

Photocathodes for high-Brightness Photo-injectors

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Outline

1. Motivation
2. Photocathode materials
3. Main challenges
4. Developing trend and new ideas
5. Summary

ELBE.

HZDR



 HELMHOLTZ
ZENTRUM DRESDEN
ROSSENDORF

1. Motivation

Electron source application

High power linac-based FELs

High current ERLs

Polarized source for future
electron-ion collider

Other uses ...

Challenge for photocathodes

High quantum efficiency (QE)

Long life time / robust

low thermal emittance (cold)

prompt time response

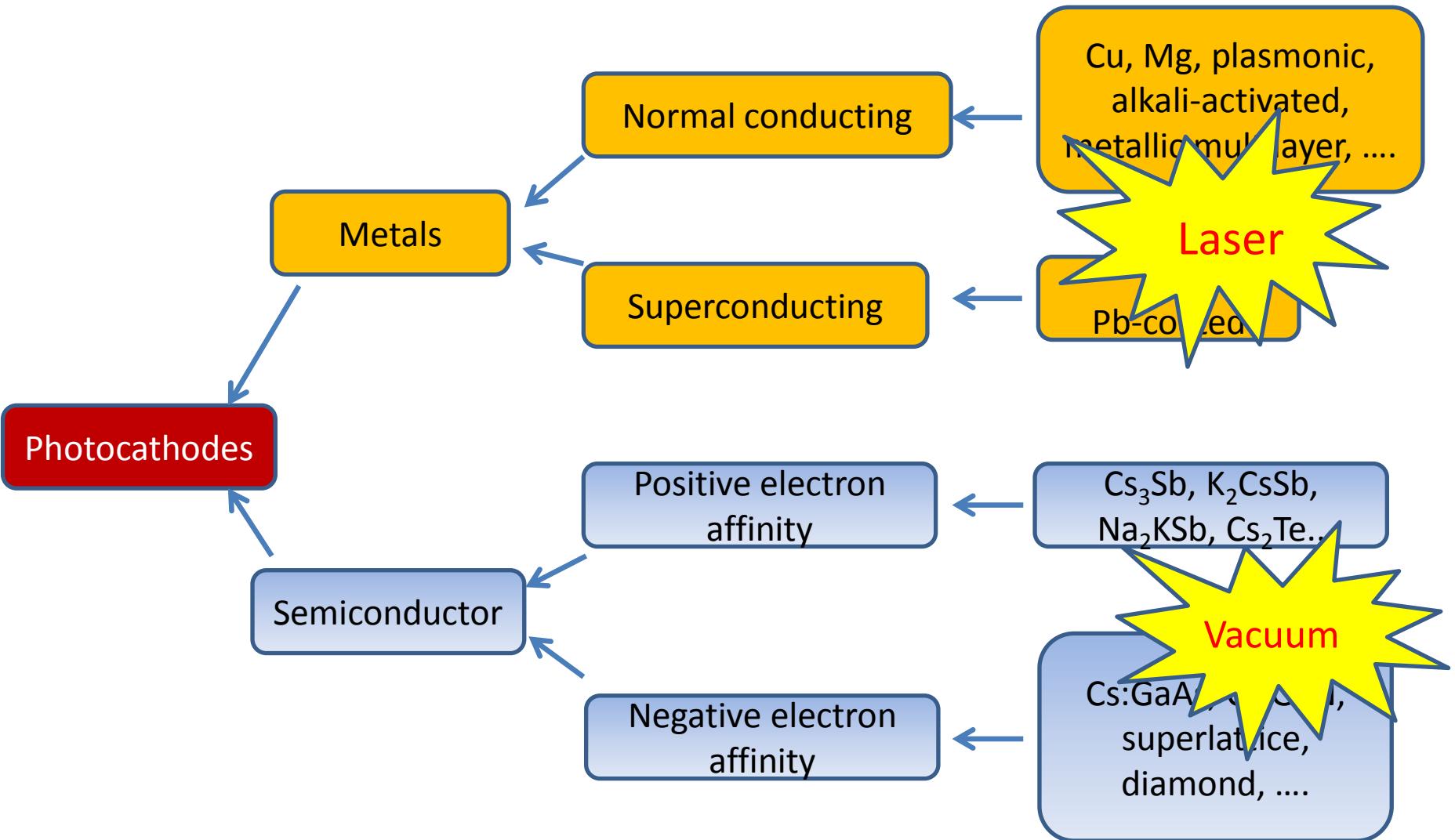
....

