Development of “green” photocathode

- **Thesis status Updates**

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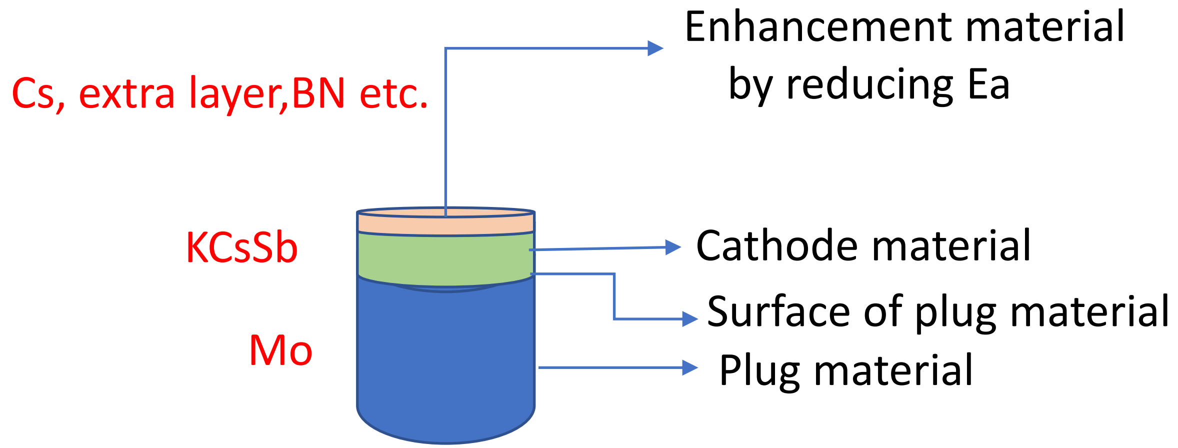
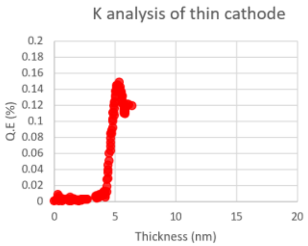
KSbCs Photocathode

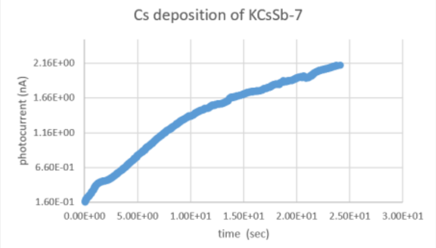
Factors affecting on Photocathode properties

- **Plug material**: Conductivity, avoid diffusion of film material (Mo, Si, Steel)
- **Surface**: Cleanliness and flatness (thermal emittance, unwanted contaminants especially oxides)
- **Cathode material:** Stoichiometry , crystal structure and orientation
- **Enhancement material**: special material like BN, graphene etc., also layer up on layer, excess Cs



KCsSb sequential growth analysis





Sb + K → K_3Sb → + Cs → KxSbCs

X=1,2 or 3

Sb

We put 5 or 10 nm

Some expirmental result show formation of island of Sb on Mo surface And mobilize to a unilayer around 10-12nm

ref: C.Ghosh Journal of Applied Physics 49, 4549 (1978)
Also by Modena group

K

Untill reach the Photocurrent yield

K_3Sb – Phase 1

Formation of K3Sb With cubic and hexagonal orientation

Ref: S.g Schubert Conference: 5th International Particle Accelerator Conference IPAC14

