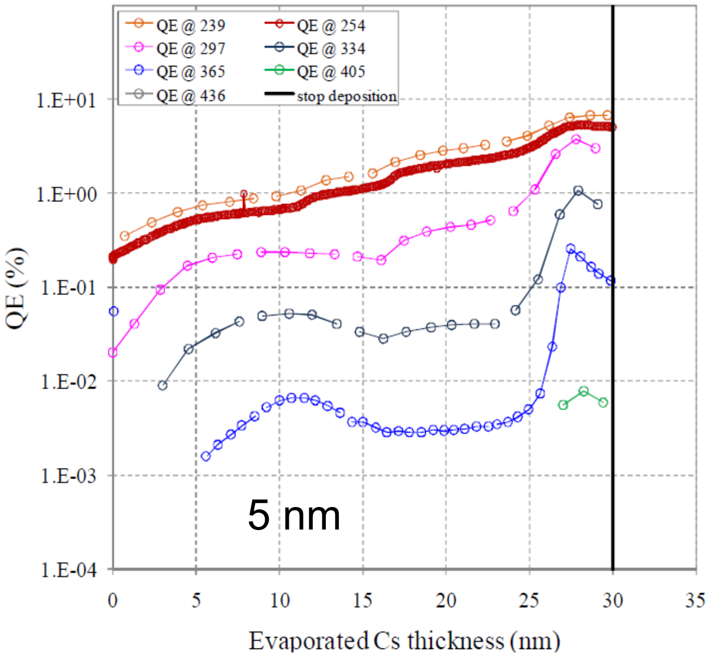
Literature review of thickness effect on cathode performance

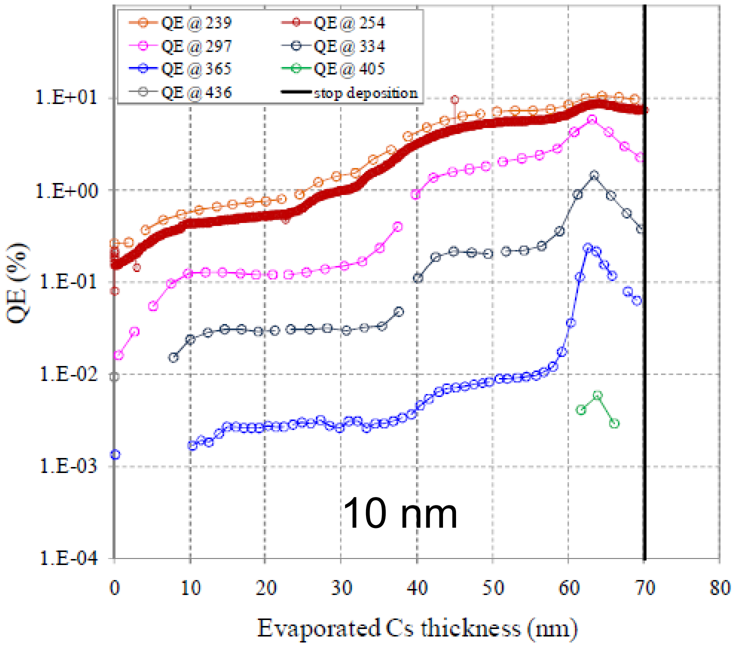
Deposition of three different

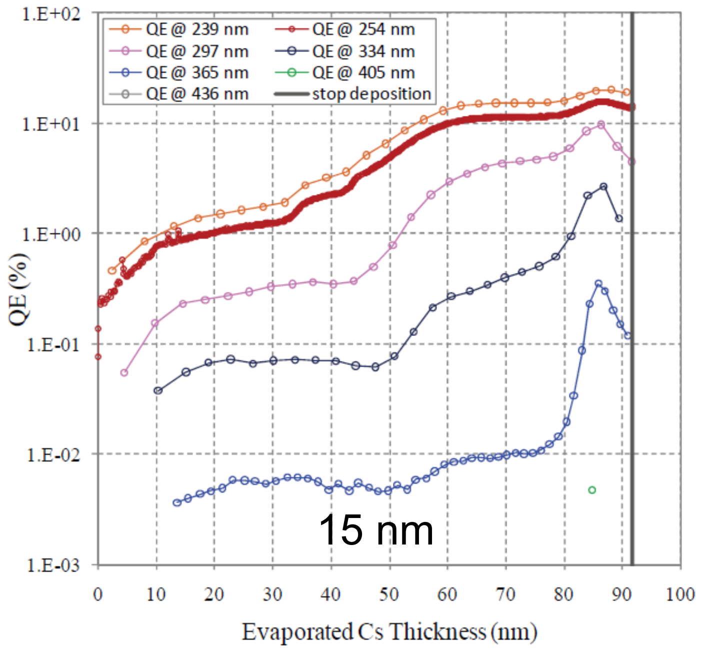
There are three types of Cs2Te cathodes

1. 5 nm Te + ~30 nm Cs
2. 10 nm Te + ~ 70 nm Cs
3. 15 nm Te + ~ 90 nm Cs

From the QE measurement during the deposition, ‘5 nm Te’ Cs2Te seems slightly different from the other two types.

