International Particle Accelerator Conference 2015
WEAD3 (14:40-15:00, May. 6, 2015)

Quantum Efficiency Improvement of Polarized Electron Source using Strain compensated Superlattice photocathode

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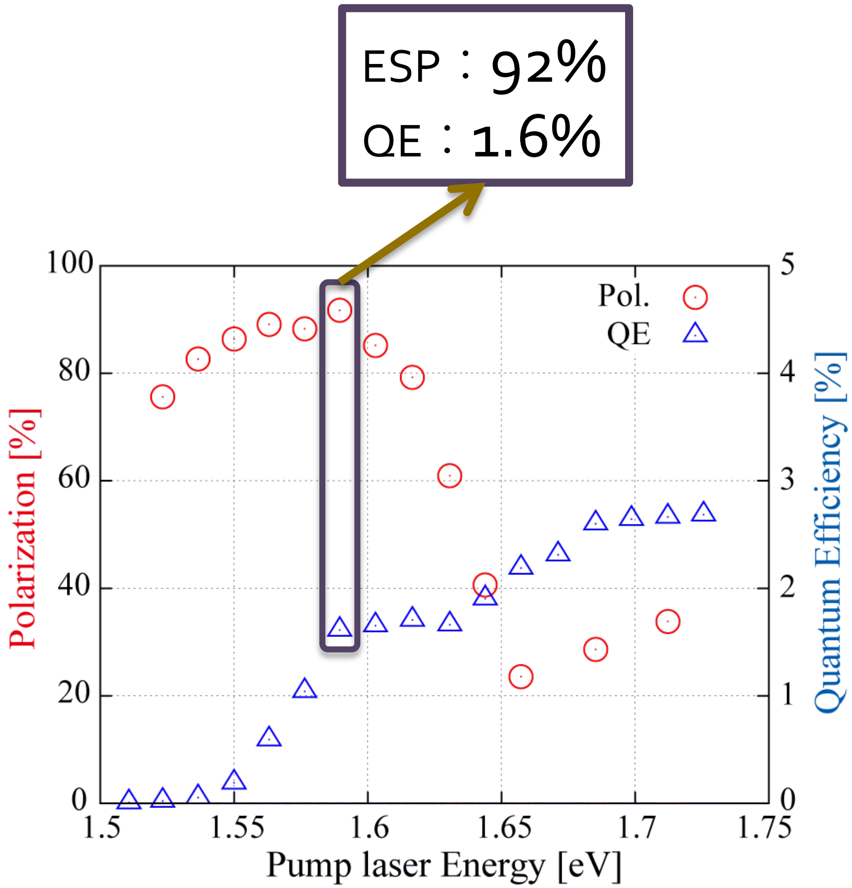
Outline

1. Introduction
2. Problem of Conv. PES PC
3. Strained Compensated PC
4. Exp. Results.
5. Summary

PES: Polarized Electron source

PC: Photocathode



Ref. X.G.Kim, et al., APL (2014)

1-1.Polarized Electron Source

Essential for future linear colliders (LCs) and electron-ion colliders (EICs)

Table. Requirement Parameters for Electron source

	LC (ILC)	EIC (eRHIC)
Electron Polarization	> 80 %	> 80 %
Bunch charge	4.8 nC	3.5 nC
Average Current	63 μA	50 mA*
Life time	> 2 weeks	long

* using several PCs

High ESP & high QE

(Electron Spin Polarization) (Quantum Efficiency)

have to be simultaneously realized.

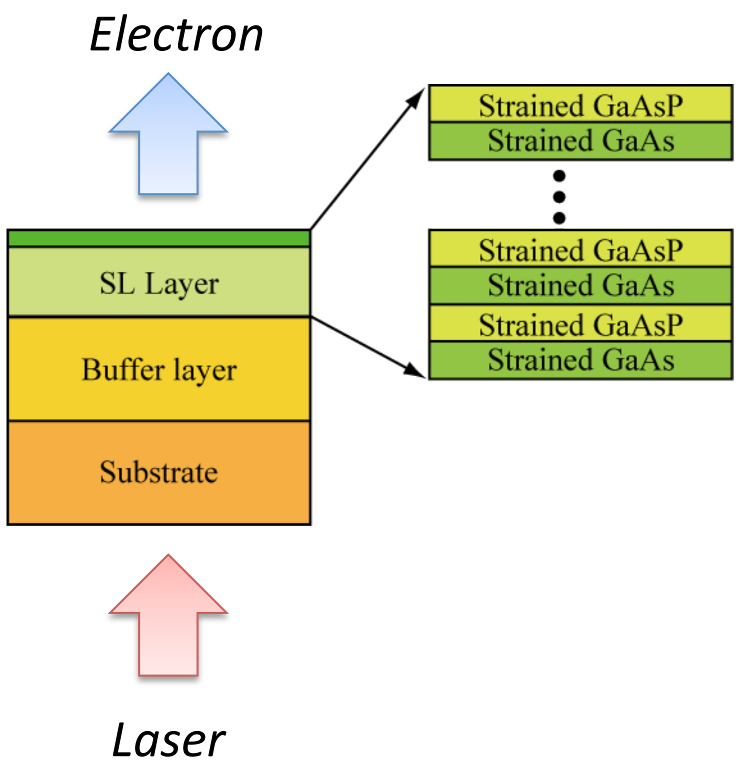
1-2. Past developments

NEA-GaAs type Polarized Electron Source

$GaAs\text{-}GaAs_xP_{(1-x)}$ ~~*Strained SL*~~

Transmission type photocathode

Strain-Compensated SL



High ESP (> 90%) & QE(~ 0.5 %)

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

T. Nishitani et al., J. Appl. Phy. **97** (2005)

Low Thermal Emittance

N. Yamamoto et al., J. Appl. Phy. **102** (2007)

High Brightness [IPAC2011's Talk]