Cs

Untill reach the Photocurrent yield

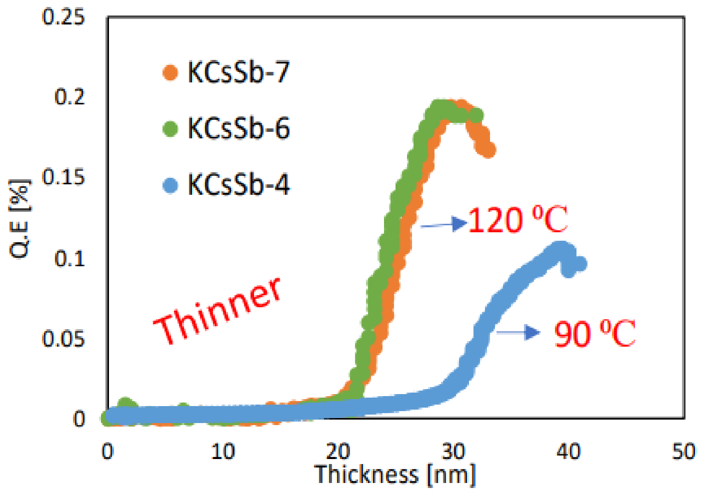
KxSbCs – Phase 2

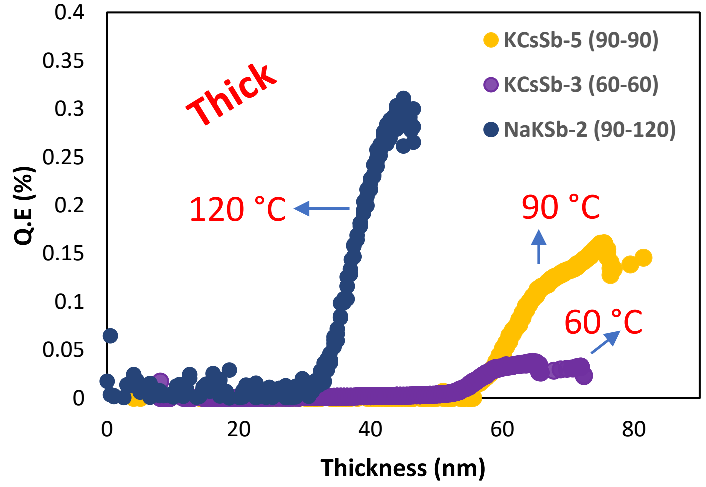
Formation of KSbCs

Sb 5nm = Thin

Sb 10 nm = Thick

K_3Sb Phase

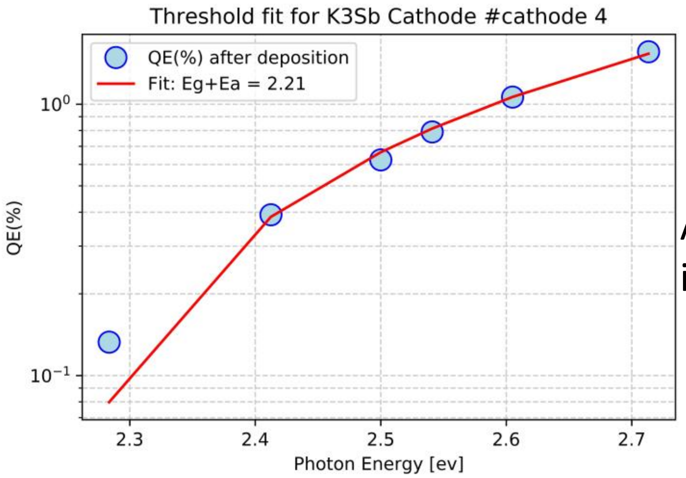




120°C : less amount require to reach threshold

- Better Chemical reaction
- Better crystallinity with less defect

compare with spicer model



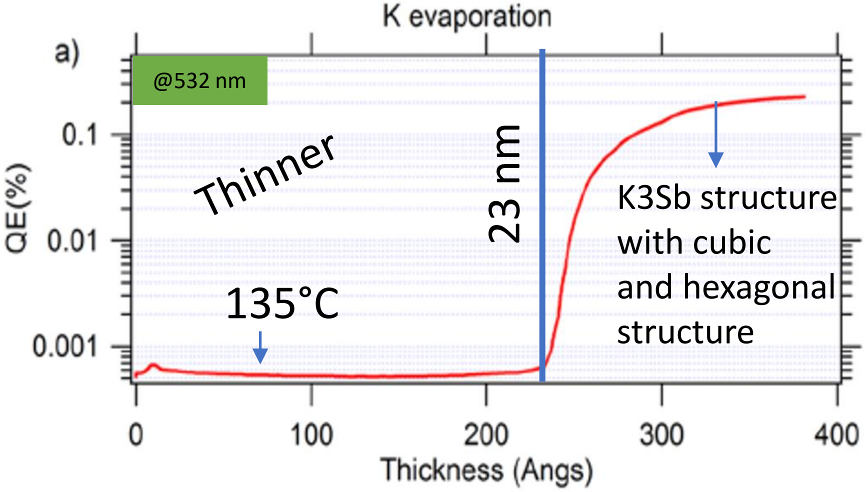
All the cathodes shows similar (Eg+ Ea) value i.e, 2.2

(Eg+ Ea)th for K3Sb= 2.2

Formula spicer model: Y (threshold) =A* [E- (Eg+Ea)^1.5] /[E- (Eg+Ea)^1.5]+B]

