ILC IDT WG2 – Sources Subgroup

Polarized Electron Source

My plan is to maintain one slide deck as a living document.

It will grow as I continue to add different Polarized Electron Source (PES) topics.

Joe Grames

Monday, October 12, 2020

Framework of these slides

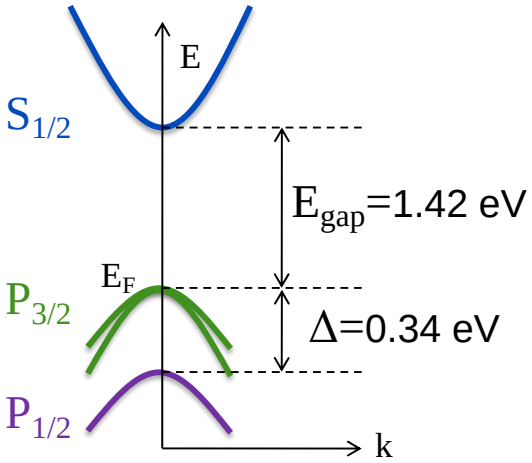
- PES Scope
  - International facilities
  - Summary table alongside ILC requirements
- PES Technologies
  - High polarization photocathodes (GaAs)
  - Extreme high vacuum
  - Reliable high voltage without field emission
  - Drive laser well-matched to photocathode and facility
- PES Performance
  - Photocathode operating lifetime
  - Measured beam qualities

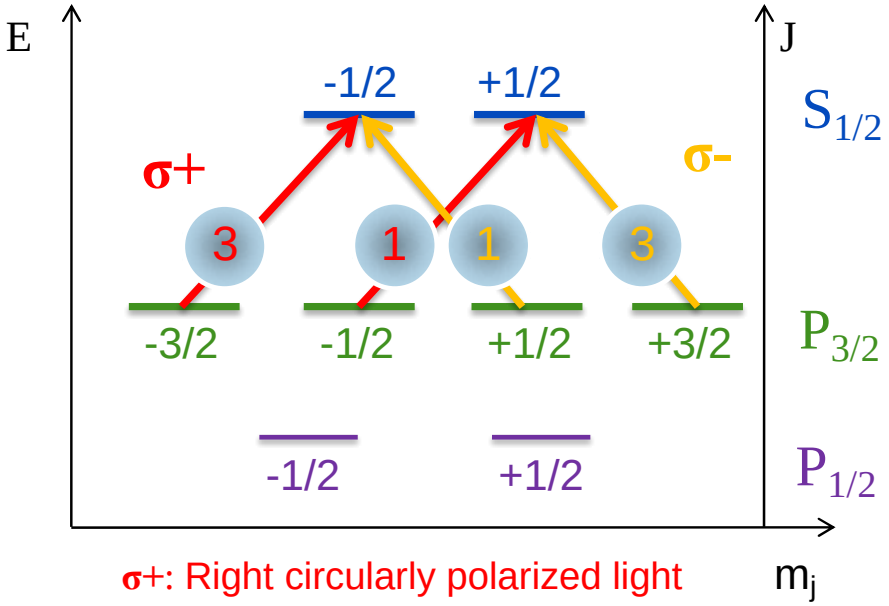
PES Technologies

High polarization photocathodes (GaAs)

PES Technologies

- GaAs-based photocathodes
  - Revolutionized polarized electron beams at accelerator facilities
  - "bulk" material provides 35-40% pol. @ 780nm with QE ~ 20%



