Highly polarized beam generation with High QE based on a transmission type cathode

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European Linear Collider ECFA Workshop Hamburg, 30 May, 2013

Outline

1. Back-ground
    1. Parameter Requirement for Polarized Electron Source
    2. Achieved performance, Equipment
2. Concept of Transmission Pol. Electron Source
3. Transmission Photocathode (T-PC)
    1. Structure design
    2. Recent progress
    3. Prospects for PC developments
4. Other Application of T-PC
5. Summary & Future plan

1-1. Electron Source Parameter (RDR)

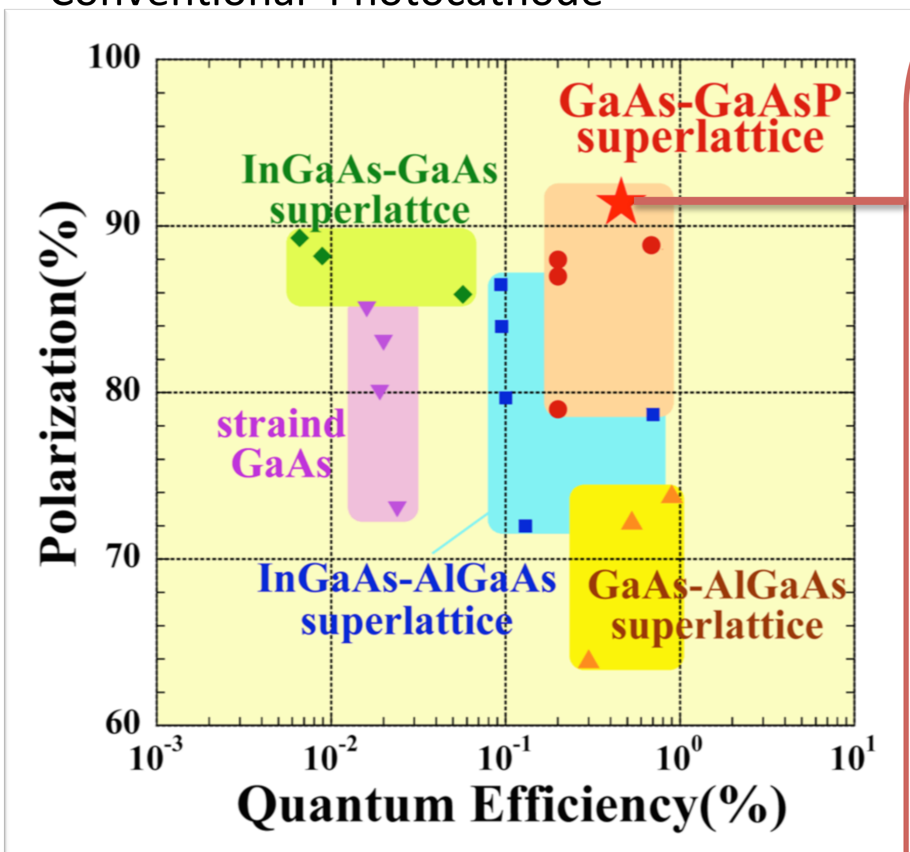
TABLE 2.2-1
Electron Source system parameters.

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

1-1. Photocathode R&D

Polarized Photocathode developed by Nagoya Group

Conventional Photocathode



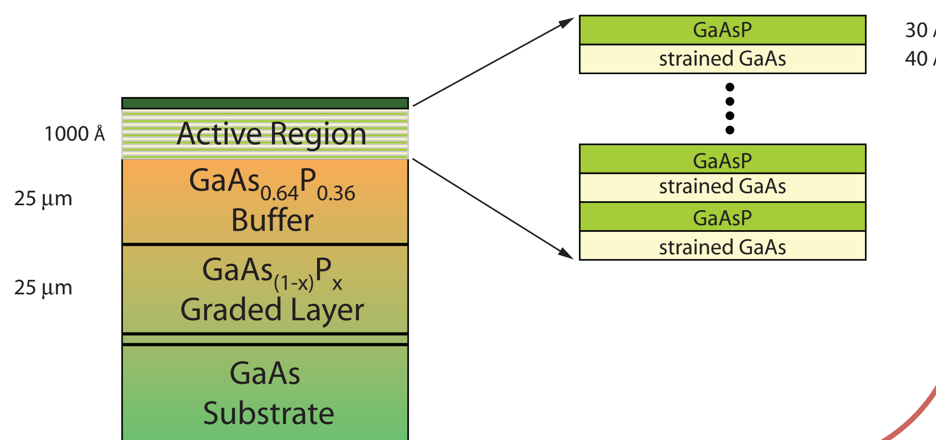
The performance of polarization and QE

Most Promising Candidates

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

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

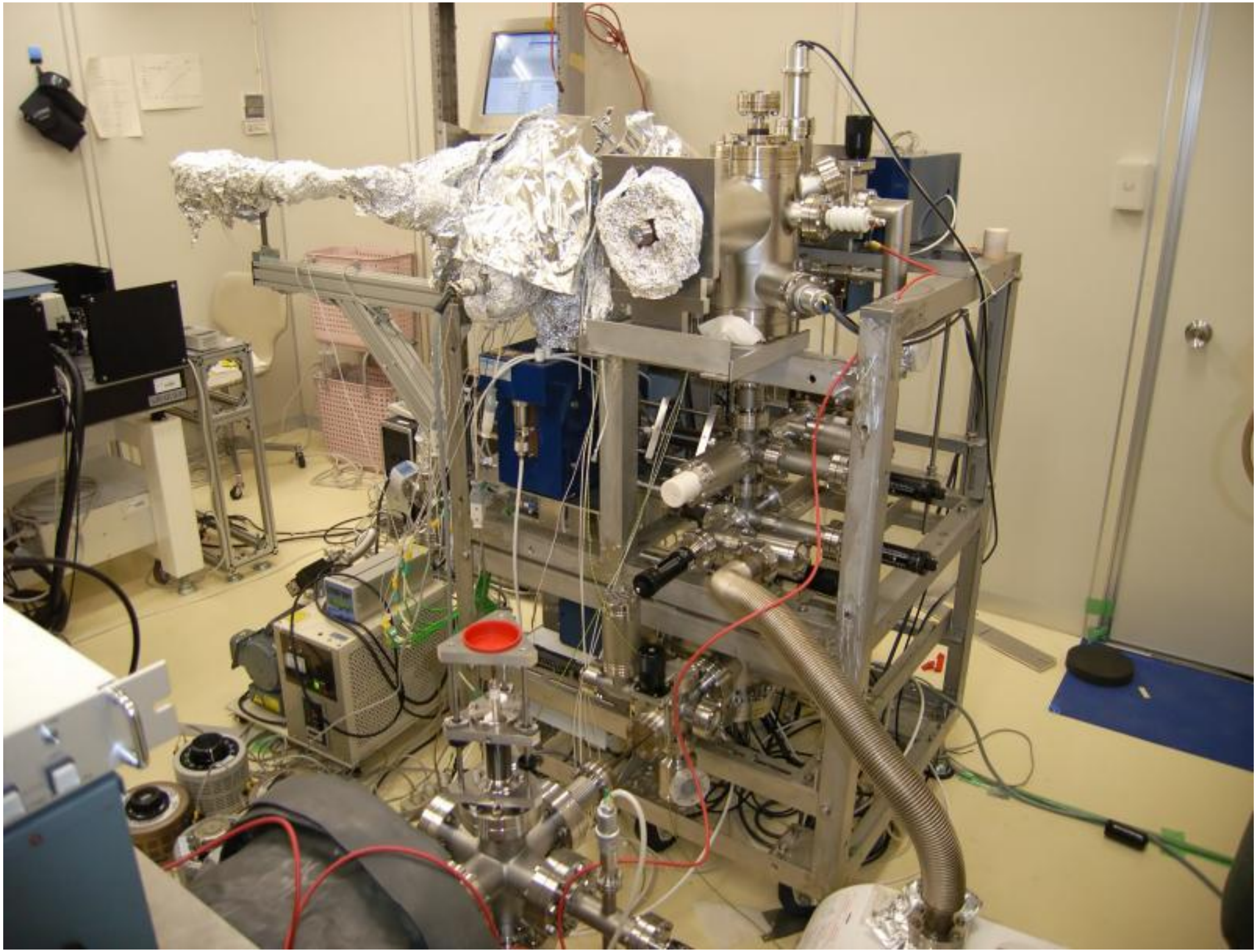
T. Nishitani et al., J. Appl. Phy. **97** (2005)



