Recent PES Photocathode R&D at Nagoya University

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Introduction

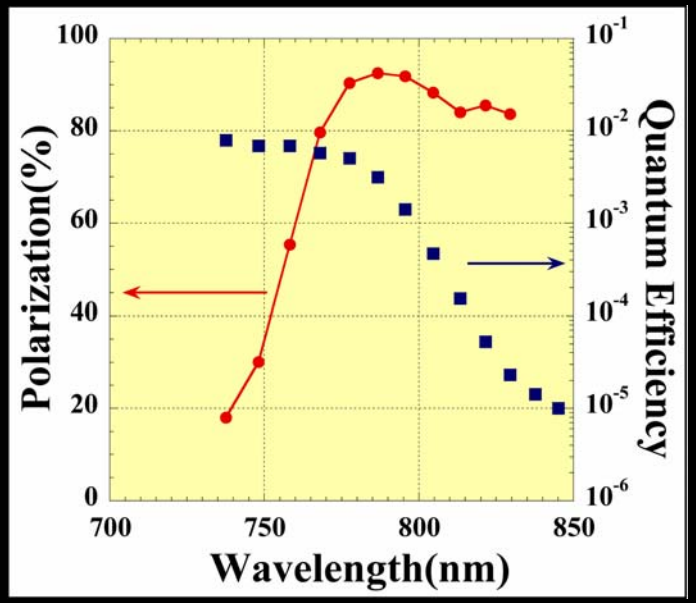
- Strained-Layer Superlattice PhotoCathode
  - Achieved Performance of GaAs-GaAsP strained SL
    - Microstructure, ESP and QE vs. wavelength
  - New Data Analysis --- Spin Resolved QE Spectrum
- Tip-GaAs
  - Motivation and method
  - Fabrication and Experiments
- Summary

GaAs-GaAsP Strained Superlattice

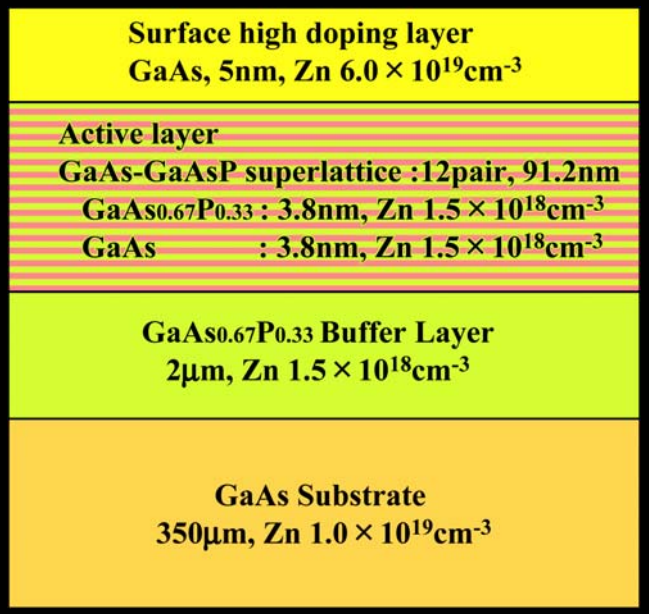
- Achieved high performance of PES photocathode

  Polarization=92±6%, @QE=0.5% (λ=778nm)

  Photocathode: GaAs-GaAsP Strained Superlattice (SLSP#16)



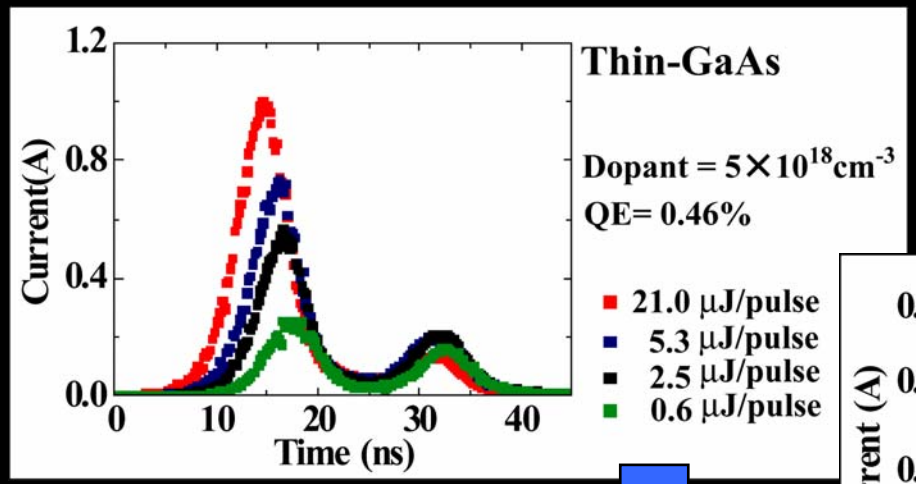
Observed polarization and QE as a function of wavelength