Compare with BNL group data

BNL Data



BNL XRD Data

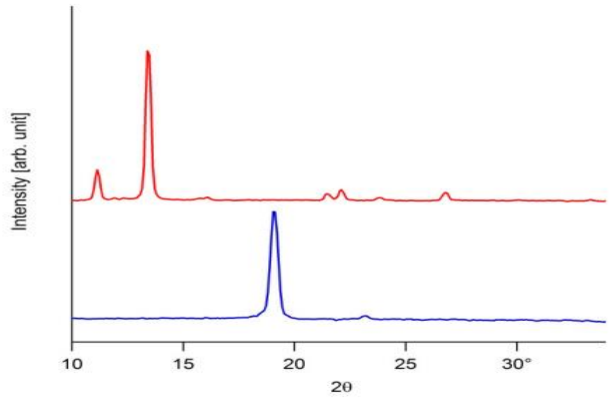
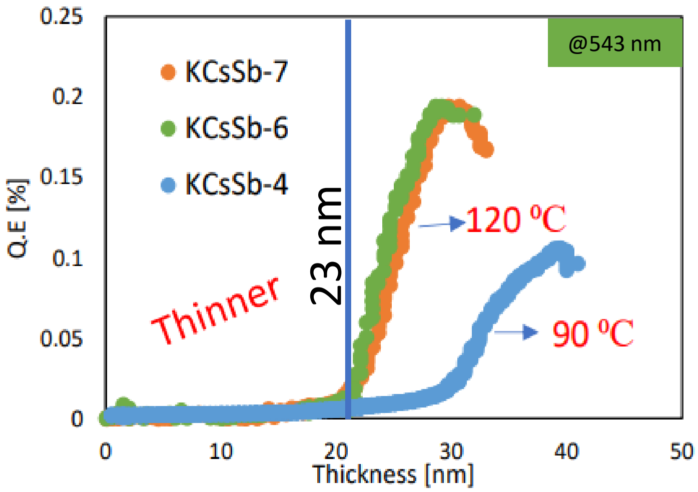


Figure 1: Sequential K_3Sb growth; blue - Sb layer and red - K_3Sb layer.

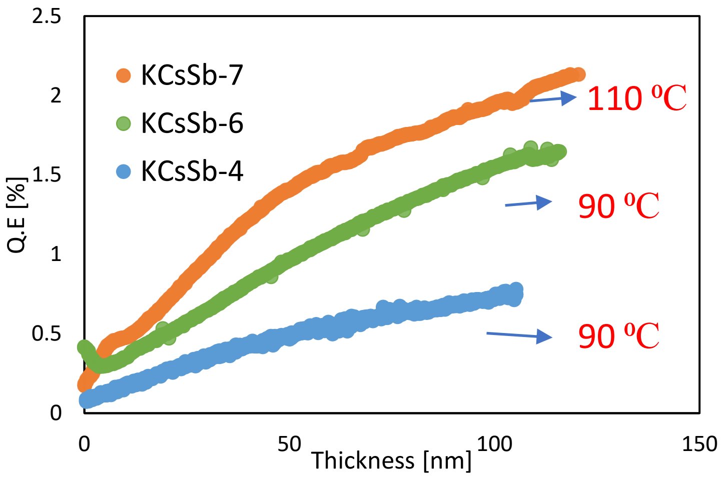
ref :APL Materials **2**, 121101 (2014); doi: 10.1063/1.4902544

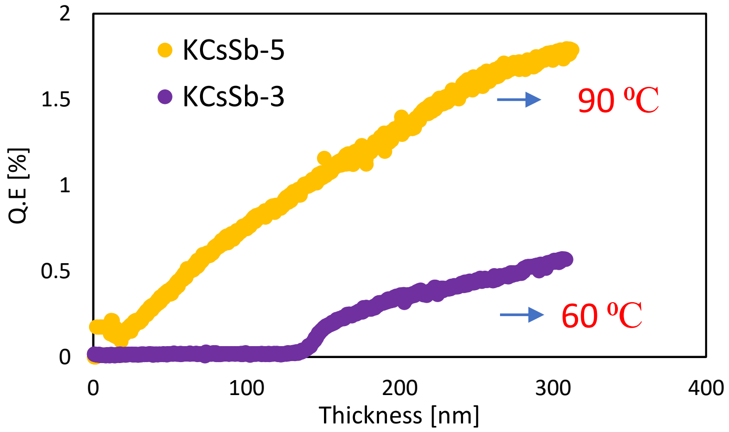
Our Data



- Improve in Q.E relate to better crystal quality which will reduce impurity scattering.
- Probable similar crystal structure occuers during growth like BNL.
- Sofar we get 0.3% @543 nm during K3Sb growth.
- But a detailed XPS or XRD study required.

