Photocathode development for accelerator in Japan

Laser - aided Accelerator Association (LAAA)

This report is a summery of discussion in LAAA
(Oct. - Nov. 2006') about photocathode
development for an accelerator in Japan.

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About Cesium-Telluride

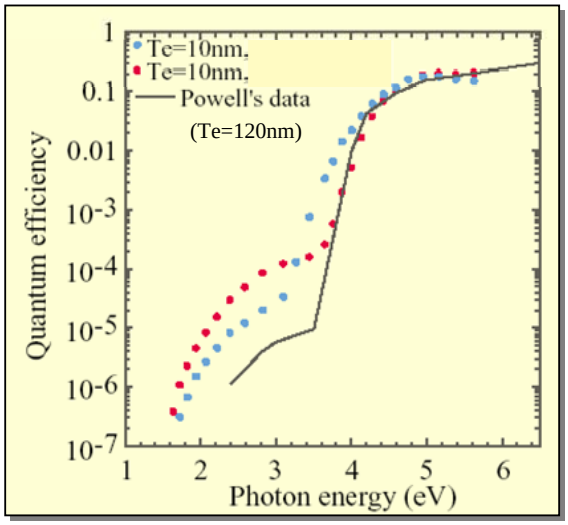
1, Wavelength of excitation light
2, Transparent type photo-cathode
3, Deterioration of QE

1. Wavelength of excitation light

・Differential of QE spectrum around the leading edge ~ 0.5eV

・Width of leading edge depends on crystalline or formation (●, ●)

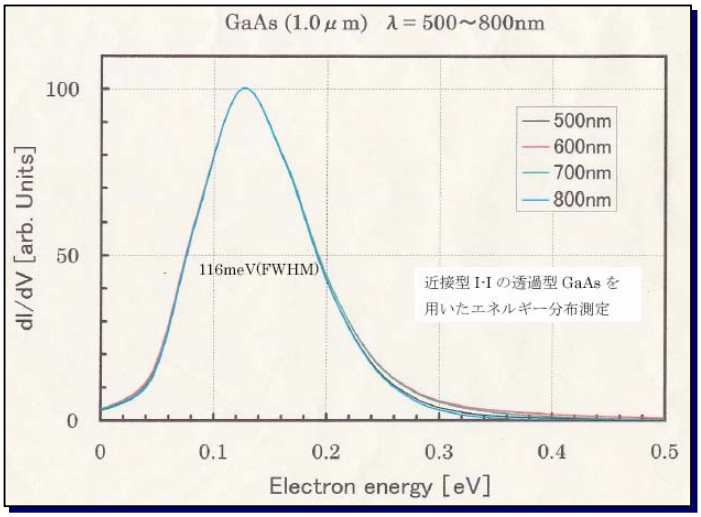
・ Behavior below the gap depends on thickness <= diffusion effect ?



[Ref] R. A. Powell, W. E. Spicer, G. B. Fisher and P. Gregory: Phys. Rev.B.8 (1973)
H. Sugiyama et al., Proceeding of The 30th Linear Accelerator Meeting in Japan ,pp.99-101(2005)

2. Transparent type

1. Backward Illumination with 3D-shaped laser pulse
2. Monochromatic energy by thermalization process

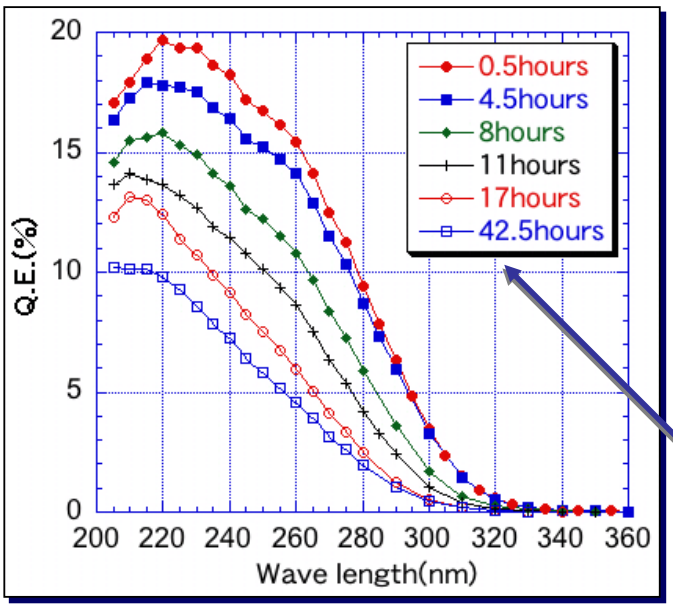


From Sasabe (Hamatsu Photonics) : GaAs+NEA cathode

This type of cathode might be realized with CsTe (much as PEA)

