SUPERLATTICE PHOTOCATHODE DEVELOPMENT FOR LOW EMITTANCE

Model approaches and predictions, comparison with data, search for the optimal combination of thermal emittance and response time from NEA.

NAGOYA UNIVERSITY
KEK

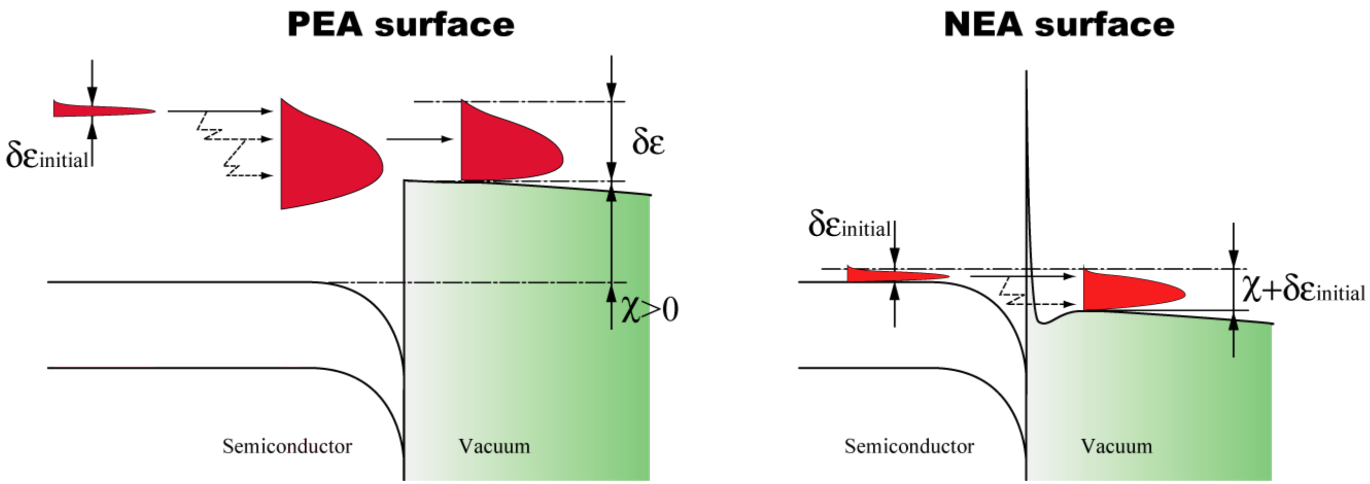
M. Kuwahara[1], M. Yamamoto[2], X. G. Jin[1], T. Ujihara[1], T. Nakanishi[1], Y. Takeda[1]
1. Nagoya University, 2. KEK

Outline

- Results of emittance measurements (e.g. GaAs, GaAs-GaAsP SL)
- QE spectra of superlattice
- SL structure for non-polarized electron source
- The energy dispersion estimated from QE spectrum
- Time response in semiconductor photocathode with the width of an active layer
- Advanced modification in photocathode (transparent substrate)
- Summary

Origin of Low Emittance in NEA Photocathode

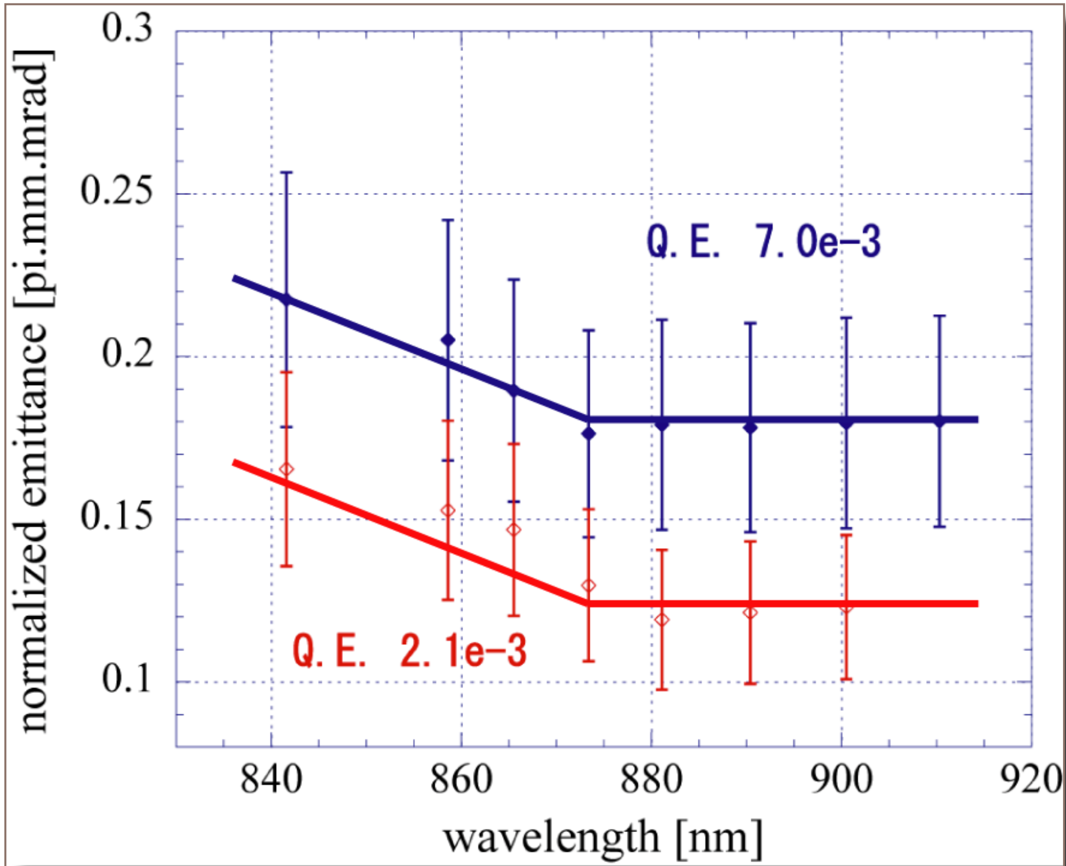
- NEA photocathode is expected to generate a low emittance beam.
  - Dependent on excitation energy, QE and acc. gradient.
- We have obtained a result that beam emittances were almost 0.1 πmm.mrad in very low-charge condition .