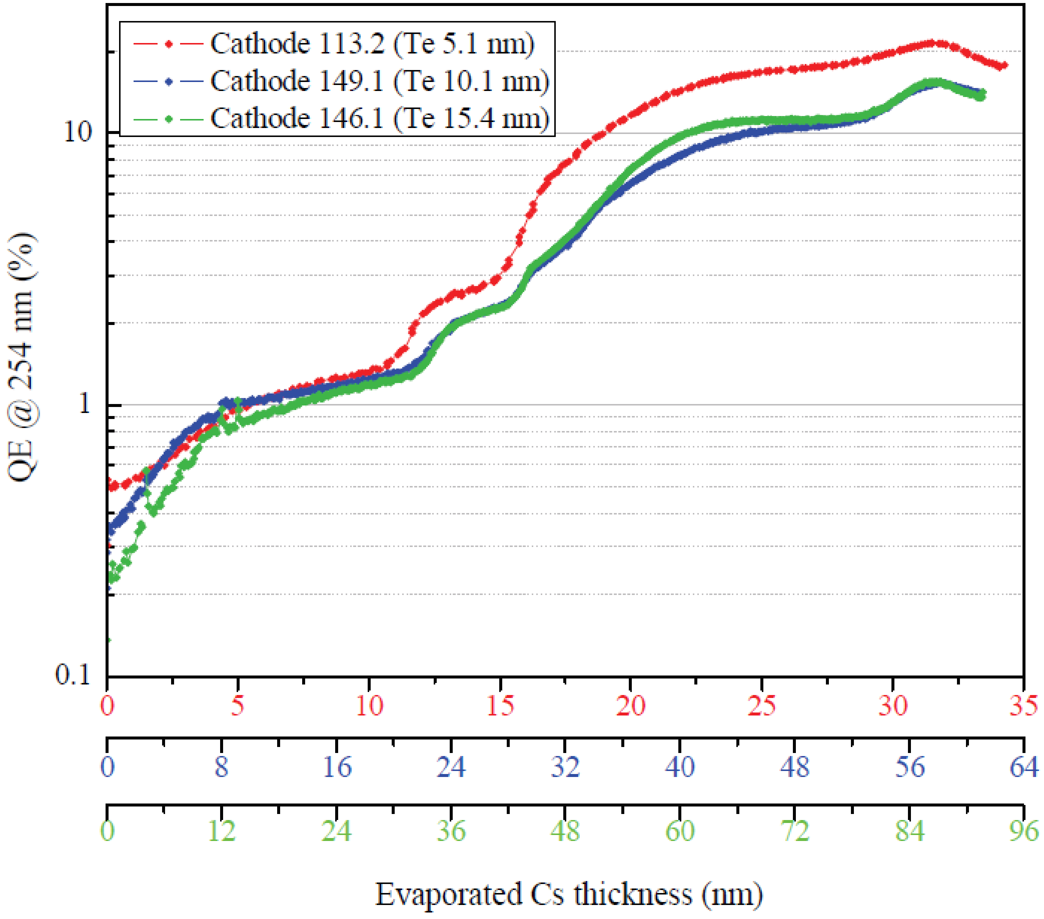






L. Monaco *et al,* MO6RFP072, PAC 09;
L. Monaco *et al*, TUPEC006, IPAC 10

Difference in chemical ratio



L. Monaco *et al*, TUPEC006, IPAC 10

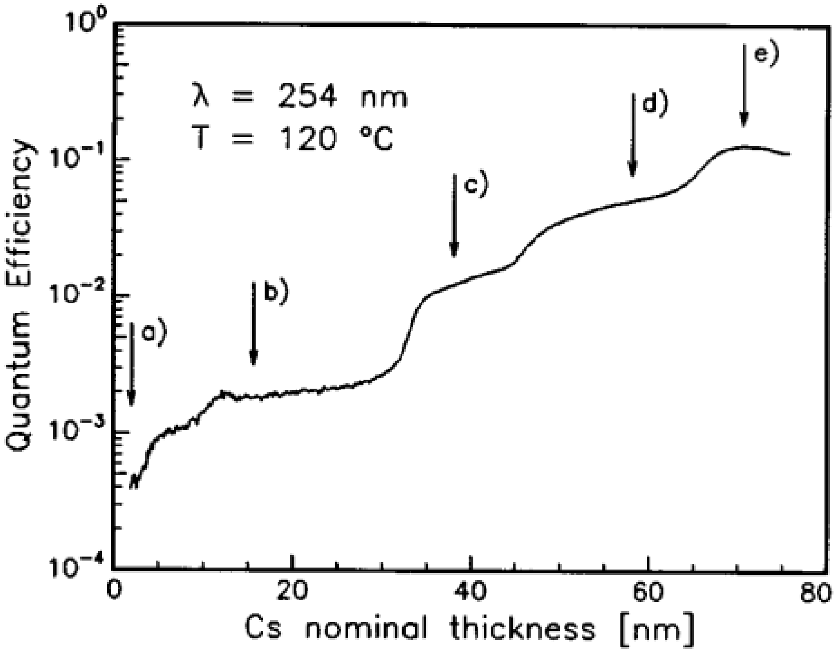
Cathode	Te thickness	Evap. Cs thickness	Last QE peak pos.	QE $^{\Theta}$
113.2	5.1 nm	34.3 nm	31.5 nm	15.3 %
149.1	10.1 nm	60.9 nm	58.2 nm	13.4 %
146.1	15.4 nm	91.7 nm	86.9 nm	13.0 %

Cs / Te	Cs / Te
6.73	6.18
6.03	5.76
5.95	5.64