1-2. Equipment

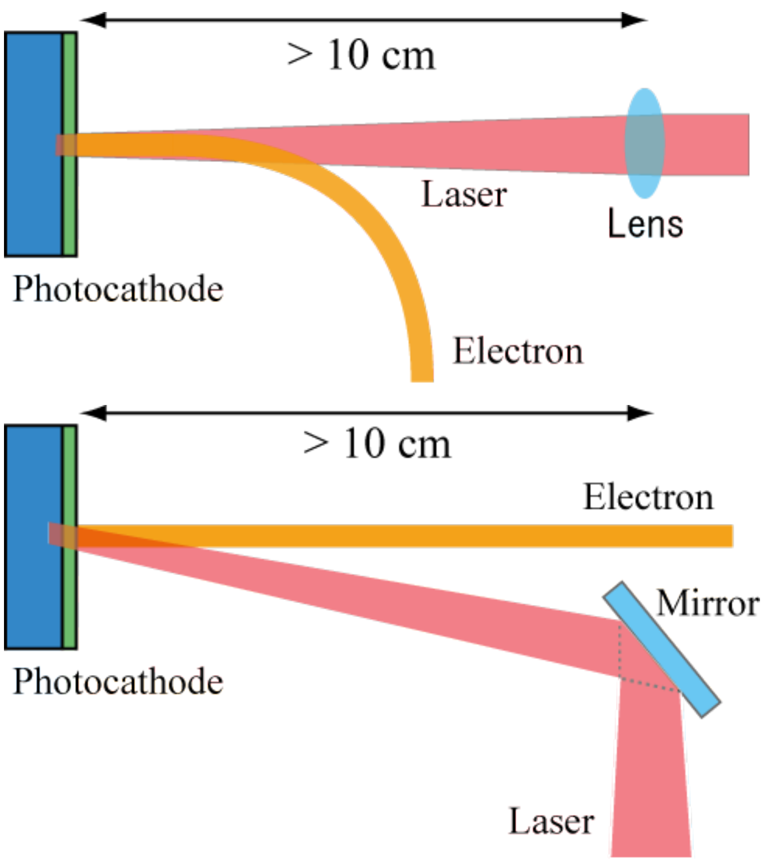
- Photocathode fabrication
  - OMVPE (a low-pressure organometallic vapor phase epitaxy) system
- Fabrication Performance test
  - AFM for surface morphology analysis
  - PL & XRD, (TEM), for super-lattice configuration analyses
- Beam Performance test
  - CW & Mode-locked (~ 100 fs) Ti-Sa laser
  - 20 kV e-gun
  - 100kV-mott polarimeter
  - Beam deflector (for pulse response study)

20 kV Gun & 100 kV Polarimeter

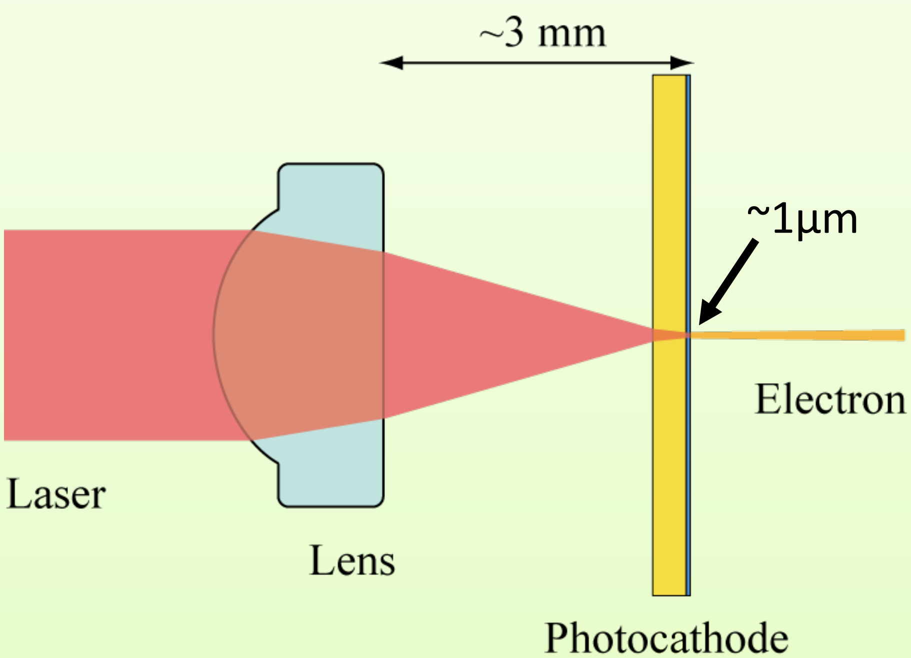


2.Concept of Transmission PES

Conventional (Reflection type)



Transmission Type



Merits :

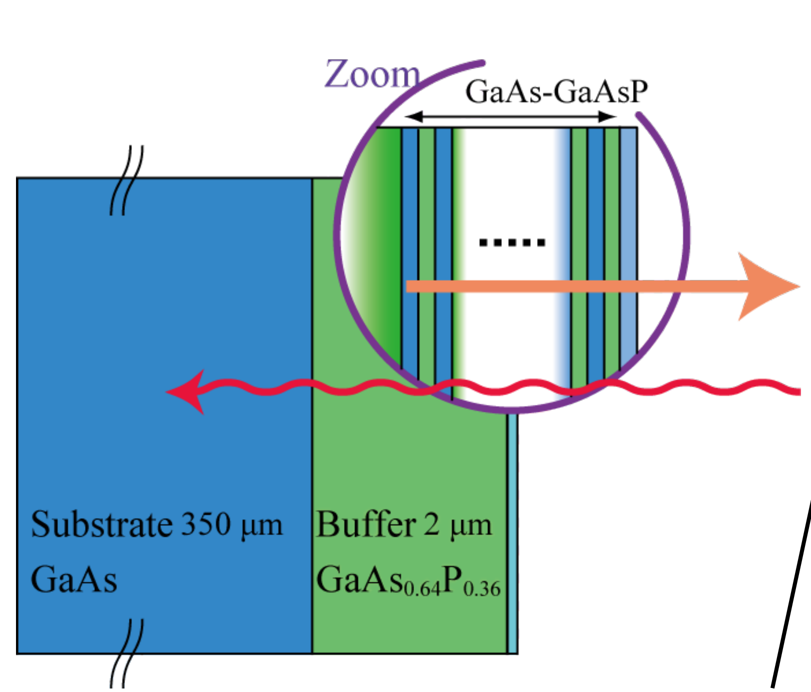
- Improve QE_{eff} w. anti-reflection coat
- Suppression of Photocathode laser-heating
- Small laser focusing (down to μm-scale)

3-1.Design of Transmission Photocathode

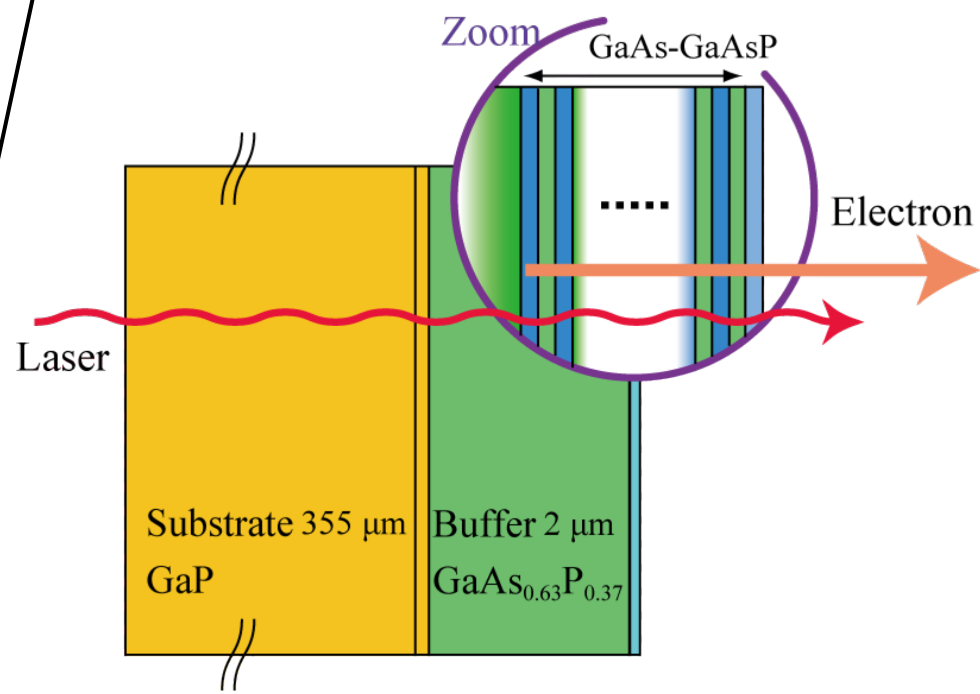
Base design: Reflected-type GaAs/GaAsP SL

