High QE and High polarization photocathode

(prospect & status for photocathode development)

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Outline

1. Introduction
    1. Required performance for LC
    2. Achieved performance
    3. Prospect for Photocathode development
2. Strategy for PC development
3. (New design PC) Strain compensated SL
4. Summary & Future plan

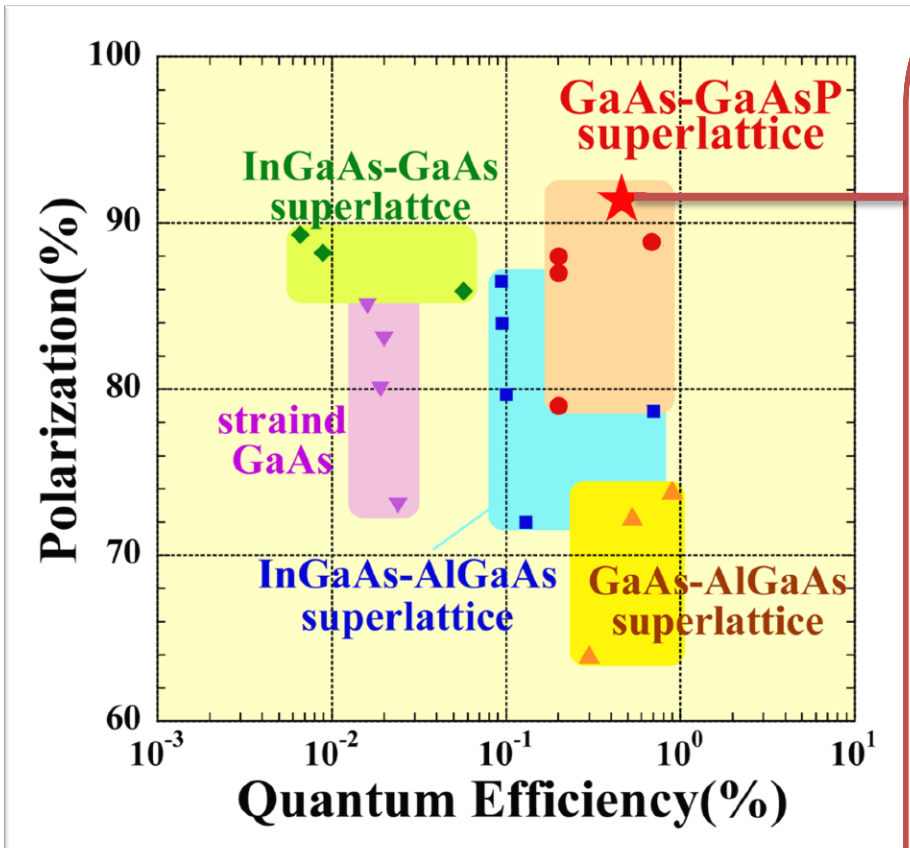
1-1. Required Performance for LC (RDR)

TABLE 2.2-1
Electron Source system parameters.

Parameter	Symbol	Value	Units
Electrons per bunch (at gun exit)	n_e	3×10^{10}	Number
Electrons per bunch (at DR injection)	n_e	2×10^{10}	Number
Number of bunches	N_e	2625	Number
Bunch repetition rate	$F_{\mu b}$	3	MHz
Bunch train repetition rate	F_{mb}	5	Hz
Bunch length at source	Δt	1	ns
Peak current in bunch at source	I_{avg}	3.2	A
Energy stability	S	<5	% rms
Polarization	P_e	80 (min)	%
Photocathode Quantum Efficiency	QE	0.5	%
Drive laser wavelength	Λ	790 ± 20 (tunable)	nm
Single bunch laser energy	E	5	μJ

1-2. Achieved Performance

Polarized Photocathode developed by Nagoya Group



The performance of polarization and QE

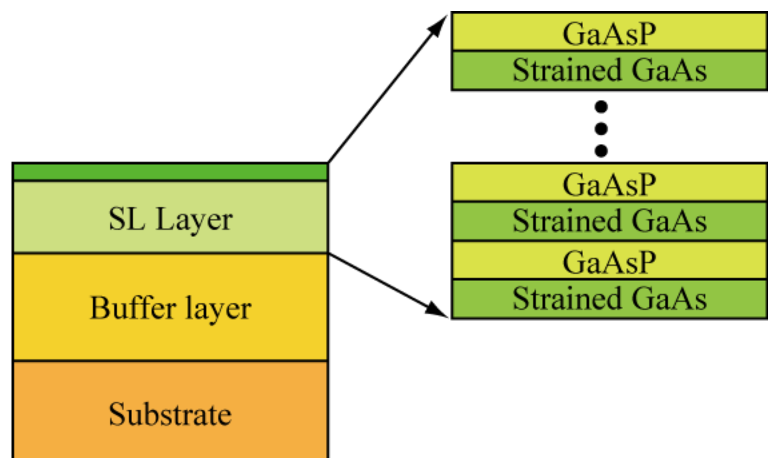
Most Promising Candidates

High polarization (> 90%) and QE(~ 0.5 %)

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

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

X.G. Jin, et al., APEX (2012)



1-3.Prospect for PC development

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Photocathode Quantum Efficiency	QE	0.5	%
Drive laser wavelength	Λ	790±20 (tunable)	nm
Single bunch laser energy	E	5	μJ

~ 95 %

> 1 %

2. Strategy for PC improvement

To realize high QE and high polarization,

high crystal quality (High Pol.)

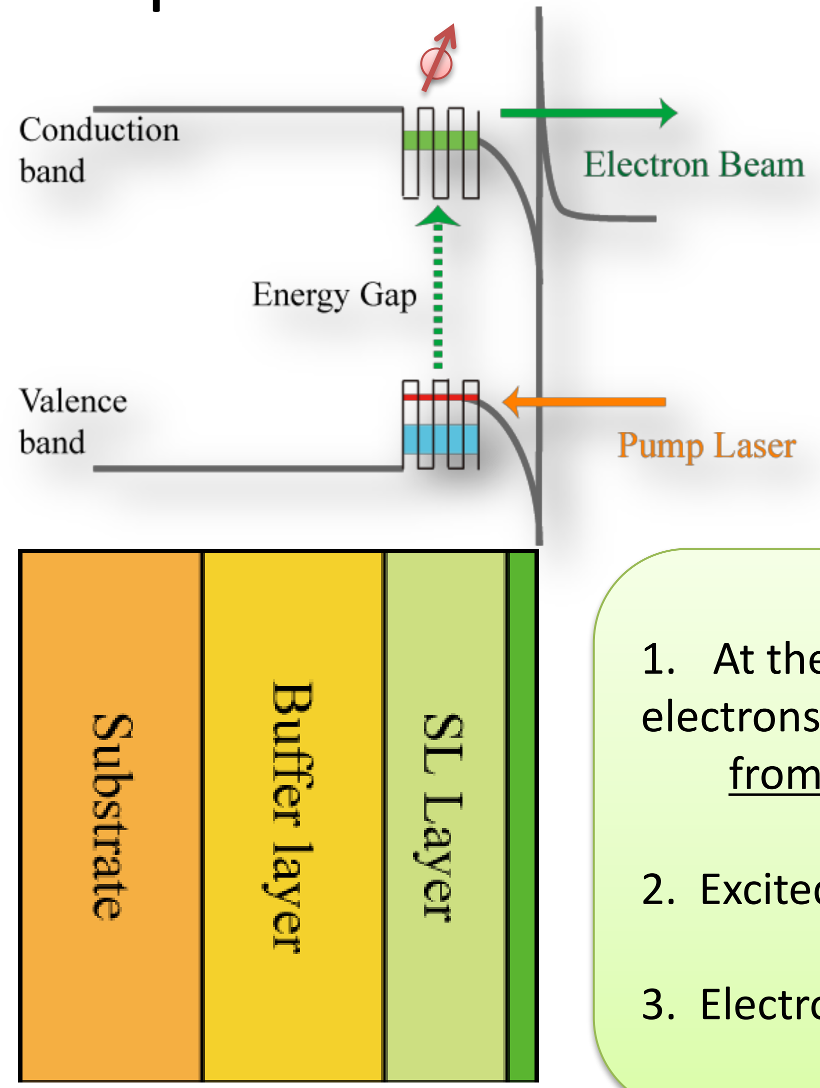
thick thickness SL (High QE) are essential.