[ref] J. Sasabe et al., NIM A, 528, pp.382-386, 2004

3. Deterioration of QE



- Q.E. dropping was measured at all wavelength.
- Peak of Q.E. seems to be shifted to the shorter wave length. It suggests the electron affinity is changing

Effect of Oxidation ?

RF field is impressed
@ KEK-ATF

[ref] N. Terunuma, http://wwwlasa.mi.infn.it/WSPhotocathodes/proceedings

NEA-GaAs photocathode

: A GaAs semiconductor with an negative electron affinity surface

•High Quantum Efficiency(QE)

Bulk-GaAs :1-4% (870nm @band-gap), 10% (shorter wavelength than 650nm)

Thin-GaAs type polarized electron source : 0.6%(770nm), 1%(740nm)
(thickness<500nm) GaAs-GaAsP GaAs-AlGaAs

•Small Energy Spread

An energy spread of excited electrons by band-gap energy is small(<0.1eV?).
(vacuum level is near the bottom of a conduction band. Excited electrons by band-gap energy can be extracted to a vacuum through the bottom of a conduction band.)

•High Polarization

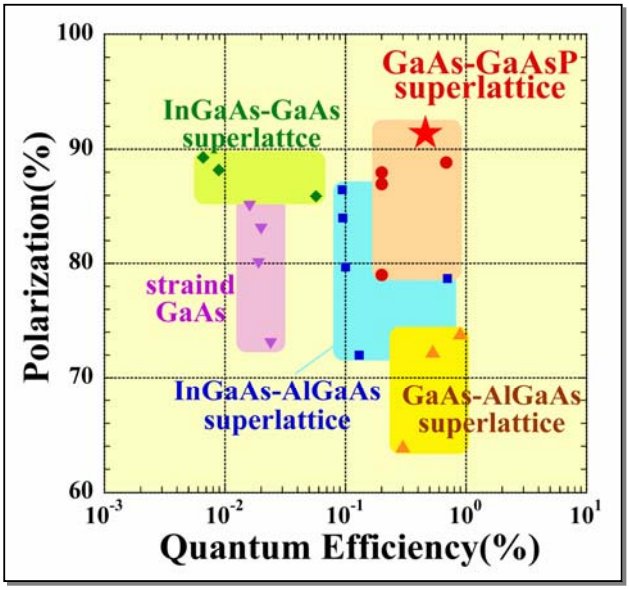
Possible to generate polarized electrons using circular polarized laser.

•Surface lifetime

An NEA surface is fragile. Extreme high vacuum is essential.

NEA-GaAs for a polarized electron source

History of photocathode development at Nagoya Univ.
(**High QE** and **High Polarization**)



Polarization and QE Performance
*T.Nakanishi et al., NIM A 455 (2000) 109.
T.Nishitani, et al., J. Appl. Phys. 97 (2005)

➢Straind GaAs (1990~)
Polarization > 50% breakthrough.
[ref] T. Nakanishi, et al., Phys. Lett. A158, 345 (1991)
T.Saka, et al., J. Crystal Growth 124 (1992) p346-351

➢GaAs-AlGaAs superlattice (SL) (1990~)
The first SL photocathode with high polarization.
[ref] T. Omori, et al., Phys. Rev. Lett. 67, 3294 (1991)