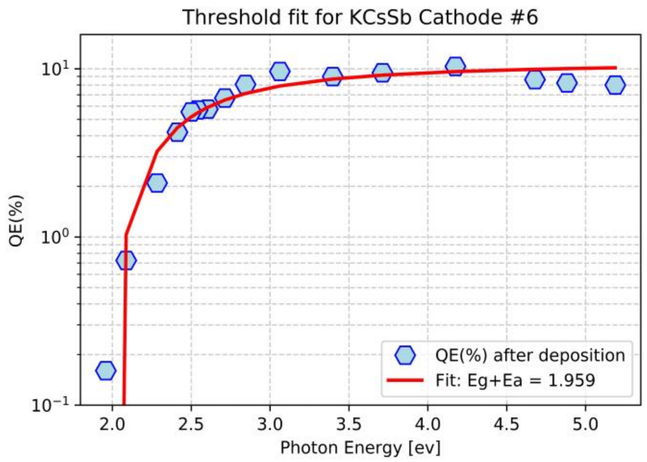
KSbCs Phase





- High temperature gives better reaction rate and better crystallinity which leads to better Q.E.

compare with spicer model

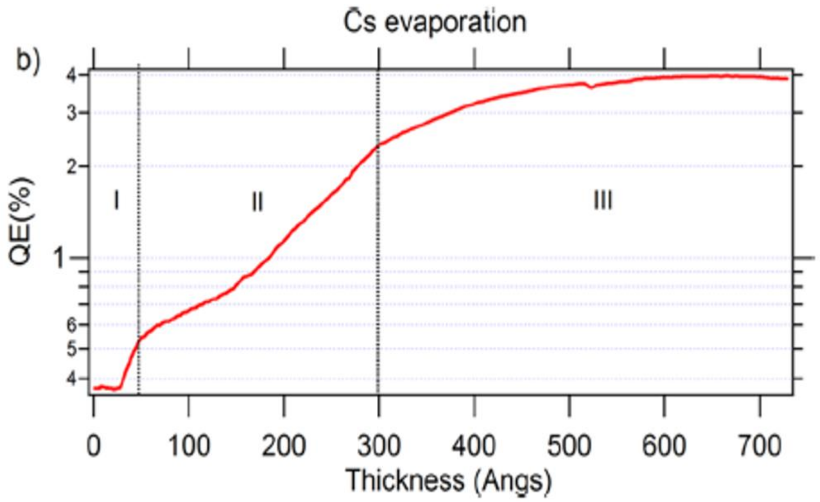


(Eg+ Ea)th for KSbCs = 1.93

Formula spicer model: Y (threshold) =A* [E- (Eg+Ea)^1.5] /[E- (Eg+Ea)^1.5]+B]

Compare with BNL group data

BNL Data



BNL XRD Data

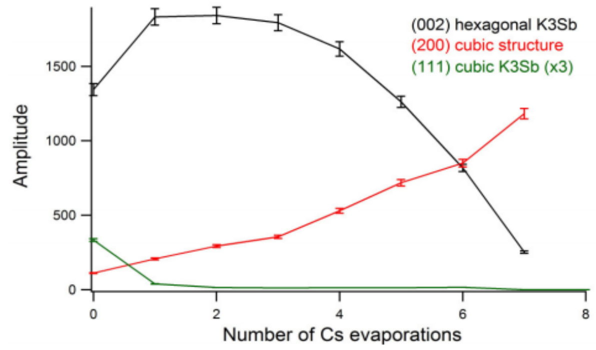
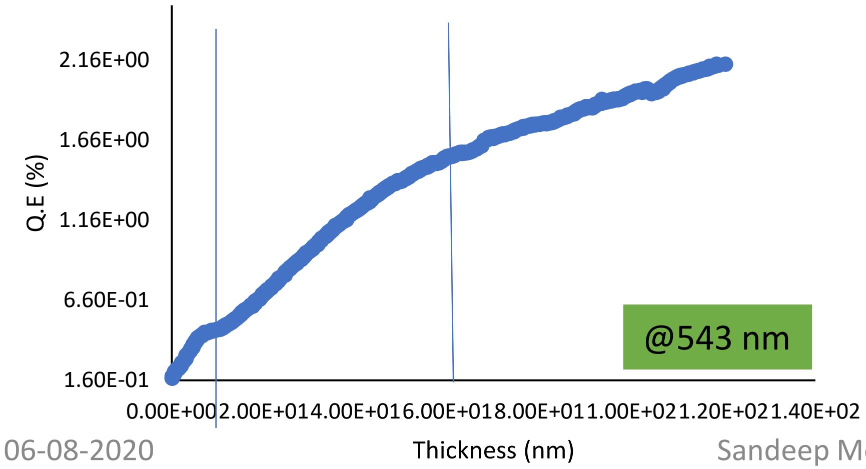


Figure 5: Change of amplitude of (111) cubic K_3Sb (green), (002) hexagonal K_3Sb (black) and (200) cubic CsK_2Sb Bragg peak upon Cs deposition onto K_3Sb cubic/ hexagonal mixture.