New PC design

Strain-Compensated Superlattice

2-1. 3 Step model for electron emission

3 Step model for electron emission



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

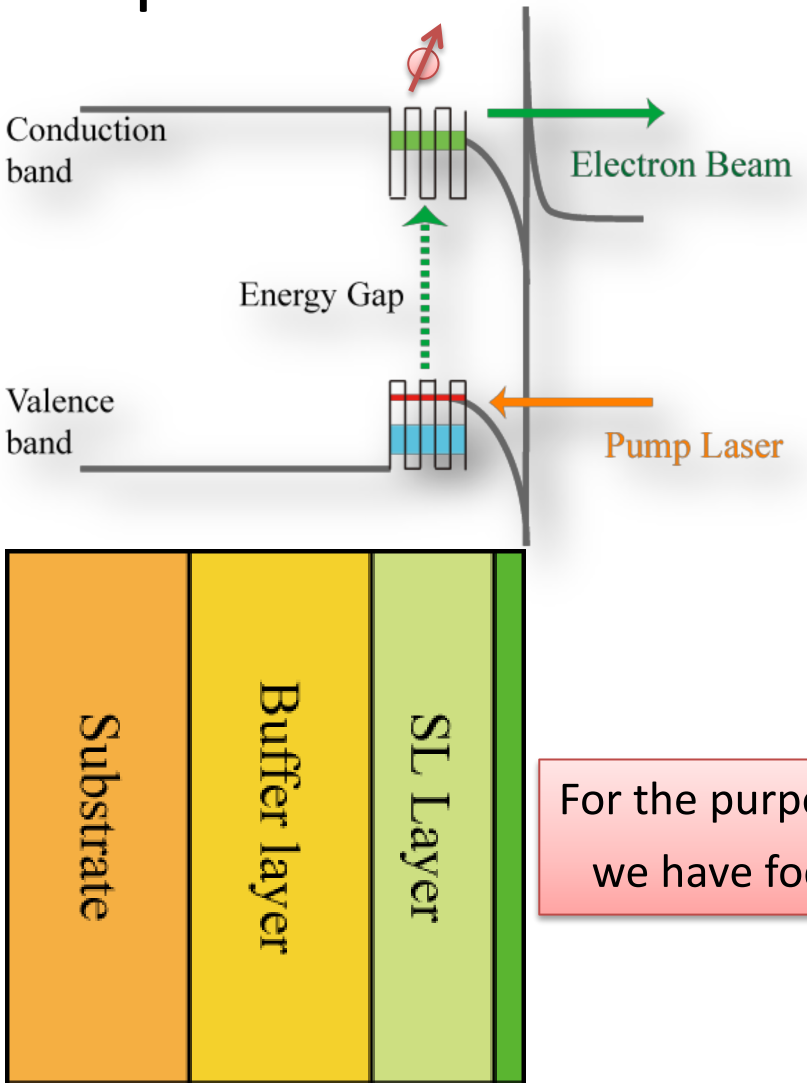
1. At the SL layers,
electrons are pumped by circularly polarized laser
from the highest valence band to conduction band.

2. Excited electrons are diffused to PC surface .

3. Electrons are emitted through the NEA surface.

2-1. 3 Step model for electron emission

3 Step model for electron emission



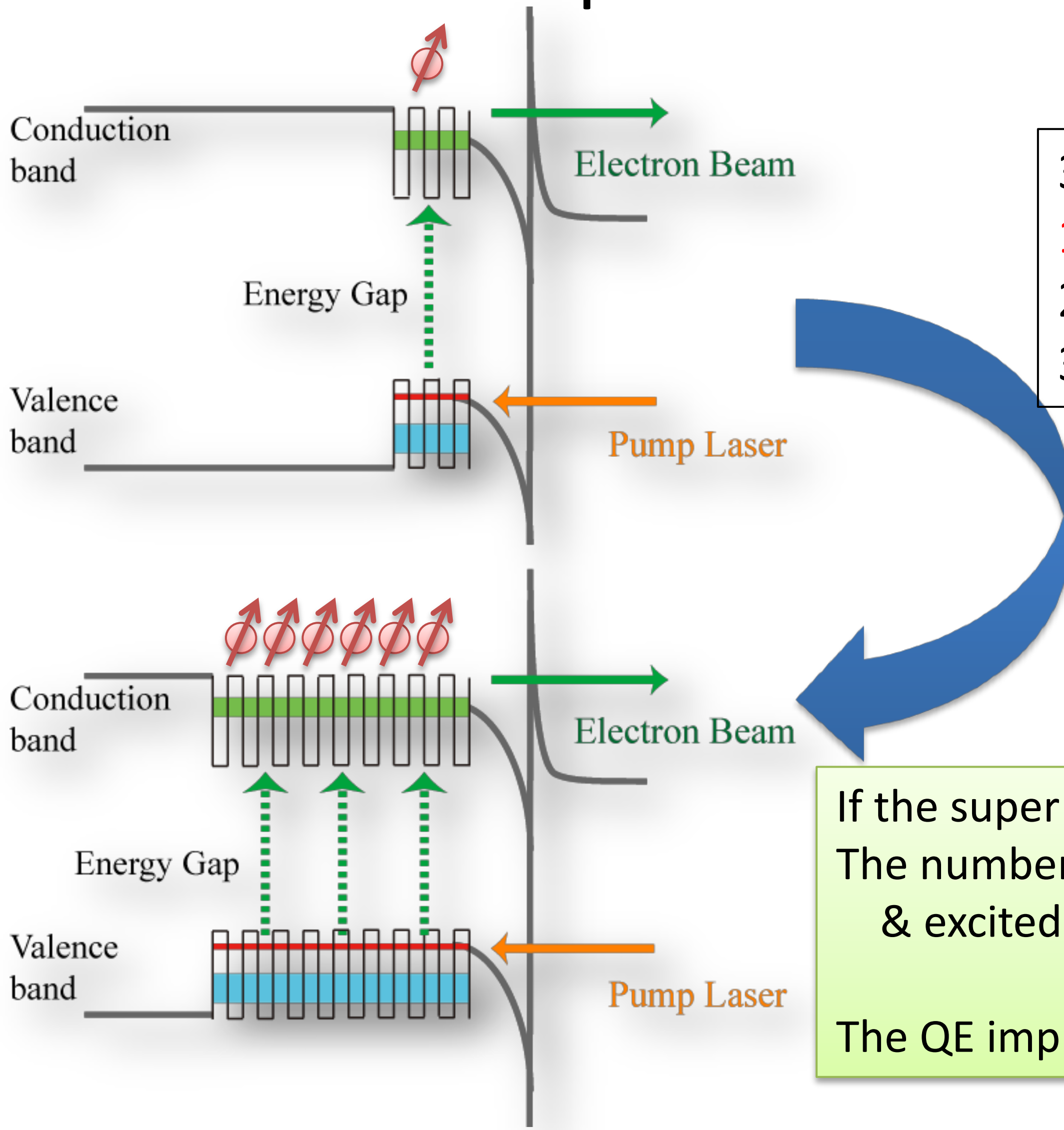
3 step model

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

For the purpose to improve the QE,
we have focused to the Optical pump process (1).

