Development of “green” photocathode

▪ Thesis status Updates

Sandeep Kumar Mohanty
PPS
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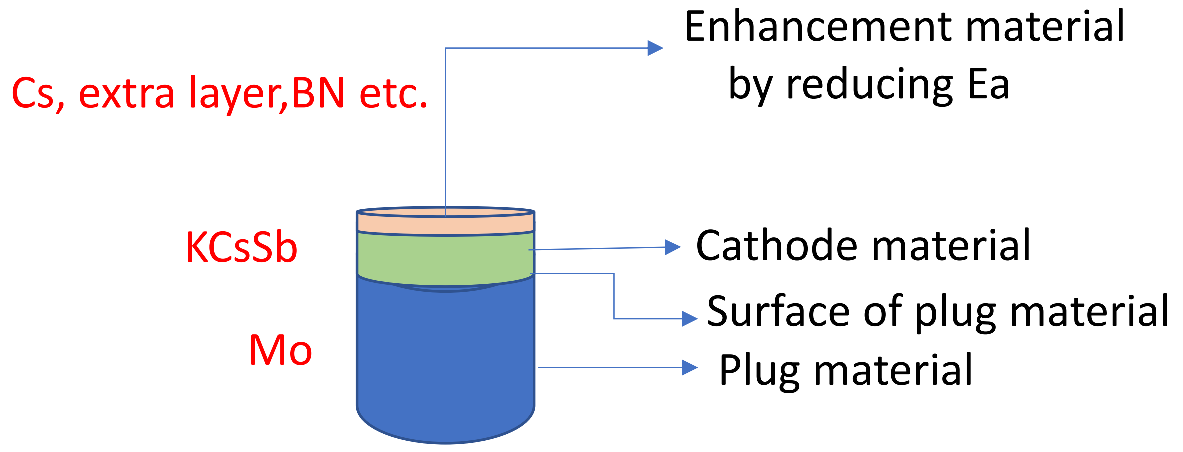
NaKSb(Cs) or S-20 Photocathode

Factors affecting on Photocathode properties

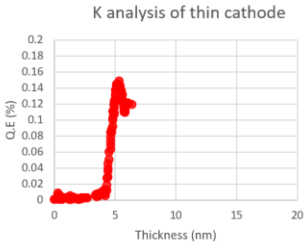
- **Plug material**: Conductivity, avoid diffusion of film material (Mo, Si, Steel)
- **Surface**: Cleanliness and flatness (thermal emittance, unwanted contaminants especially oxides)
- **Cathode material:** Stoichiometry , crystal structure and orientation
- **Enhancement material**: special material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



Motivation

- High Q.E (relatively similar to KCsSb based cathode) at the green wavelength
- Can withstand at higher temperature
- Low response time (below 1 ps) (according to Cornell University data)
- Low intrinsic emittance
- Wide range of spectral response especially in the visible spectrum (active up to 830 nm)
- Comparatively less studied than the KCsSb photocathode

NaKSb(Cs) sequential growth analysis



Sb + K → K_3Sb → + Na → Multiple deposition with Sb,K, Na → Deposition of CsSb layer

Sb

We put 5 or 10 nm

- Sb 5nm = Thin
- Reflectivity fall up to 30% (Sb 8 nm)