Crystal microstructure of SLSP#16

GaAs-GaAsP Strained Superlattice (2)

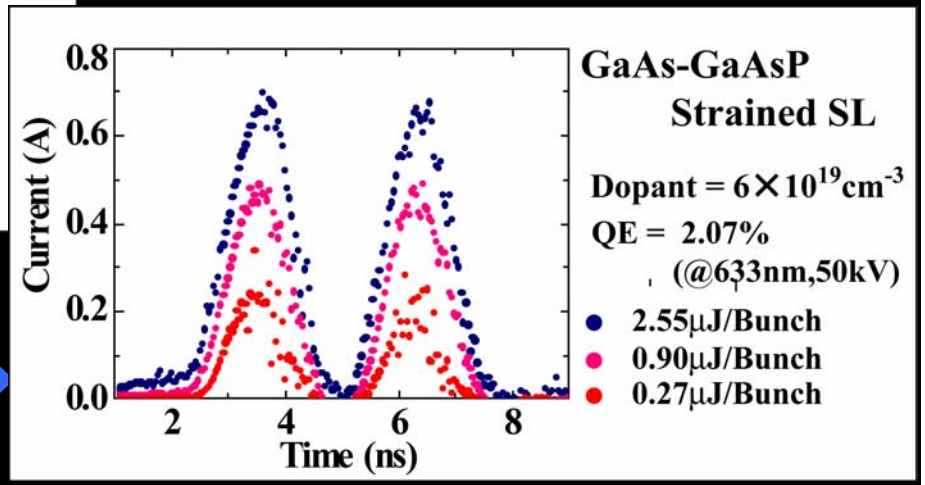
- GaAs-GaAsP strained SL photocathode had overcome the SCL effect.