2-2. improving optical pump process

Thick Thickness Super Lattice



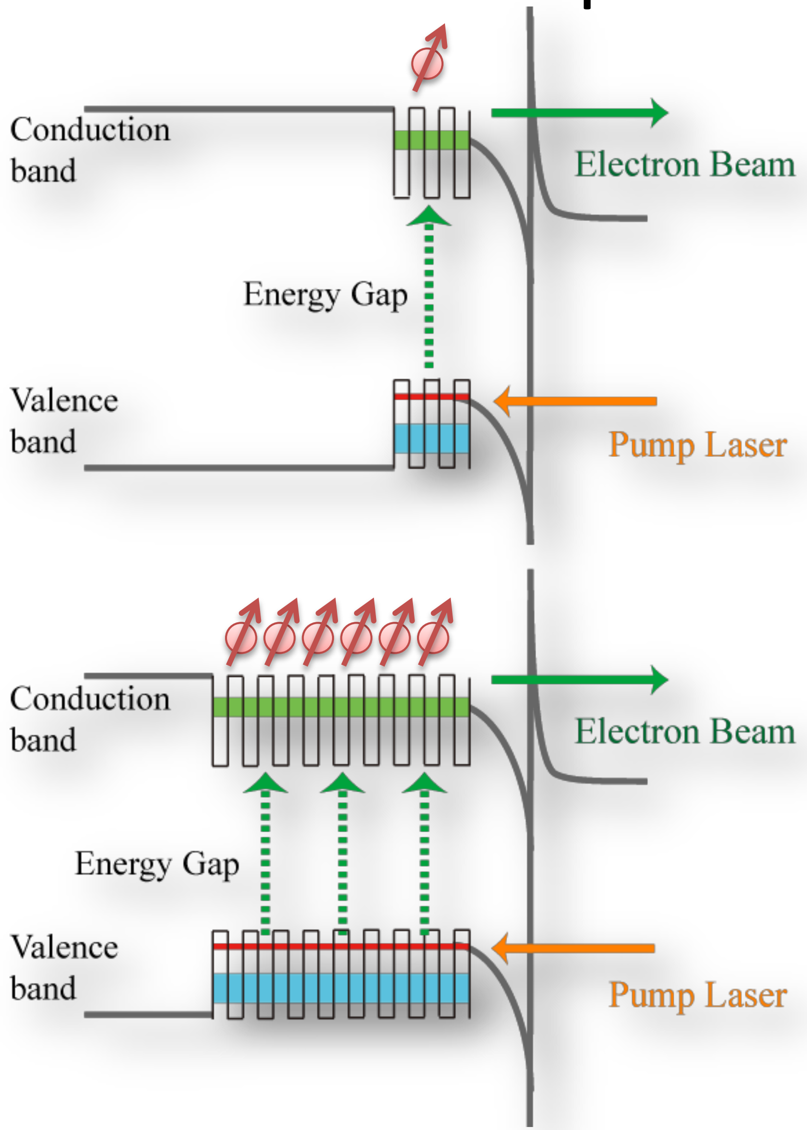
3 step model
1. Optical pump
2. Diffusion at conduction band
3. Emission from NEA surface

If the super lattice thickness increase,
The number of absorbed photon
& excited electron would be increased.

The QE improvement will be expected.

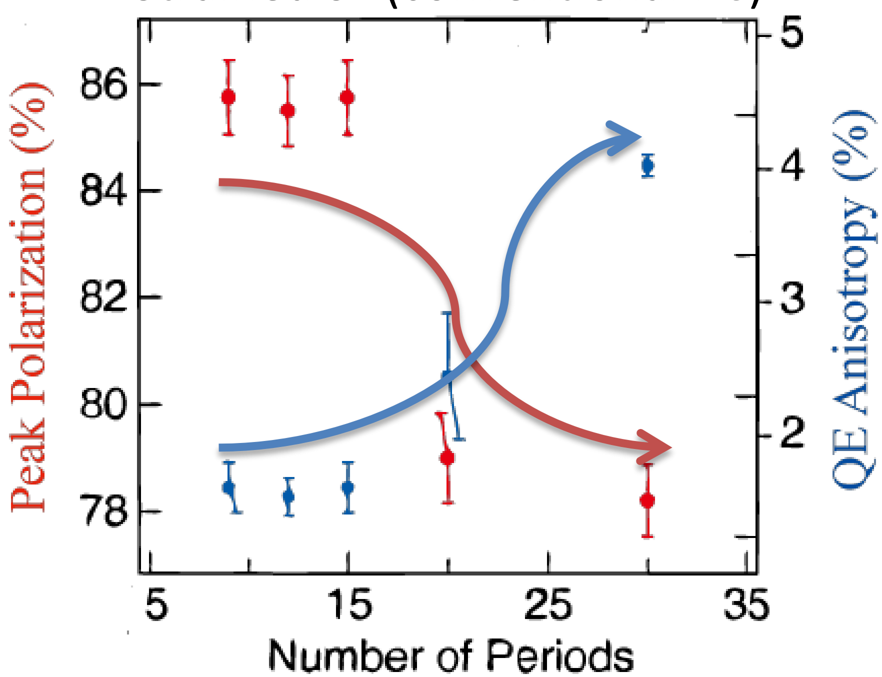
2-3.Previous study by SLAC group

Thick Thickness Super Lattice



The result of previous study

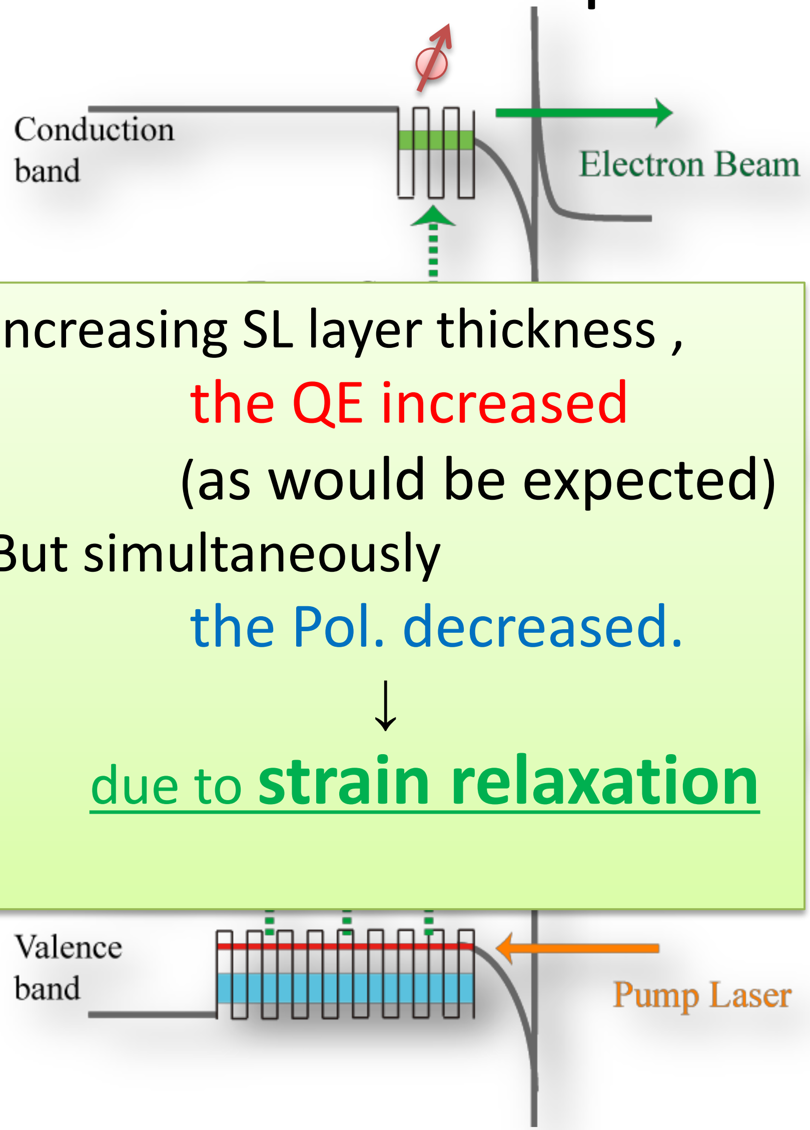
Strained SL (conventional PC)