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

Same as KCsSb cathode

Na

Untill reach the Photocurrent yield

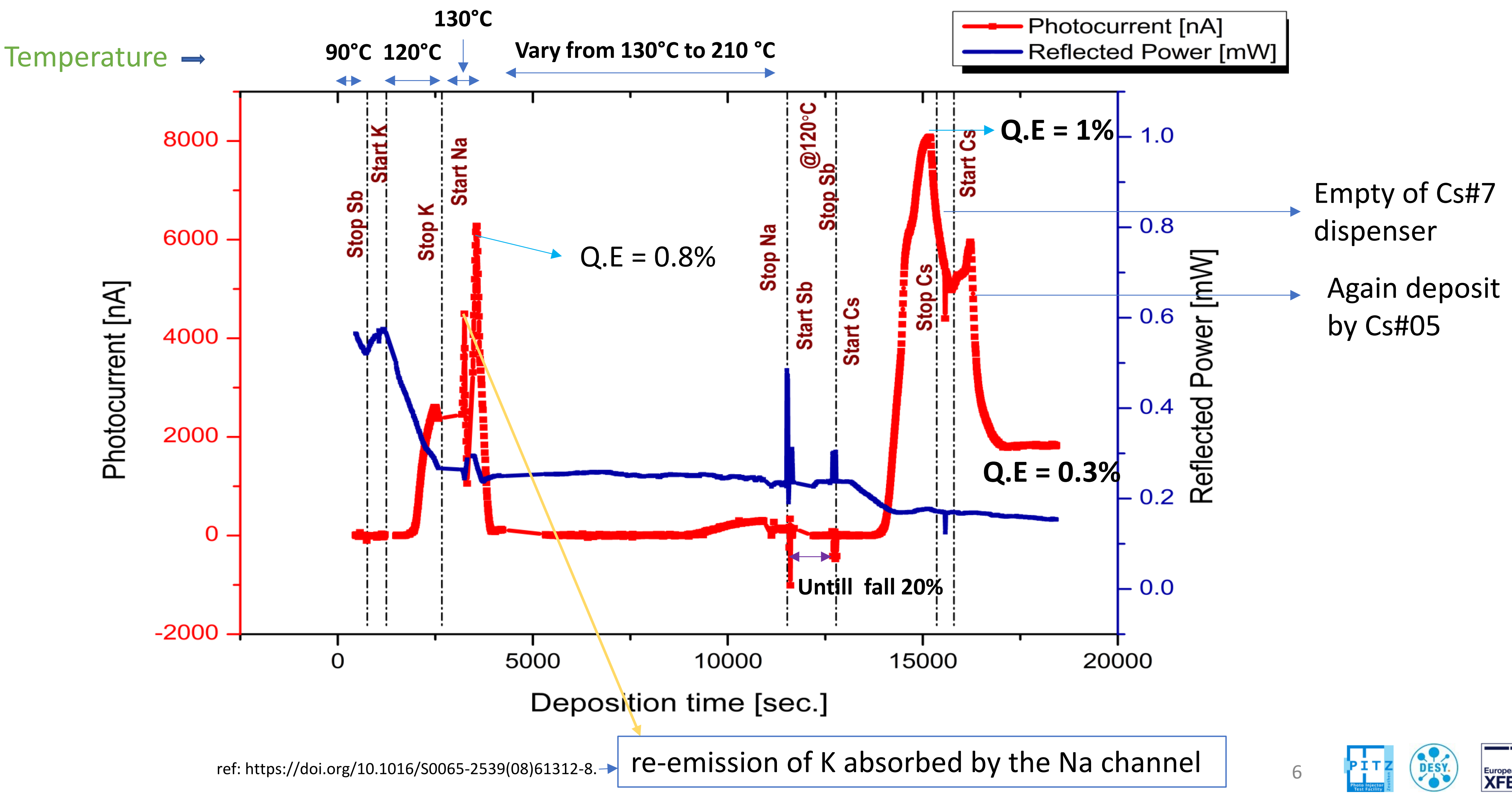
Multiple deposition with Sb,K, Na

Formation of NaKSb

Deposition of CsSb layer

Formation of NaKSb(Cs)

NaKSb(Cs)-1 (Sb= 5 nm)



ref: https://doi.org/10.1016/S0065-2539(08)61312-8.

KSb Phase

XPS data from Sonal PhD thesis

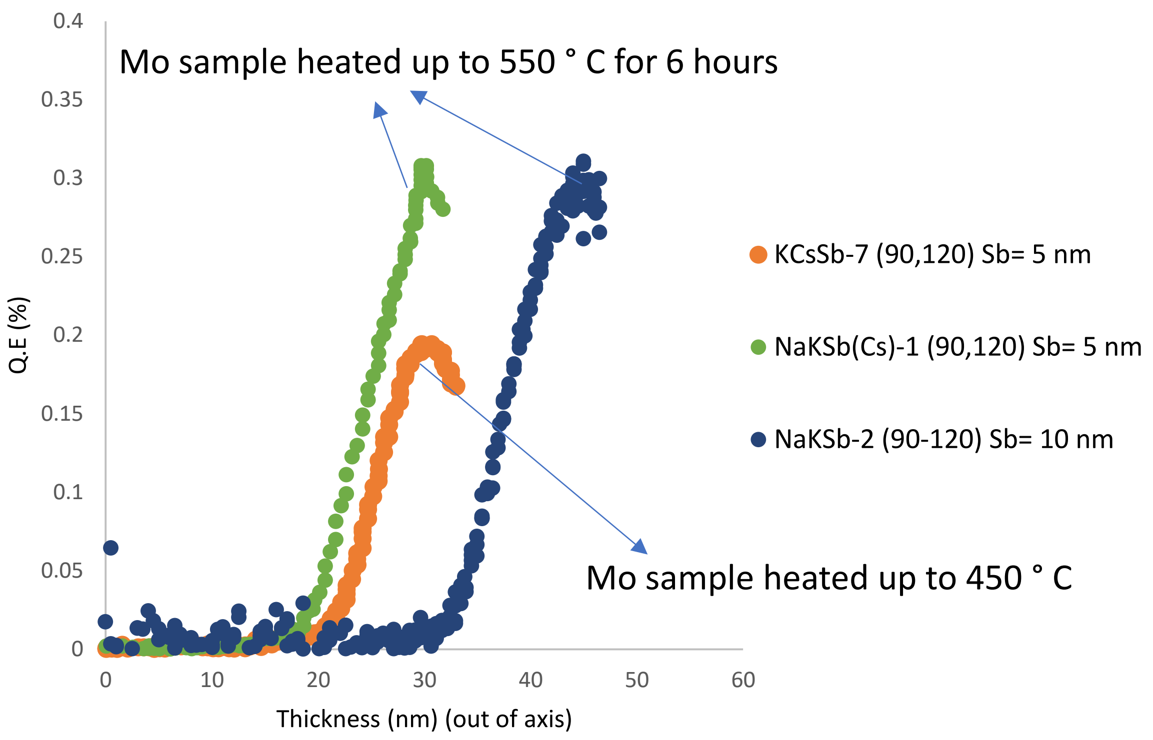
TABLE 4.7: Summary of quantitative XPS data from Mo 3d region spectra.