$$B_n = \frac{2I}{\pi^2 \epsilon_{n,x} \epsilon_{n,y}}$$

For higher brightness,
beam current \uparrow , emittance \downarrow



2. Photocathode materials



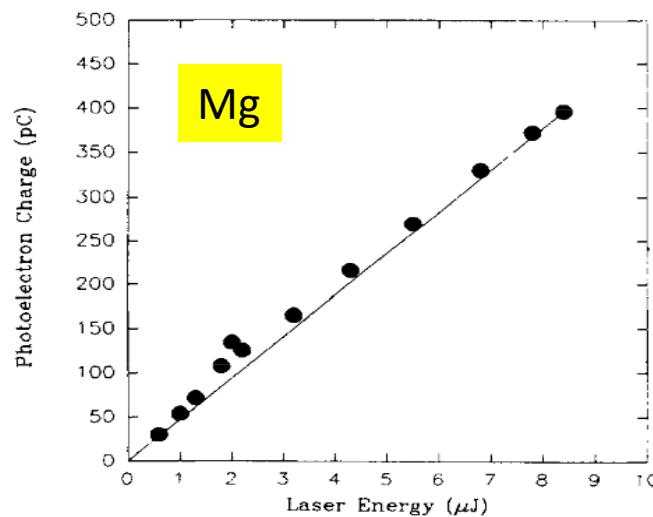
2. Photocathode materials

Metal
Conventional

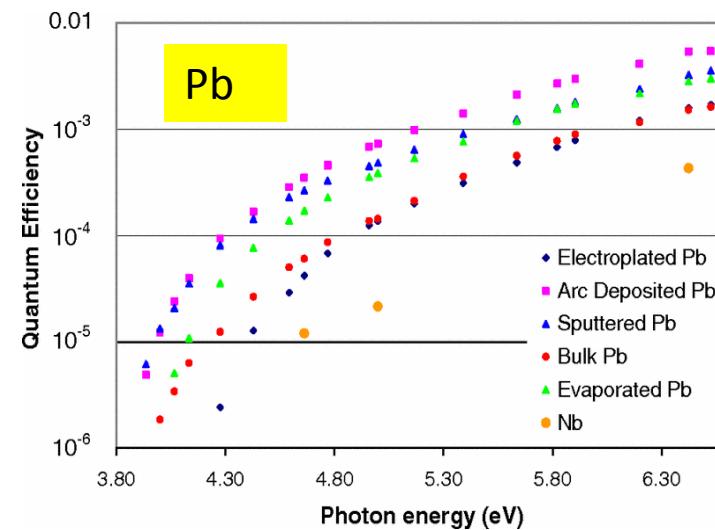
best life time, robust
Fast response time
Low thermal emittance



Low QE → Powerful UV Laser



50MV/m, 2.5×10^{-4} @266 nm

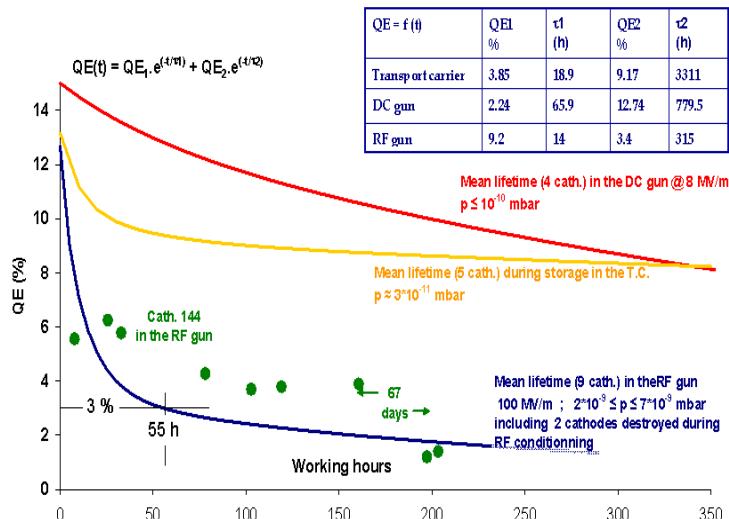


0.2% @ $\lambda < 213$ nm, for all-SRF gun

2. Photocathode materials

PEA semiconductor
 Cs_2Te , Cs_2KSb , ...