Generation of double bunch beam

Overcome the SCL Phenomenon

p-p : 2.8ns,
bunch-width : 0.7ns
Charge: 1nC/bunch

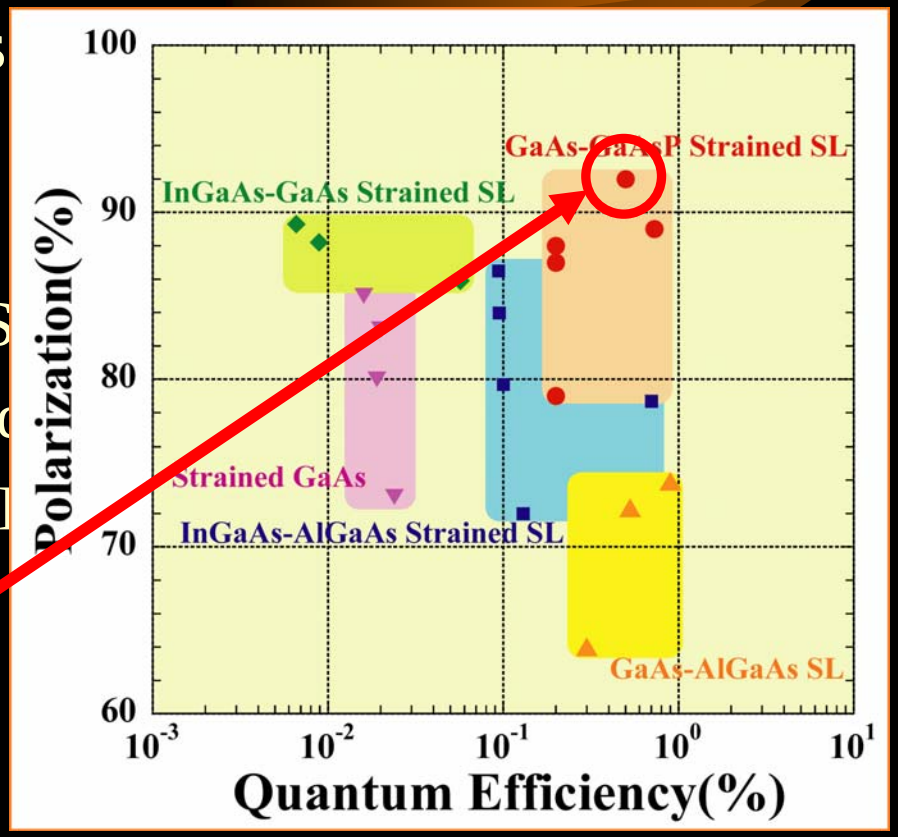


Achieved extraction of sub-nanosecond double-bunch beam

Photocathode Performances of Polarization & QE

- Developed Photocathodes
  - Strained GaAs
  - GaAs-AlGaAs SL
  - InGaAs-GaAs Strained S
  - InGaAs-AlGaAs Strained
  - GaAs-GaAsP Strained Sl

GaAs-GaAsP
(SLSP#16)



Why does SLSP#16 have highest performance ?

Data Analysis

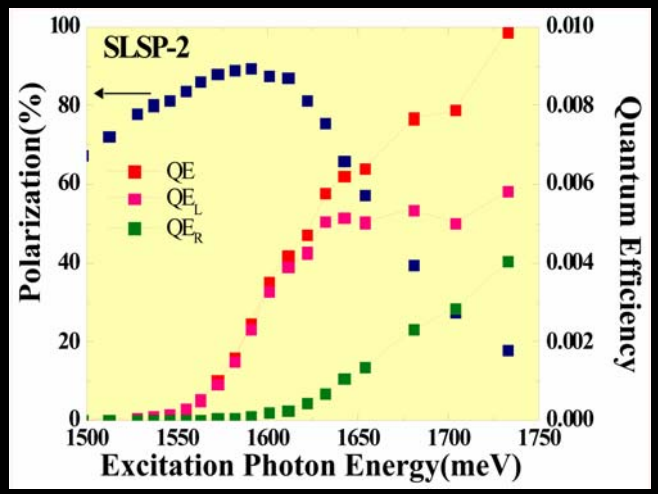
- Spin Resolved QE Spectrum using experimental data

QE, ESP are written,

$$QE=\frac{N_L+N_R}{n},\quad ESP=\frac{N_L-N_R}{N_L+N_R}$$

$$QE_L=\frac{N_L}{n},\quad QE_R=\frac{N_R}{n}$$ QE_L: left handed QE, QE_R: right handed QE

$$QE_L=\frac{QE\times(1+ESP)}{2},\quad QE_R=\frac{QE\times(1-ESP)}{2}$$



Spin resolved QE of extracted electrons

→Spin dependence of photo-absorption coefficient

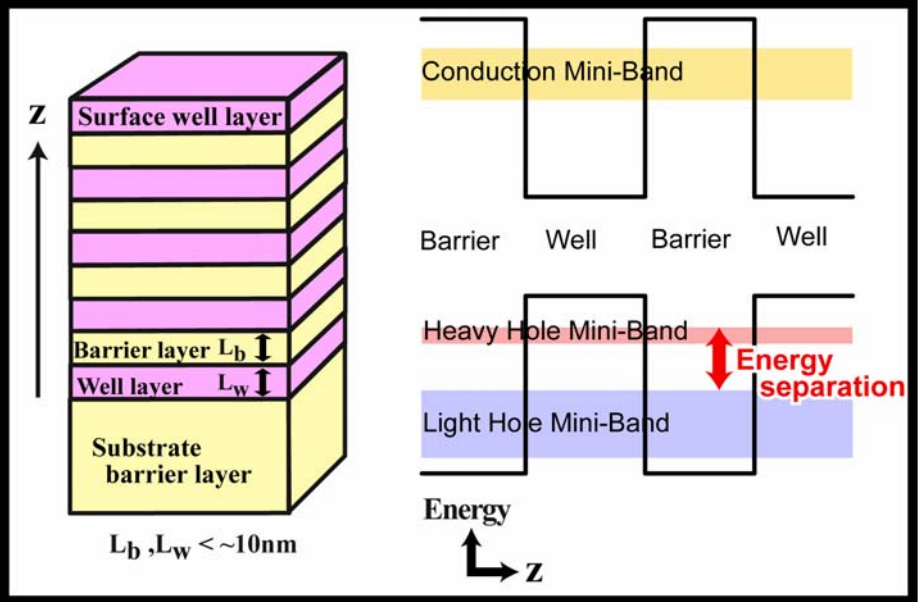
→Energy separation between heavy hole state and light hole state