Ar plasma treated Mo	Mo metal (%)	MoO2 (%)	MoO3 (%)
Ar plasma	37	0	63
Heated 250°C	46	43	11
Heated 450°C	67	33	0
Heated 550°C	86	14	0

ref: https://repository.lboro.ac.uk/articles/Preparation_and_evaluation_of_metal_surfaces_for_use_as_photocathodes/9410345

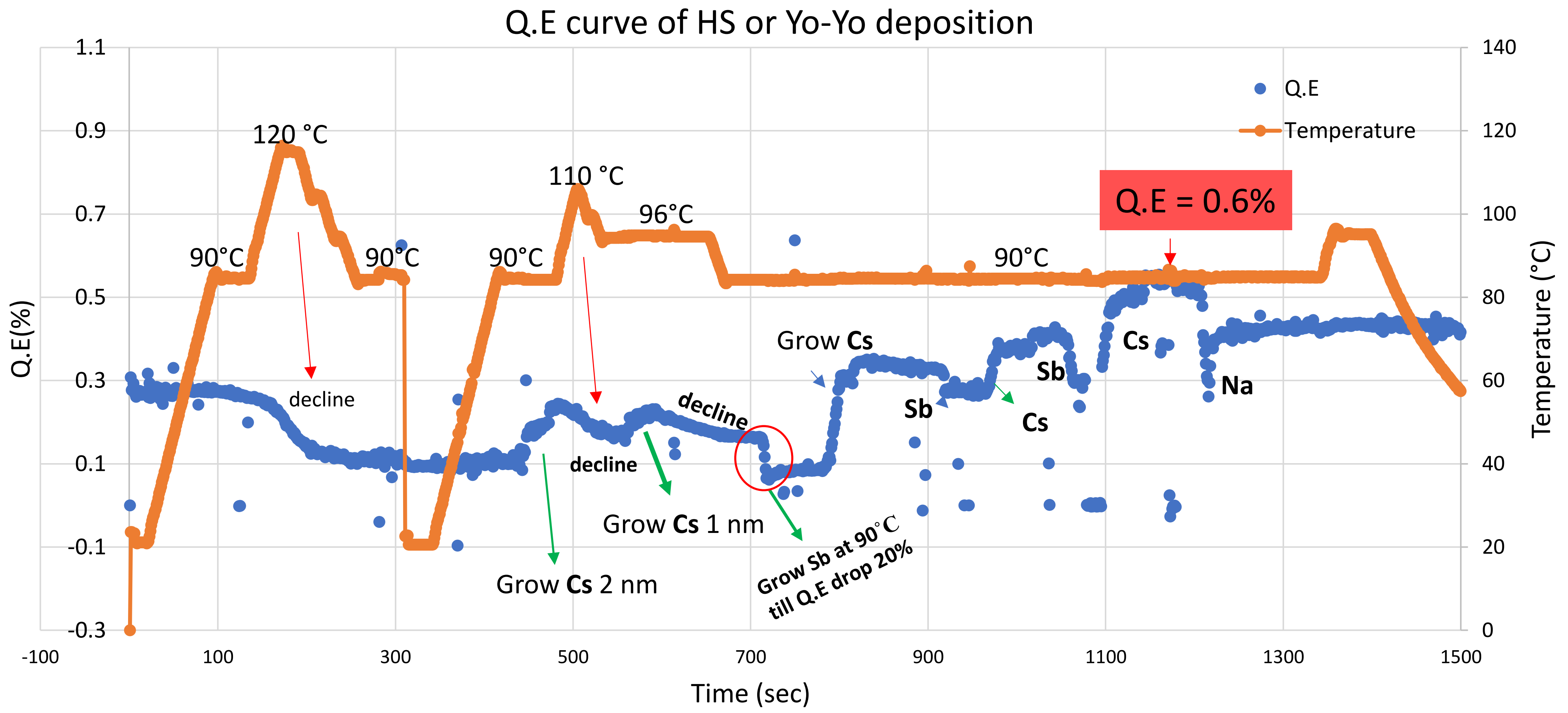
- Improve in Q.E could be a result of better surafce quality with less oxides layers on Mo sample.

KSb growth analysis of NaKSb compare with KCsSb cathodes



@543 nm

Yo-Yo or Heterostructure growth



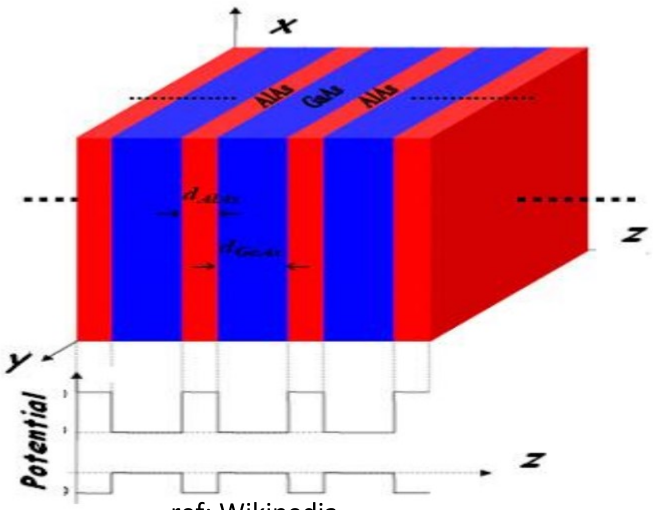
Initial Q.E 0.3%-> Cs(2nm @120) -> Cs(1nm@110)->Sb(@90)->Cs(@90)->Sb(@90)->Cs(@90) [Final Q.E 0.6%]->Na

Mechanism of Super lattice and Hetero structure

Hetero structure : Growing a two dissimilar semiconductor material material by layer up on layer method. Generally these materials are having different bandgaps and lattice contacts. The junction of these two materials are known as heterojunction.