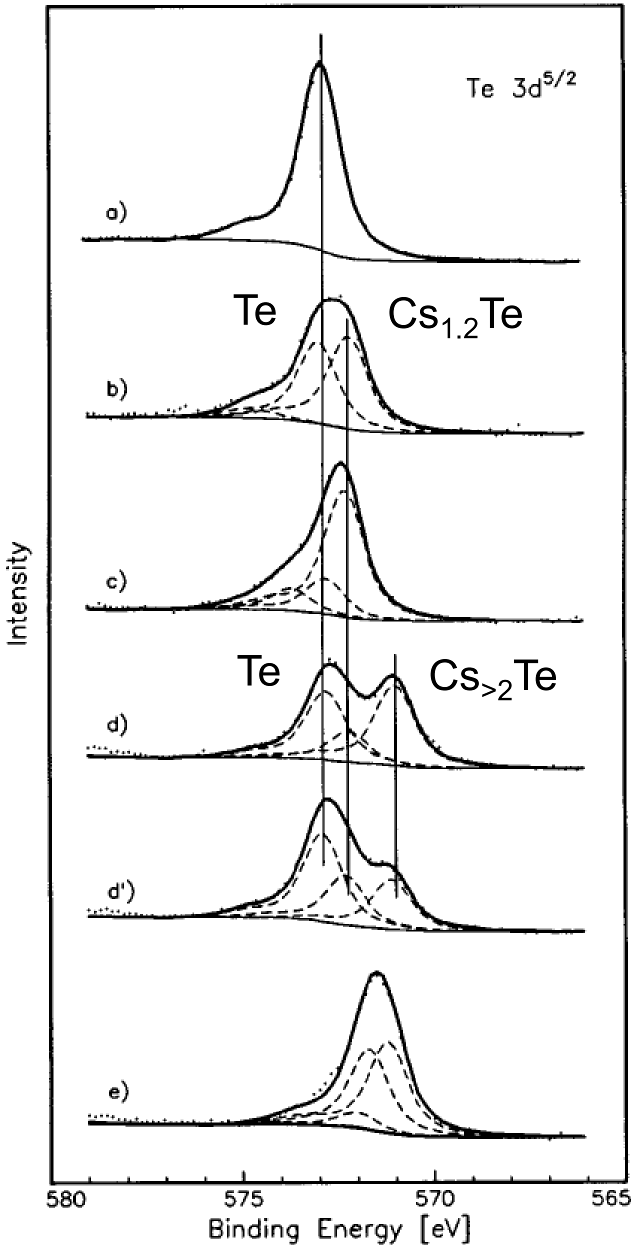
The above shows the thickness ratio between Cs and Te, which differs from the chemical ratio only by a constant, the quotient between the density of Cs and Te. The chemical ratio at the last peak QE position should be the same since it refers to the formation of a complete cathode.

XPS analysis

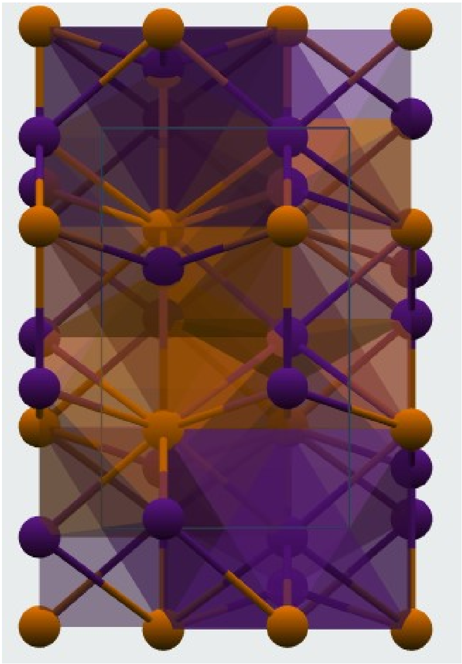
Auger and x-ray photoemission spectroscopy study on Cs_2Te photocathodes