Spin resolved QE spectrum obtained from experimental QE and ESP spectra

JDOS of Strained Superlattice

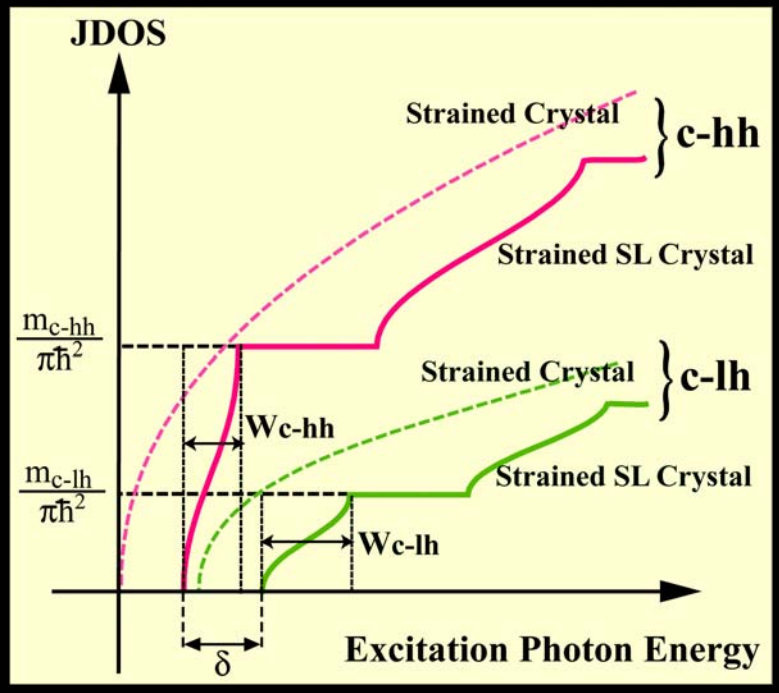
- Energy band structure and Joint Density of State(JDOS) of strained Superlattice

Schematics of SL mini-band structure



Calculated with Kronig-Penny model

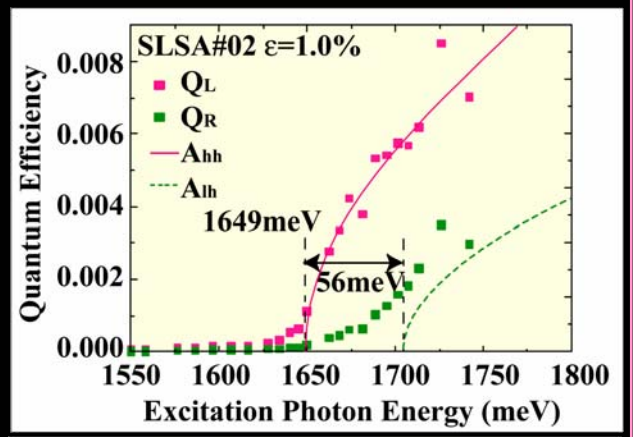
Schematic of JDOS as a function of excitation photon energy