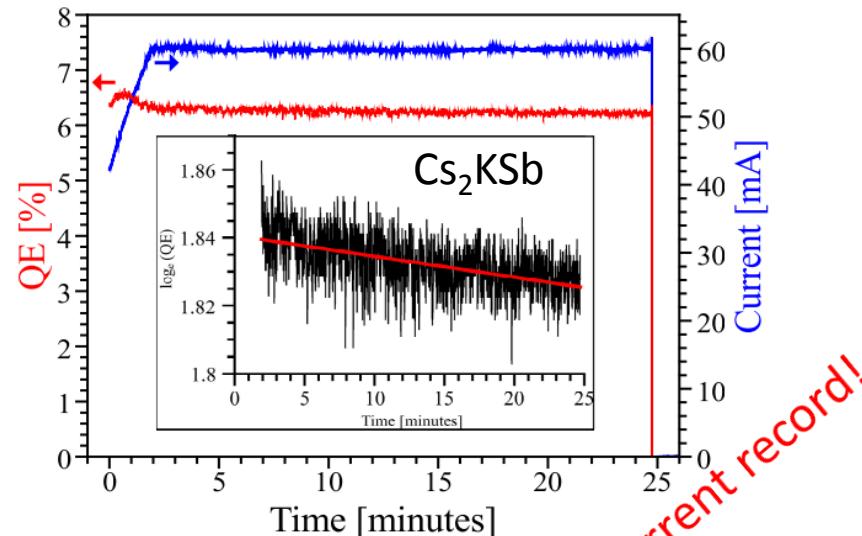
High QE >10%
long life time in XHV
Fast response time
Low thermal emittance



Cs_2Te photocathodes

RF guns: CERN, DESY, LBNL, KEK

SRF gun: HZDR, PKU



Alkali-antimonide

DC guns: Cornell

RF guns: CERN, LBNL

SRF gun: HZB, BNL

2. Photocathode materials

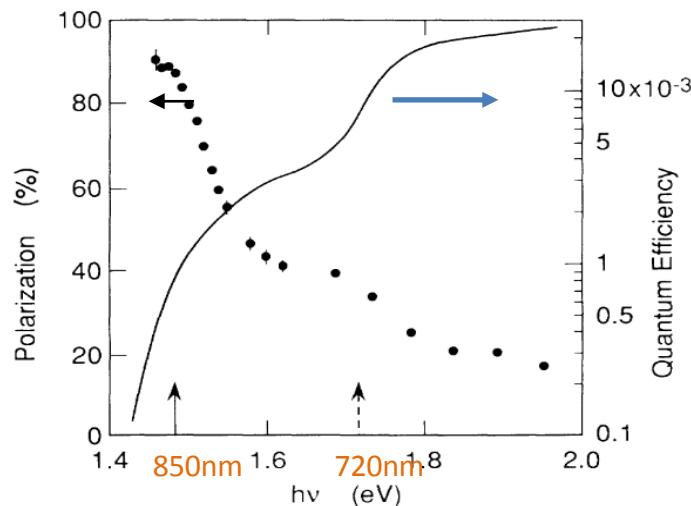
NEA Semiconductor GaAs(Cs,O)

DC guns: JLAB, SLAC, MIT, Cornell,
Daresbury, Mainz, Darmstadt, KEK
SRF guns: BNL, HZDR

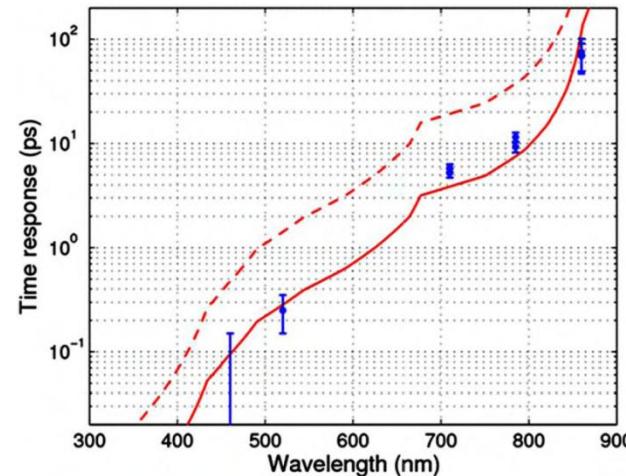
Possible spin-polarized electron source
High QE @ visible wavelength
Very cold beam (meV MTE)