	Cs/Te	
	Normal	Grazing
Fig. 1(b)	0.6	⋯
Fig. 1(c)	1.2	⋯
Fig. 1(d)	1.9	1.8
Fig. 1(e)	2.5	2.4



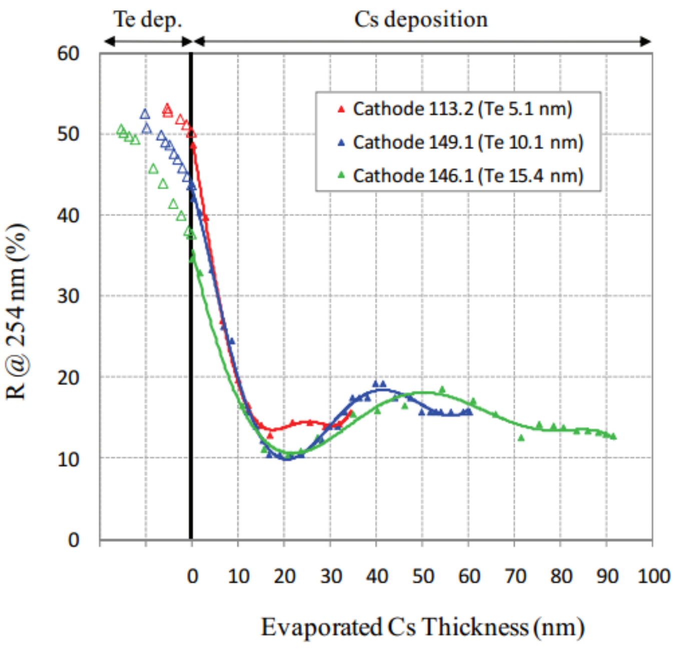
Cs_2Te

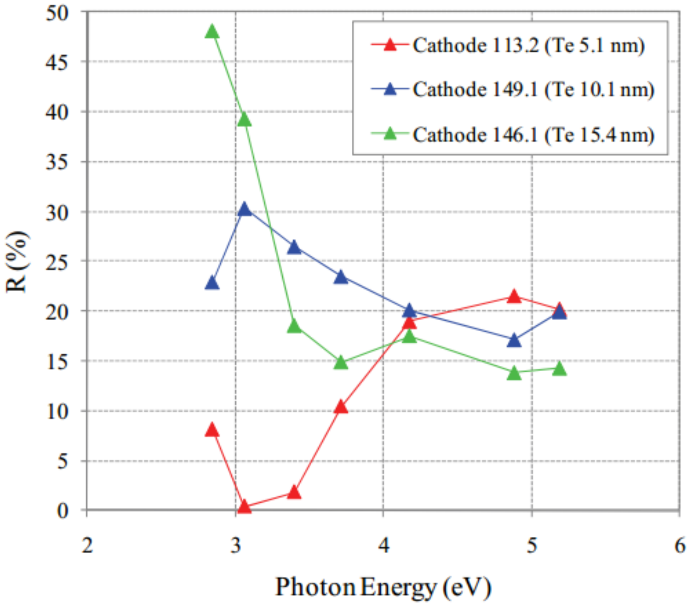


The final cathode seems to be a mixture of different compositions, not just Cs2Te.

di Bona et al, J. Appl. Phys., Vol. 80, No. 5, 1 September 1996;
Persson, Kristin, materials project, 10.17188/1276525

Reflection





Cathode	R (Mo)	ΔR decrease§	R % (Cs_2Te)
113.2	52.8%	5.4%	21.5 %
149.1	52.8%	16.7%	17.1%
146.1	51.4%	25.6%	13.8%

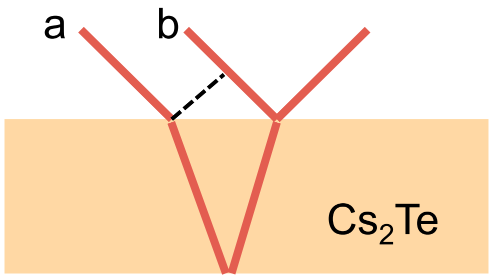
§ Reflectivity decrease during the Te deposition on Mo (λ = 254 nm)

L. Monaco *et al*, TUPEC006, IPAC 10

The reflection differs greatly in the low photon energy region among three cathodes.