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

2-3.Previous study by SLAC group

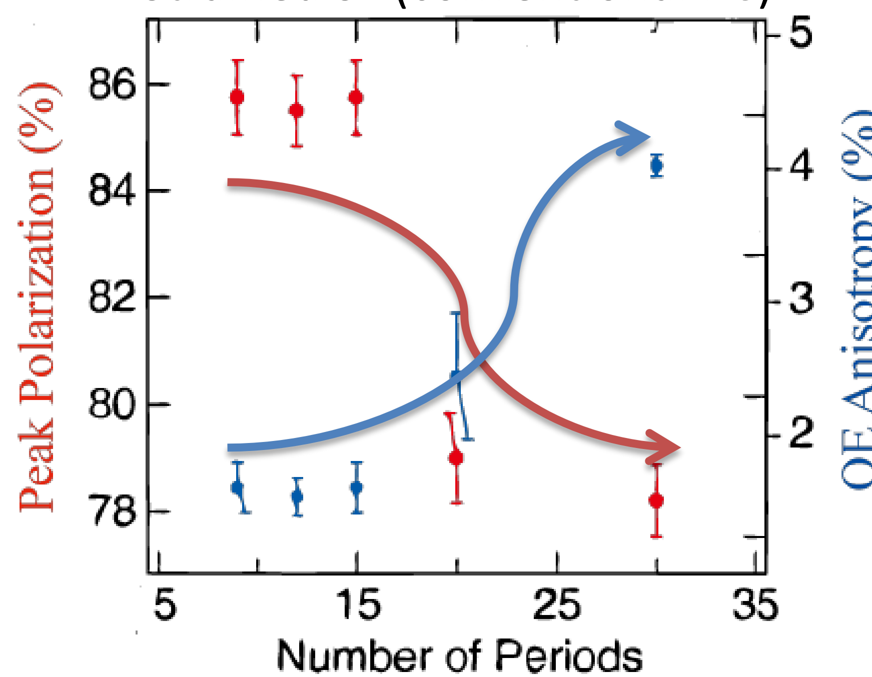
Thick Thickness Super Lattice



Increasing SL layer thickness ,
the QE increased
(as would be expected)
But simultaneously
the Pol. decreased.
↓
due to **strain relaxation**

The result of previous study

Strained SL (conventional PC)



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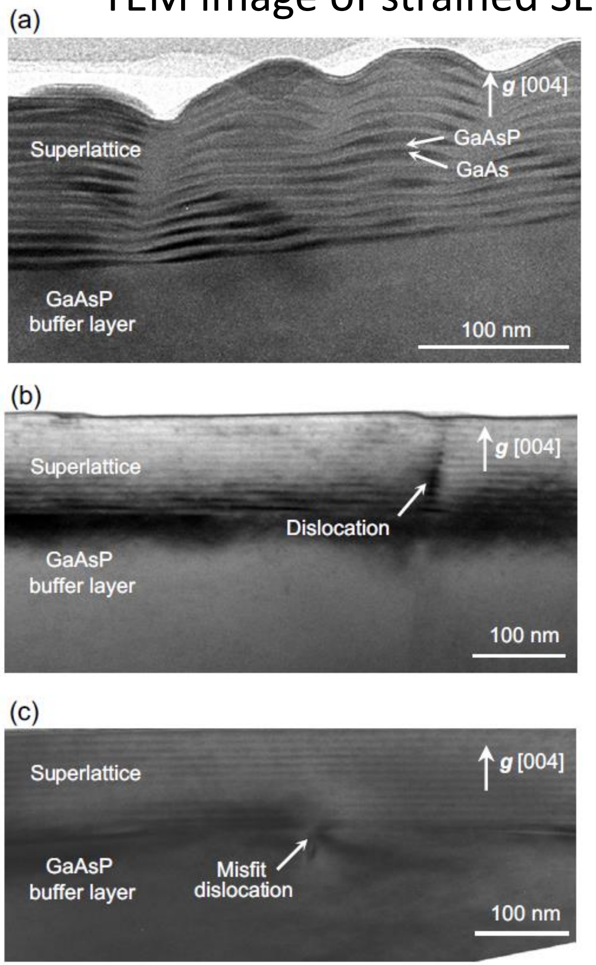
2-3. Strain relaxation

Thick Thickness Super Lattice -> Strain relaxation

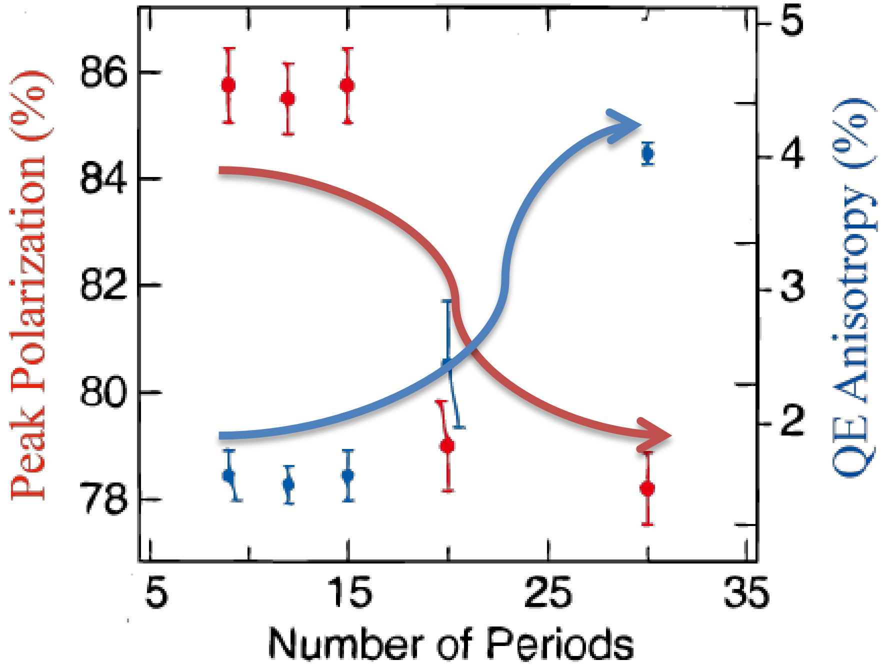
TEM image of strained SL Layer on GaAsP buffer



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

The result of previous study

Strained SL (conventional PC)