Extremely sensitive
Response time -> long pulse tail
NEA -> unwanted beam



T. Maruyama, et al., Phys. Rev. B 46, 4261



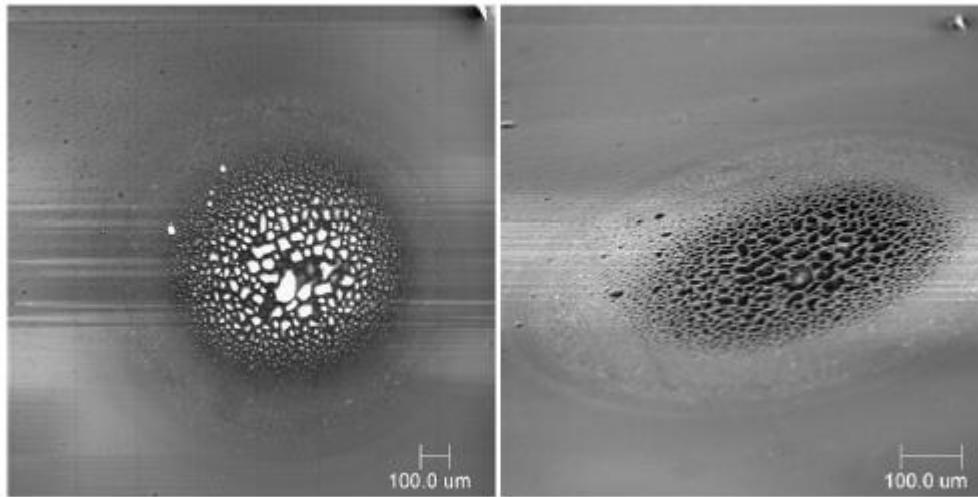
Book from T. Rao and D. H. Dowell, ISBN-13: 978-1481943222, ISBN-10: 1481943227



3. Main challenge

1. Cathode life time (user beam time)

- Vacuum ($< 10^{-11}$ mbar)
- Ion beam back bombardment
 - reduce rest gas around cathode
 - cathode away from the beam axis
- Protective coatings?



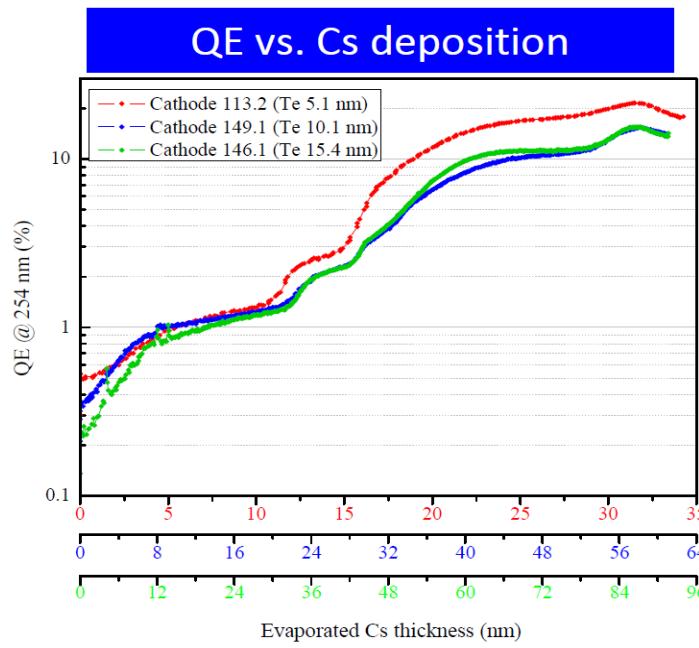
SEM micrographs of the used K_2CsSb photocathode

L. Cultrera et al., *PRSTAB* **14** (2011) 120101

3. Main Challenge

2. Higher Quantum Efficiency (deemphasize laser requirement)

- Vacuum in preparation chamber ($< 10^{-11}$ mbar)
- Good growth recipes, accurate deposition control
- Material fundamental understanding (theoretical work)
chemical stoichiometric
lattice structure, interface physics, surface topography