Substrate : GaAs -> **GaP**

Conventional (Reflection type)



Transmission Type

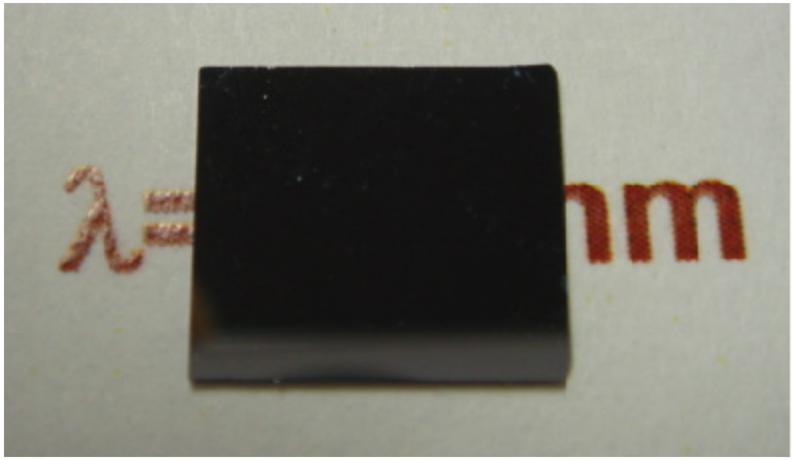


3-1.Design of Transmission Photocathode

Base design: Reflected-type GaAs/GaAsP

Substrate : GaAs -> **GaP**

Conventional (Reflection type)