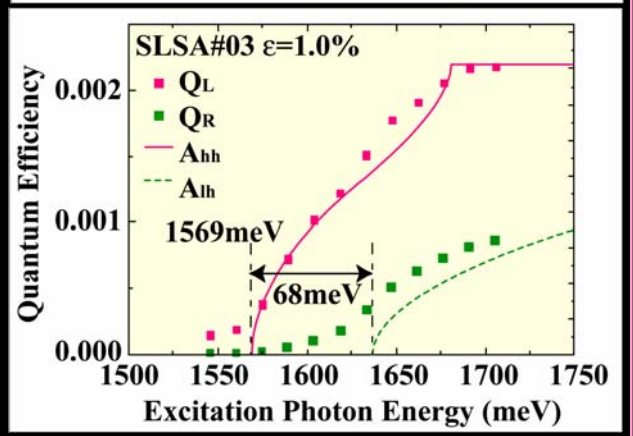


Results of Data Analysis

Compared GaAs-GaAsP with InGaAs-AlGaAs

InGaAs-AlGaAs



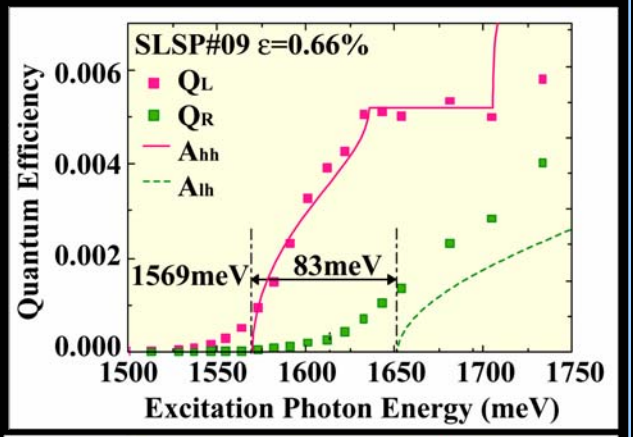


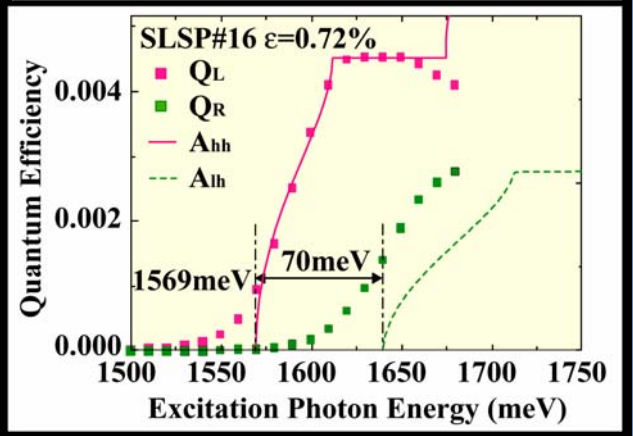
① δ width is wider

② Mini-band width is narrower

③ Overlapping of mini-band JDOS is smaller

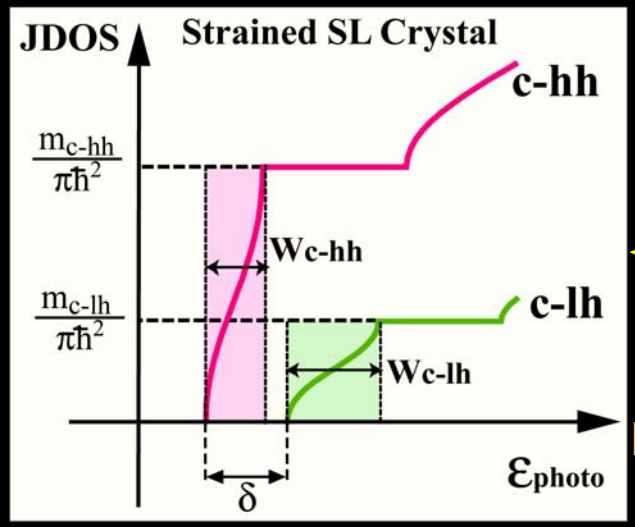
GaAs-GaAsP





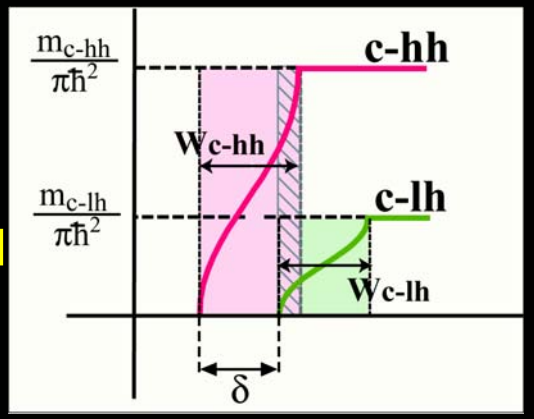
Criteria of High ESP & QE

- By this analysis, we suggested as follows
  1. Mini-band width of $W_{c\text{-}hh}$ is narrow.
  2. δ width is wide
     (for avoiding JDOS overlapping between hh and lh)
     $$\delta > W_{c\text{-}hh} + E_{thermal}$$
  3. Depolarization along drifting in a crystal is small.