Possible reasons:

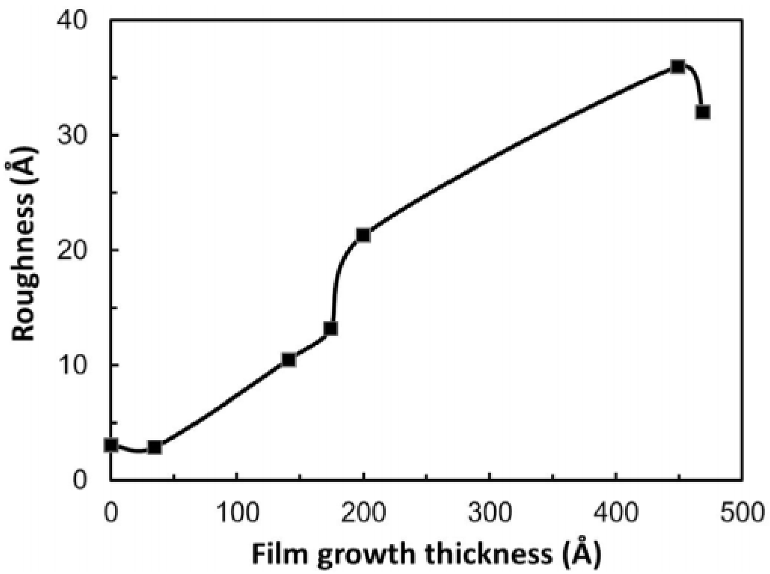
1. The formed ‘Cs2Te’ is not the same in chemistry.
2. The surface condition, some free Cs atoms, oxidation, ……
3. Cs2Te is transparent to photon with energy below 3.3 eV (the band gap) in principle. If the optical path difference between ‘a’ and ‘b’ happens to be the integer times of wavelength, then the reflection would be enhanced.