GaAs substrate
band gap energy: 1.42 eV

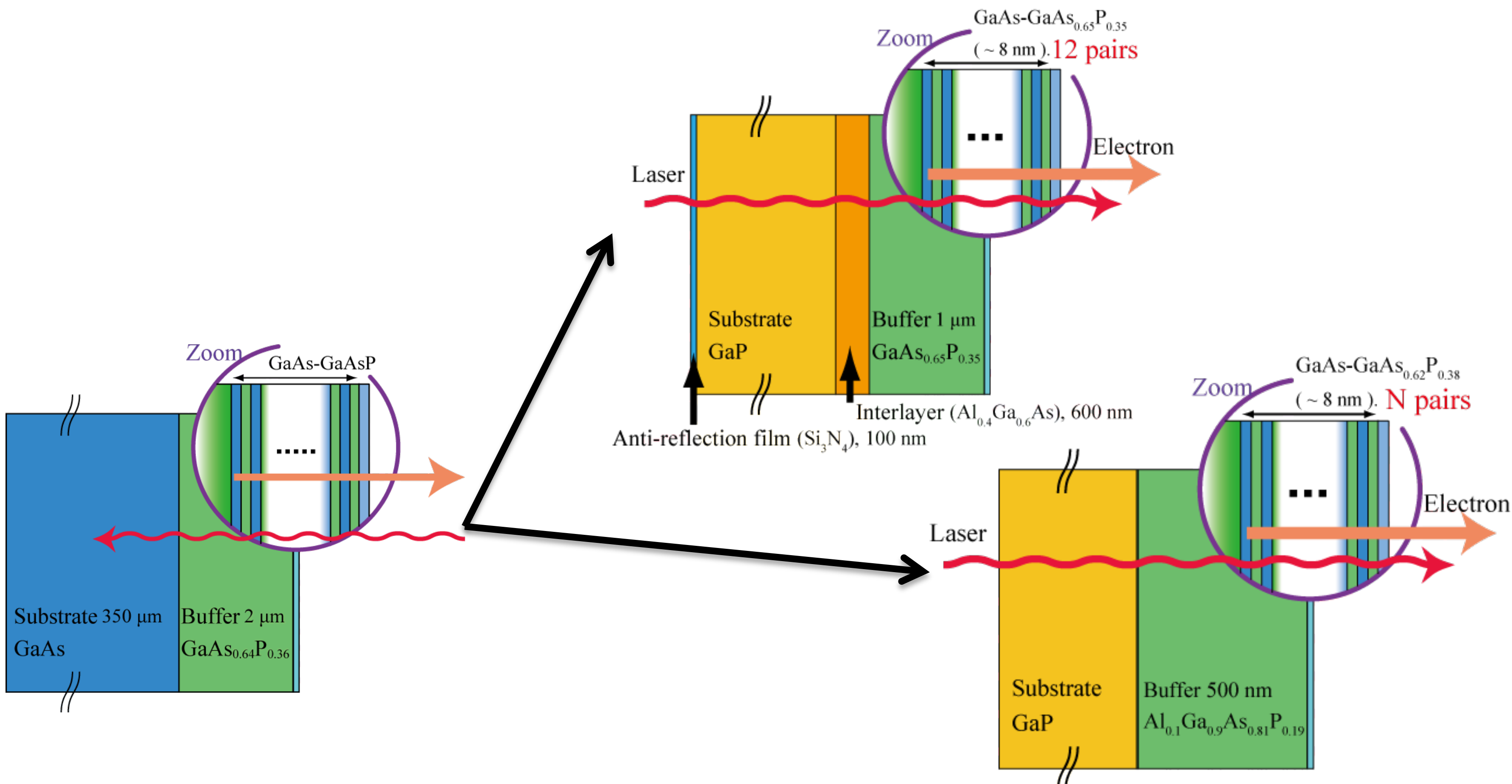
Transmission Type

GaP substrate
band gap energy: **2.26 eV**

Pump laser light energy: **1.4~1.8 eV**

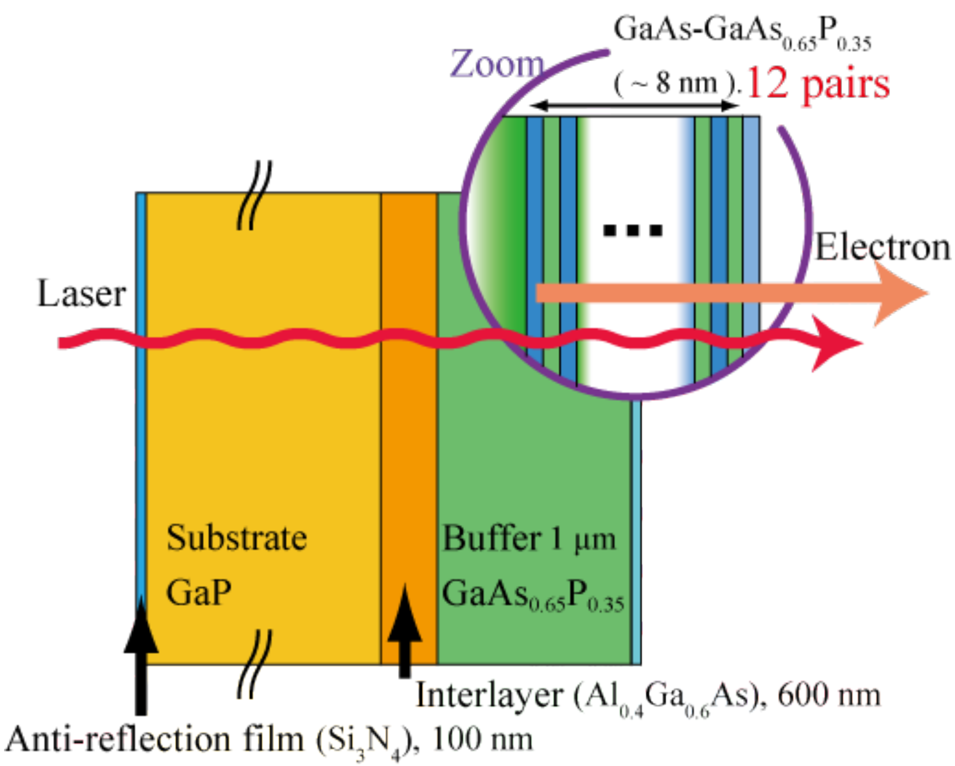
3-2.Recent progress of T-PC

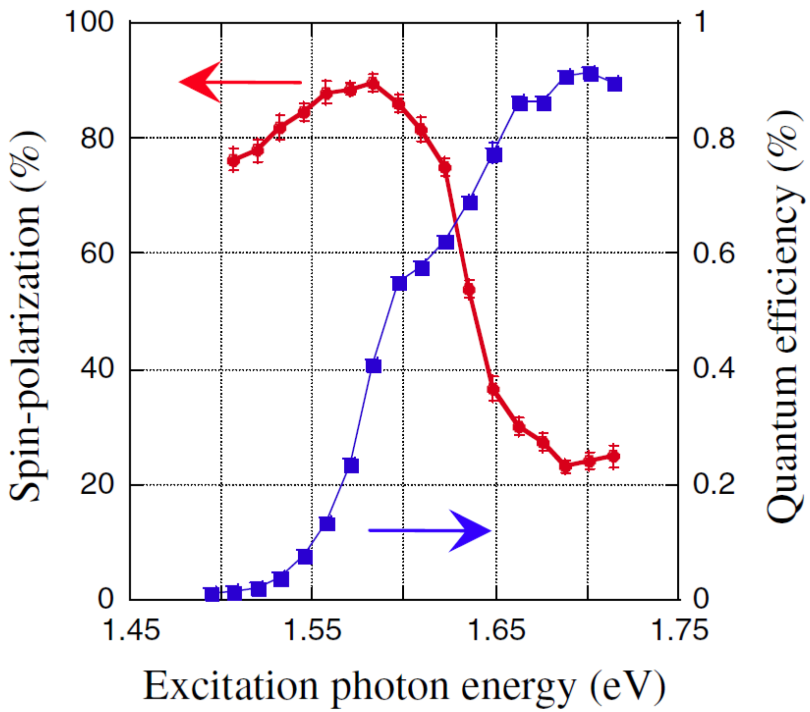
- GaAs-GaAsP strained SL with anti-reflection film
- GaAs-GaAsP Strain–Compensated SL



3-2. Strained SL with anti-reflection film

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





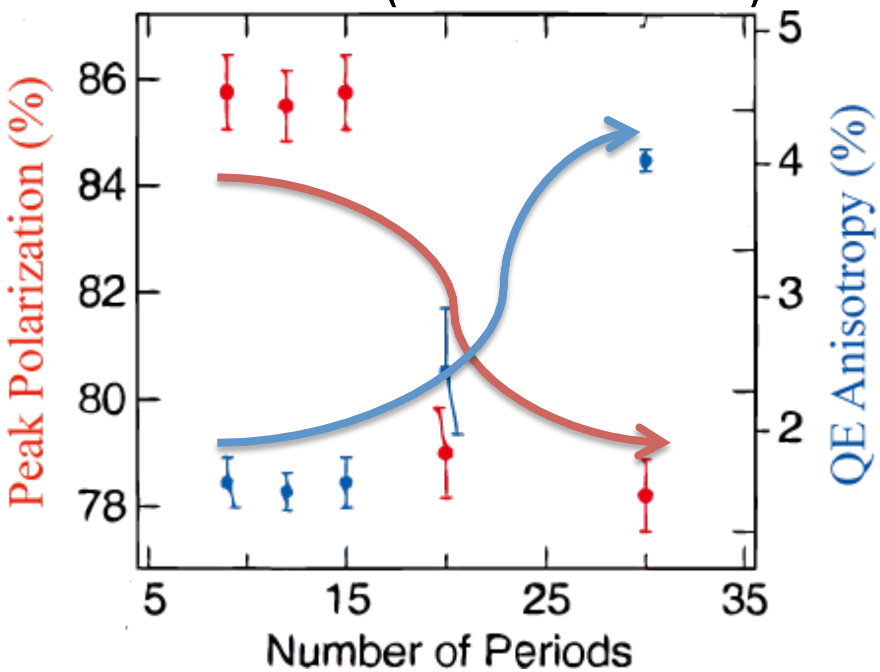
Feature:
- Inter-layer for control the lattice constant
- Anti-reflection film
  (Reflection rate. 30 % -> 10%)

Polarization : ~ 90%
Quantum Efficiency : 0.4 %

3-2.Strain–Compensated SL

What is Strain–Compensated SL ?

Strained SL (conventional PC)



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

In the strained SL structure,
increasing SL layer thickness ,
the polarization is decreased.
(due to strain relaxation)

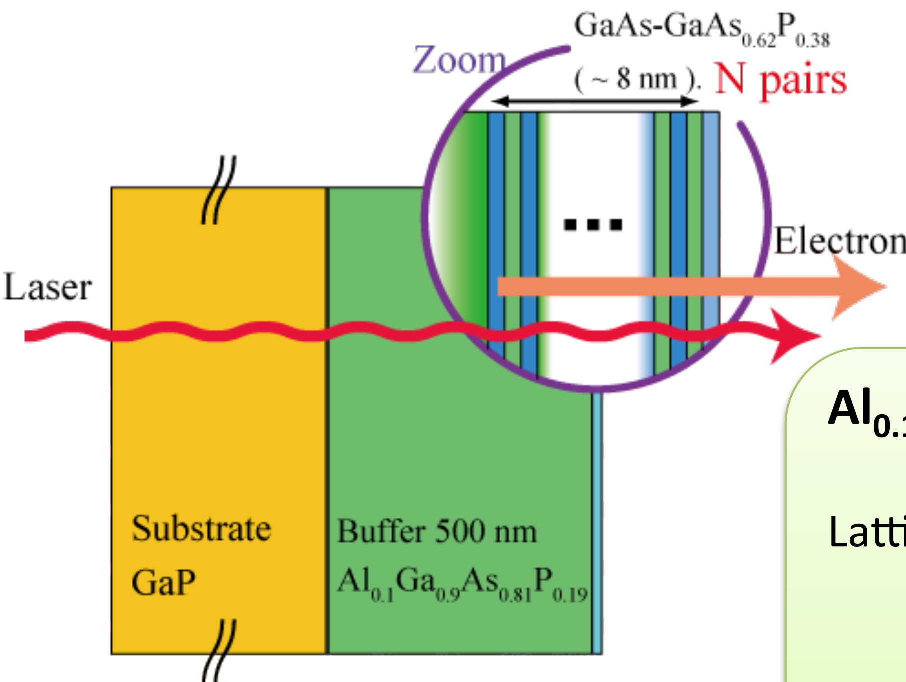
A smaller SL layer thickness is
one reason behind the limited QE value .