Don't overlap

Better structure of Energy band



Details are under submitting to Journal of Applied Physics

Tip-GaAs (Needle like shape)

- Motivation

  We have succeeded in achieving high Polarization with high QE .

  Next R&D targets

1. **Low Emittance and High Brightness Polarized e^- beam**
   for the high quality and high density beam.
2. **Extraction of Polarized e^- beam without NEA surface**
   for the NEA lifetime problem.

Method

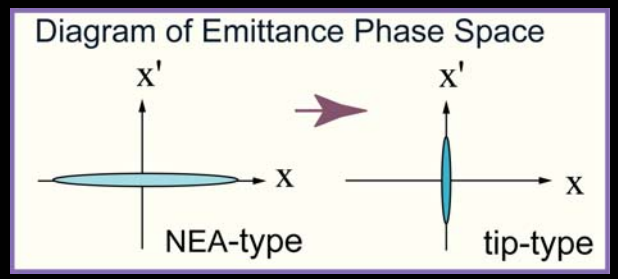
1. Low emittance polarized e^- beam

   [i] Spin polarization

   → Using GaAs type semiconductor

   [ii] Low emittance

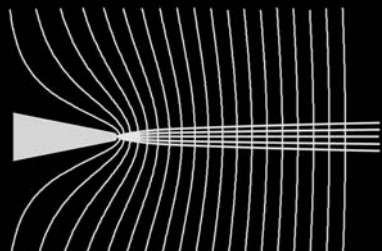
   → Extracting from a small cross sectional area



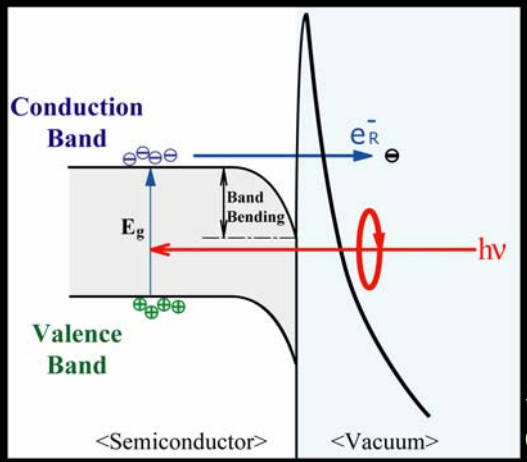
2. Without NEA surface

   → Field Emission

GaAs tip with a shape of needle



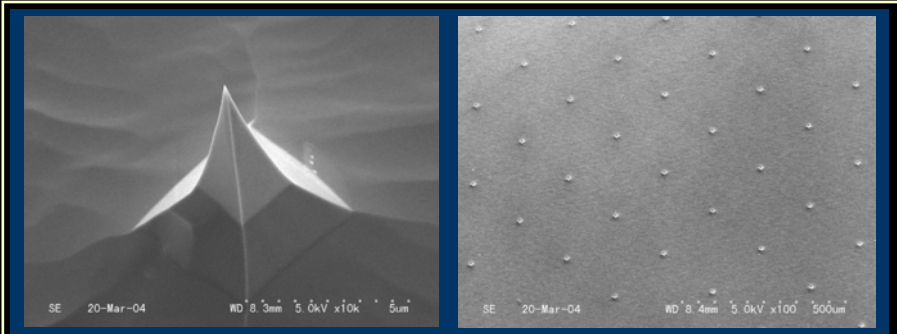
Field concentration at the top of needle



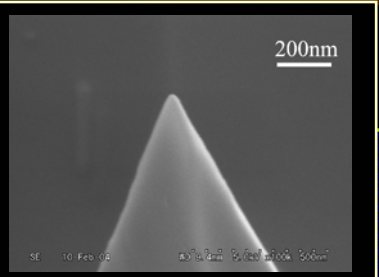
Schematic of polarized electron extraction used field emission