NEA photocathode is expected to generate very low initial emittance beam with high QE.

Emittance measurement results (bulk-GaAs)

- Emittance of bulk-GaAs measured in 120-keV by NPES*



$$\varepsilon = \frac{R}{2}\sqrt{\frac{2E}{3m_e c^2} + \frac{k_B T}{m_e c^2}}$$

E: electron extra energy
R: beam spot size

QE = 7.0 e-3

Average in constant region:

$\boxed{\varepsilon = 0.18 \pm 0.03 \pi \text{mm.mrad}}$

$k_B T$ -> 66 meV (fit)

QE = 2.1 e-3

Average in constant region:

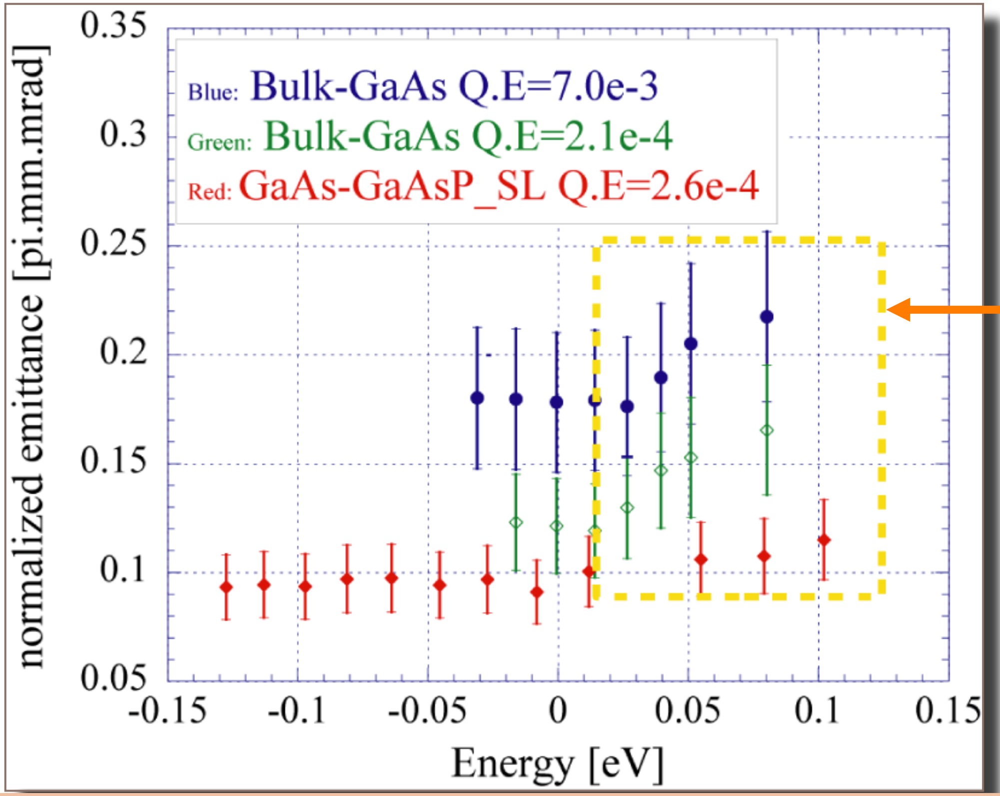
$\boxed{\varepsilon = 0.12 \pm 0.02 \pi \text{mm.mrad}}$

$k_B T$ -> 29 meV (fit)