N. Yamamoto et al., J. Appl. Phy. **103** (2008)

X.G. Jin, et al., APEX, **51,** 108004 (2012)

↓

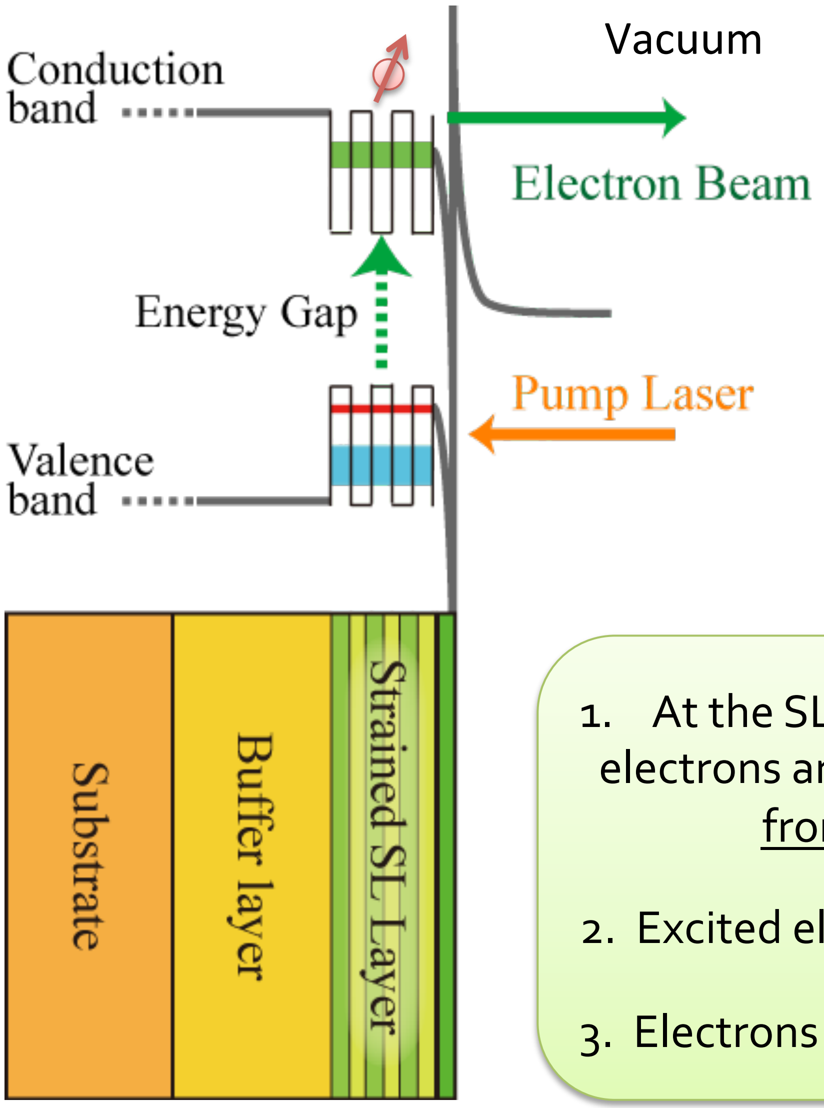
High ESP (92%) & <u>High QE (1.6%)</u>

[This talk]

X.G.Kim, et al., APL (2014)

1-3. Generation of polarized electron

3 step model for electron emission



3 step model
1. Optical pump
2. Diffusion at conduction band
3. Emission from NEA surface

1. At the SL layers,
   electrons are pumped by ***Circularly polarized laser*** from the valence band to the conduction band.

2. Excited electrons are diffused to PC surface .

3. Electrons are emitted through the ***NEA surface***.

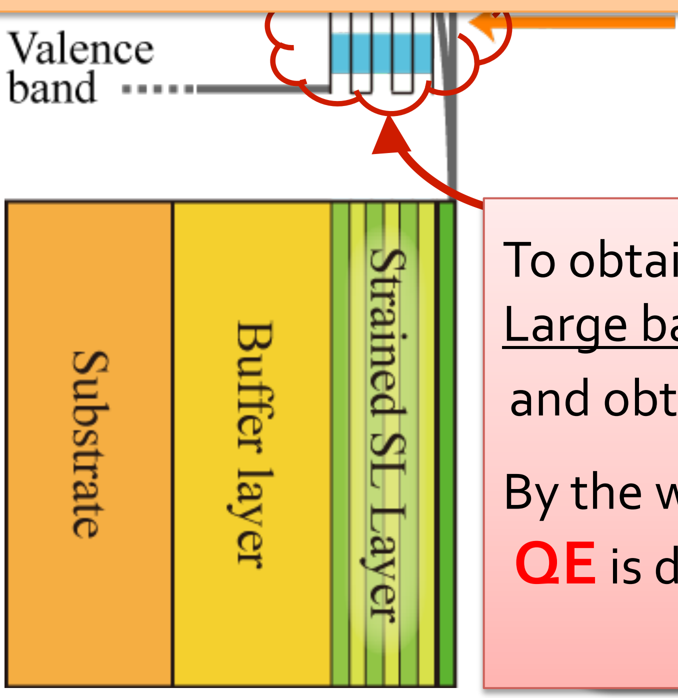
1-3. Generation of polarized electron

To realize high ESP & high QE,

Keeping

Strain SL structure & High Crystalline quality

at the same time is key.