In order to overcome this problem, **strain relaxation** has to be suppressed.
For this purpose,
We introduced equivalent compressive and tensile strains for SL layers.
(net strain = 0)

3-2.Strain–Compensated SL

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

GaAs-GaAsP Strain–Compensated SL



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

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

Lattice constant →
medium value between GaAs and GaAsP

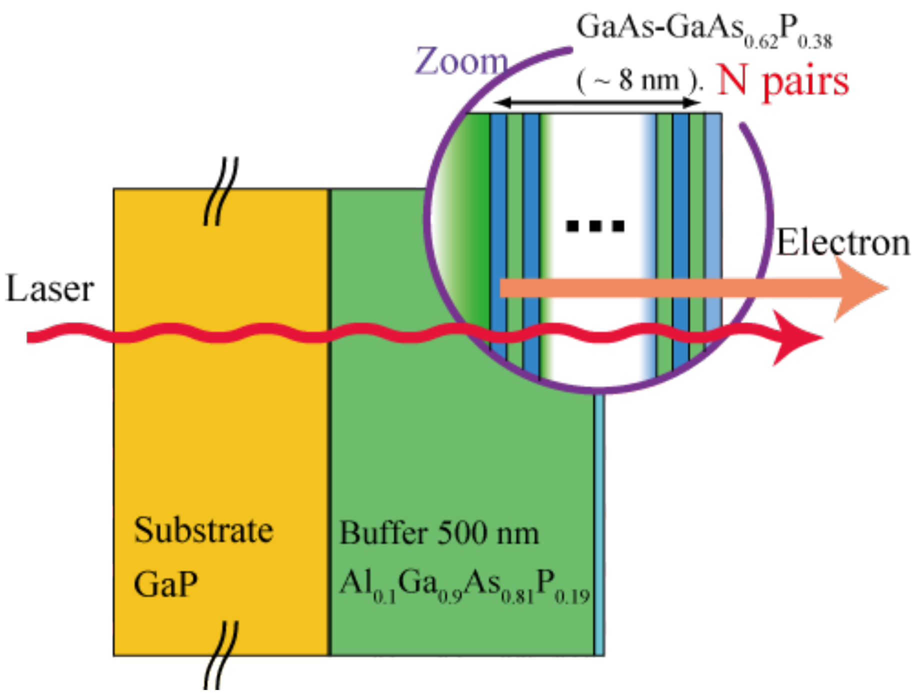
Band gap energy (1.77eV) →
higher than that of SL layers

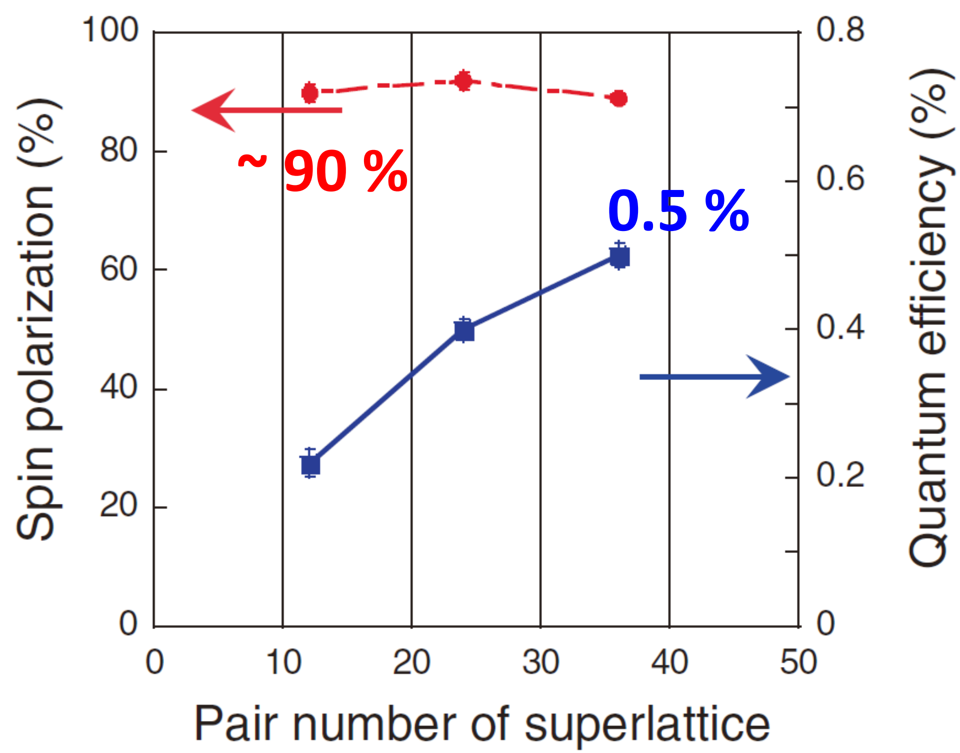
In order to overcome this problem, **strain relaxation** has to be suppressed.
For this purpose,
We introduced equivalent compressive and tensile strains for SL layers.
(net strain = 0 → thicker SL)

3-2. Strain–Compensated SL

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

GaAs-GaAsP Strain–Compensated SL





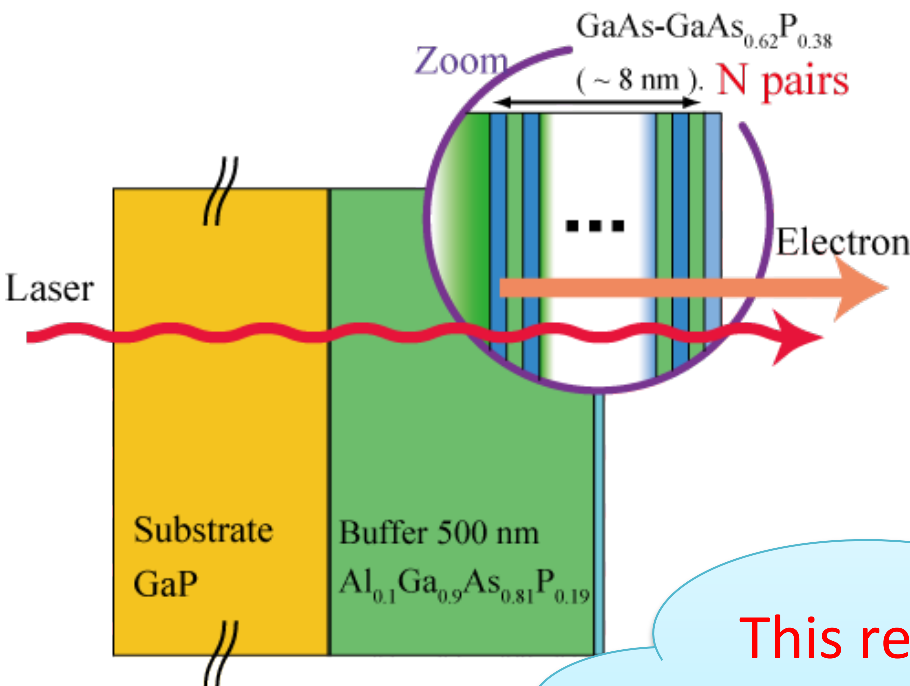
(Thickness : x 8 nm)

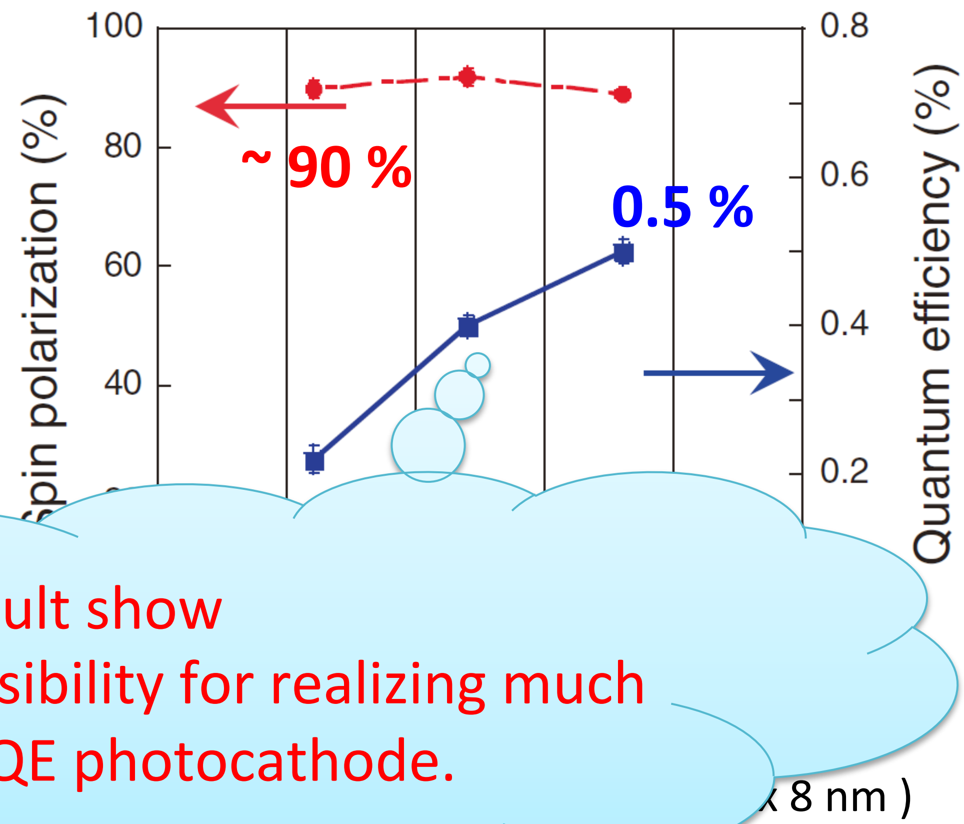
In the SL thickness increasing,
The degradation of spin polarization can not be observed.
The QE increased steadily.