QE of Cs_2Te only depends on the stoichiometric rate

Daniele Sertore, workshop for photocathodes in RF guns, 1-3 Mar. 2011, Italy

3. Main Challenge

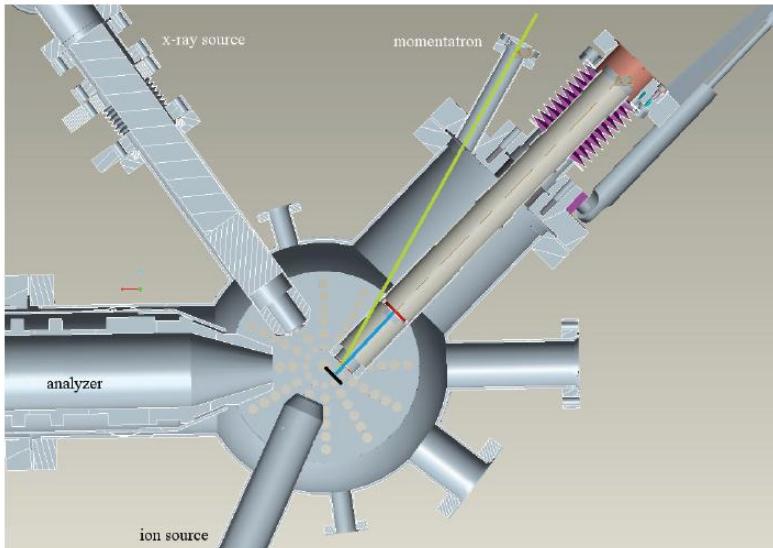
3. Low Thermal emittance

- Theoretical work
- Surface topography
- Measurement methods for meV energy

Normalized emittance:

$$\epsilon_{nx,th} = \sigma_x \sqrt{\frac{MTE}{3m_0c^2}}$$

Mean Transverse Energy (MTE): $k_B T = \frac{\sigma_{p_{x,y}}^2}{m_e} = \langle m_e v_x^2 \rangle = \left\langle \frac{1}{2} m_e v_x^2 + \frac{1}{2} m_e v_y^2 \right\rangle$



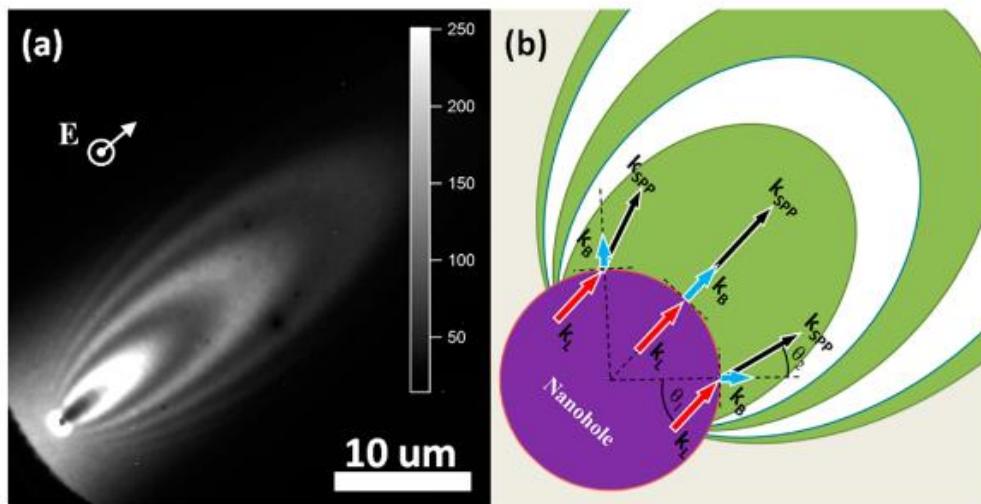
One of the measurement idea
In-situ momentumtron

M. A. H. Schmeißer, et al., IPAC2014, Dresden, Germany

4. Developing trend and new ideas

1. modify present cathodes with novel methods

- Improve the life time through protect layer
- Improve QE of metals with alkali treatment
- Plasmonic enhancement
- Needle cathode