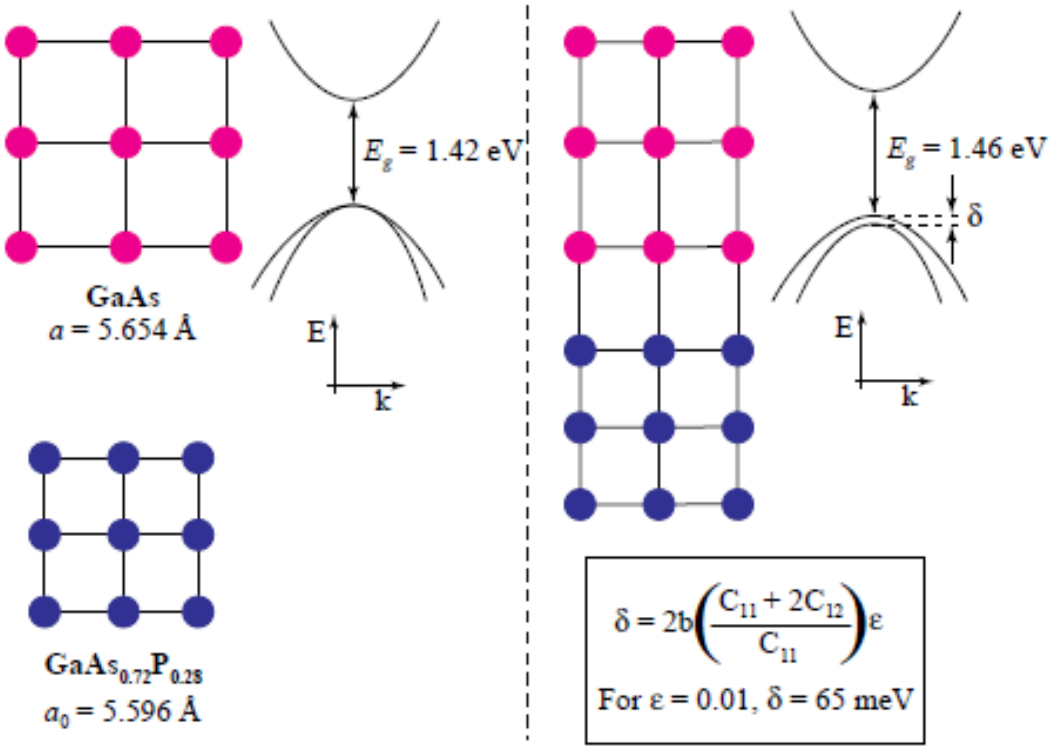


- Laser excitation from $P_{3/2}$ to $S_{1/2}$: $E_{gap} < E_g < E_{gap}+\Delta$
- Electron Polarization: $P_e < \frac{3-1}{3+1} = 50\%$
- Reverse electron polarization by reversing light polarization

PES Technologies

- Breaking $P_{3/2}$ degeneracy

Lattice mismatch provides stress



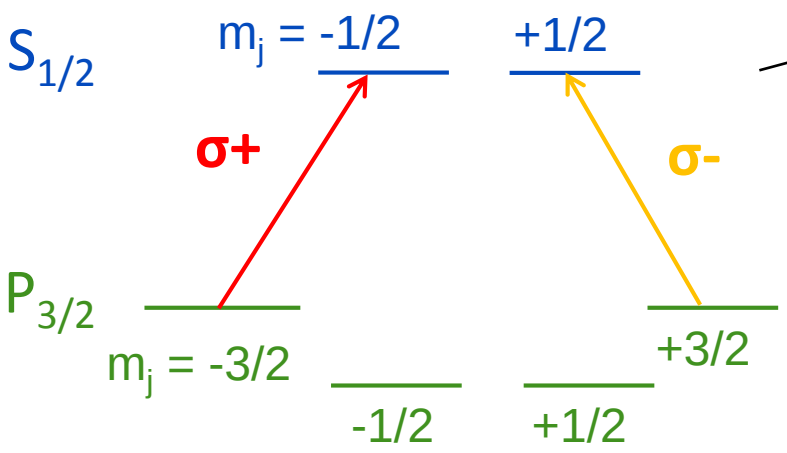
- The band gap of the substrate layer must be larger than surface layer
- Lattice constants must differ enough to introduce suitable strain
- Adjust lattice constant of substrate by varying concentration of third element

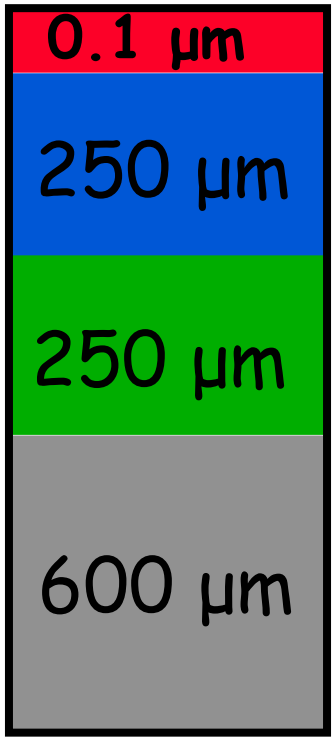
Pablo Saez, PhD Thesis, SLAC Report 501, 1997

1% lattice mismatch provides equivalent force as hydraulic press!