3-3. Prospects for PC developments

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

GaAs-GaAsP Strain–Compensated SL



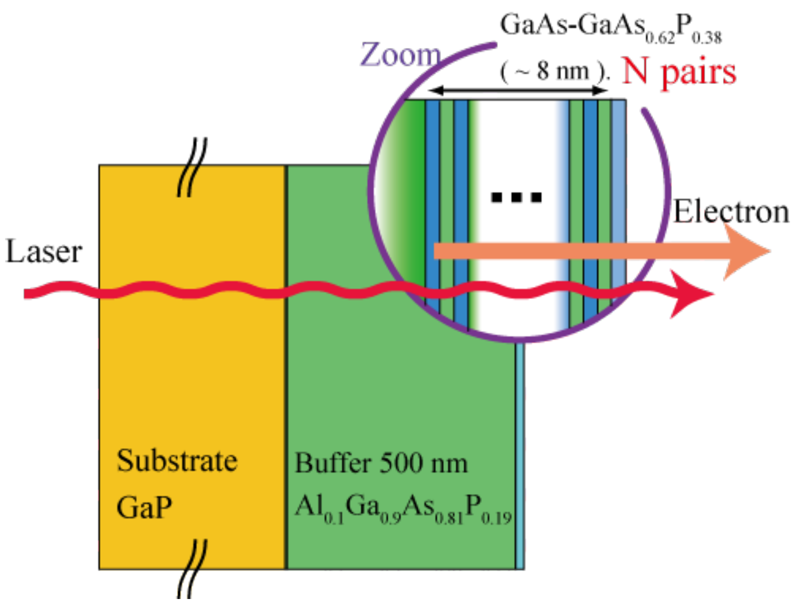


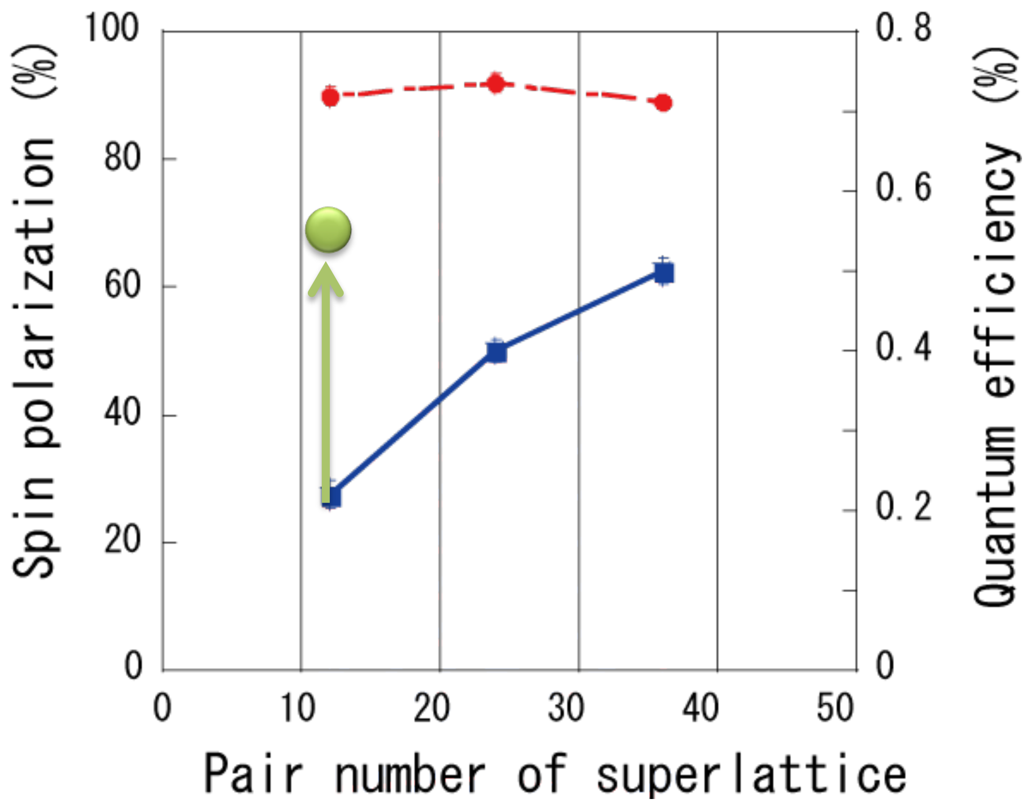
This result show
the possibility for realizing much
higher QE photocathode.