ref :APL Materials **2**, 121101 (2014); doi: 10.1063/1.4902544

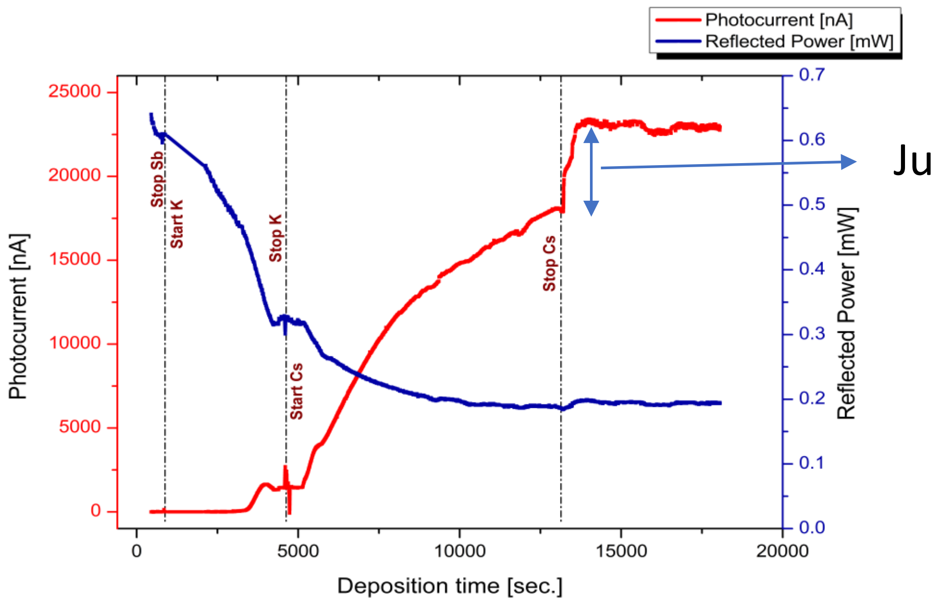
Our Data

Cs deposition of KCsSb-7



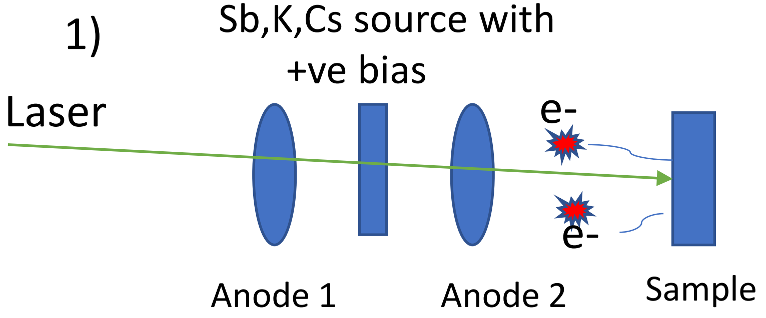
- Cs can better react with cubic type of K3Sb structure.
- Reaction between Cubic type K3Sb with Cs will lead to a better Q.E of final cathode.

Cs Jump analysis

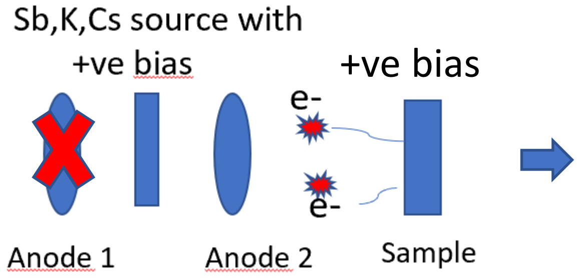


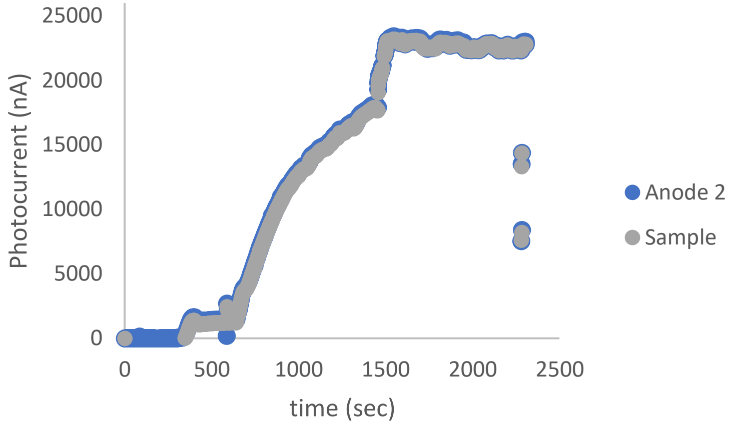
Jump?