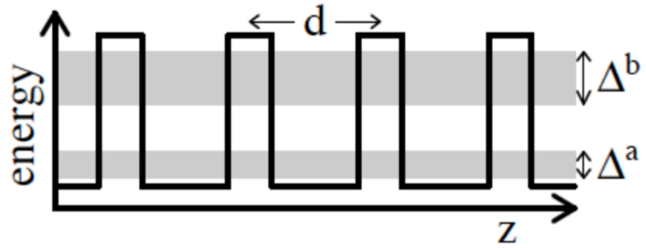
Superlattice heterostructure: Growing multiple heterojunctions of two different materials with periodic repetition. But generally here thickness of each layer is very thin (1-10 nm depending up on lattice mismatch)

Advantages: superlattice could also be used as THz source generator since **Bloch** oscillation is possible due to larger lattice constant which leads to a larger oscillation frequency in THz range.
e.g.: Santa Barbara FEL, frequency doubling and tripling of THz radiation in a voltage-biased GaAs/AIAs



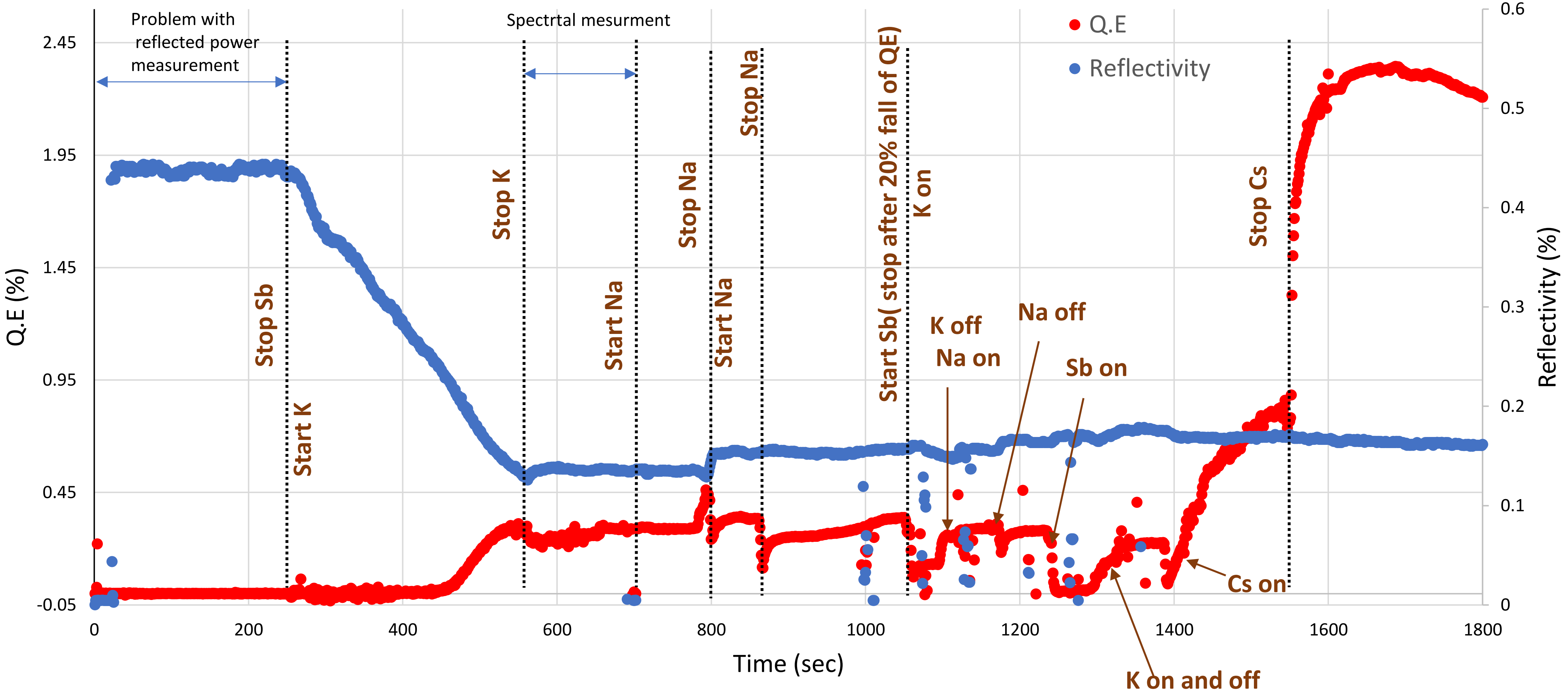
ref: Wikipedia

- barrier width is small enough that the different quantum wells are coupled with each other.
- Mobility of charge carriers can be enhanced, hence we can see a increase in Q.E.