PES Technologies

- Strained layer SL-GaAs





Strained GaAs

$GaAs_{1-x}P_x$ (x=0.29)

$GaAs_{1-x}P_x$ (0<x<0.29)

p-type GaAs substrate

- ✓ Strain relaxes in 0.1 µm layer
- ✓ Not all electrons reach surface
- ✓ Polarization 75% >> 50% ☺
- ✓ QE 0.1% << 6% ☹
- ✓ ~6% anisopotry in QE ☹

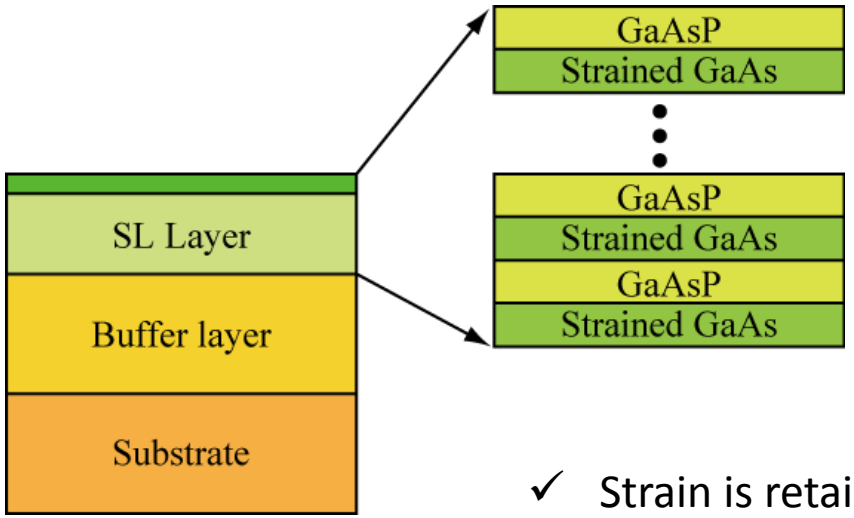
MOCVD-grown epitaxial spin-polarizer wafer

PES Technologies

- Strained Layer Superlattice (SLSP) GaAs

N. Yamamoto[1],
X.G. Jin[2], A. Mano[1], and Y. Takeda[1]

LCWS 2014, 6-10 October 2014



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

High polarization (> 90%)

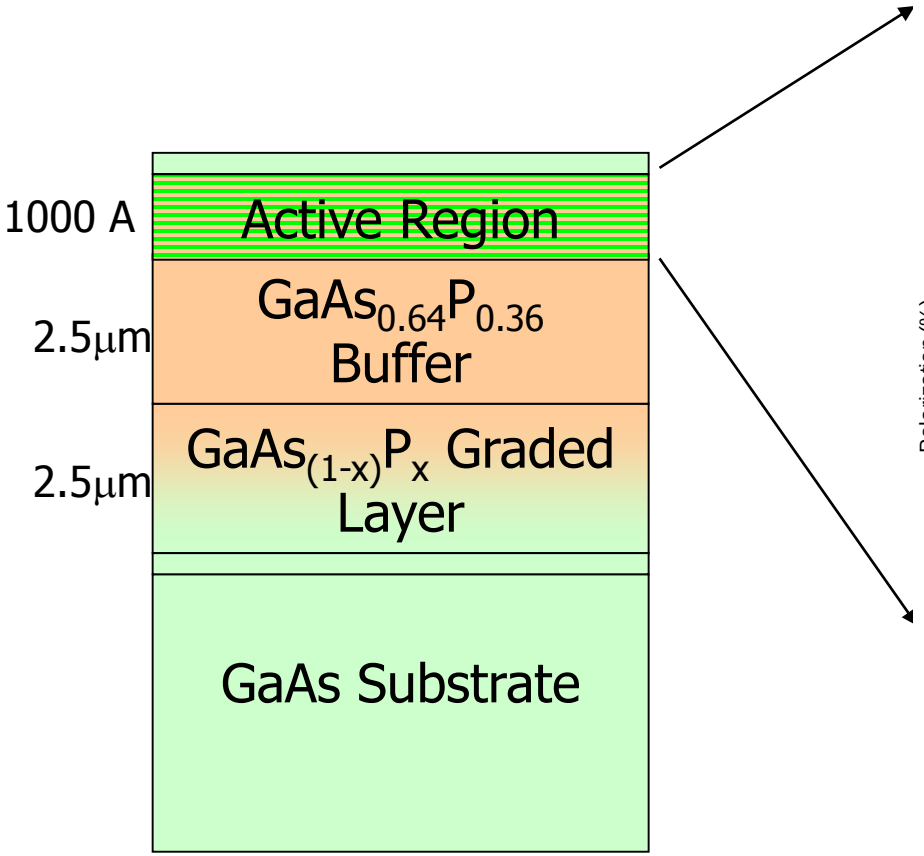
QE(~ 0.5 %)