1)



Wrong





Jump analysis of thin cathode

Partial wrong

2)

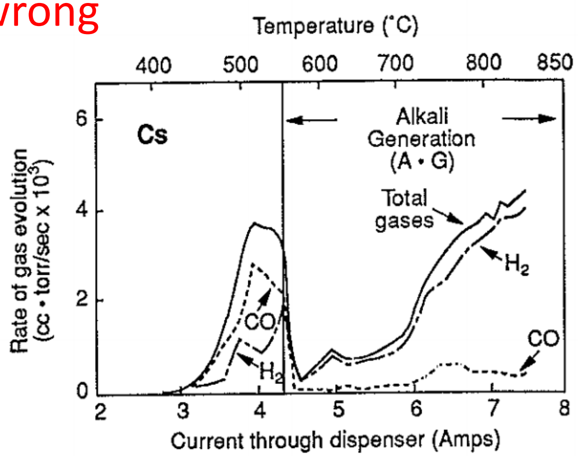
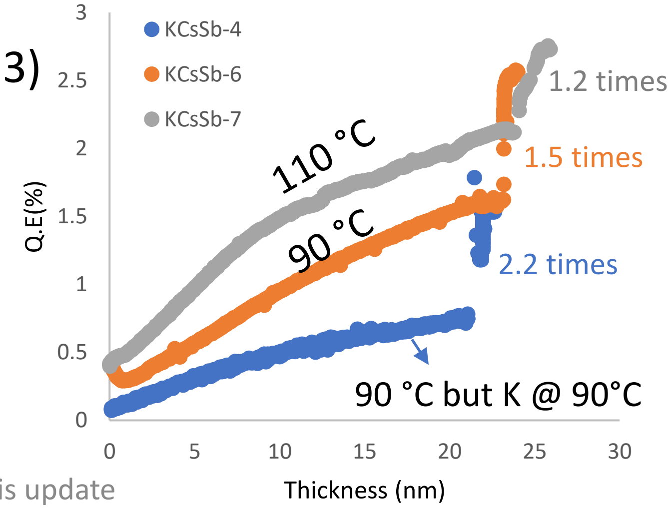


Fig. 5. Gas evolution from a SAES St 101-Cs dispenser.

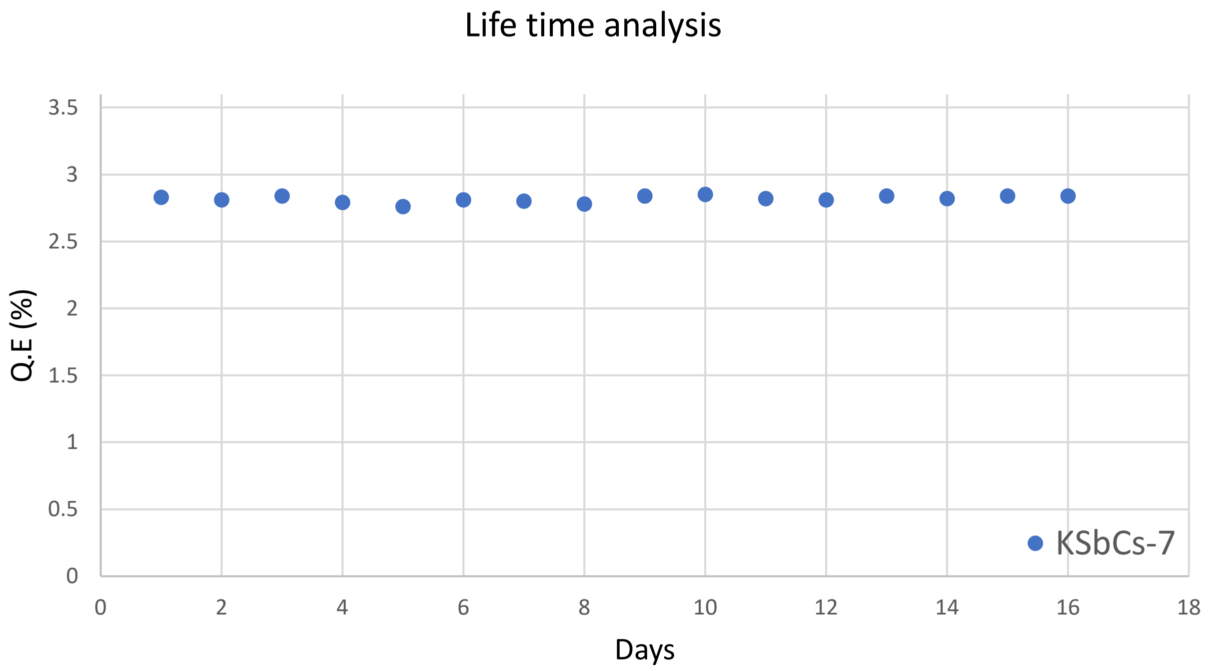
3)



