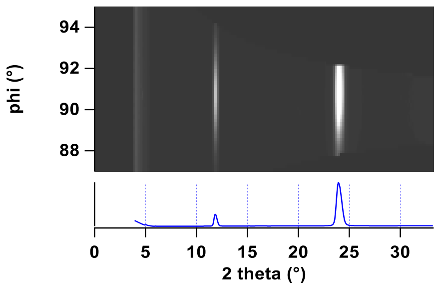
HKL	Theory_d spacing	Exp_d spacing
222 Cs_2Te	2.307	2.315
111 Cs_2Te	4.613	4.615

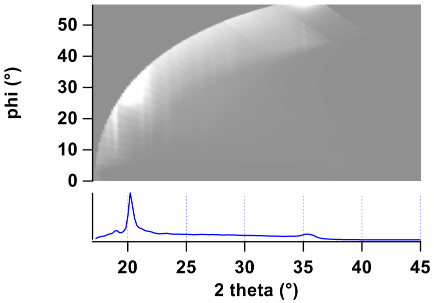
- **Sequential cathode is consist of possibly Cs_2Te_3 and Cs_2Te**
- **The crystalized phase in the co-dep cathode is Cs_2Te**

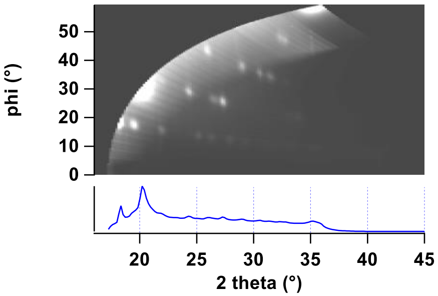
Sequential growth

Co- deposition



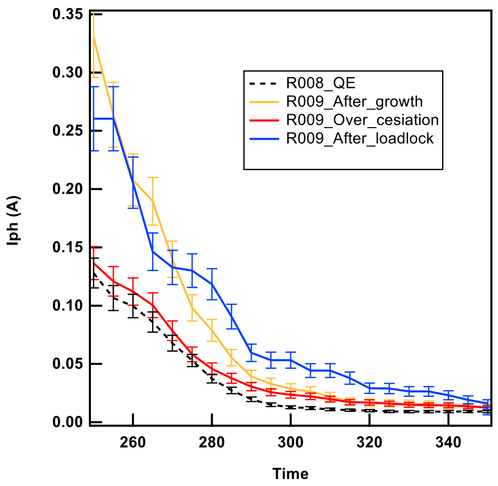


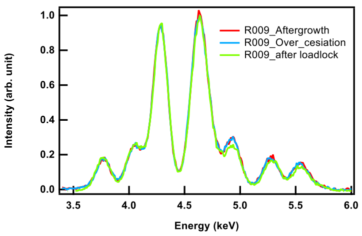




Highly textured CsTe phase!