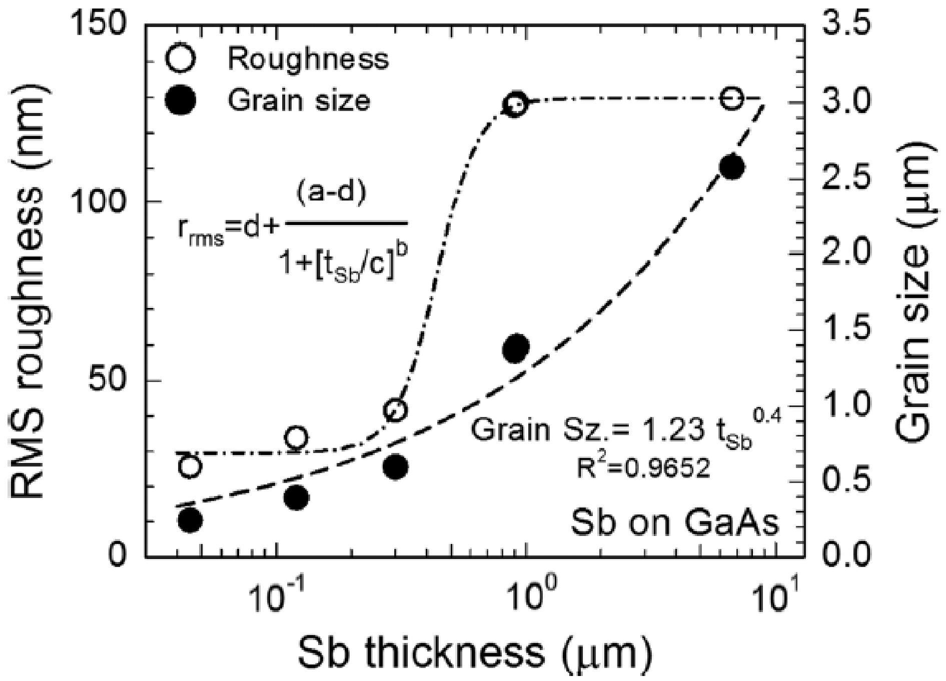
Thickness effect on thermal emittance

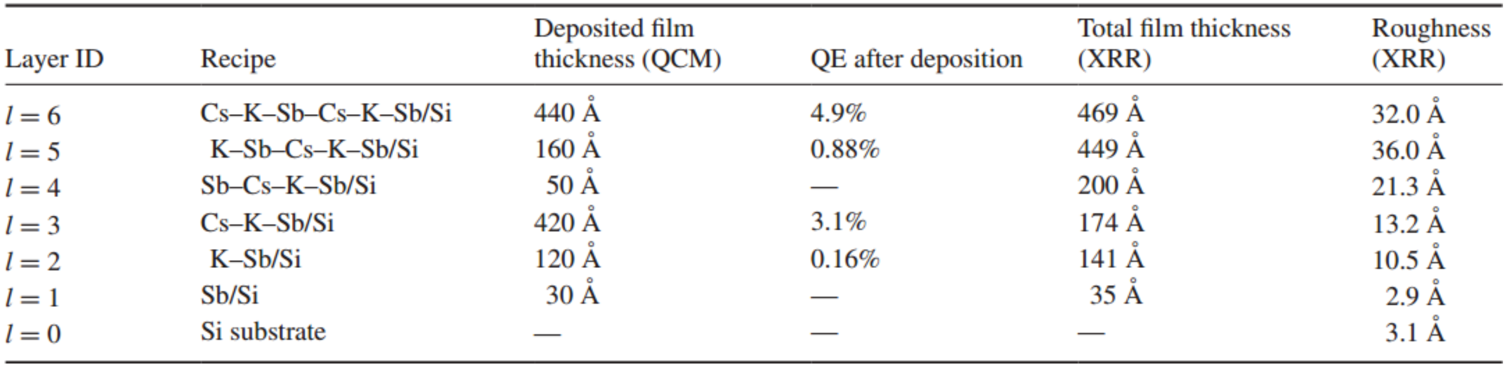
- Roughness

smaller thickness might result in smaller roughness



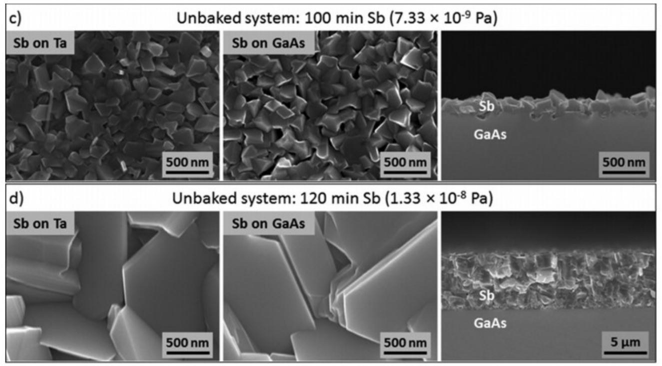
- ➢ The multi-step growth of K2CsSb, exhibits roughness in an order of magnitude lower than the normal sequential process.
- ➢ The alkali species Cs and K were codeposited onto relatively thick layers of Sb





Layer ID	Recipe	Deposited film thickness (QCM)	QE after deposition	Total film thickness (XRR)	Roughness (XRR)
$l = 6$	Cs–K–Sb–Cs–K–Sb/Si	440 Å	4.9%	469 Å	32.0 Å
$l = 5$	K–Sb–Cs–K–Sb/Si	160 Å	0.88%	449 Å	36.0 Å
$l = 4$	Sb–Cs–K–Sb/Si	50 Å	—	200 Å	21.3 Å
$l = 3$	Cs–K–Sb/Si	420 Å	3.1%	174 Å	13.2 Å
$l = 2$	K–Sb/Si	120 Å	0.16%	141 Å	10.5 Å
$l = 1$	Sb/Si	30 Å	—	35 Å	2.9 Å
$l = 0$	Si substrate	—	—	—	3.1 Å

J. Xie et al, J. Phys. D: Appl. Phys. 50 (2017) 205303



Mamun et al. Journal of Vacuum Science & Technology A 34, 021509 (2016)

Thickness effect on thermal emittance

- More scattering for the electrons excited in the deeper film. The higher energy loss results in lower transverse energy.

$$\mathrm{MTE}_{\mathrm{re}} = \frac{1}{3}\left[\mathrm{E}_{\mathrm{ex}} - \frac{\overline{\mathrm{dE}}\left(\alpha - (\alpha + d)e^{-\frac{d}{\alpha}}\right)}{l_{\mathrm{mfp}}\left(1 - e^{-\frac{d}{\alpha}}\right)}\right], \qquad (1)$$

$$\mathrm{MTE}_{\mathrm{tr}} = \frac{1}{3}\left[\mathrm{E}_{\mathrm{ex}} - \frac{\overline{\mathrm{dE}}\left(-2\alpha + d + (2\alpha + d)e^{-\frac{d}{\alpha}}\right)}{l_{\mathrm{mfp}}\left(1 - e^{-\frac{d}{\alpha}}\right)}\right], \qquad (2)$$

From the analytical calculation, the scattering cooling effect is not so significant for the reflection mode. However, the analytical model do not consider the contribution of backscattering. For cathodes with larger thickness, the electrons have higher possibility to be backscattered and then reach the front surface. In this case, they would experience more scatterings and hence have lower transverse energy.