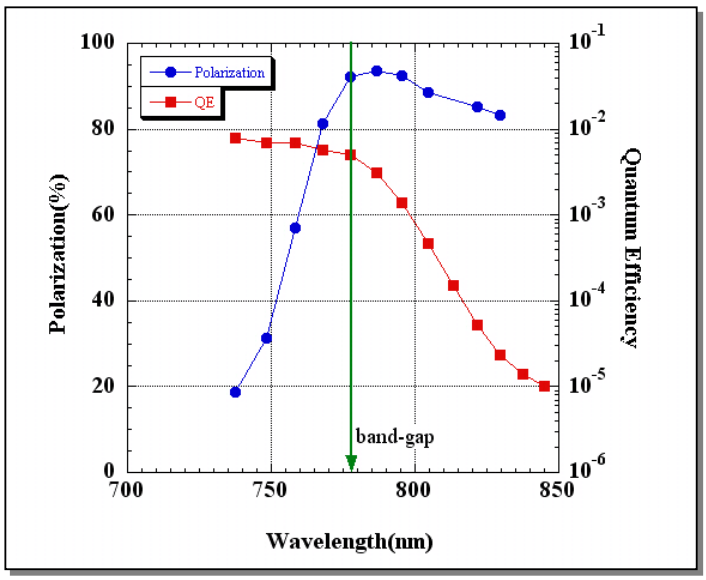
➢InGaAs-GaAs strained layer SL (1994~)
The first SL photocathode with a strained layer structure.
[ref] T. Omori, et al., Jpn. J. Appl. Phys. 33, 5676 (1994)

➢InGaAs-AlGaAs strained layer SL (1996~)
Higher Q.E. than that of InGaAs-GaAs SL.
[ref] T. Nakanishi, et al., AIP Conf. Proc., 421, 300 (1998)

➢GaAs-GaAsP strained-layer SL (2000~)
The highest performance photocathode of all test samples.
[ref] T. Nakanishi, et al., NIM A455(2000)109
T.Saka, et al., Surface Science 454-456 (2000)
T.Nishitani, et al., J. Appl. Phys. 97 (2005)

NEA-GaAs for a polarized electron source

The relationship between QE, polarization and excitation wavelength



The dependence of QE and polarization on excitation wavelength
(GaAs-GaAsP strained-layer photocathode)
T.Nishitani, et al., J. Appl. Phys. 97 (2005)

➢The excitation laser wavelength tuned to the band-gap energy is suitable for a high polarization.

➢High polarization (>80%) can achieved by photocathodes with various band-gap energy. (1.28-1.65eV / 740-920nm)

: InGaAs-GaAs, InGaAs-AlGaAs, GaAs-GaAsP strained-layer superlattice

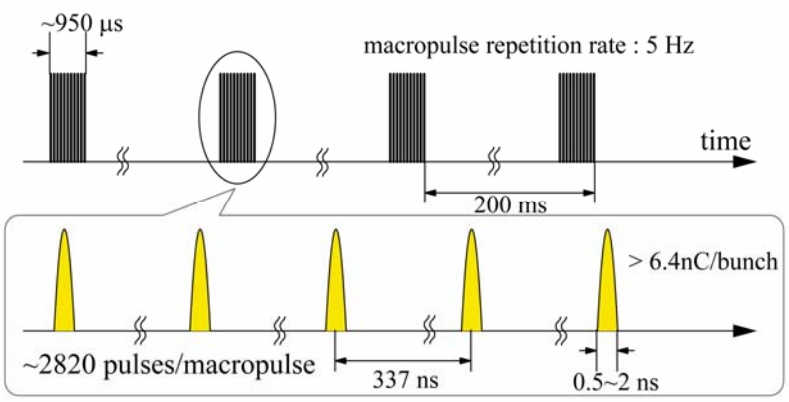
*T.Nakanishi et al., NIM A 455 (2000) 109.

➢Larger band-gap photocathode is more suitable for higher QE photocathode.

*T. Nakanishi, et al., AIP Conference Proceedings 421 (1998) p. 300-310

NEA-GaAs for a polarized electron source

Requirements for ILC



Polarized electron beam structure *http://www.linearcollider.org/wiki/

➢When QE at the excitation wavelength of 780nm is 0.1%, pulse laser energy is needed 10mJ/micropulse (~30mJ/macropulse) for 6.4nC/bunch .

➢2ns bunch width is compressed less than 50ps by sub harmonic bunching system. (Timing jitter of several tens ps may be acceptable.)