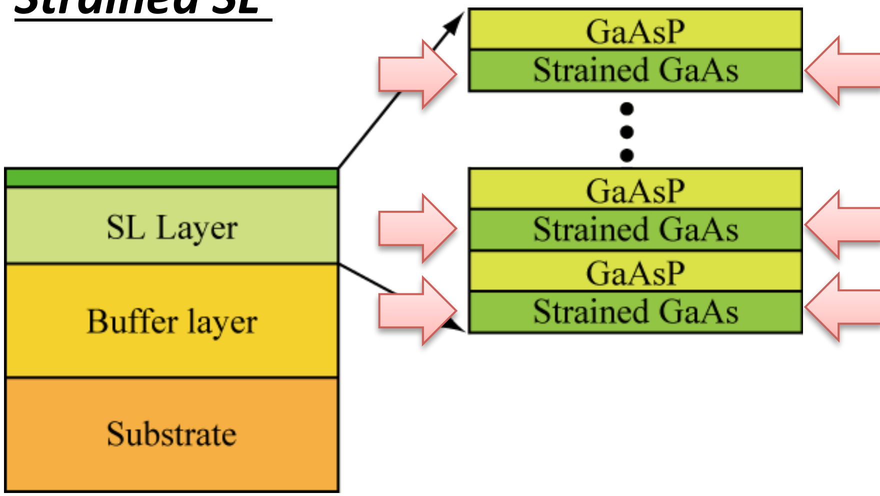
To obtain **high ESP**,
Large band split between HH & LH bands is required
and obtained by introducing **Strain** & **SL structures**.

By the way,
QE is directly affected
by **Crystal Quality** and **SL Thickness.**

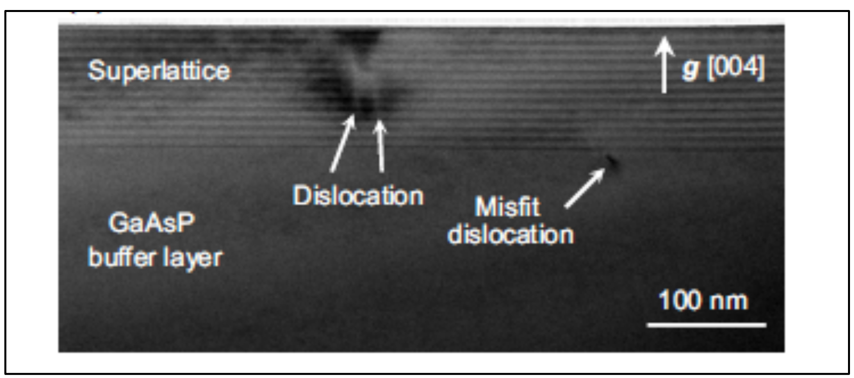
2.Problem of Conv. Strained SL PC

Strain & **SL** are essential for **High ESP**, but bringing

Strained SL



Bad crystal quality.
(Low QE)



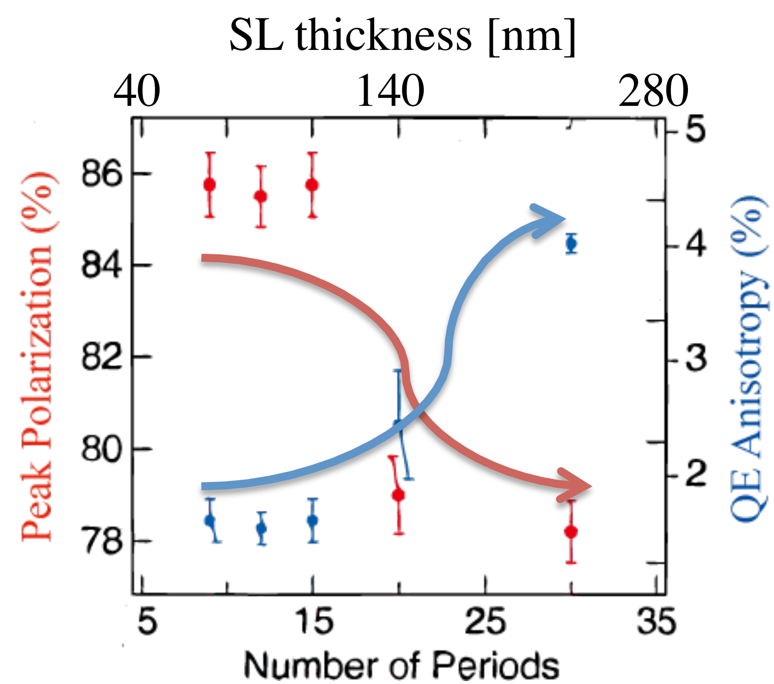
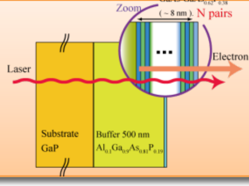


Fig. TEM image of GaAs/GaAsP Strain SL PC

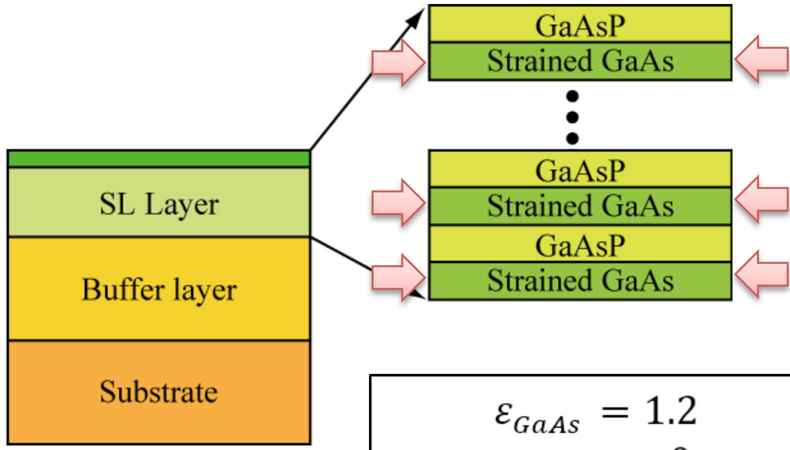
Ref. T. Maruyama, et al., APL (2004)

Ref. X.G.Kim, et al., JAP (2010)