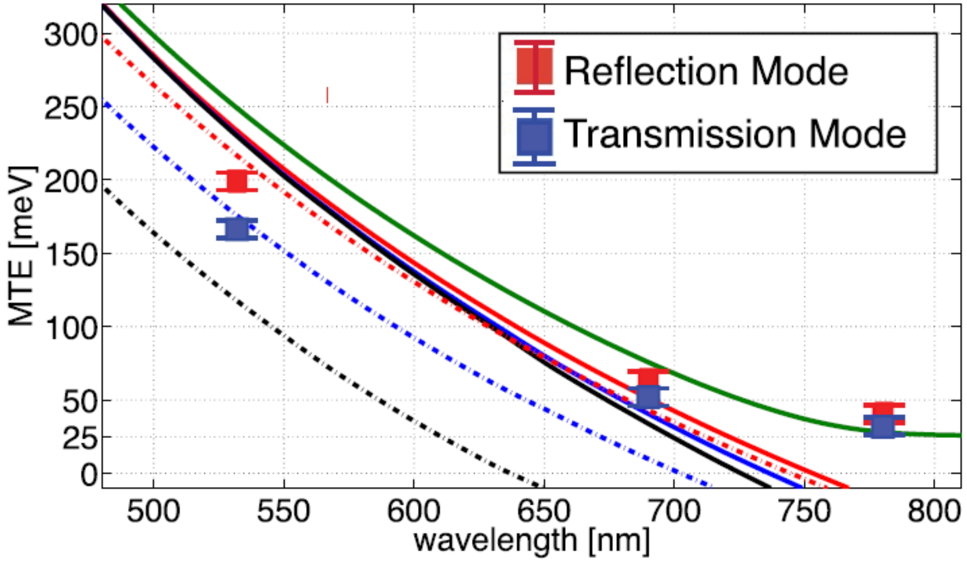
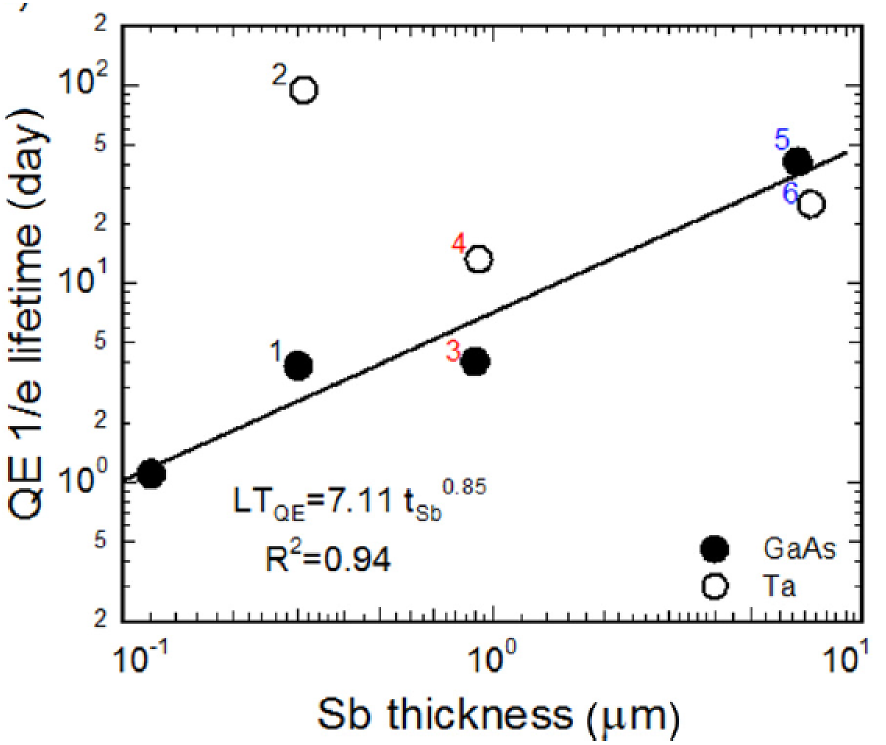


FIG. 4. MTE from analytical formulas (Eqs. (1) and (2)) at three different photocathode thicknesses: 150 (red), 300 (blue), and 500 (black) nm. Dotted lines represent the transmission mode. The green line is calculated with the model from Ref. 9.

Hyeri Lee et al, Appl. Phys. Lett. 108, 124105 (2016)

Thickness effect on lifetime



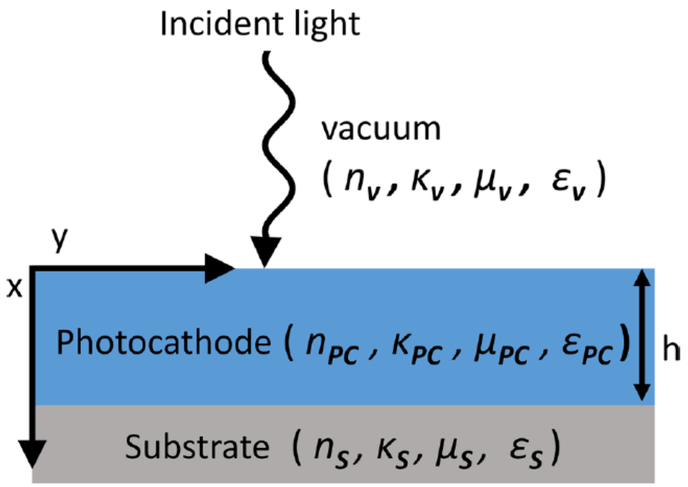
Mamun et al. Journal of Vacuum Science & Technology A 34, 021509 (2016)
E. J. Montgomery et al, Journal of Directed Energy, 3, Fall 2008, 66–79

Thin Sb layers provided a relatively dense smooth surface, whereas thick Sb layers appeared porous with increased surface roughness.