➢Energy jitter should be less than 1% (rms). (Bunch charge can induce many problems. (energy spread, beam instability,...))

NEA-GaAs for a high brightness electron source

The strategy of higher brightness photocathode than the exist GaAs (JAEA)

(**High QE**-large current- , **Small Energy Spread** and **Long Lifetime**)

- **Higher QE**
- **Longer Surface Lifetime**

  Larger band-gap energy and smaller electron affinity

JAEA PHOTOCATHODE DC-GUN FOR AN ERL INJECTOR
T. Nishitani, R. Hajima, H. Iijima, R. Nagai, M. Sawamura, N. Kikuzawa, N. Nishimori, E. Minehara
Proceedings of the 28th International FEL Conference, (2006) to be published

- **Smaller Energy Spread**

  A superlattice structure

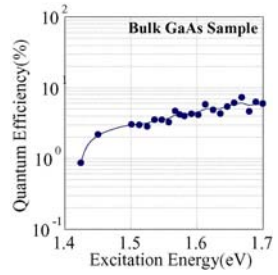
  - quantum confinement of electron energy state -

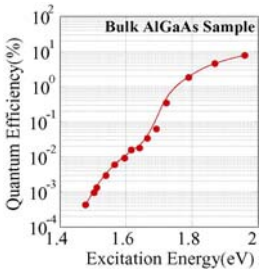
Photocathodes for the energy recovery linacs
T. Rao, A. Burrill, X.Y. Chang, J. Smedley, T. Nishitani, C. Hernandez Garcia, M. Poelker, E. Seddon, F.E. Hannon, C.K. Sinclair, J. Lewellen, D. Feldman
Nuclear Instruments and Methods in Physics Research A 557, pp.124–130, (2006)

NEA-GaAs for a high brightness electron source

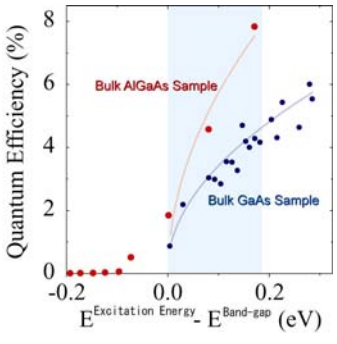
Development of a bulk-AlGaAs (JAEA & Takeda Lab.-Nagoya Univ.-)

High QE





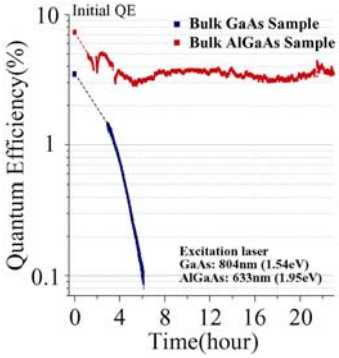
*QE spectrum of a bulk-GaAs and a bulk-AlGaAs sample.



*These samples were fabricated by Molecular Beam Epitaxy.
(Takeda lab. and Venture Buissiness Labolaty, Nagoya University.)

The QE of bulk-AlGaAs is 2~8%.
(Two times higher than that of the bulk-GaAs.)
*the band-gap energy to 0.2eV above the band-gap energy

Long Surface Lifetime



*Lifetime of bulk-GaAs and bulk-AlGaAs sample, where laser photon energy was chosen at 0.1 eV above the band-gap for each sample

The bulk-AlGaAs has a longer lifetime of NEA surface than the bulk-GaAs.
*These results agree with our prediction that smaller electron affinity is suitable for longer NEA life.

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NEA-GaAs for a high brightness electron source

Excitation laser ?

- The excitation laser wavelength tuned to the band-gap energy is suitable for a small electron beam energy spread.
- Higher QE than that of the exist GaAs can achieved by bulk-AlGaAs with various band-gap energy. (1.4-1.8eV / 690-870nm)
  (JAEA & Takeda Lab.-Nagoya Univ.-)
- Larger band-gap photocathode is more suitable for higher QE photocathode.

→ **Possible band-gap range of Ⅲ-Ⅴ semiconductor is 0.4-3.5eV.**
(several μm - 350nm)

→ **Possible large current depend on trade-off between QE and laser power.**