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

3-3. Prospects for PC developments

High Polarization & High QE photocathode

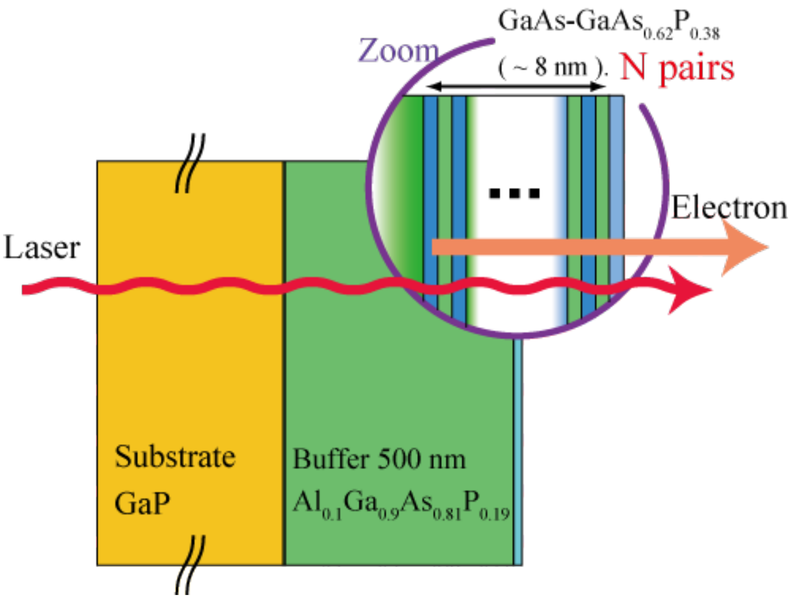


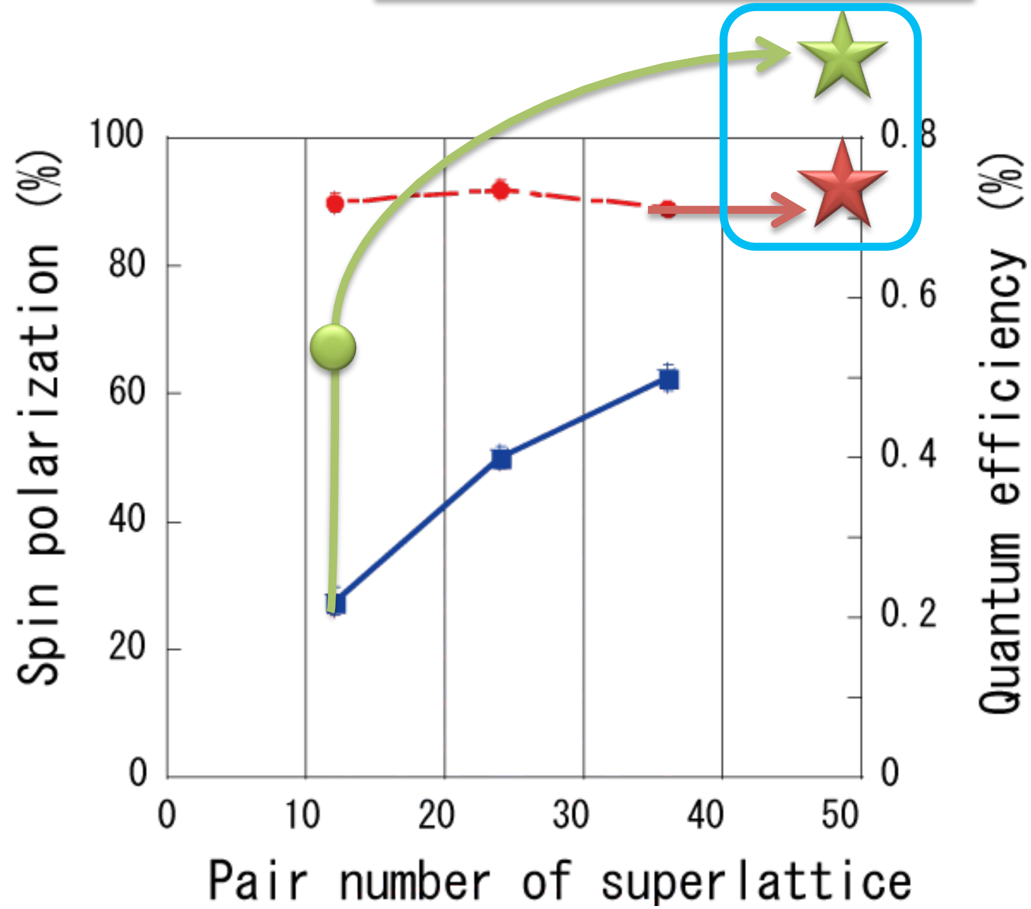


3-3. Prospects for PC developments

High Polarization & High QE photocathode

Expected Values:
Pol. > 90%, QE > 1%





4. Other Application of T-PCs

The T-PCs have been supplied for various application.

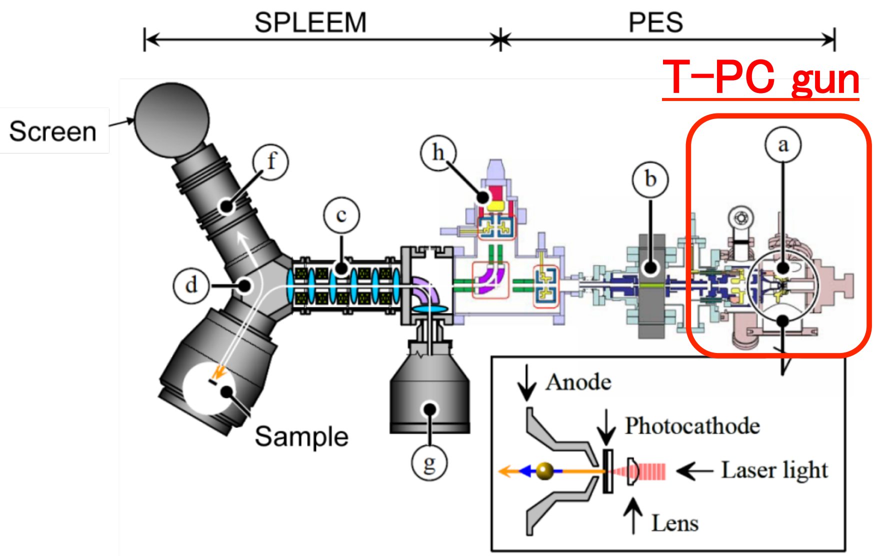
Pol. > 90 %, QE > 0.4 %

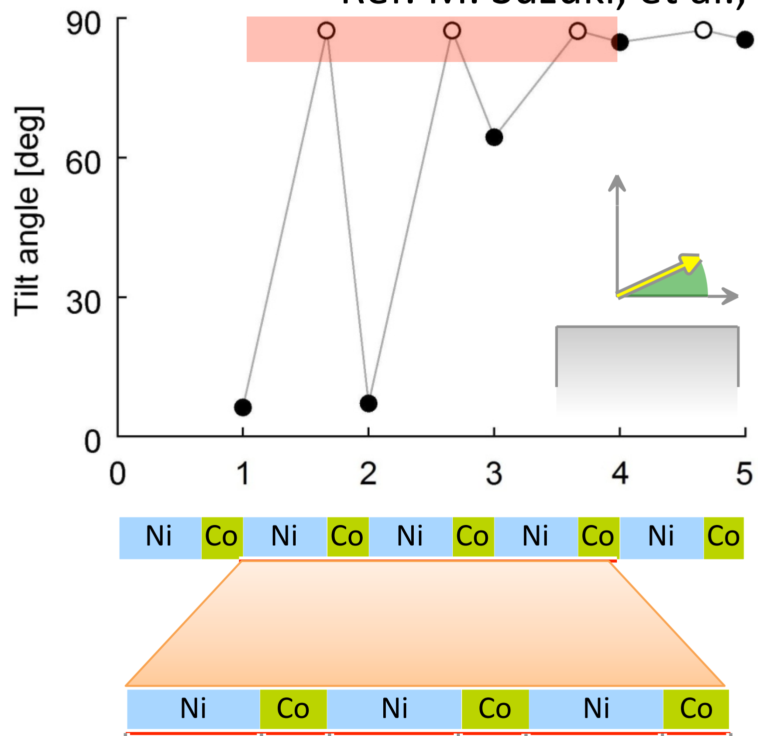
- Spin Polarized Low Energy Electron Microscope (SPLEEM)
  - Osaka Electro-Communication University, Japan
  - Max-Plank Institute, Germany
  - Forschungszentrum Juelich GmbH, Germany
  - The University of Hong Kong, China
  - Chongqing University, China
  - California University, USA
- Spin Electron diffraction
  - Shanghai Jiao Tong University, China
- Planning,
  - Pulsed Spin Tem
  - Inverse Photoemission Spectroscopy
  - Mu-on microscope
  - Electron Beam Lithography Exposure

4-1.SPLEEM (from 2008)

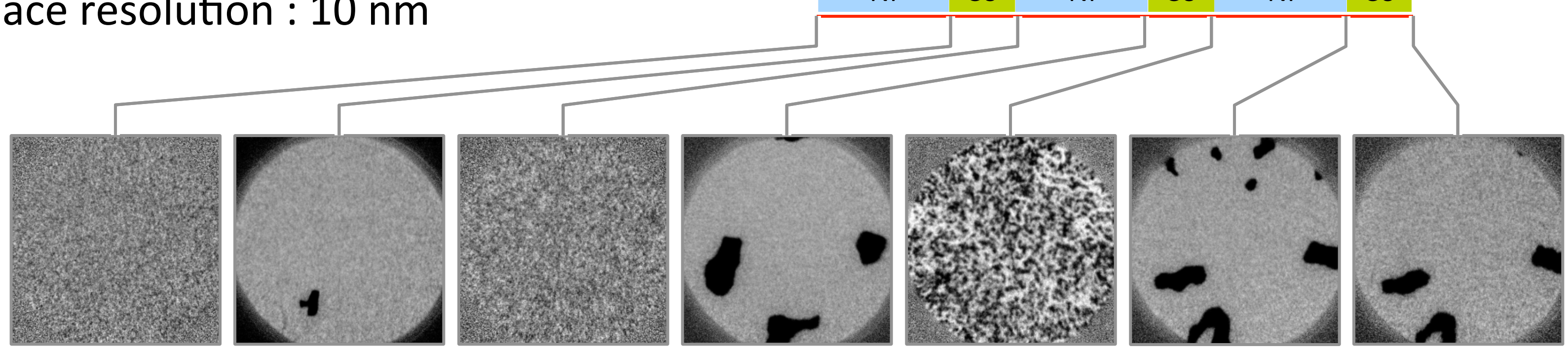
Real Time Magnetic Imaging during the growth of Co on W(110)

Ref. M. Suzuki, et al., APEX (2010)