CsTe cathode Quantum efficiency

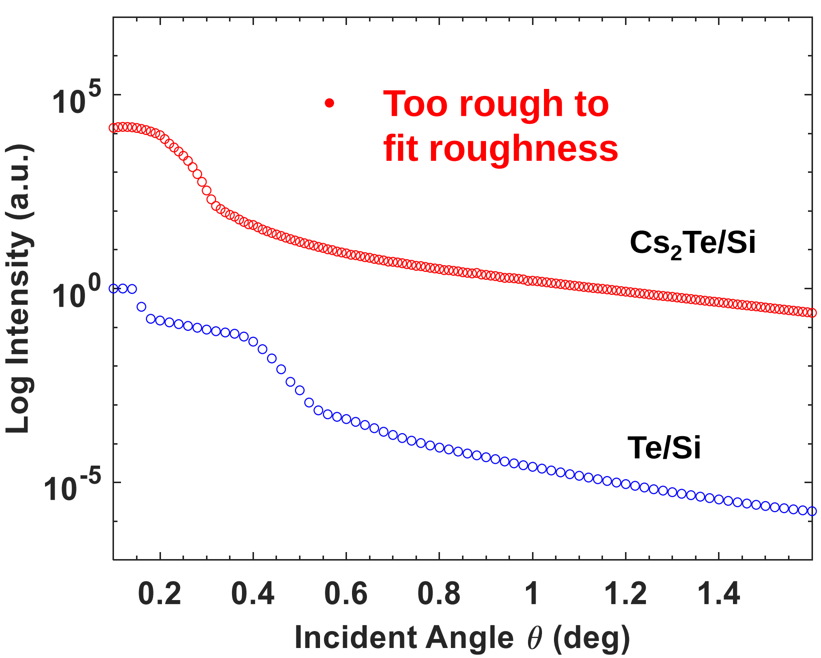




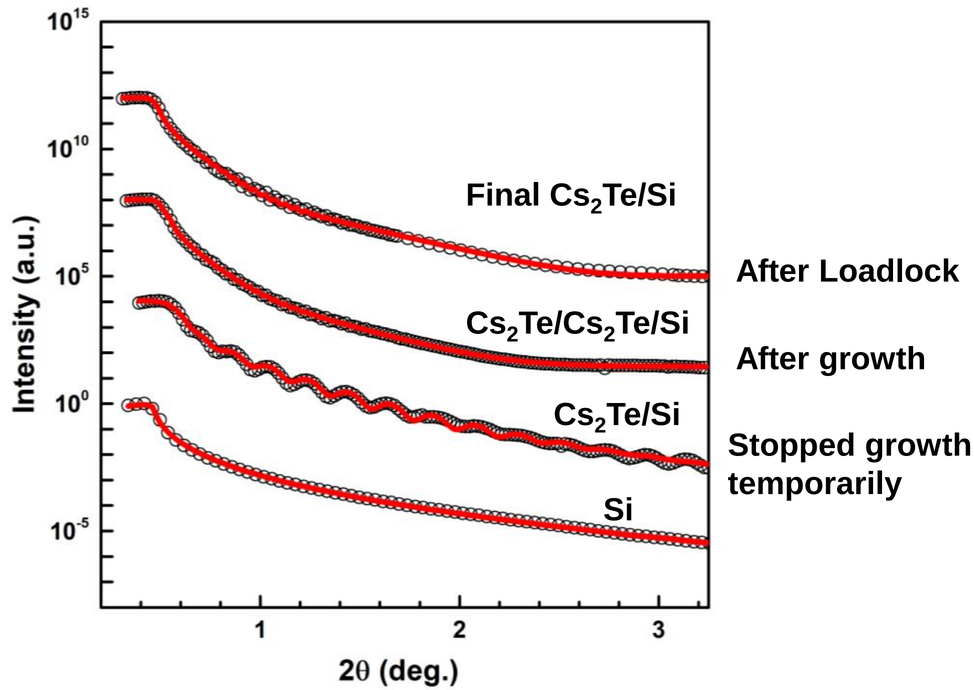
- Co-dep can result in much higher QE than sequential
- over cesiation might lead to Cs build-up on the cathode surface and lower the QE
- QE can be recovered by removing the access Cs

CsTe cathode surface roughness: XRR analysis

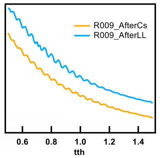
R008 Sequential - CsTe on Si



R009 Co-dep - CsTe on Si



	Thickness (Å)	Roughness (Å)
FINAL Cs2Te/Cs2Te	968.3 ± 2.9 (total Cs_2Te)	19.1 ± 0.2
Cs2Te/Cs2Te	1026.1 ± 1.6 (total Cs_2Te)	19.10 ± 0.07
Cs2Te	245.5 ± 1.7	9.55 ± 0.14
Si Substrate	-	3.75 ± 0.02



Summary

We presented results of real time structural analysis and in situ XRF, XRR and spectral response measurements.

The cathode from our deposition procedure yields stoichiometry that is less than Cs: Te = 2:1, The comparison between sequential and co-dep shows that the co-dep method incorporates more Cs than sequential method

CsTe photocathodes grown by pure alkali effusion cells and co-deposition method have stable and highly textured crystal structure and ultra smooth surface

QE of Co-dep cathode is higher in both high energy and low energy region. Excess Cs might result in lower QE.

Thanks for your attention!

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