3.Strain–Compensated SL



Strained SL



$$\varepsilon_{GaAs} = 1.2$$
$$\varepsilon_{GaAsP} = 0$$
$$L_{GaAs} \cong L_{GaAsP} = 4nm$$

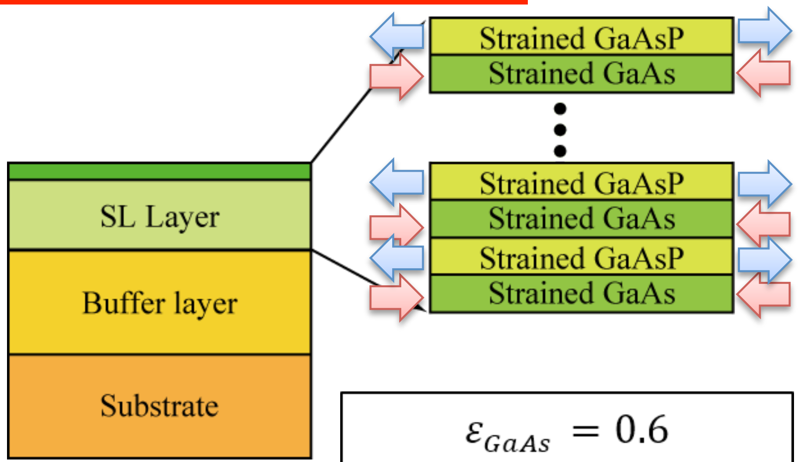
Net strain $\cong 0.6$

Strain accumulation
Low Crystal quality

$$Net\ strain = \frac{\varepsilon_{GaAs} \cdot L_{GaAs} + \varepsilon_{GaAsP} \cdot L_{GaAsP}}{L_{GaAs} + L_{GaAsP}}$$

ε : Strain values for each SL layer
L : Thickness period of each SL layer

Strain-compensated SL



$$\varepsilon_{GaAs} = 0.6$$
$$\varepsilon_{GaAsP} = -0.6$$
$$L_{GaAs} \cong L_{GaAsP} = 4nm$$

Net strain ≅ *0*

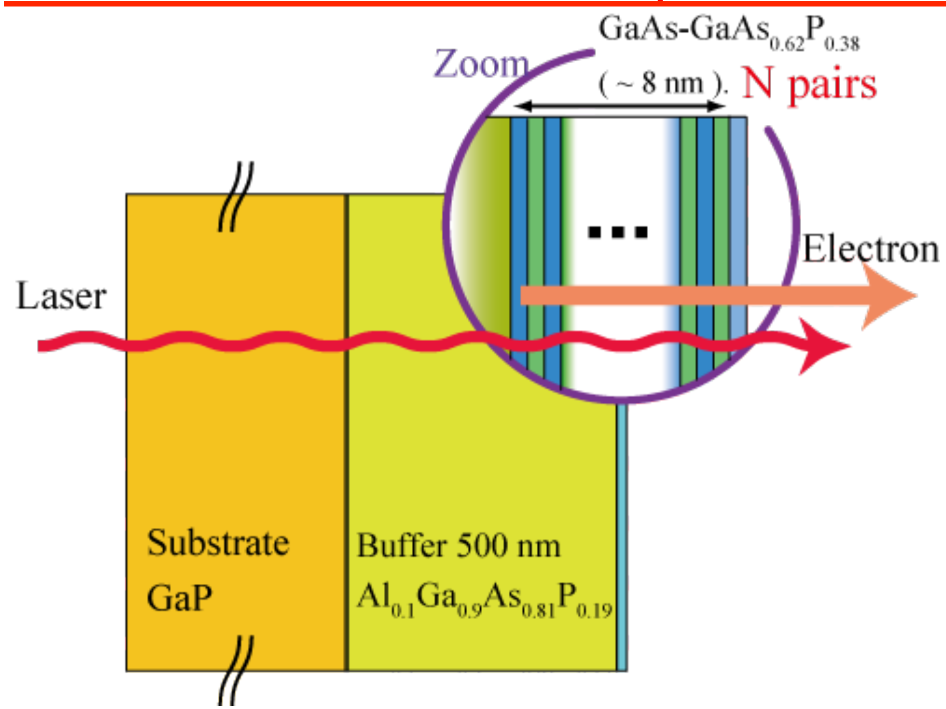
No Strain accumulation

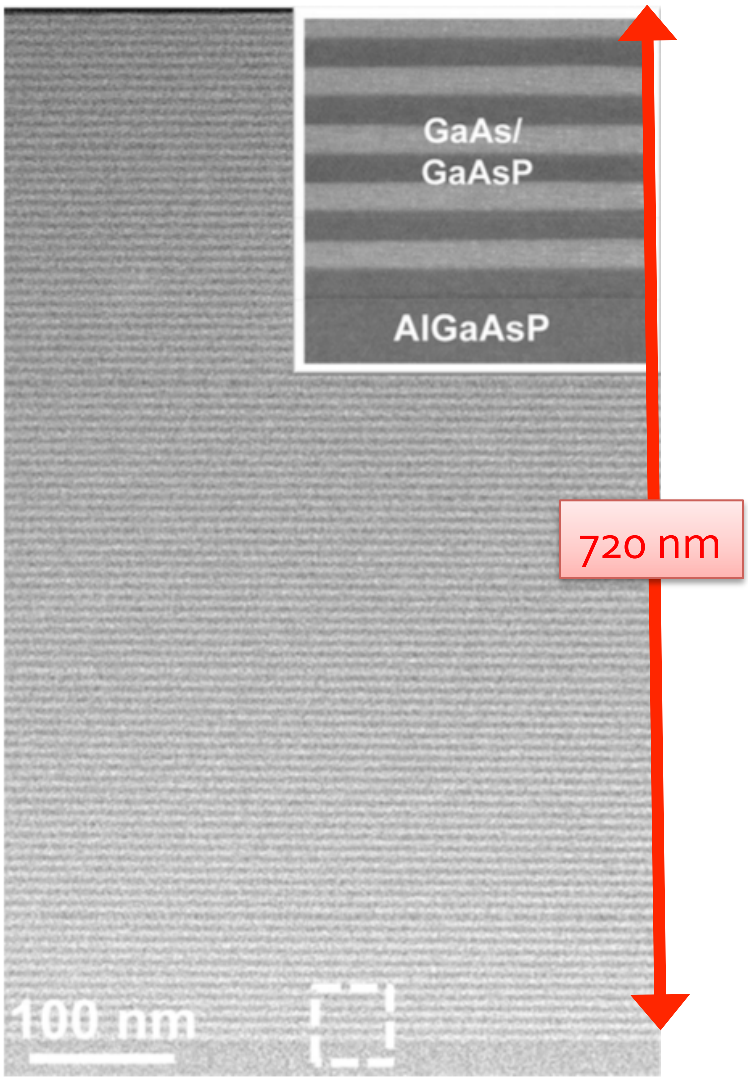
High Crystal Quality
Higher ESP
Higher QE (Thickness SL layers)