Very complex

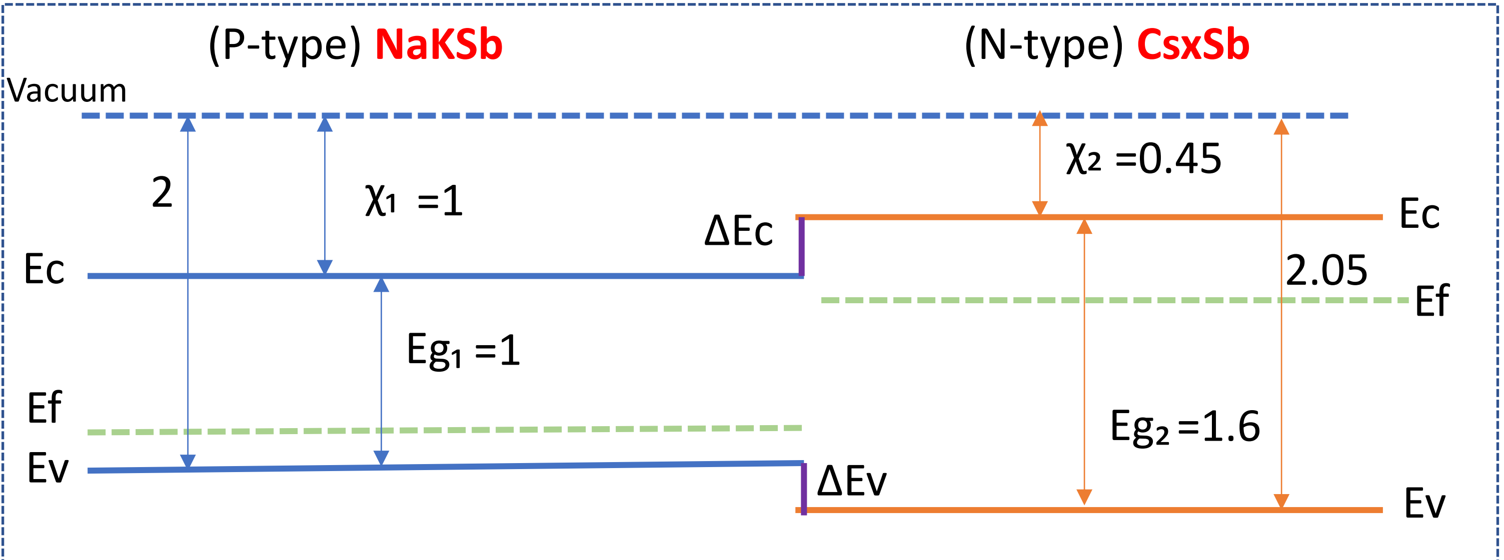
NaKSb(Cs)-2 (Sb deposition untill reflectivity fall up to 30%)



Sb (7nm)@90°C -> K(until max.)@120°C->Na (until max.)@90°C ->Sb->K->Na->Sb->K->Cs