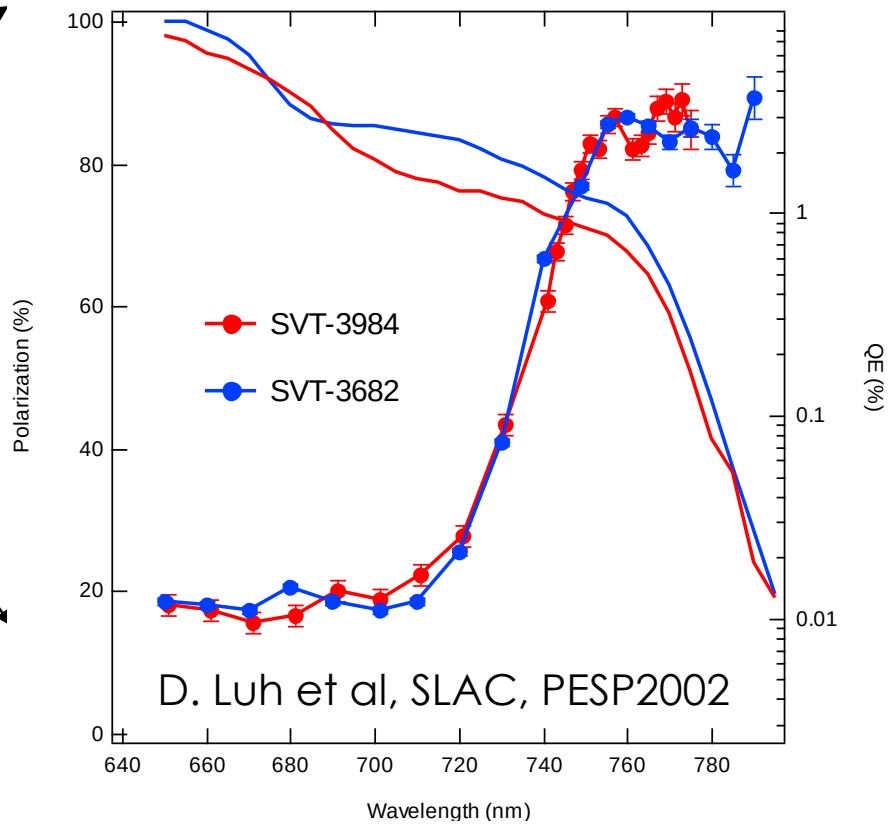
T. Nakanishi et al., NIM A. **455,** 109-112 (2000)
T. Nishitani et al., J. Appl. Phy. **97,** 094907 (2005)
X.G. Jin, et al., APEX, **51,** 108004 (2012)

- ✓ Strain is retained in larger N-layer heterostructure
- ✓ Larger volume ~100 nm within optical absorption thickness
- ✓ Electrons tunnel in quantum well structure toward surface