Time resolution : 200 ms
Space resolution : 10 nm



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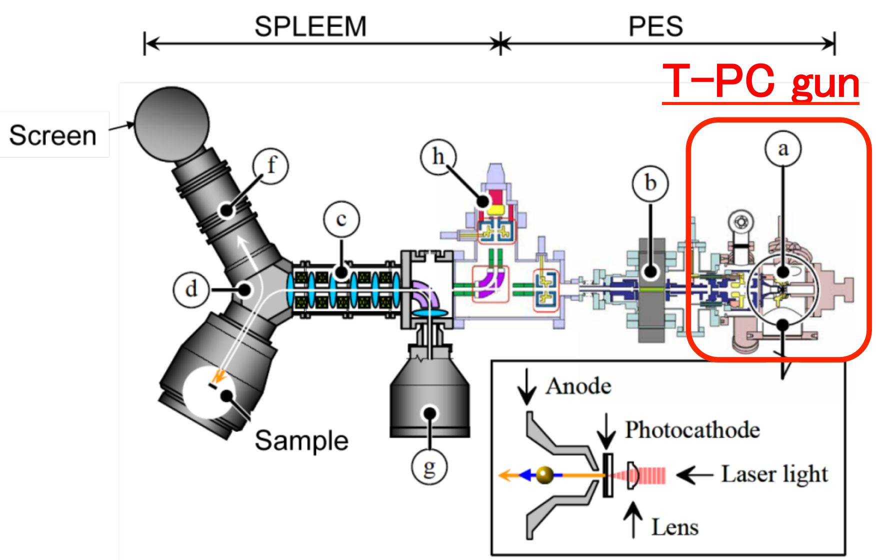
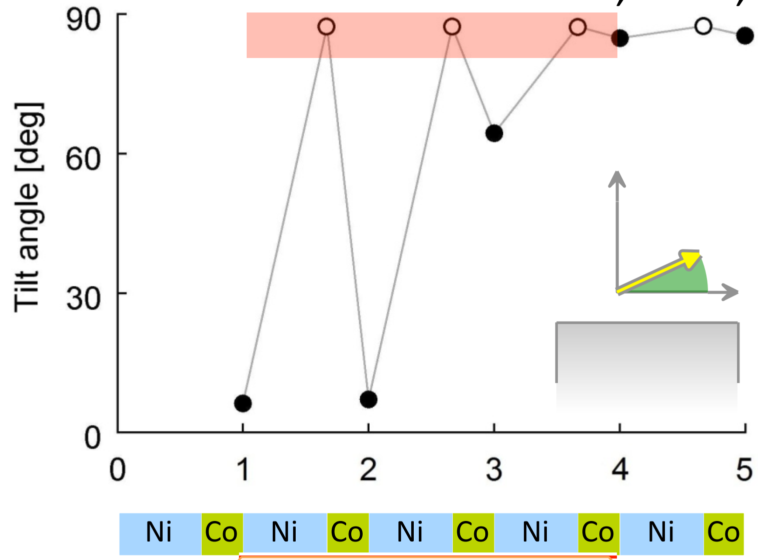


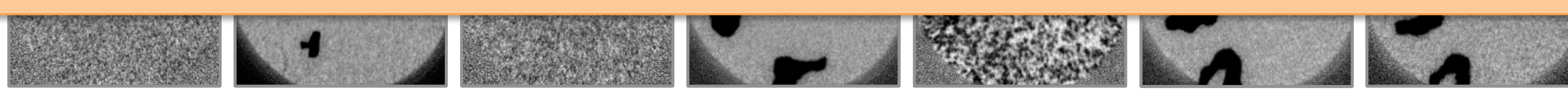


In user experiments (Polarized Electron Microscopy),

One PC sample has been used for **> 3 years**.

Once NEA surface is activated,

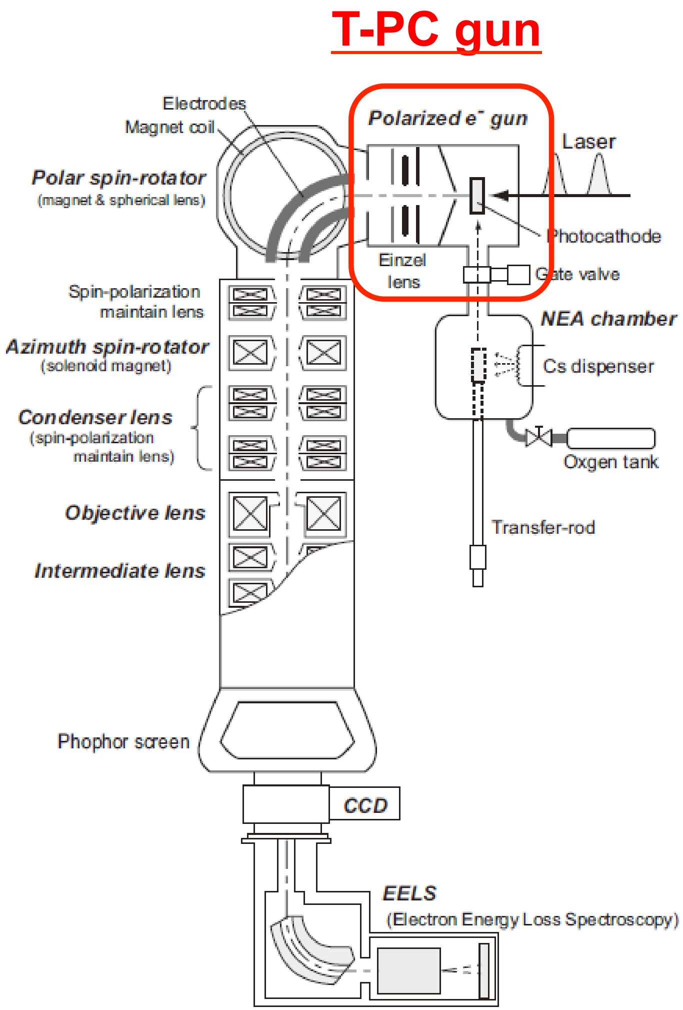
~ 1 μA currents can be extracted for **3 months**.

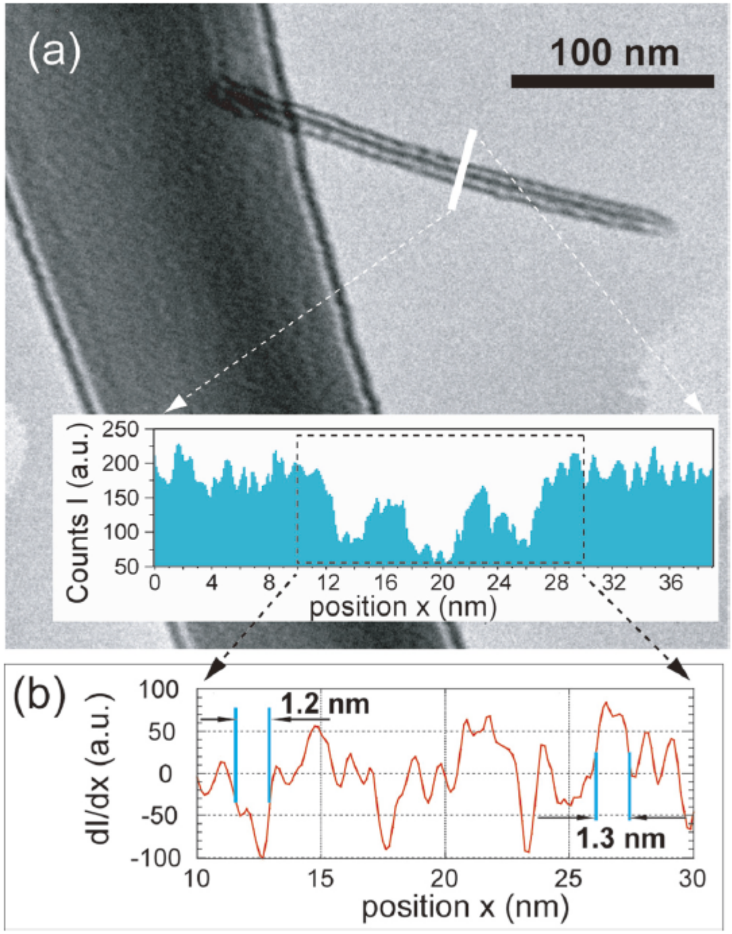


4-2. Pulsed Spin - TEM

Under -construction

a spatial resolution of the order of 1 nm for at 30 keV





Ref. M. Kuwahara, et al., APL (2012)

5.Summary & Future plan

We have developed Transmission-type PC.

Up to now, Electron Spin polarization of 90 %

& Quantum Efficiency of 0.5 % were promisingly achieved.

Our T-PCs have supplied to various laboratories.

In future,

We are planning to develop higher performance photocathode.

Quantum Efficiency improvements (1 %)

Pulse response study (using deflecting cavity).

5.Summary & Future plan

TABLE 2.2-1
Electron Source system parameters.

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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

$>$ 90 %
$>$ 1 %

Thank you for your attention.