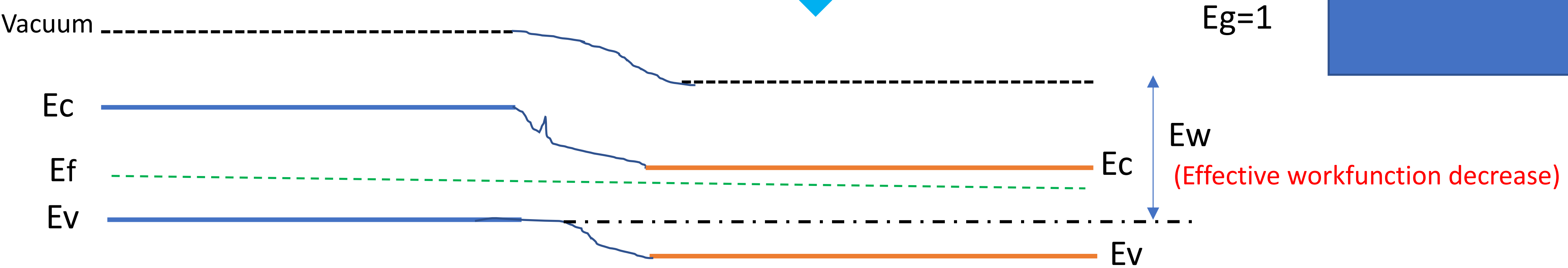
Yo-Yo

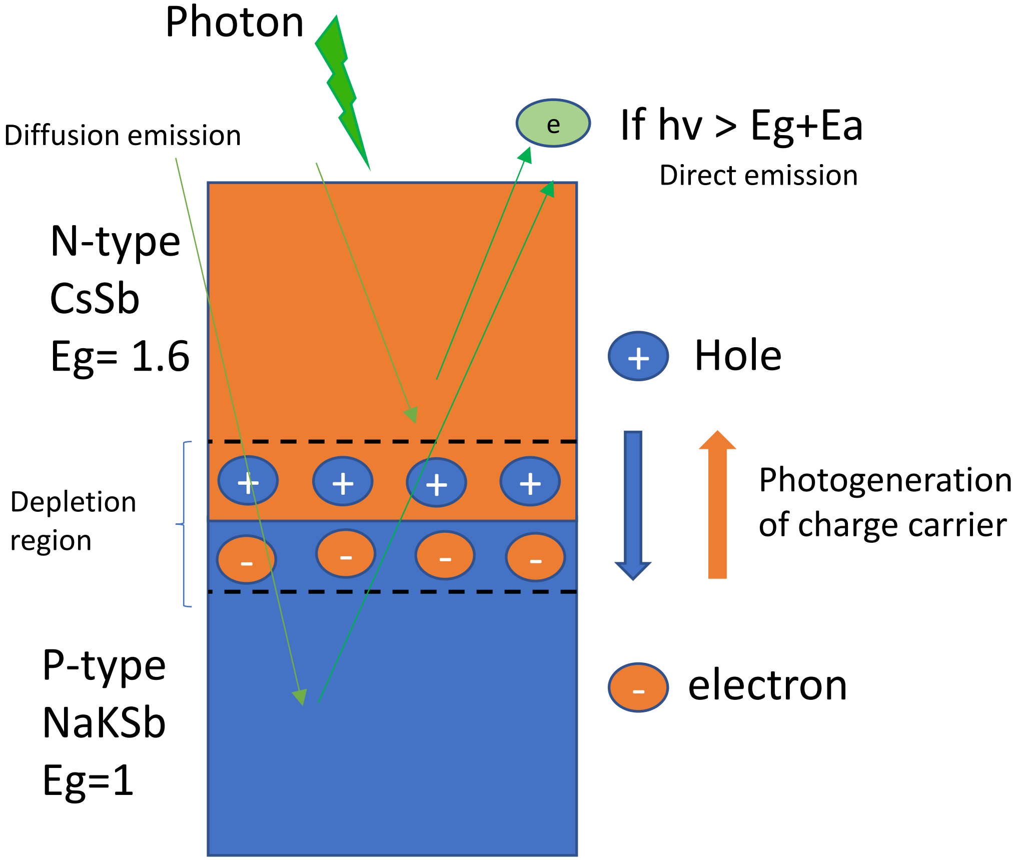
Mechanism of NaKSb(Cs) based photocathode



$\Delta E_c = \chi_1 - \chi_2 = 1 - 0.45 = 0.55$

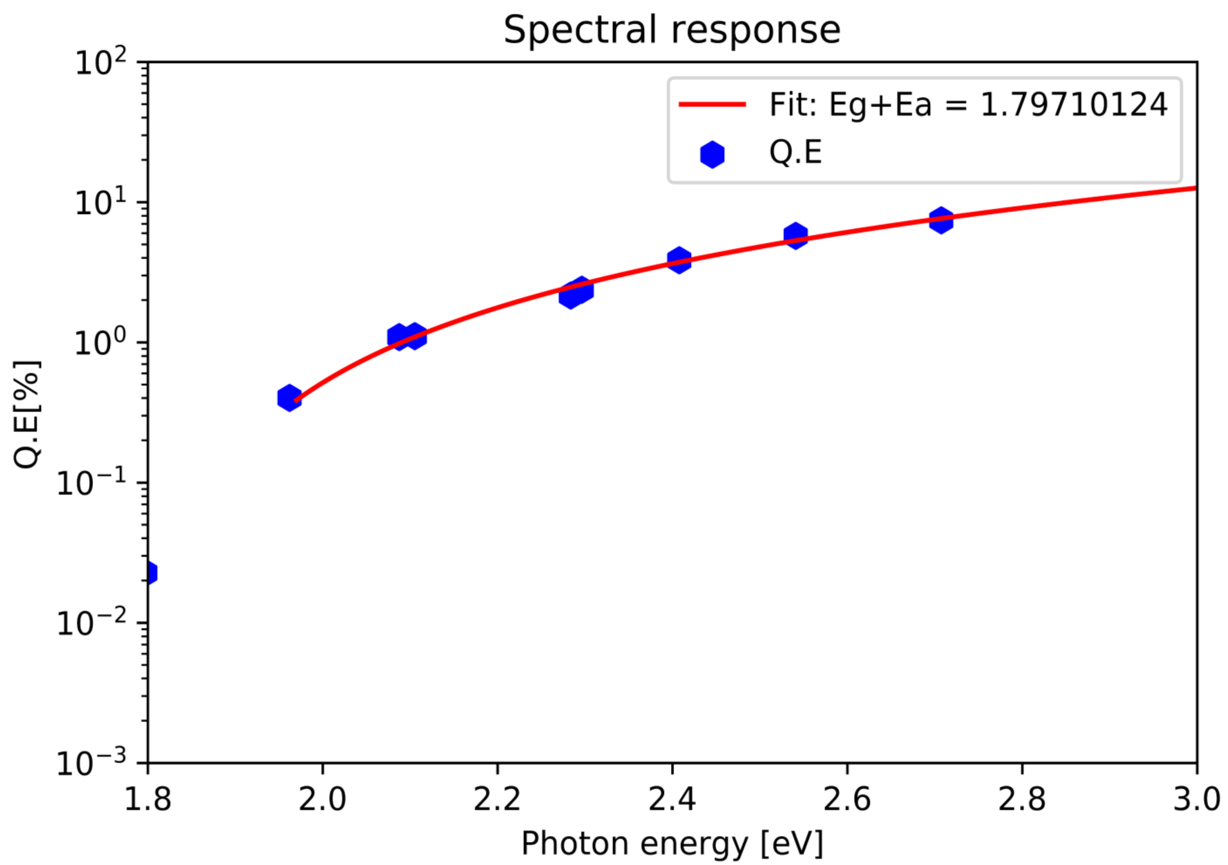
$\Delta E_v = \Delta\chi - \Delta E_g = 2 - 2.05 = -0.05$





X = electron affinity, Ec,Ev,Ef = energy of conduction, Valance and fermi level, Ew= effective work function