GaAs tip sample

- Sample (GaAs tip) (p-GaAs substrate, Zn-dope:$2\times10^{19}cm^{-3}$)

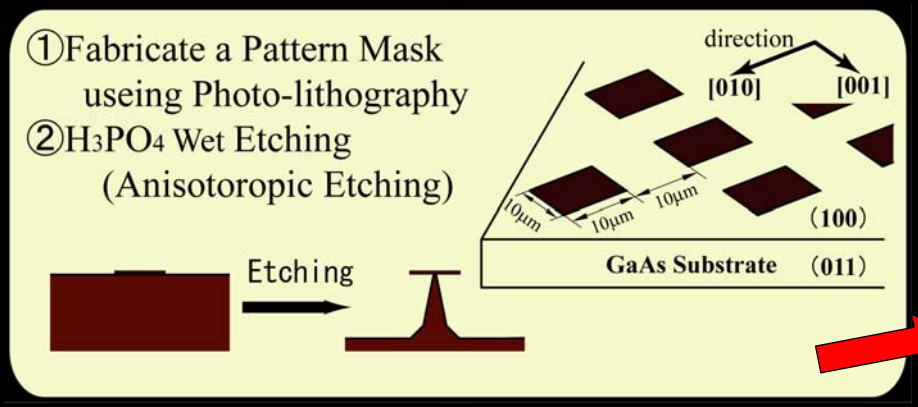


SEM images (left:×25k, right:×100)

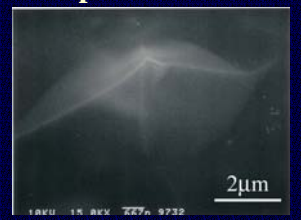


Height :～10μm
Radius :～25nm

- Fabrication methode

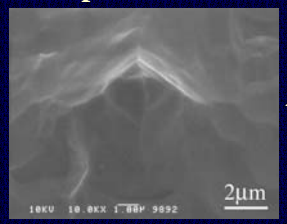


H_3PO_4:H_2O_2:H_2O=10:1:1
Temperature 20℃

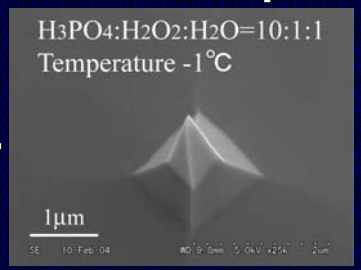


temperature ↑

H_3PO_4:H_2O_2:H_2O=5:1:1
Temperature -1℃



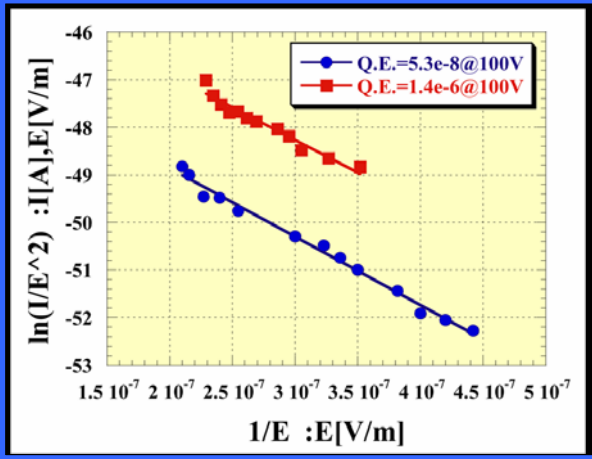
ratio ←



H_3PO_4 etching solution's condition, mixing ratio and temperature

Preliminary Experimental Result

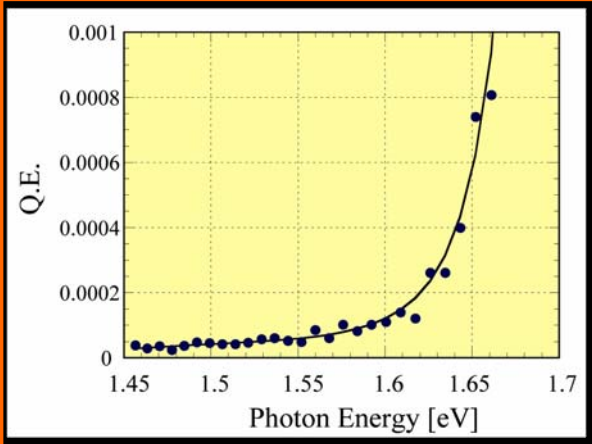
- Behaviors under impressing electric field & illumined