*NPES: Nagoya Polarized Electron Source

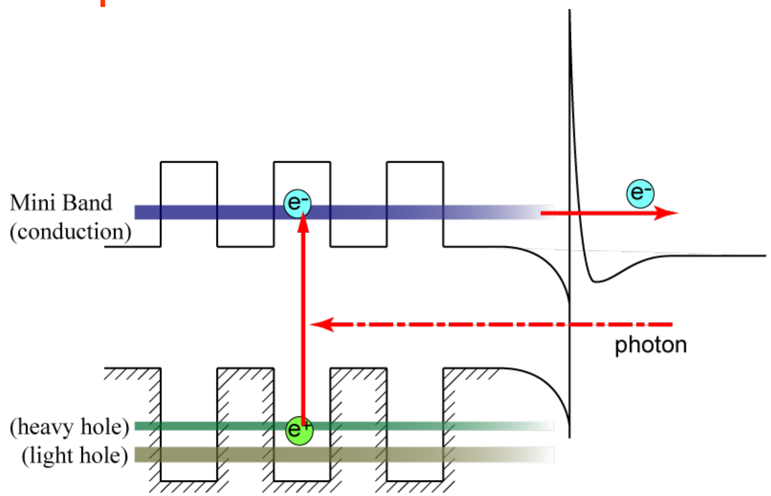
Emittance measurement result (SL)

- Photon energy dependence (SL and Bulk-GaAs)



In SL photocathode, the increase of emittance is lower than that of bulk-GaAs

This effect is explained by the dispersion of the JDOS.

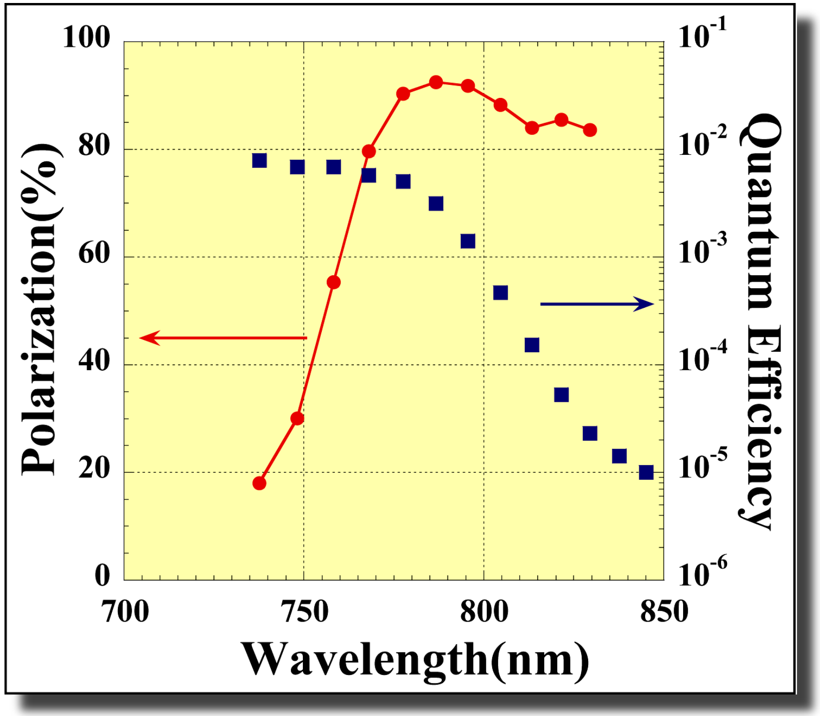


The DOS in C.B. is quantized and shrinks.
(Miniband is formed by the micro-structure.)

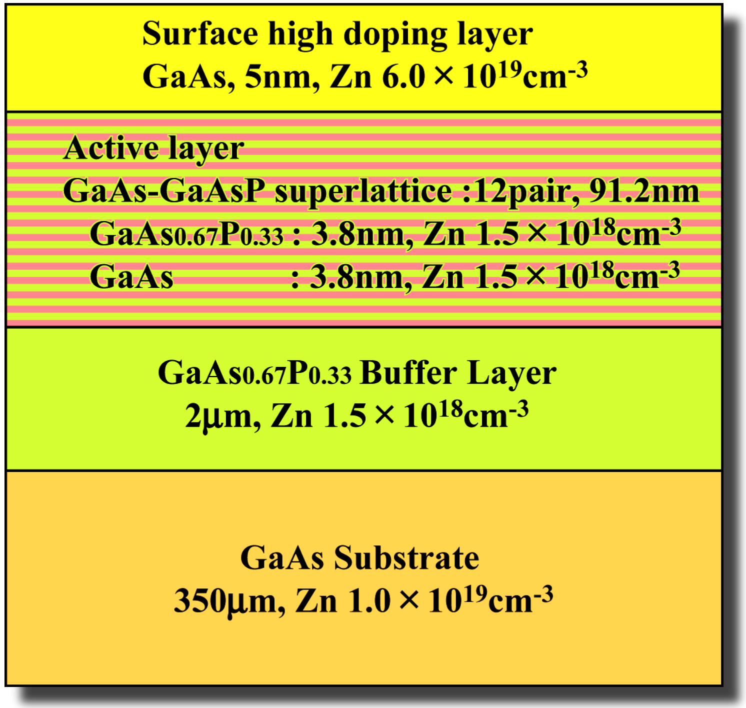
⇒ An emittance growth is suppressed in shorter wavelength
SL structure has a low emittance with high QE comparing with a bulk-GaAs