4.EXPERIMENTAL RESULT

4-1.GaAs-GaAsP Strain compensated SL

GaAs-GaAsP Strain–Compensated SL





Ref. X.G.Kim, et al., APL (2014)

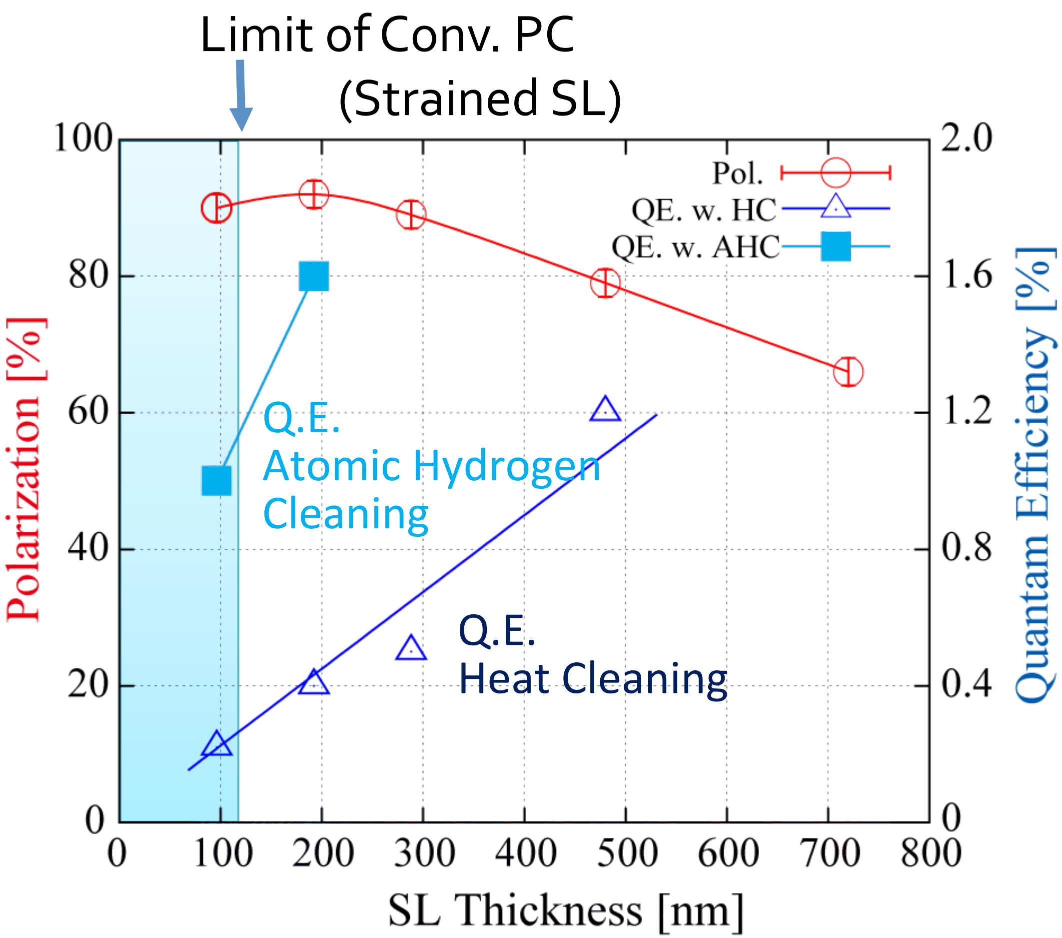
$Al_{0.1}Ga_{0.9}As_{0.81}P_{0.19}$ Buffer Layer :