PES Technologies

- SLSP GaAs/GaAsP experience at Jefferson Lab





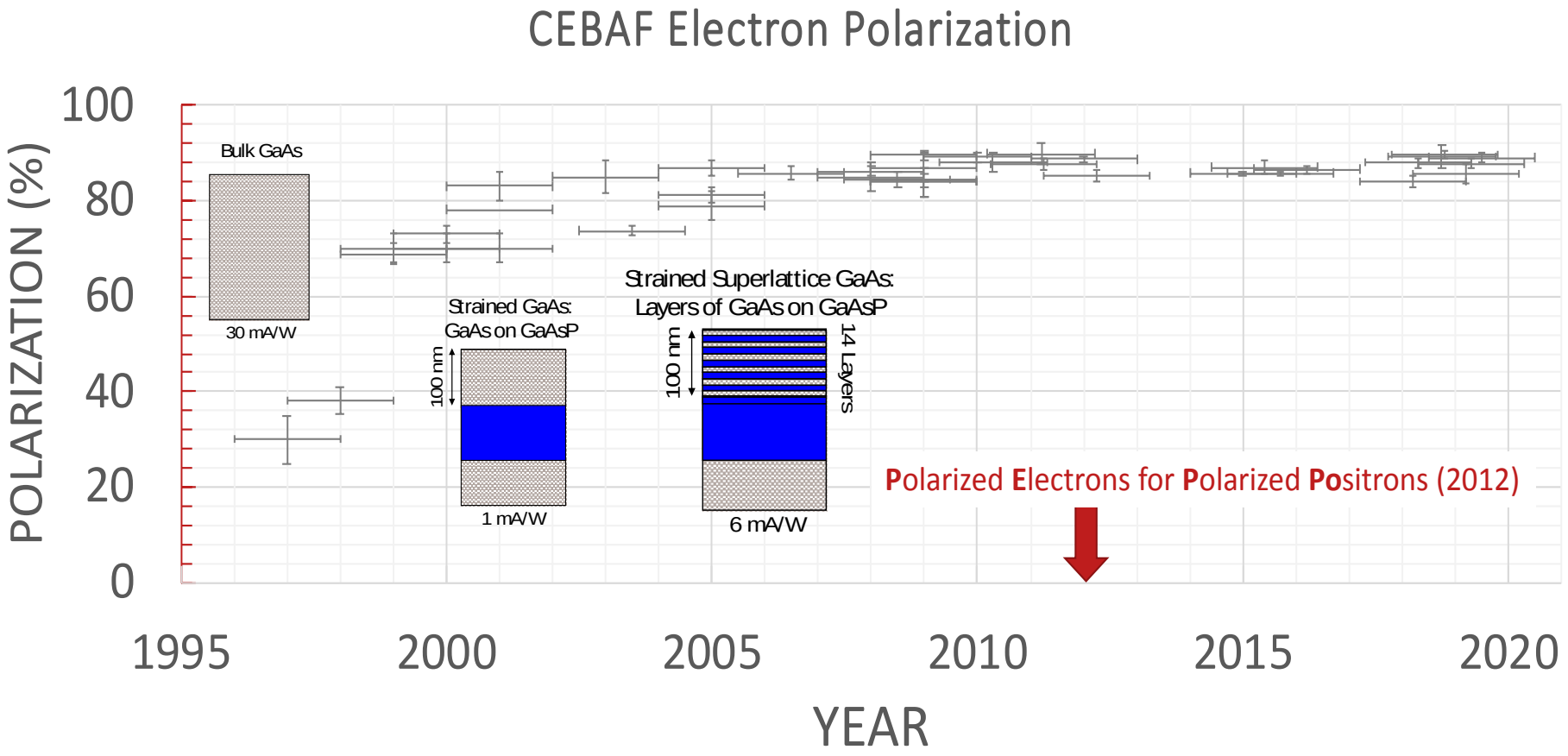
QE 1% and Polarization 85%

From Aaron Moy, SVT Assoc and SLAC, PESP2002

Jefferson Lab

PES Technologies

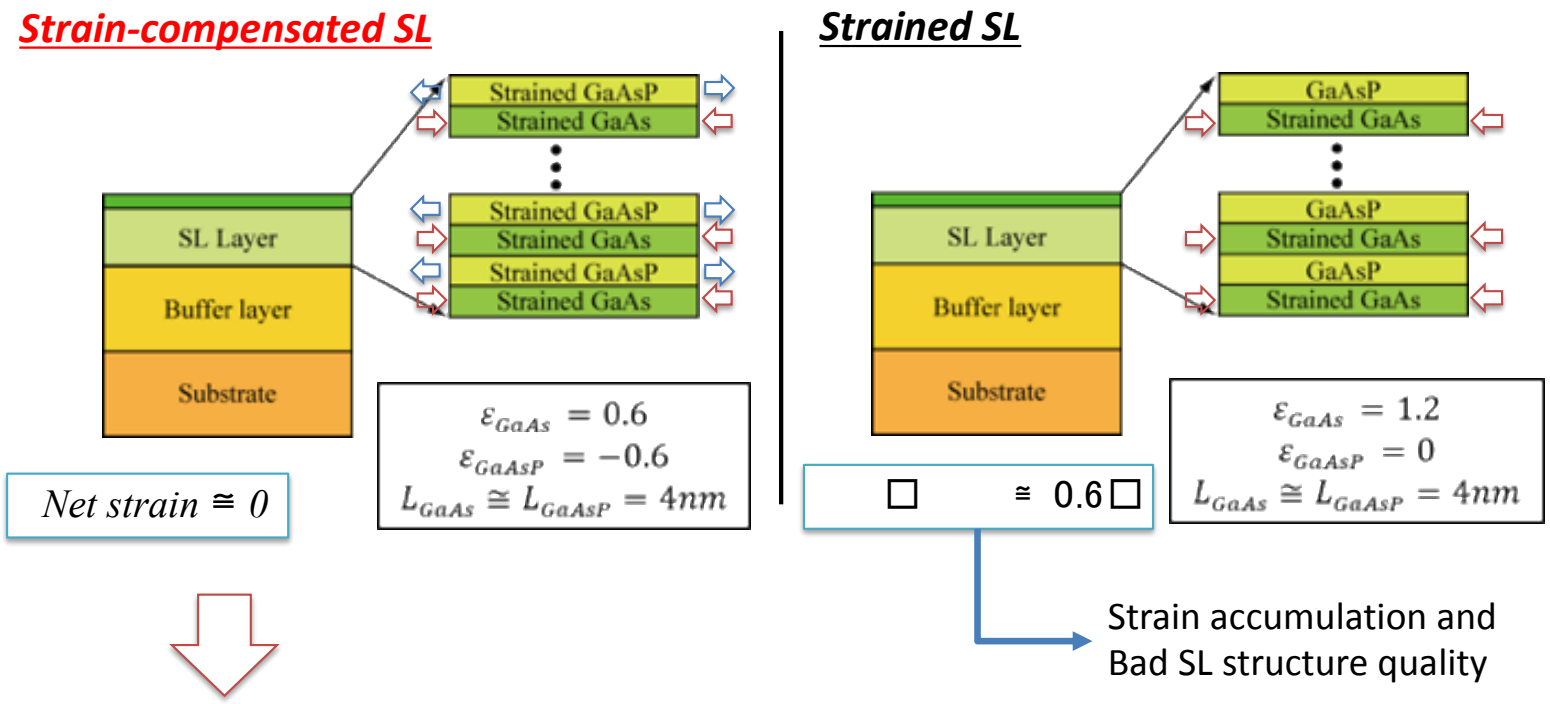
- Physics program at JLab motivated US Dept. of Energy funding



Jefferson Lab