The QE lifetime results shown in figure indicated that photocathodes with more alkali storage provided longer lifetime in a manner similar to that of porous substrates used in a dispenser photocathodes, which served as an alkali-reservoir.

The dispenser concept promises in situ rejuvenation of cesiated surface layers by gently heating the cathode and allowing cesium to diffuse controllably to the surface through a porous substrate from a subsurface reservoir.

Thickness effect on QE



An enhancement of photoemission efficiency is based on a careful consideration of wave interference effects in the film and the consequent modulation of the absorption profiles and electron emission probabilities.

$$r_{V-\mathrm{PC}} = \frac{\tilde{n}_V - \tilde{n}_{\mathrm{PC}}}{\tilde{n}_V + \tilde{n}_{\mathrm{PC}}}$$

$$r_{\mathrm{PC}-S} = \frac{\tilde{n}_{\mathrm{PC}} - \tilde{n}_S}{\tilde{n}_{\mathrm{PC}} + \tilde{n}_S}.$$

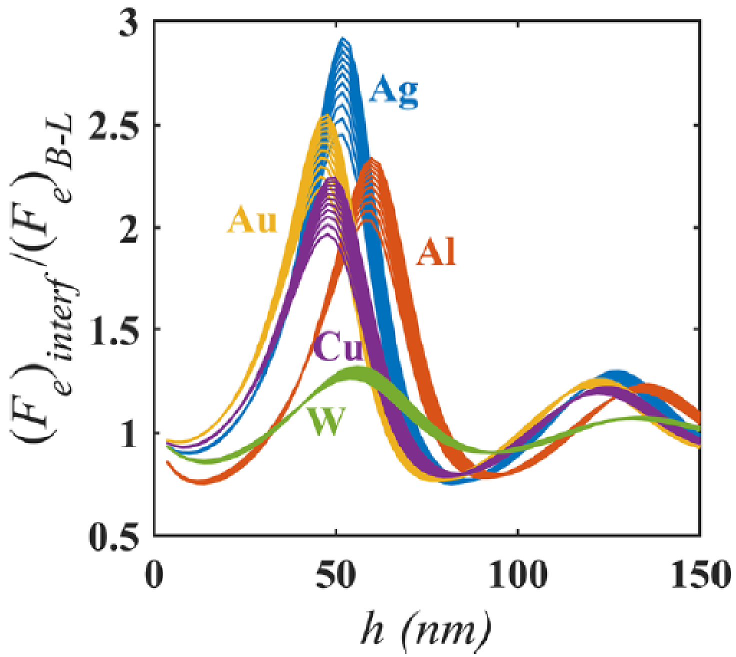
$$E_x = E_o e^{i\omega t}(c_f e^{i\tilde{n}_{\mathrm{PC}}kx} + c_b e^{-i\tilde{n}_{\mathrm{PC}}kx}).$$

$$a(x) = I_o^f |e^{-(x/2\lambda_{opt})} + r_{PC-S} e^{2i\tilde{n}_{PC}kh} e^{(x/2\lambda_{opt})}|^2;$$

$$F_e = \int_0^h a(x) e^{-(x/\lambda_{esc})}\, dx$$

$(F_e)_{interf}$ includes forward and back ward waves.

$(F_e)_{B\,\_\,L}$ only include forward waves.



Alexander, Moody, and Bandaru, Journal of Vacuum Science & Technology B, 022202 (2017),

Experiment

Cathode order: 5 nm, 15nm and finally 10 nm

Measure:

1. QE measurement at the center.
2. QE and thermal emittance varied with electric field at the center
3. Thermal emittance map
4. QE map (automatic measurement at night)
5. Injector emittance at XFEL working point (probably one day)
6. Redo the QE map and thermal emittance map

a. QE & QE map – homogeneity, thickness effect on QE (reflection, more amount of Cs2Te can be used)
b. Thermal emittance vs Electric field : a method to estimate the roughness
c. Thermal emittance map : homogeneity, the correlation with QE
d. Injector emittance at XFEL working point (cathode’s influence on the moderate charge operation)
e. Redo the map measurement (to see any degradation on the cathode, dark current induced bombardment, chemical poisoning , laser cleaning,…)