The photocathode

- GaAs-GaAsP Strained Superlattice on GaAs substrate



Observed polarization and QE as a function of wavelength



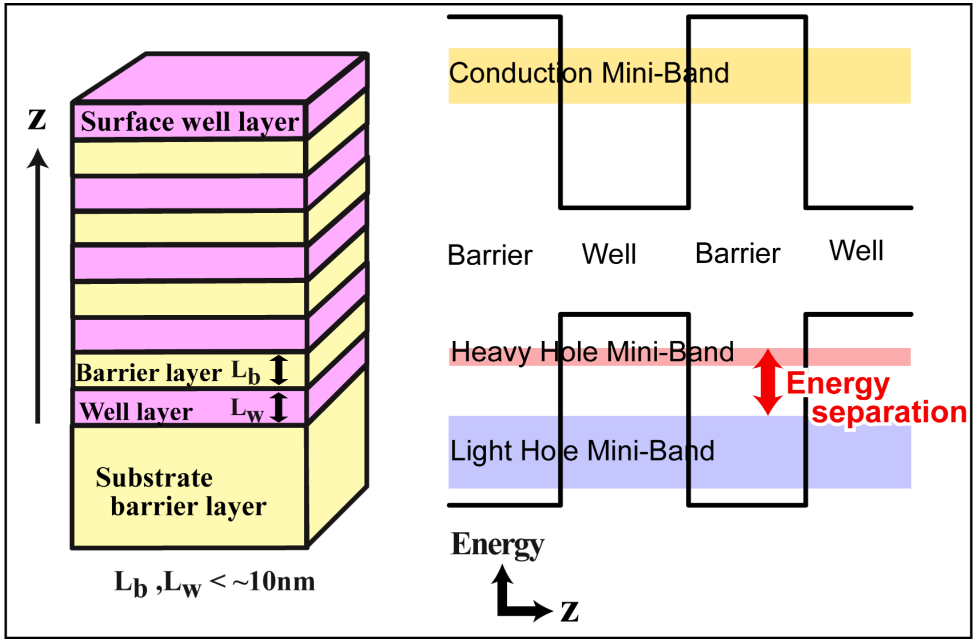
Layer structure and doping level of SLSP#16

Ref. ; T. Nishitani, *et al.*: J. Appl. Phys. 97 (2005) 094907 1-6.

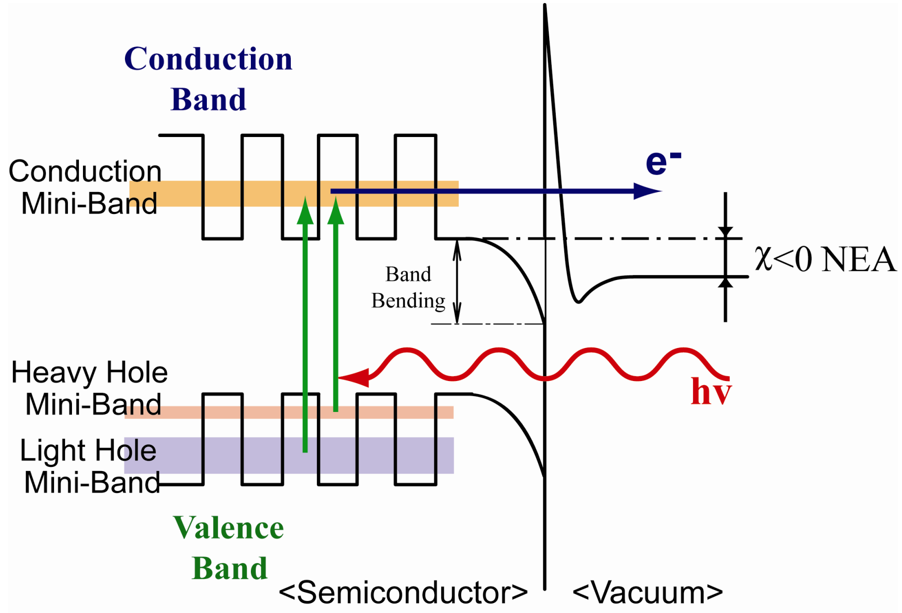
Superlattice photocathode

- Toward a low emittance with a high QE

1. Layer-structure -> SL (suppressing the emittane growth with increasing the excitation energy)
2. Using excitation both of HH and LH
3. Expand the active layer with suppressing the expansion of pulse width