Lattice constant →
medium value between GaAs and GaAsP

Band gap energy (1.77eV) →
higher than that of SL layers

4-2.Performances of Strain–Comp. SL

➢ SL Thickness Dependence



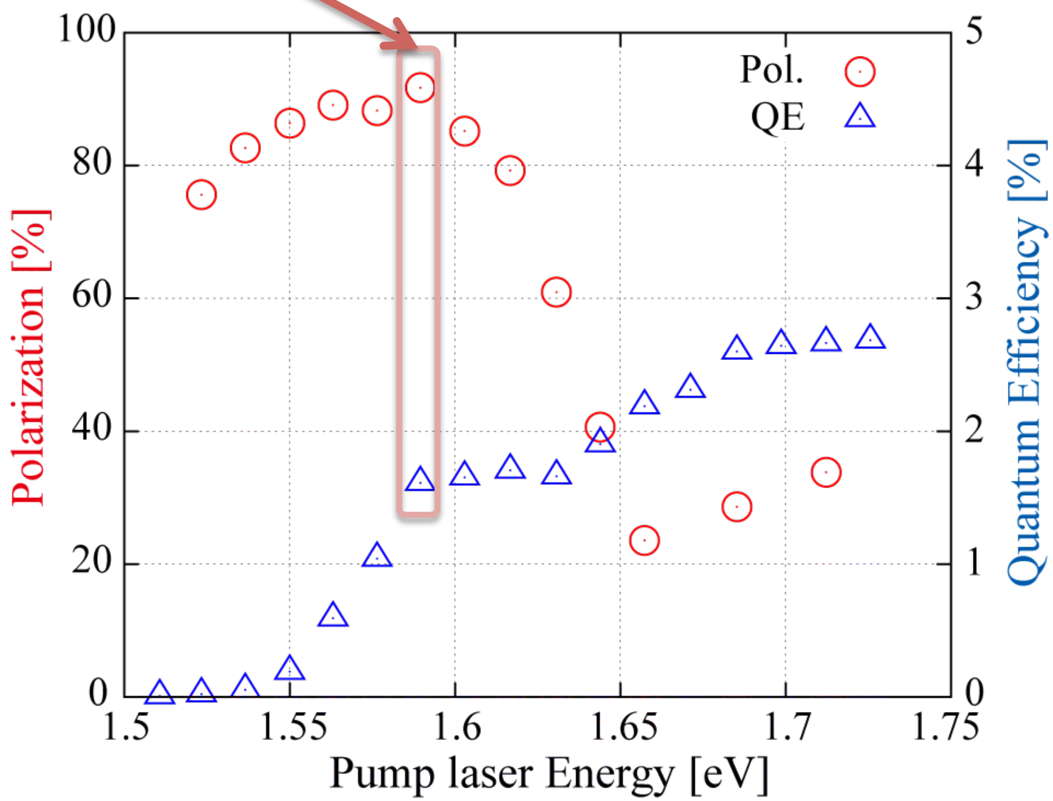
- We succeed to fabricate the Strain-Compensated SL PC.
- ESPs of ~ 90% are obtained below the thickness of 288 nm.
- QE increases proportionally below the thickness of 500 nm.
- QEs are improved by using Atomic Hydrogen Cleaning.

* The polarization was measured with back-side laser illumination.

4-2.Performances of Strain–Comp. SL

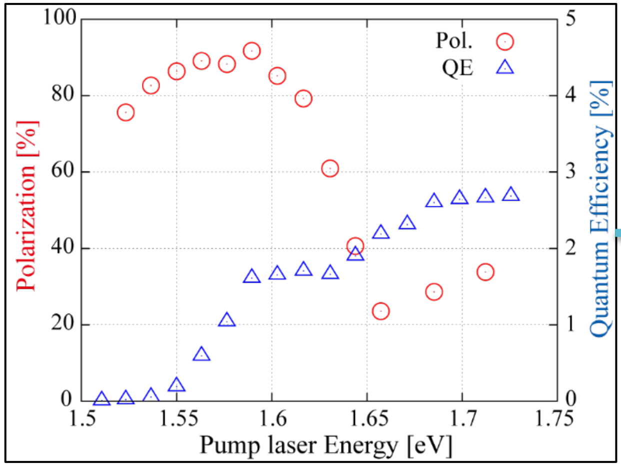
➢ Best Data (Tentative , 24-pair (192 nm) PC)

ESP ：92%, QE ：1.6%



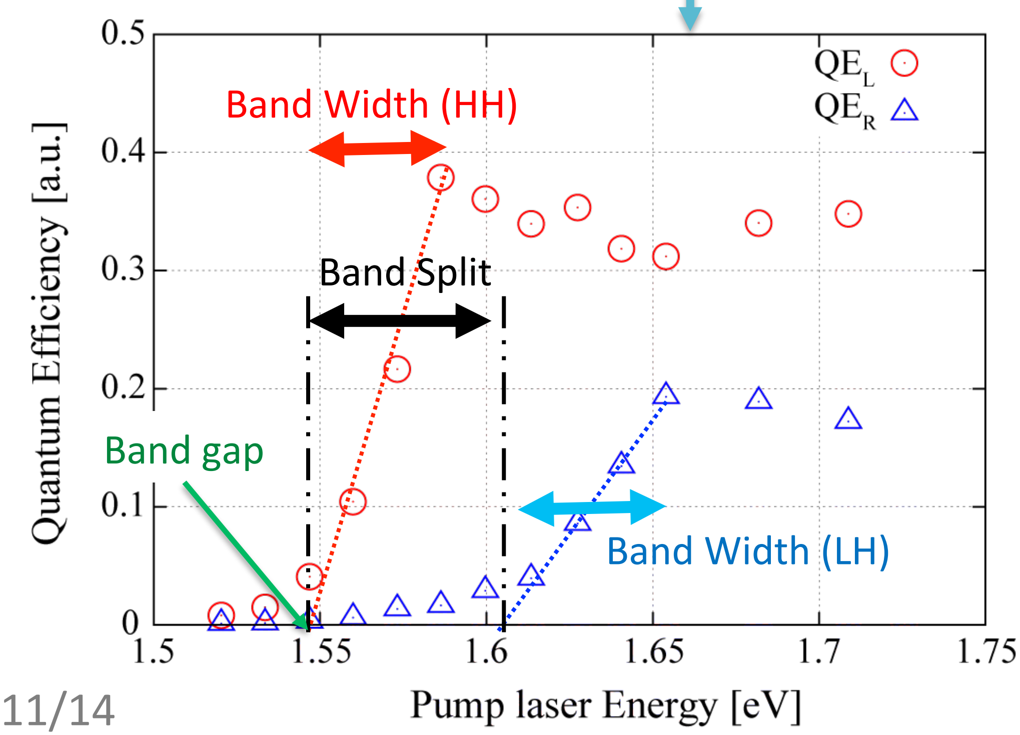
Ref. X.G.Kim, et al., APL (2014)