Surface Plasmon Assisted
Photoemission on gold thin film
magnitudes enhancement

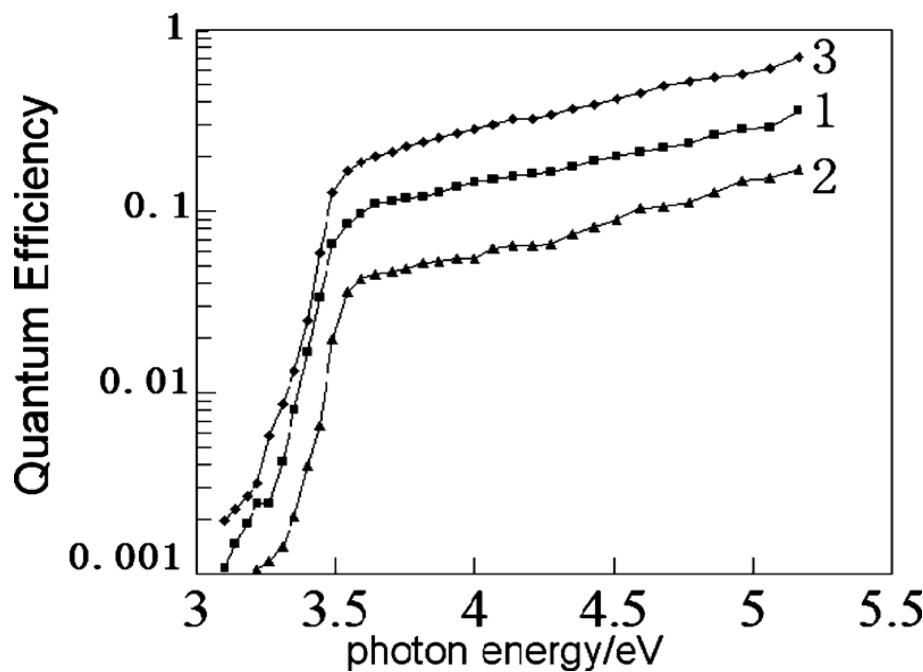
Gong, Hess, et al., *J. Phys. Chem. C*, 2014, 118 (44), pp 25671–25676

A. Mustonen et al., *Nanotechnology* 25, 085203 (2014)

4. Developing trend and new ideas

2. Search for new material

- NEA GaN(Cs) : UV driven, high QE, robust
- Diamond amplifier
- Multilayer



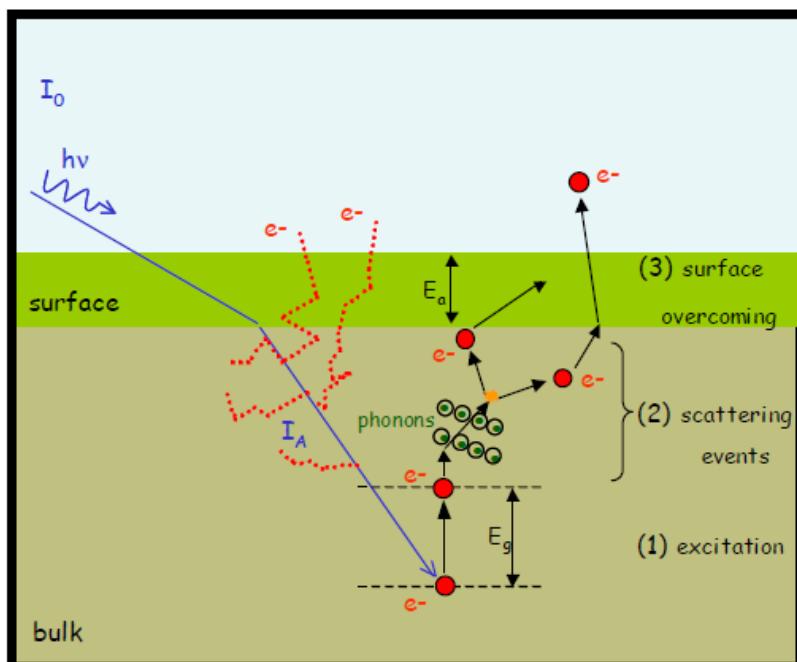
GaN(Cs) highest QE 68.7% @ 240 nm

X. Guo, et al., APL **97**, 063104 (2010)

4. Developing trend and new ideas

3. Theoretical work

- Better photoemission process understanding
- Surface science theory
- Study beam dynamics near cathode
- Computer simulation (dynamics simulation code)
-



Quantum photoelectric effect
and
three-step theory
(WE Spicer - Applied physics, 1977)

Daniele Sertore, workshop for photocathodes in RF guns, 1-3 Mar. 2011, Italy

5. Summary

Work for a “dream” photocathode for high brightness beam
High QE, Long life time, Low emittance ...

- ✓ Optimize growth parameters to improve cathode quality and reproducibility
- ✓ XHV technology for preparation, transfer, and gun.
- ✓ Theoretical study
- ✓ Characterize photocathode accurately
- ✓ Develop cooperation between labs / share of facilities
- ✓

Thank you for your attention