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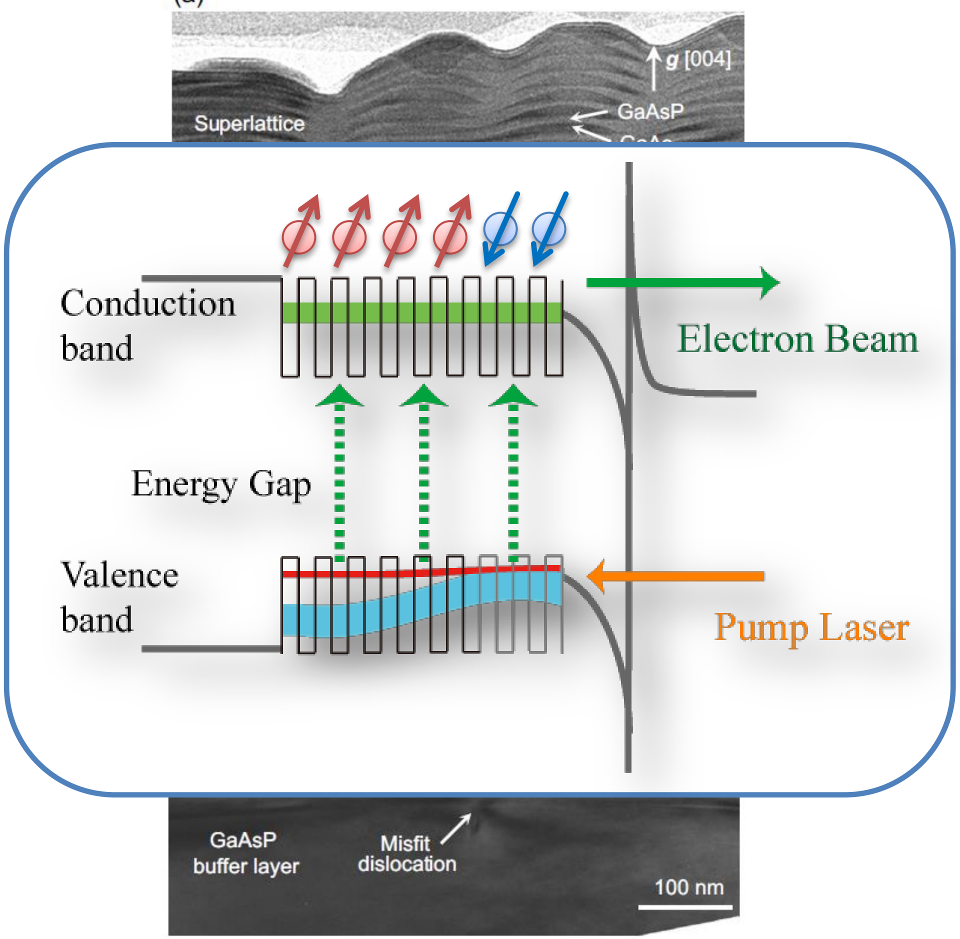
2-3. Strain relaxation

Thick Thickness Super Lattice -> Strain relaxation

TEM image



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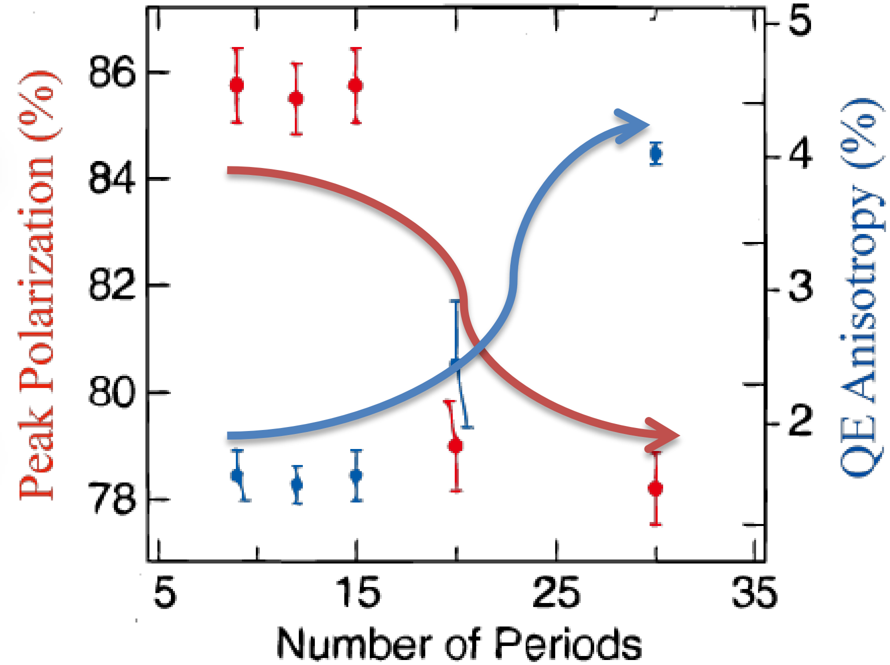

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2-3. Strain relaxation

Thick Thickness Super Lattice -> Strain relaxation

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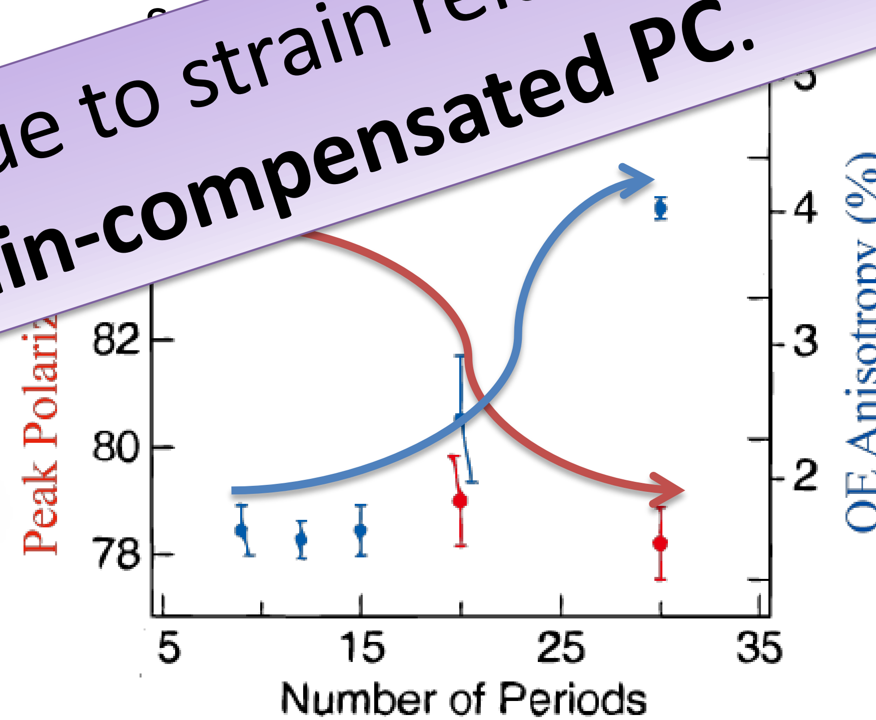
The result of previous ...