Compare with Spicer Model



Ethreshold = Eg+Ea

Eth NaKsb = 2

Eth NakSb(Cs) = 1.75

Eth KCsSb= 1.93

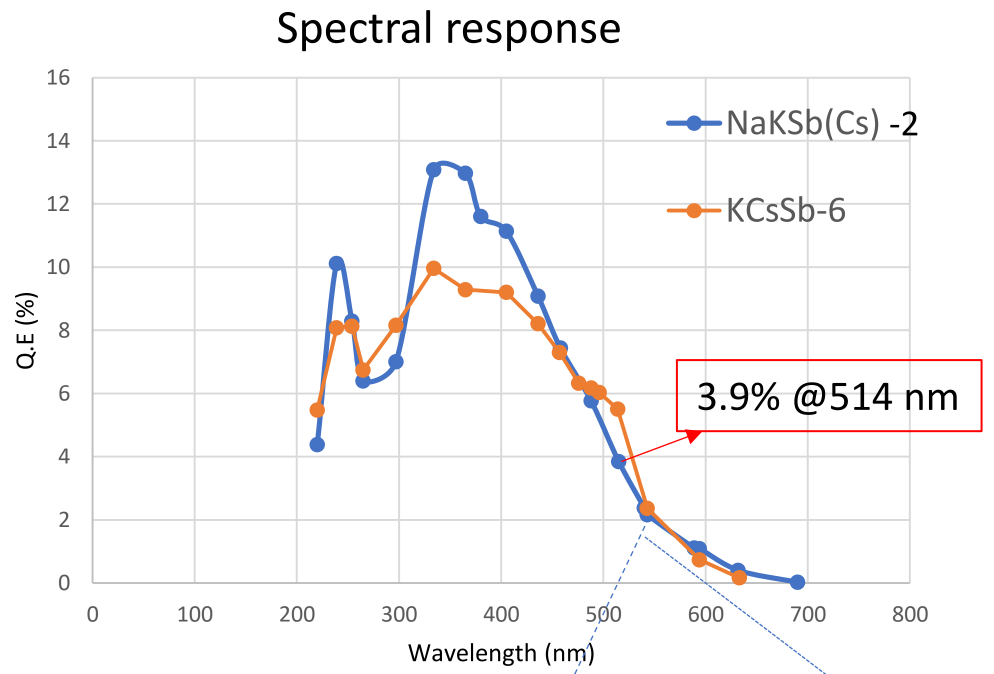
Eth CsSb = 2.05

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

Future steps,Spectral responce

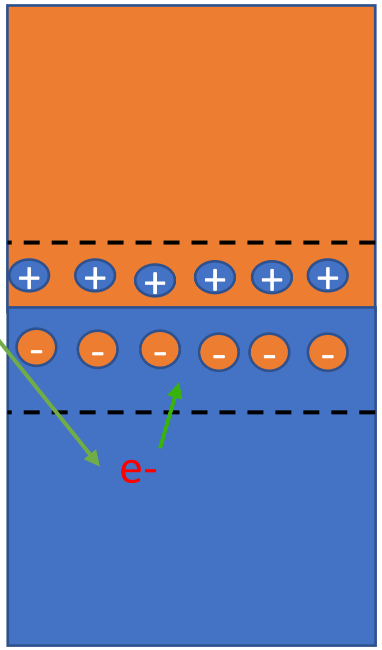
Natrajan et al. theoritical findings: @ photon energy 2.24 eV (541 nm)

Cathode	1	2	3	4	5
Width of depletion on p side (A°)	940	560	364	224	31
Width of depletion on n side (A°)	94	140	182	224	310
Q.E (electron / photon)	0.2989	0.2921	0.2823	0.2709	0.2494