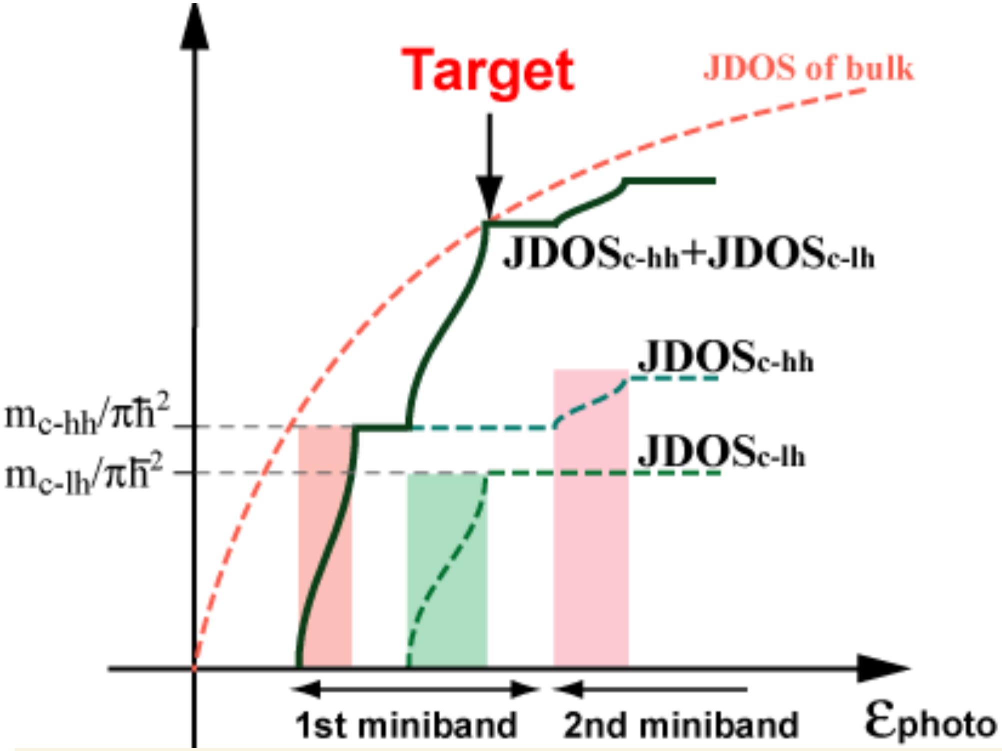
The JDOS of C.B. is quantized and shrinks.
(Miniband is formed by the superlattice)



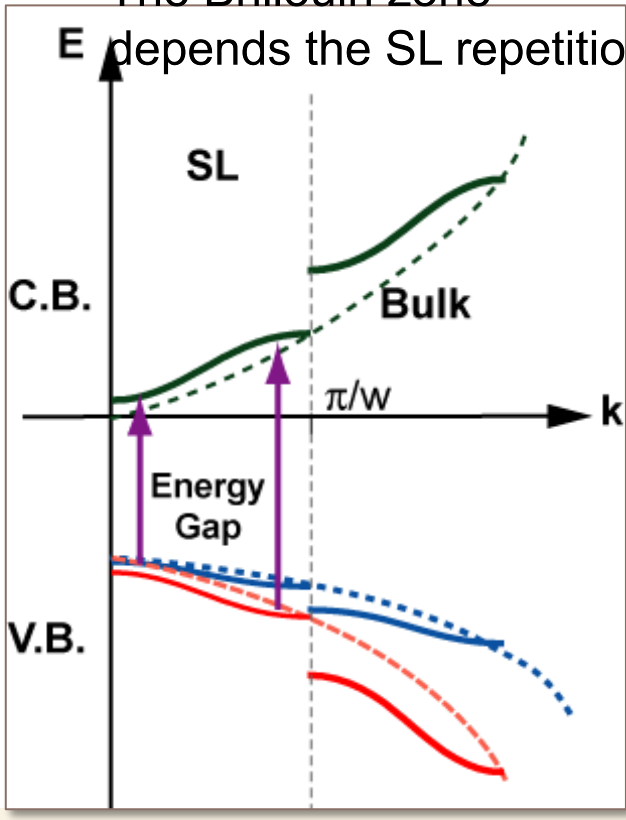
Schematic of an extraction process in a SL photocathode