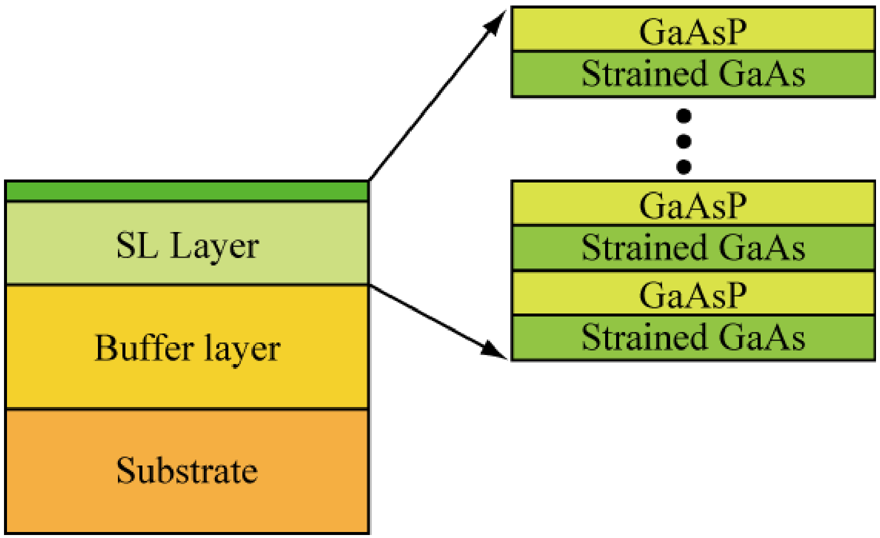


Ref. T. Maruyama, et al., APL (2004)

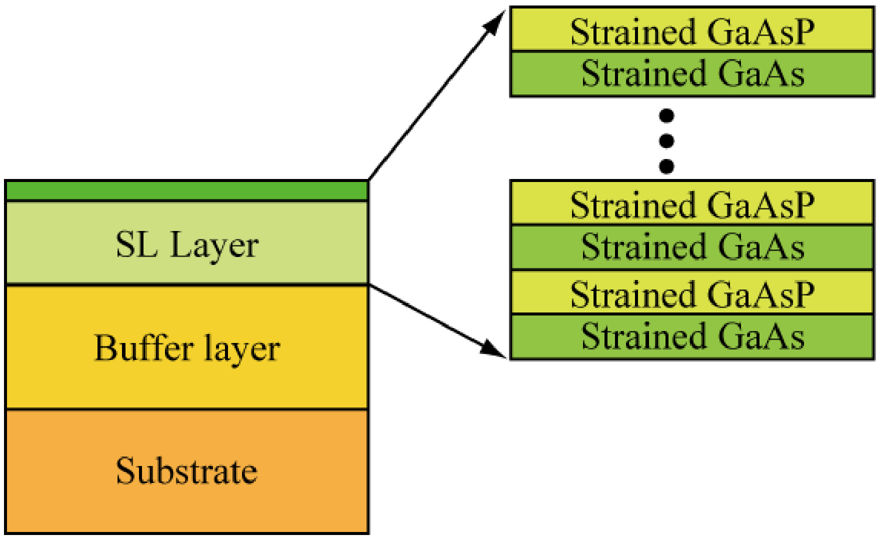
To overcome the limit due to strain relaxation,
We proposed **Strain-compensated PC**.

3-1. Strain-Compensated PC

Strain SL (conventional)

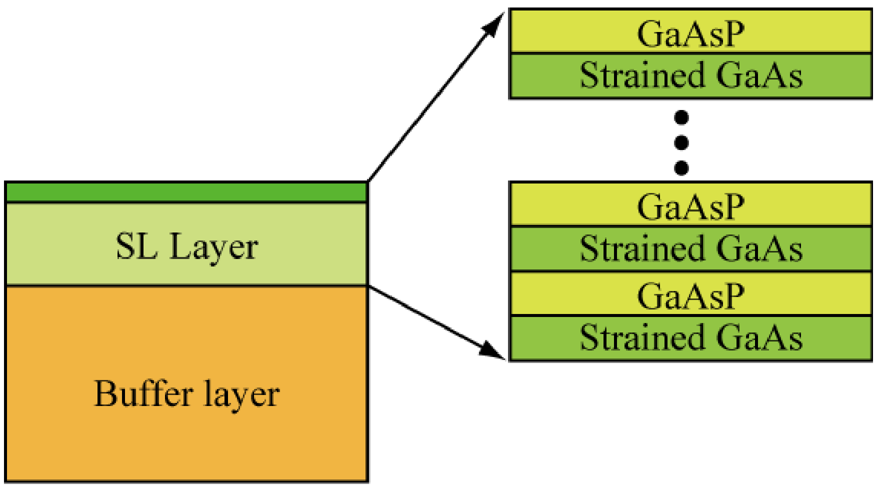


Strain Compensated SL

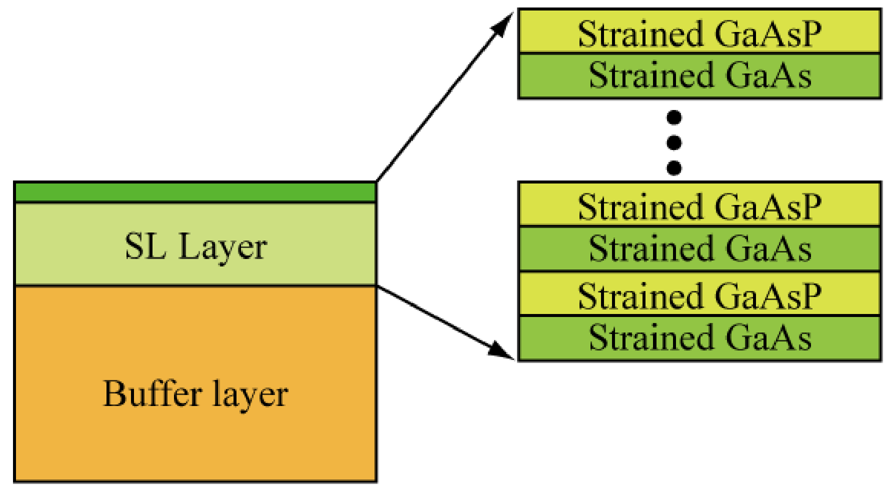


3-1. Strain-Compensated PC

Strain SL (conventional)