At higher wavelength

Depletion side more towards
P side by increase its thickness

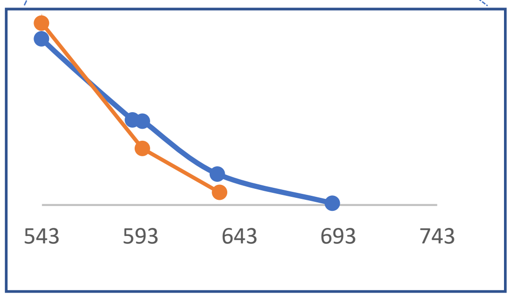


N-type

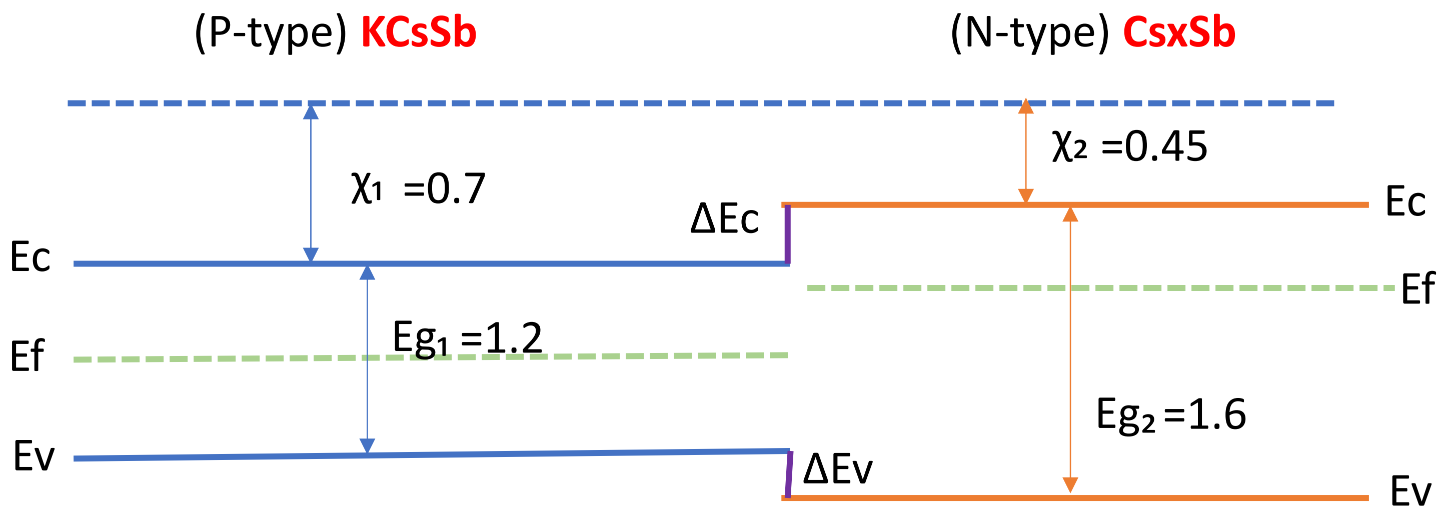
Photogeneration
of charge carrier

P-type

Improvement in QE
At higher wavelength



Try the superlattice type of growth on KCsSb photocathode

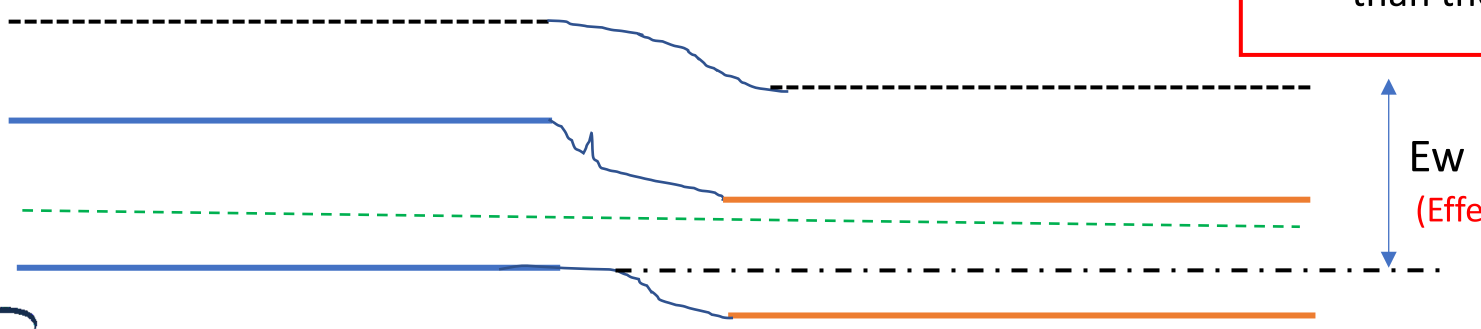


Worth try!!!

$\Delta Ec = \chi_1 - \chi_2 = 0.7\text{-}0.45 = 0.25$

$\Delta Ev = \Delta\chi - \Delta Eg = 1.9\text{-} 2.05 = -0.15$

- ✓ Different in band structure
- ✓ The second layer should have a small electron affinity
- ✓ Band gap (Eg_1) of first layer should be smaller than the second layer



Importance varity of photocathode

- We can customize our photocathode according to our requirment
- Understand the mechanism of different photocathodes through brief comparison.

- For example , QE is not always very important interms of better beam quality
- Low emittance could improve the beam quality too.

intrisic emittance = $\sigma_x \sqrt{\frac{MTE}{mc^2}}$

Red color is not bad!

$$\text{MTE} = \frac{(h\nu - \varphi\,)}{3}$$ (simple model)

- If we have QE(NaKSb(Cs))= 0.4%(632 nm), 0.022% (690 nm) for NaKSb photocathode then we can generate beam like metals , Q.E (Cupper) = 0.014 % @266 nm

Cornell lab

- 1MHz high brightness photoinjector delivering 100 pC bunch charges from NaKSb using 690 nm light.
- They tested in a high voltage DC gun and registered an increase in wavelength decrease in intrinsic emittance, for them the QE was 0.0002% @690 nm.

Ref: https://aip.scitation.org/doi/am-pdf/10.1063/1.4922146

Outlook

- KCsSb photocathodes recipe are reproducible with around 6% Q.E @514 nm and with 17 % Q.E threshold @ 297 nm.
- Further optimization is possible for KCsSb cathode. Some hypothesis will discuss in next talk.
- Hetero structure type of growth could be try on KCsSb photocathodes to improve Q.E.
- More optimization/test is needed for NaKSb(Cs) to finalize the recipe.
- Develop an another kind of phtocathode i.e, Cs_3Sb Photocathode could be possible, since last part of NaKSb(Cs) cathode is similar.
- Wide variety of photocathodes gives us the customize option.
- 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

- Single type (KCsSb, NaKSb, Cs3Sb)
- Hetero structure
- Layer up on layer or Yo-Yo

Thanks!

New Cathode System (extra slide)

- 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!