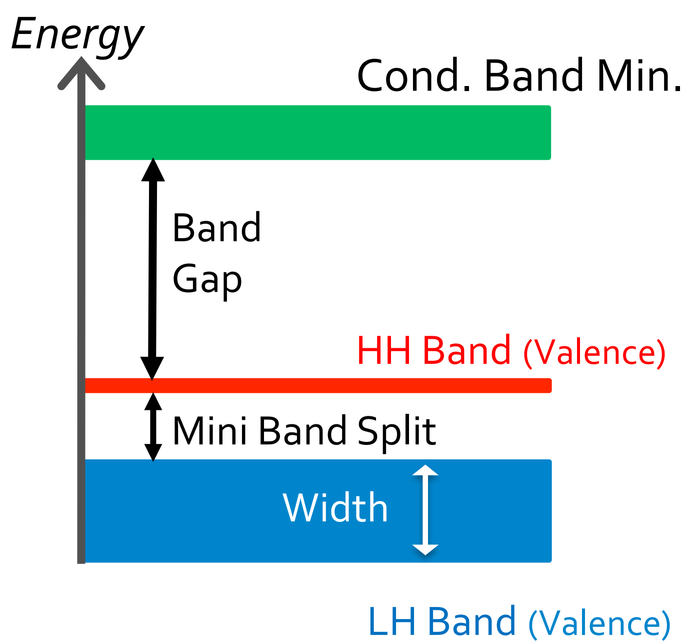
4-3. Analysis of Crystal Quality from ESP-QE Spectra



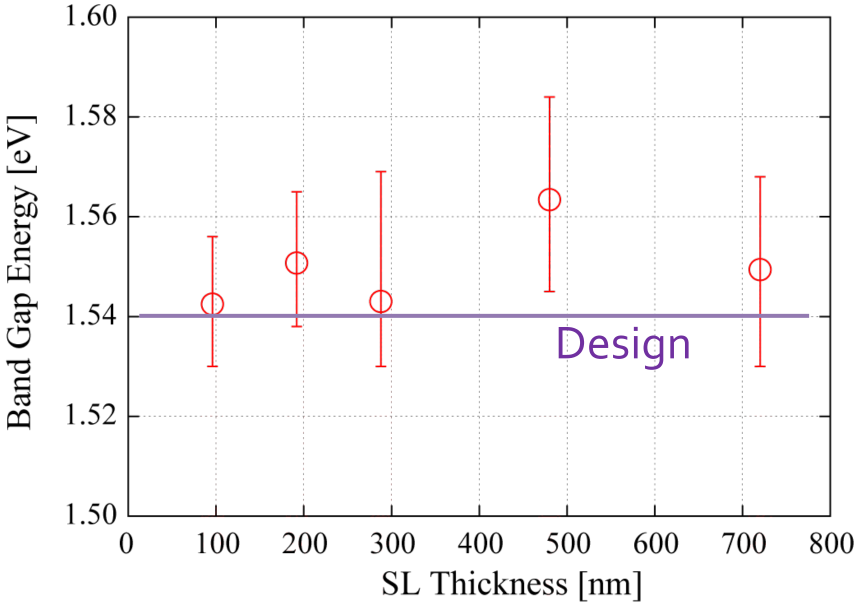
Spin-resolved QE Analysis

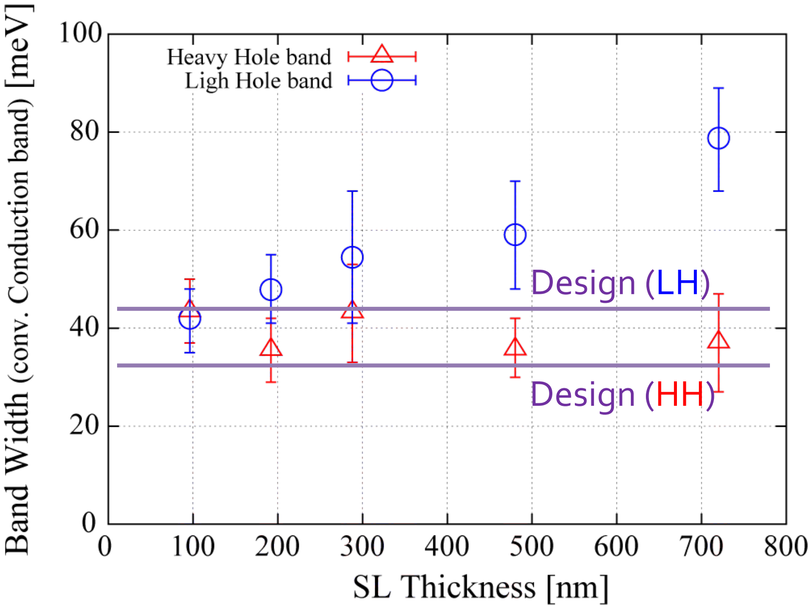
$$QE_{L(R)} = \frac{QE(1 \pm ESP)}{2} \,.$$