Superlattice photocathode

- Excitation energy toward the high QE
  - Joint Density of State



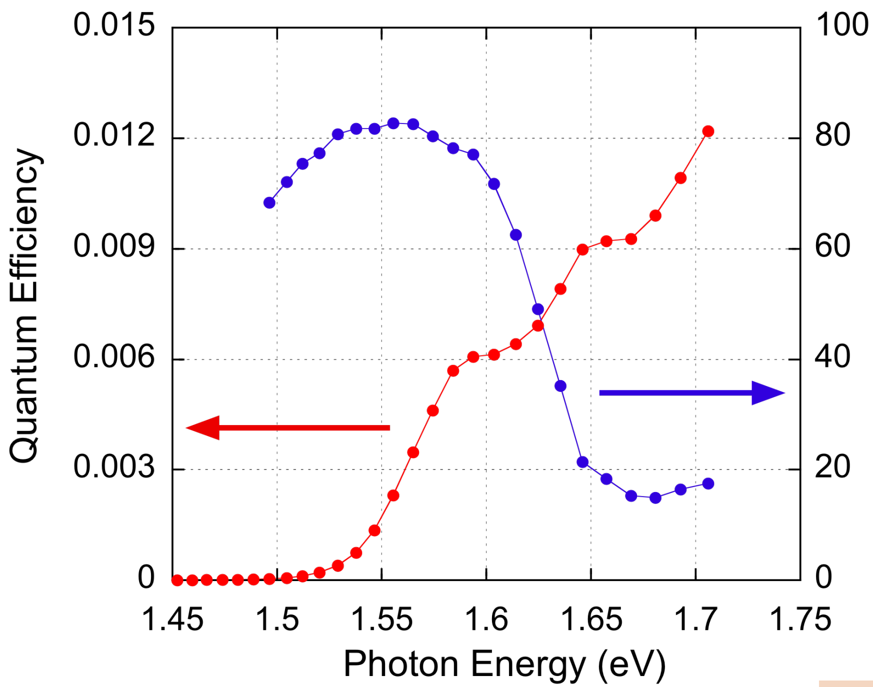
The Brillouin zone depends the SL repetition

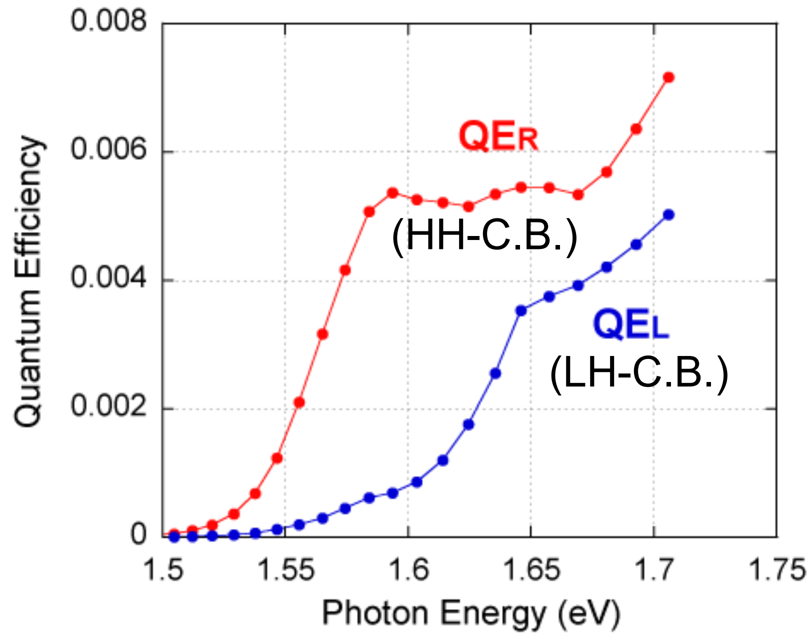


The dispersion of JDOS is dominantly determined by the C.B. because the effective mass is smaller than that of V.B.
Separation between 1st and 2nd mini-band in C.B. must be larger than that of HH and LH.

Typical QE spectra in SL

- GaAs-GaAsP strained superlattice (strain compensated)





The QE has some steps which feature the JDOS of SL clearly.

QER and QEL are corresponding with the excitations of HH-C.B. and LH-C.B., respectively.
If the spin-flip phenomena is negligible, the shape of QE shows the SL's JDOS directly.

Dispersion of JDOS in SL photocathode

- Estimation of energy dispersion in SL from QE spectrum and Pol. spectrum.

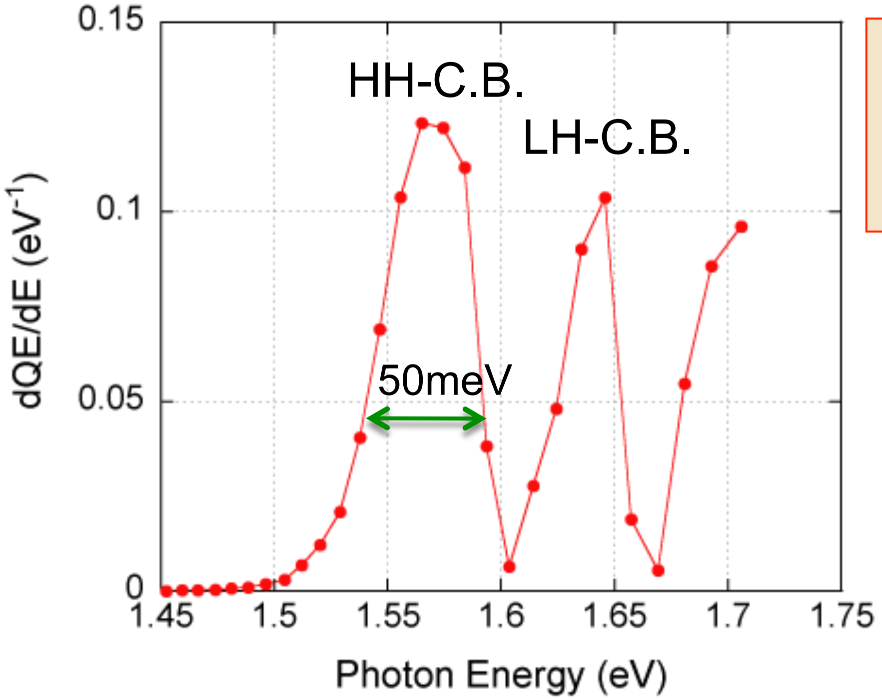


Fig. Differential of QE as a function of excitation photon energy.