I-V characteristic
→ F-N(Fowler-Nordheim) plot

Not observe by GaAs without tip

Tunneling effect through
a surface barrier
(Field emission)



QE vs. Photon energy
at high gradient field
(E=3.4MV/m @Flat)

well fit

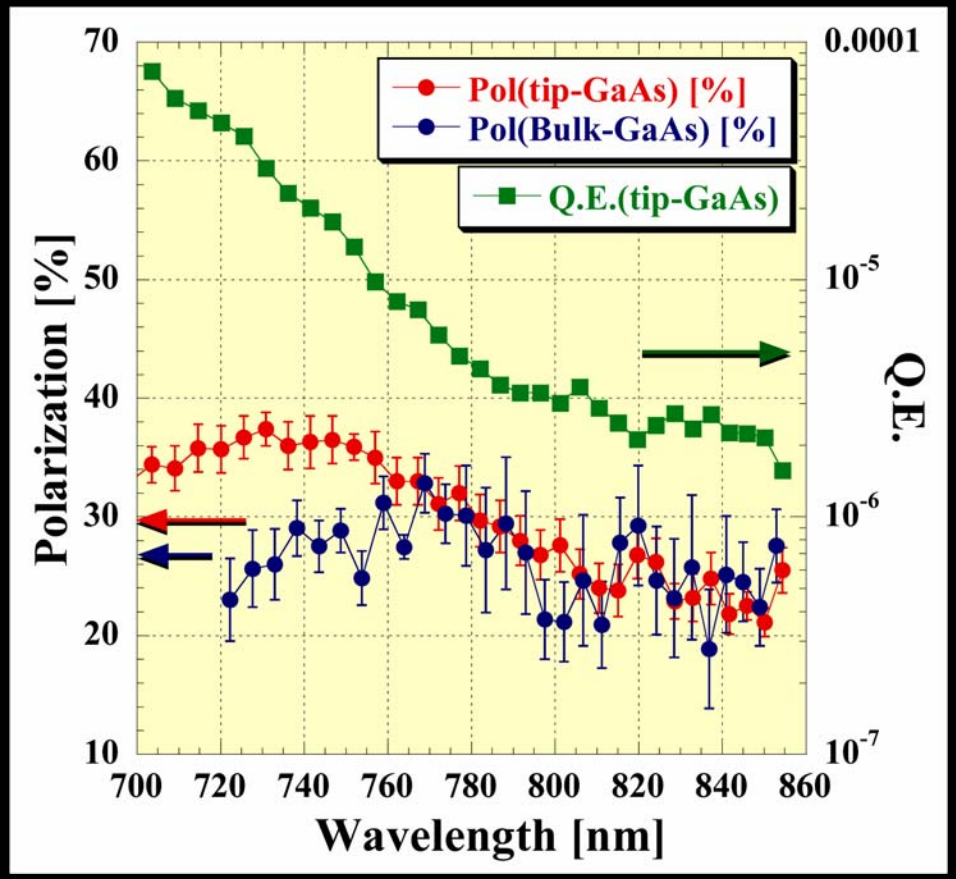
Fitting curve is estimated by
WKB approximation.

Confirmed
a Field Emission

Photon-excited
electrons
were extracted
by F.E.mechanism

Preliminary Experimental Result (2)

- Polarization and QE from tip-GaAs



1) Polarization : 20～40%

≧Bulk-GaAs' Polarization

2) Polarization of tip-GaAs is higher than Bulk-GaAs at shorter wavelength

λ < 760nm (1.6eV)

Coincide with rising edge of QE

Spin polarized electron can be extracted, while F.E.mechanism was substituted for NEA.

Summary

(1).GaAs-GaAsP shows highest performance.

Pol ～92%±6%, QE 0.5%,

SCL effect was well relaxed.

Experimental spin resolved QE spectra made clear the criteria of Strained SL for high polarization and high QE.

(2).Spin polarized electron can be extracted from tip-GaAs with F.E. mechanism.

This result have a chance to develop (apply) a new type PES.