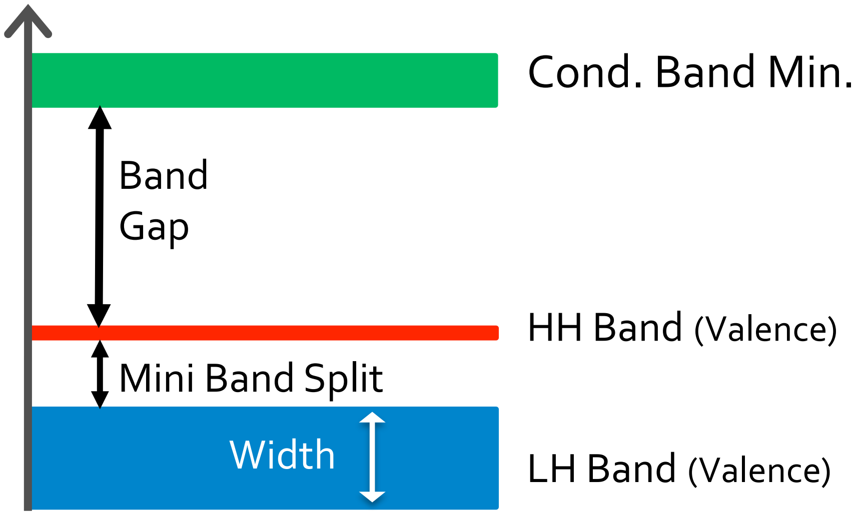


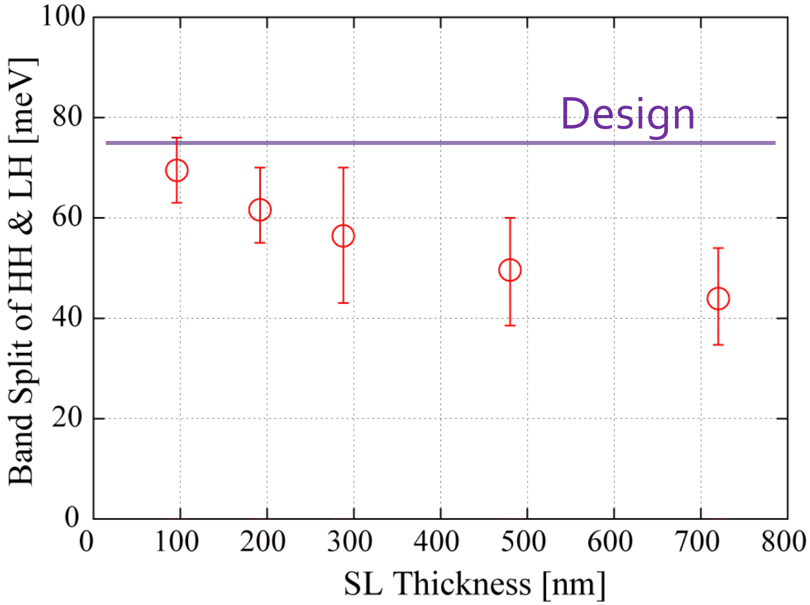


4-3. Analysis of Crystal Quality from ESP-QE Spectra



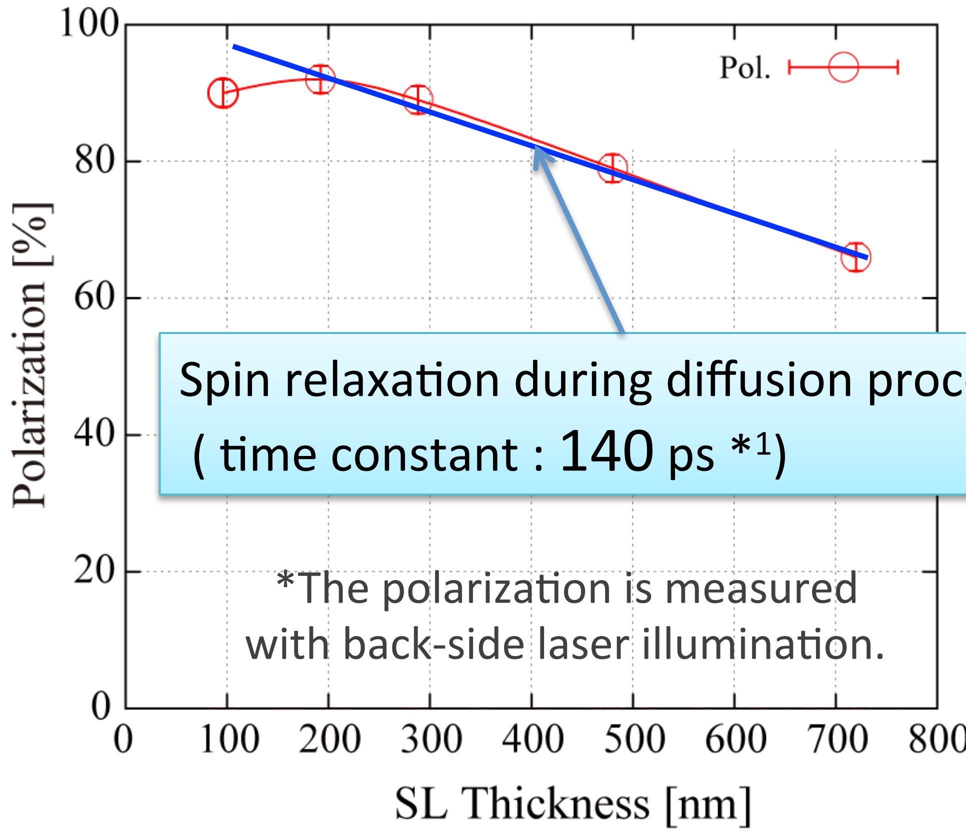






4-4.Discussion of ESP degradation

- Degradation of Spin polarization



Spin relaxation during diffusion process
(time constant : 140 ps *1)

*The polarization is measured
with back-side laser illumination.

Observed degradation is understood by spin relaxation
during electron transport process.

*1. Ref. X.G.Kim, et al., APEX (2013)

Summary

- GaAs/GaAsP Strain-compensated SL PCs have been developed and were successfully fabricated.
  - Up to 90 pairs (720 nm) Thickness PCs were tested.
  - The QEs increase proportional to the SL thickness.
  - Strain-compensated SL effectively prevents strain accumulations.
    - ✓ No Serious Degradation of Crystalline quality was observed.
  - For thicker PCs, Spin relaxation effect limits the ESP value.
    - ✓ Spin relaxation time : 140 ± 12 ps

- Up to now, Using the 24-pair (192 nm) PC,

  ESP of 92 % & QE of 1.6 % were achieved.

  (3 times higher than conv. PC)

In future, optimizing the SL thickness,

Further QE Improvement is expected.