Quantized state is essential for realization of a low emittance beam by using SL.

The width of the differential QE

~ 50 meV

The energy dispersion of extracted beam will be suppress in below 50 meV

Temporal response in SL (not in Bulk)

- Average emission time

In Bulk-GaAs, the pulse width is mainly determined by the absorption length. However, if the active-layer thickness is limited, the tail can be cut.

$$\langle t \rangle \approx \frac{d^2}{12D} = \frac{d^2}{12 \cdot 27 cm^2/s} = 2ps$$

$$d \sim 254 nm$$

$GaAs/GaAsP\ \ Supperlattice$

$\tau_{re} = 55ps, \tau_s = 140ps, \alpha = 7 \times 10^3 cm^{-1}$

$D = \mu_e k_B T/e = 1000 cm^2/Vs \cdot 27mV = 27 cm^2/s$

Ref.: K. Aulenbacher, et al., J. Appl. Phys. 92 (2002) 7536.

Using the QE of 0.9% @751nm in active-layer width of 96nm,

In the case of 254-nm width, QE is expect to be 2.1%. (Without recombination effect)

- Simple estimation using Pol. , relaxation time and recombination time

$$P_{CW} = P_0 \frac{\alpha\langle v \rangle + 1/\tau_r}{\alpha\langle v \rangle + 1/\tau_s + 1/\tau_r} \frac{1 - \exp\left(-(\alpha\langle v \rangle + 1/\tau_s + 1/\tau_r) \cdot d/\langle v \rangle\right)}{1 - \exp\left(-(\alpha\langle v \rangle + 1/\tau_r) \cdot d/\langle v \rangle\right)} = 0.92$$

$$\langle v \rangle \approx 9 \times 10^4 m/s$$

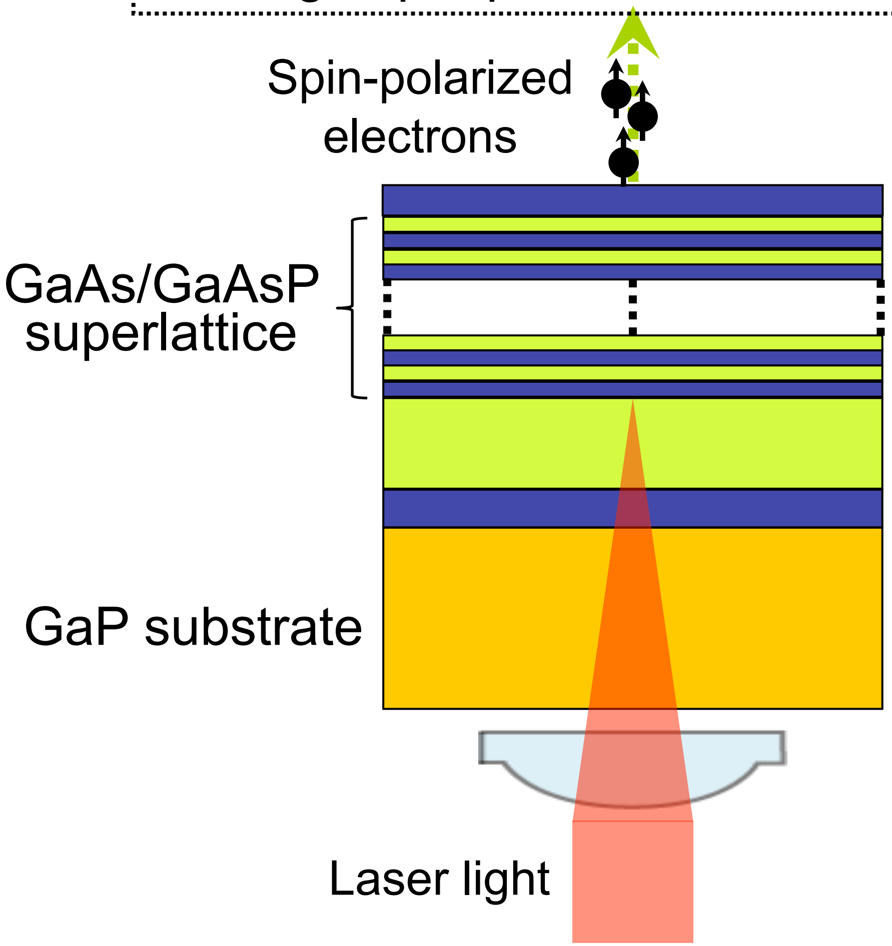
$$\langle t \rangle = 96nm/\langle v \rangle \approx 1ps$$

Corresponding with the temporal response time in short pulse

The difference ~ additional spin-relaxation time or scattering in drifting process or BBR ?