Strain Compensated SL



Net Strain of SL pairs

ε (GaAs) + 0 (GaAsP) = ε

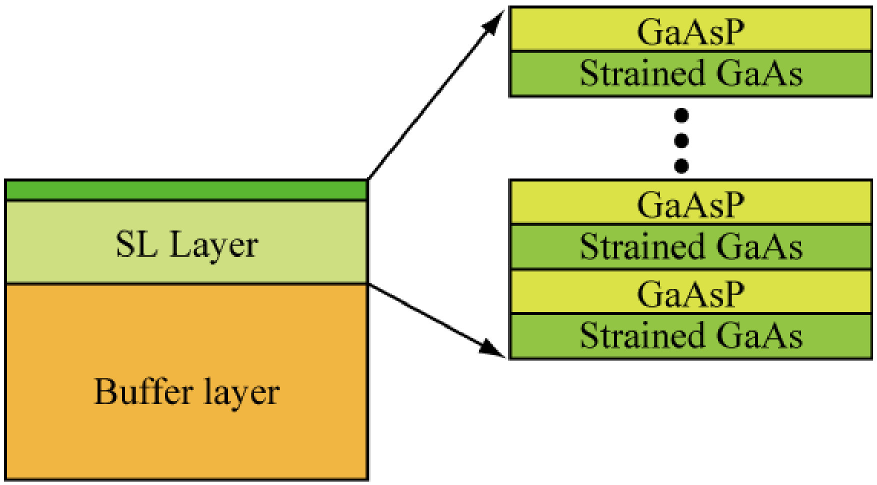
/

Net Strain of SL pairs

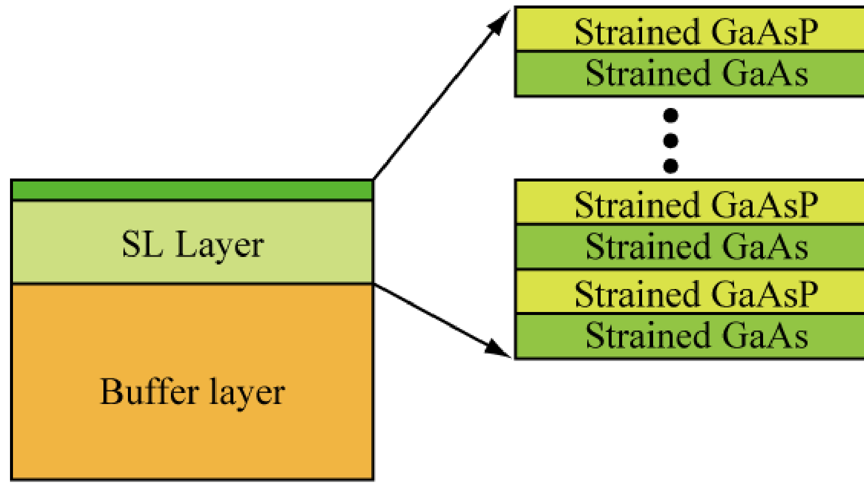
$\varepsilon / 2$ (GaAs) + $-\varepsilon / 2$ (GaAsP) ≈ 0

3-1. Strain-Compensated PC

Strain SL (conventional)



Strain Compensated SL



Net Strain of SL pairs

ε (GaAs) + 0 (GaAsP) = ε

Net Strain of SL pairs

$\varepsilon / 2$ (GaAs) + $-\varepsilon / 2$ (GaAsP) ≈ 0

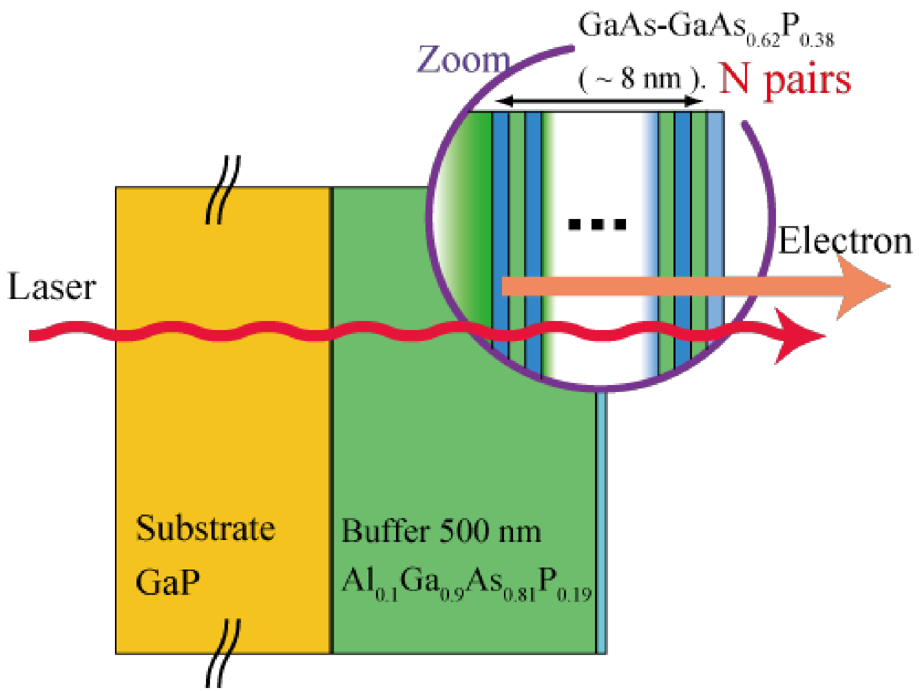
Strain relaxation suppressing

We can expect High Crystal Quality

3-2. Test sample of Strain–Compensated SL

GaAs-GaAsP Strain–Compensated SL

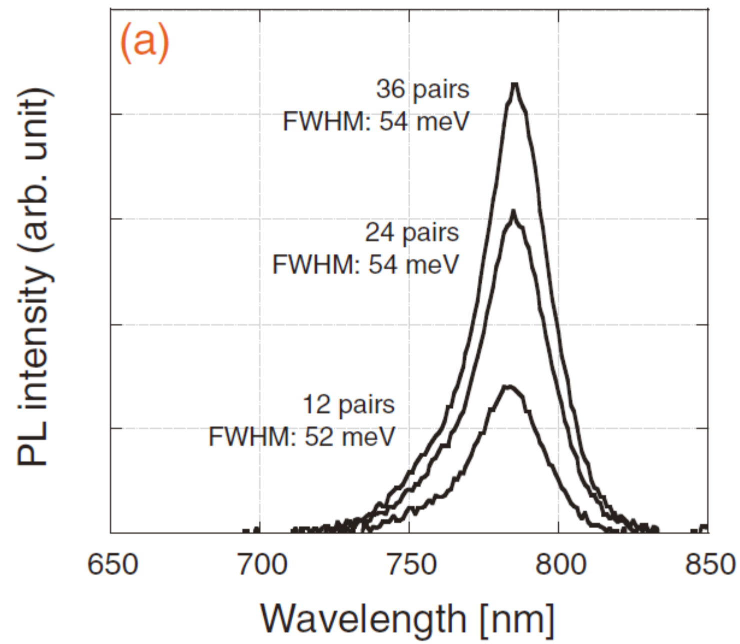
Ref. X.G. Jin, et al., APEX (2012)