Temperature dependance and Relate to the Cs reaction

- Either increase T
- Or decrease rate of deposition

Life time

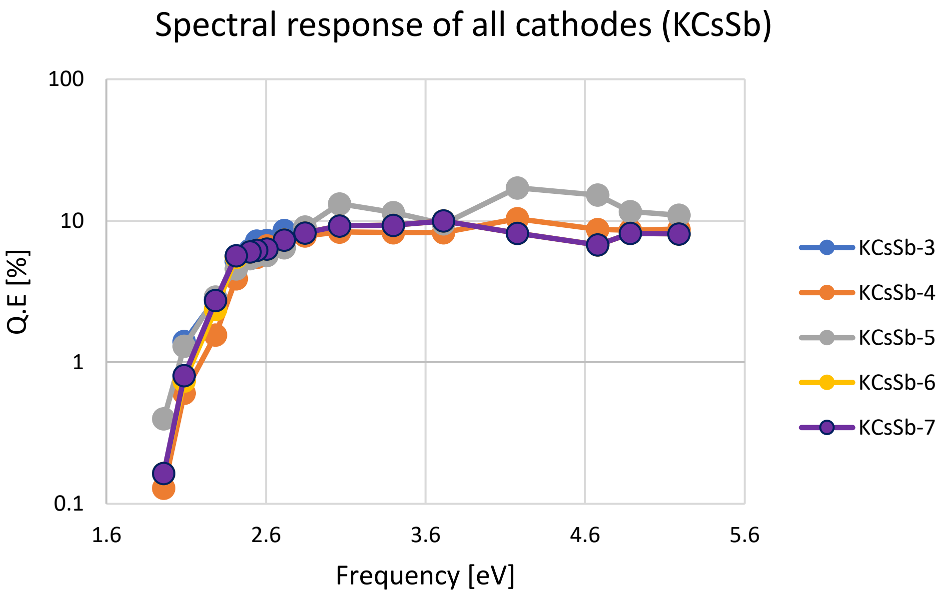


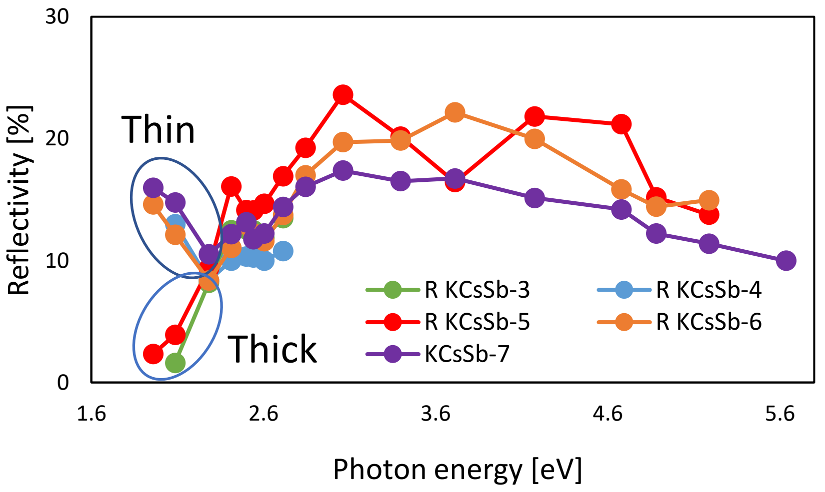
Laser power : 2 mw of 543nm

Avg. Photocurrent : 23 micro amp

Avg. Q.E: 2.8% @543 nm

Ratio,Q.E, Reflectivity





- 5.7% Q.E @514 nm is achived from cathode 7 with 17% yield @297 nm

Thin Cathode

Cathodes	Sb[nm]		K [nm]		Cs[nm]	Q.E.(%)@514nm
KCsSb-7 [90-120-110]	5		34		121	5.7
KCsSb-6 [90-120-90]	5		32		117	5.2
KCsSb-4 [90-90-90]	5		41		106	4.2
Ratio	1	:	~(7-8)	:	~23	

Thick Cathode

Cathodes	Sb[nm]		K [nm]		Cs[nm]	Q.E.(%)@514nm
KCsSb-5 [90-90-90]	10		75		316	5.2
KCsSb-3 [60-60-90]	10		66		313	5.2
Ratio	1	:	~7	:	~31	

Q.E is Independent of cathode thickness
But thin cathode can give low surface roughness