Recent R&D

A transmission-type spin-polarized photocathode has been developed for application to several types of electron microscopy, e.g., spin-polarized LEEM, spin-polarized TEM and so on.



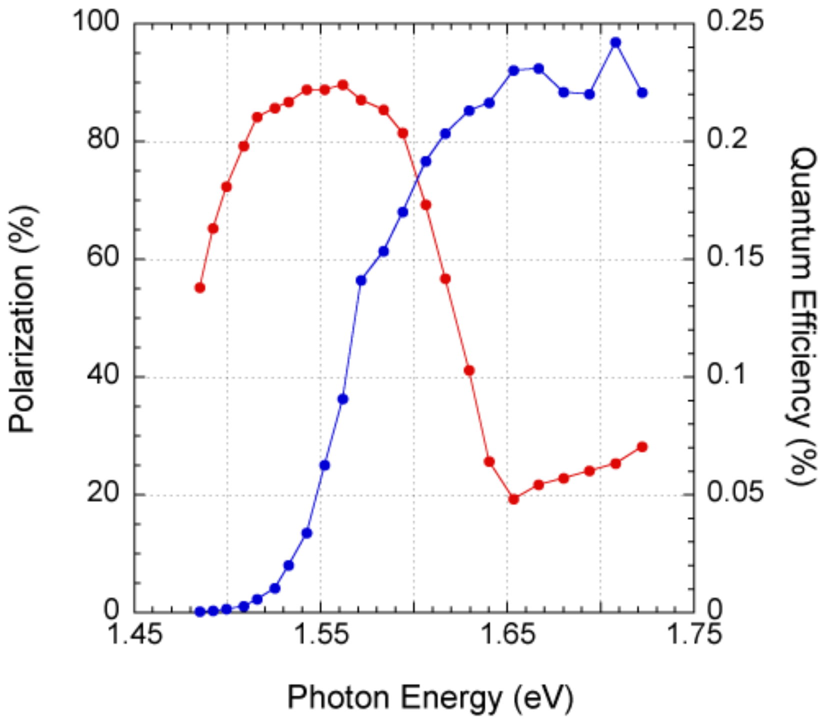
Transmission-type photocathode with GaAs/GaAsP strained superlattice

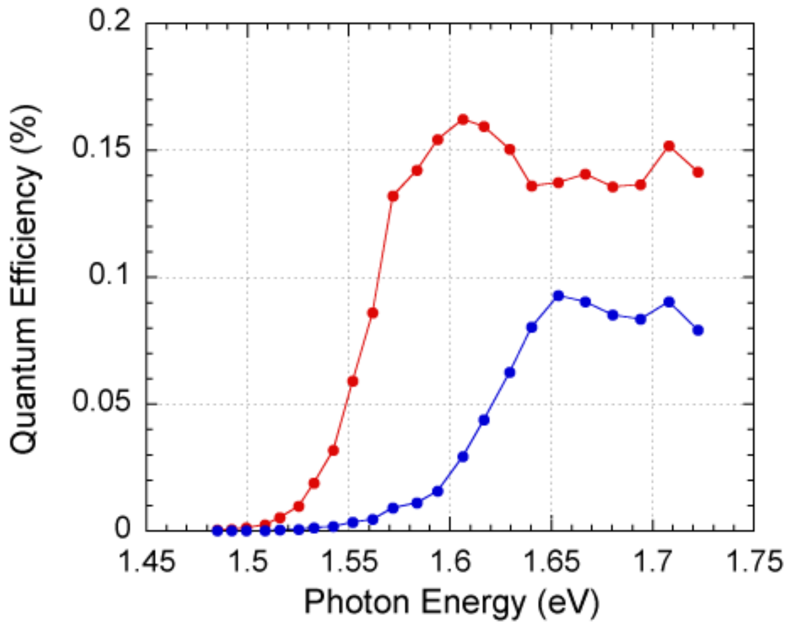
- High spin-polarization : **90%**
- Super-high brightness : **1.3×10^{7} A·cm^{-2}·sr^{-1}** (@20 kV)

Xiuguang JIN *et al.*, Appl. Phys. Express **1** (2008) #045002

High current operation with high power laser

- Transmossion type photocathode





In the case of a high current operation, we suggest that a transparent substrate is effective to realize a high current mode operation because it can suppress a thermal heating induced by an absorption of residual photon energy.

Summary

- SL for non-polarized electron source
  - Photocathode structure for a low emittance beam : SL structure
  1. Suppression of energy dispersion by quantized effect (DOS of C.B.)
  2. High JDOS comparing with Bulk (large absorption coefficient)
  3. Temporal response is determined by the width of active layer

     -> Photo absorption length is expected to be small

     -> SL has a high absorption coefficient induced by the localization effect
- To realize a high current mode operation
  - We suggest a transparent substrate to suppress the thermal heating in substrate due to its dominant absorption.