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

Lattice constant →
medium value between GaAs and GaAsP

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



No shift of the PL peak or
broadening of the FWHM

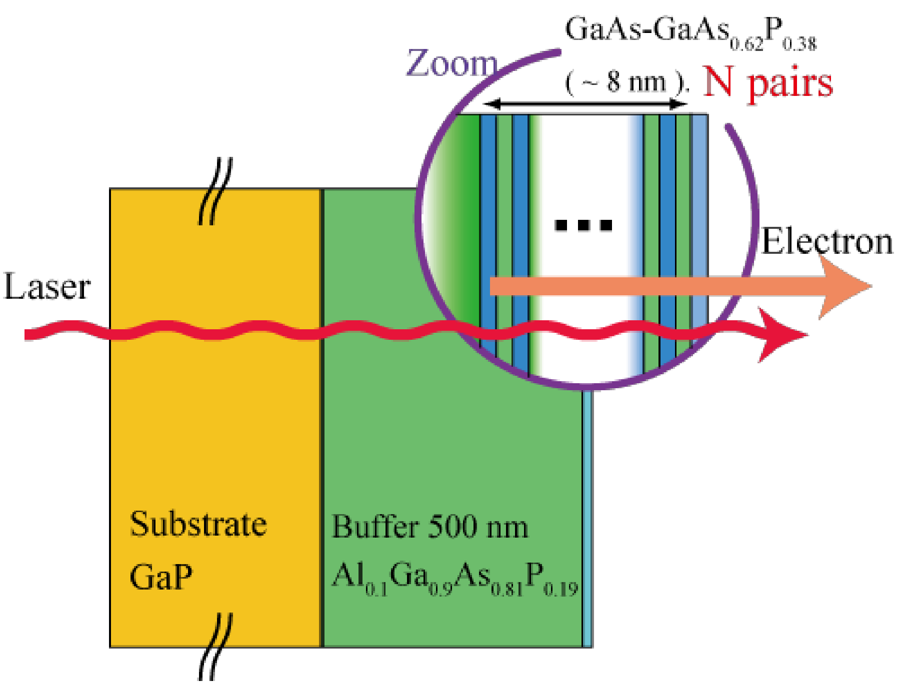
No strain relaxation

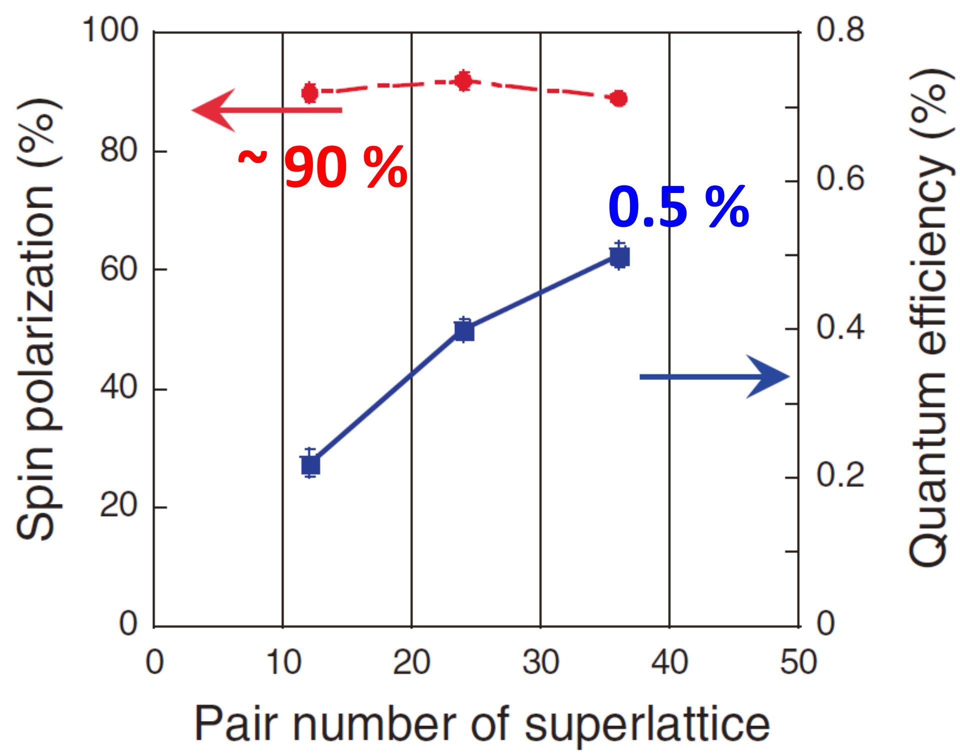
3-2. Test sample of Strain–Compensated SL

Ref. X.G. Jin, et al., APEX (2012)

GaAs-GaAsP Strain–Compensated SL

* In this design,
* the parameter for higher QE is not optimized.





(Thickness : x 8 nm)

In the SL thickness increasing,
The degradation of spin polarization can not be observed.
The QE increased steadily.

3-2. Test sample of Strain–Compensated SL

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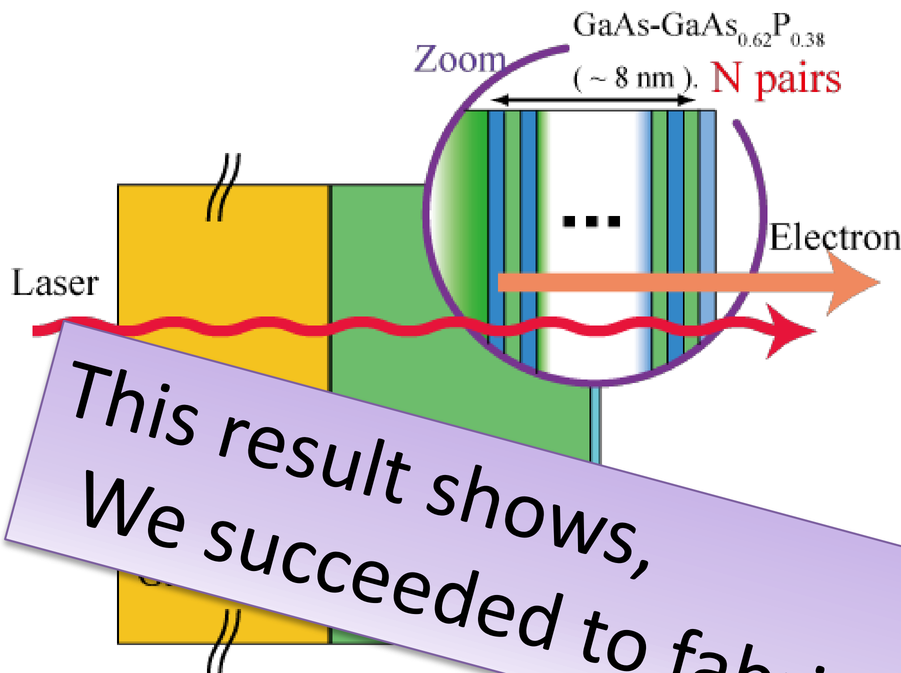

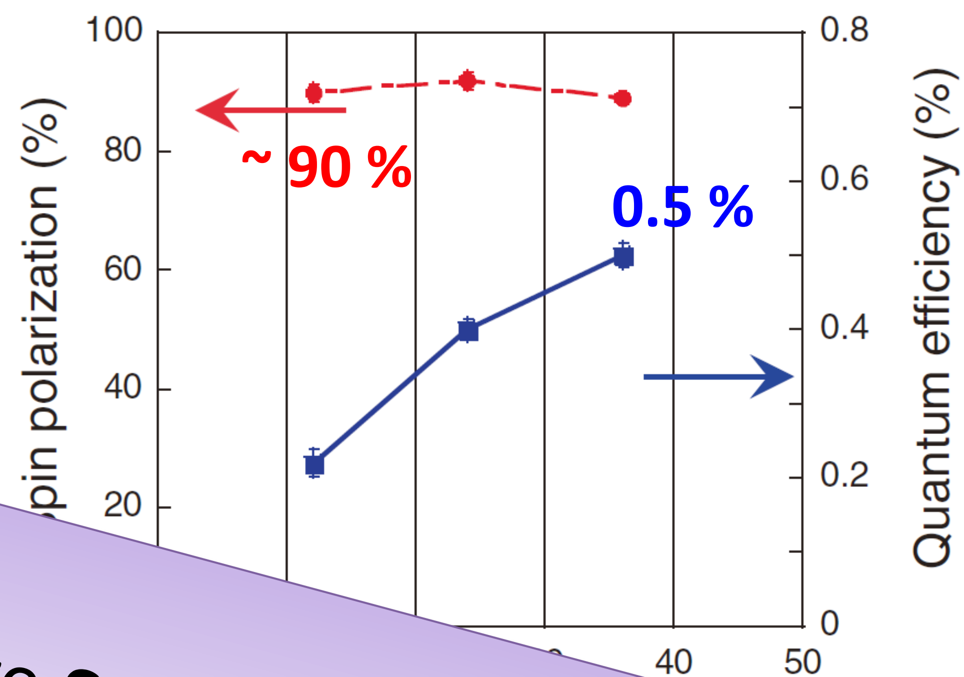

This result shows,
We succeeded to fabricate **Strain-compensated PC.**

In the SL thickness increasing,
The degradation of spin polarization can not be observed.
The QE increased steadily.

5.Summary & Future plan

We have proposed and developed Strain-Compensated SL PC.

Up to now,

We succeed to fabricate the Strain-Compensated SL PC.

Electron Spin polarization of 90 %

& Quantum Efficiency of 0.5 % were promisingly achieved.

In future,

By optimizing

strain parameter, Zn-doping density, fabrication condition ..,

We are planning to develop higher performance PC .

Our Next targeted values,

Spin Polarization : ~ 95 %

Quantum Efficiency : > 1 %

Thank you for your attention.