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

Table. Requirement Parameters for Electron source

<table>
<thead>
<tr>
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<th>LC (ILC)</th>
<th>EIC (eRHIC)</th>
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<tbody>
<tr>
<td>Electron Polarization</td>
<td>&gt; 80 %</td>
<td>&gt; 80 %</td>
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<tr>
<td>Bunch charge</td>
<td>4.8 nC</td>
<td>3.5 nC</td>
</tr>
<tr>
<td>Average Current</td>
<td>63 μA</td>
<td>50 mA*</td>
</tr>
<tr>
<td>Life time</td>
<td>&gt; 2 weeks</td>
<td>long</td>
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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-GaAs$_x$P$_{1-x}$ \textit{Strained SL}

\textbf{Transmission type photocathode}

\textbf{Strain-Compensated SL}

- High ESP ($> 90\%$) & QE ($\sim 0.5 \%$)
  
  T. Nakanishi et al., NIM A. \textbf{455} (2000)
  

- Low Thermal Emittance
  

- High Brightness [IPAC2011’s Talk]
  
  

- High ESP ($92\%$) & High QE ($1.6\%$)
  
  [This talk]
  
  X.G.Kim, et al., APL (2014)
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*. 

3 step model for electron emission:

1. Optical pump
2. Diffusion at conduction band
3. Emission from NEA surface
To realize high ESP & high QE, keeping \underline{Strain SL structure & High Crystalline quality at the same time} is key.

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

By the way,
\textbf{QE} is directly affected by \textbf{Crystal Quality} and \textbf{SL Thickness}.
Strain & SL are essential for High ESP, but bringing Bad crystal quality. (Low QE)

**Strained SL**

Fig. TEM image of GaAs/GaAsP Strain SL PC

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

3. Strain–Compensated SL

**Strained SL**

- SL Layer
- Buffer layer
- Substrate

GaAsP
Strained GaAs

**Strain-compensated SL**

- SL Layer
- Buffer layer
- Substrate

GaAsP
Strained GaAs

ε_{GaAs} = 1.2
ε_{GaAsP} = 0
L_{GaAs} ≈ L_{GaAsP} = 4nm

ε_{GaAs} = 0.6
ε_{GaAsP} = -0.6
L_{GaAs} ≈ L_{GaAsP} = 4nm

Net strain $\approx 0$

No strain accumulation

**Net strain**

$$\frac{\varepsilon_{GaAs} \cdot L_{GaAs} + \varepsilon_{GaAsP} \cdot L_{GaAsP}}{L_{GaAs} + L_{GaAsP}}$$

$\varepsilon$: Strain values for each SL layer
$L$: Thickness period of each SL layer

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

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

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Ref. X.G. Kim, et al., APL (2014)
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)
Spin-resolved QE Analysis

\[ QE_{L(R)} = \frac{QE(1 \pm ESP)}{2} \]
4-3. Analysis of Crystal Quality from ESP-QE Spectra

- Cond. Band Min.
- HH Band (Valence)
- LH Band (Valence)
- Band Gap
- Mini Band Split
- Band Split of HH & LH

Graphs showing:
- Band Gap Energy [eV] vs. SL Thickness [nm]
- Band Width (conv. Conduction band) [meV] vs. SL Thickness [nm]
- Band Split of HH & LH [meV] vs. SL Thickness [nm]
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.

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.