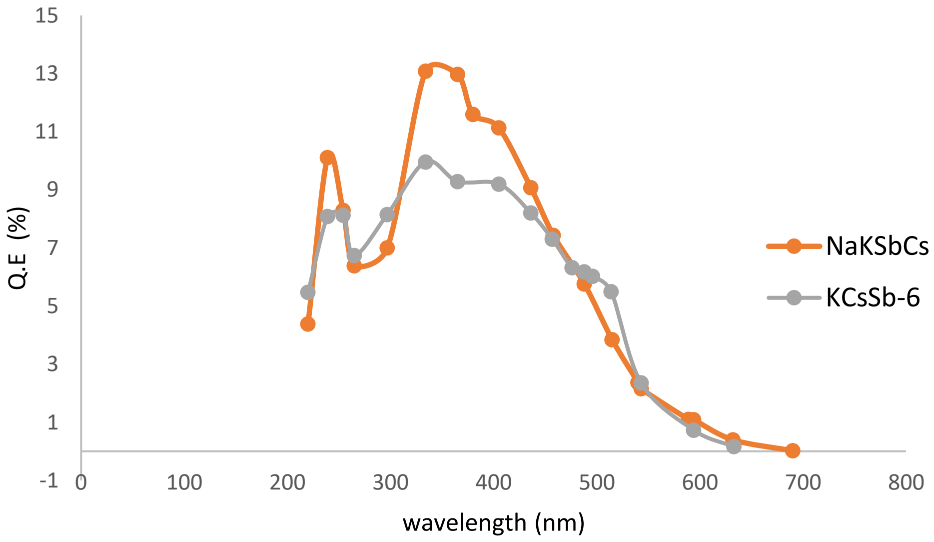
NaKSb (Cs)

- Motivation: higher stability in higher temperature and high Q.E

Procedure:

Sb -> K -> Na -> Sb -> K -> Na -> Sb->Cs

Layer up on layer or super lattice method



- NaKSb(Cs)-1 is partial successful with Q.E 2% @514 nm
- Layer up on layer procedure was successful.
- NaKSb(Cs)-2 with Q.E 3.9% @514 nm

Outlook

- KCsSb photocathodes are reproducible with around 6% Q.E @514 nm and with 17 % Q.E threshold @ 297 nm.
- Further optimization is possible for KCsSb cathode.
- Layer- up on layer could be try on KCsSb photocathodes to improve Q.E.
- More optimization is needed for NaKSb(Cs).
- Develop an another kind of phtocathode i.e, Cs_3Sb Photocathode could be possible, since last part of NaKSb(Cs) cathode is similar.
- Prepare the new production chamber.
- Co-deposition procedure could be try.

Prepare the recipe → Produce the real cathode → Test at PITZ → XPS, XRD study at Modena → Final

KCsSb, NaKSb(Cs), Cs3Sb

New Cathode System

- The Green Cathode System parts acquisition is on going.
- The vacuum chamber has been fabricated, successfully leak check and Residual Gas Analyzer controlled.

Vacuum chamber

- Major components already in house
  - Vacuum chamber
  - RGA
  - Vacuum probes and controller
  - Translators
  - Microbalance
  - Cathode heater and masking system
  - Bake out system (shared with Cs_2Te system) to be assembled
  - Some instrumentation can be shared with Cs_2Te system at the beginning and w
    have a stand-alone system

Thanks!

• Backup Slides

Cathode type	Cathode	Typical wavelength & energy, λ_{opt} (nm), (eV)	Quantum efficiency (electrons per photon)	Vacuum for 1000 h (Torr)	Gap energy+ electron affinity, E_G+E_A (eV)	Thermal emittance (microns/ mm(rms))	
						Eq. (7)	Expt.
PEA: mono-alkali	Cs_2Te	211, 5.88	0.1	10^{-9}	3.5 [42]	1.2	0.5 ± 0.1 [35]
		264, 4.70	–	–	"	0.9	0.7 ± 0.1 [35]
		262, 4.73	–	–	"	0.9	1.2 ± 0.1 [43]
	Cs_3Sb	432, 2.87	0.15	?	1.6+0.45 [42]	0.7	?
	K_3Sb	400, 3.10	0.07	?	1.1+1.6 [42]	0.5	?
	Na_3Sb	330, 3.76	0.02	?	1.1+2.44 [42]	0.4	?
	Li_3Sb	295, 4.20	0.0001	?	?	?	?
PEA: multi-alkali	Na_2KSb	330, 3.76	0.1	10^{-10}	1+1 [42]	1.1	?
	$(Cs)Na_3KSb$	390, 3.18	0.2	10^{-10}	1+0.55 [42]	1.5	?
	K_2CsSb	543, 2.28	0.1	10^{-10}	1+1.1 [42]	0.4	?
	$K_2CsSb(O)$	543, 2.28	0.1	10^{-10}	$1+<1.1$[42]	~0.4	?
NEA	GaAs(Cs,F)	532, 2.33	0.1	?	1.4 ± 0.1[42]	0.8	0.44 ± 0.01[44]
		860, 1.44	0.1	?		0.2	0.22 ± 0.01[44]
	GaN(Cs)	260, 4.77	0.1	?	1.96+?[44]	1.35	1.35 ± 0.1[45]
	$GaAs(1-x)Px$ $x \sim 0.45$ (Cs,F)	532, 2.33	0.1	?	1.96+?[44]	0.49	0.44 ± 0.1[44]
S-1	Ag–O–Cs	900, 1.38	0.01	?	0.7[42]	0.7	?

D.H. Dowell et al. / Nuclear Instruments and Methods in Physics Research A 622 (2010) 685–697