PES Technologies

- Strain compensated SLSP (X.G. Gin *et al.*)



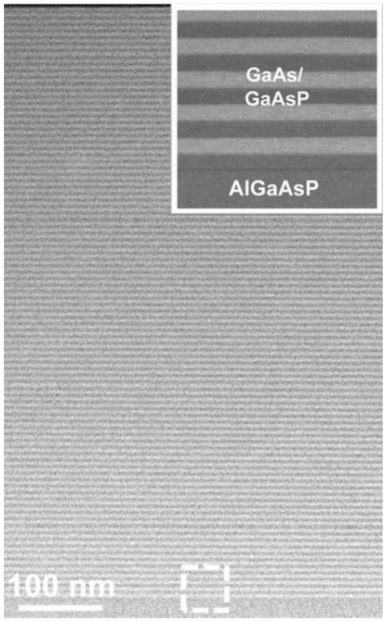
High Crystal Quality
Higher Electron Polarization
Higher QE (Thickness SL layers)

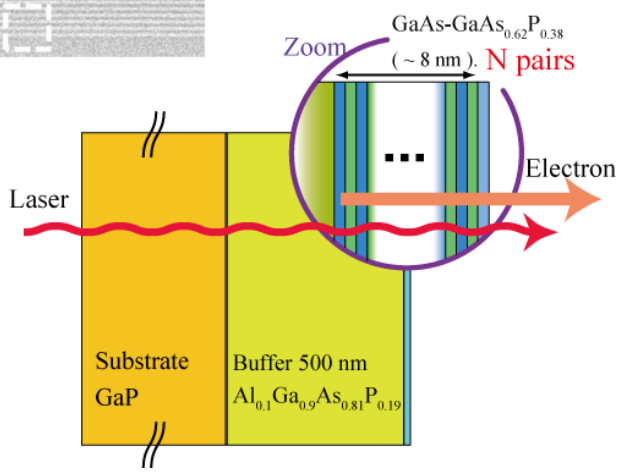
$$Net\ strain = \frac{\varepsilon_{GaAs} \cdot L_{GaAs} + \varepsilon_{GaAsP} \cdot L_{GaAsP}}{L_{GaAs} + L_{GaAsP}}$$

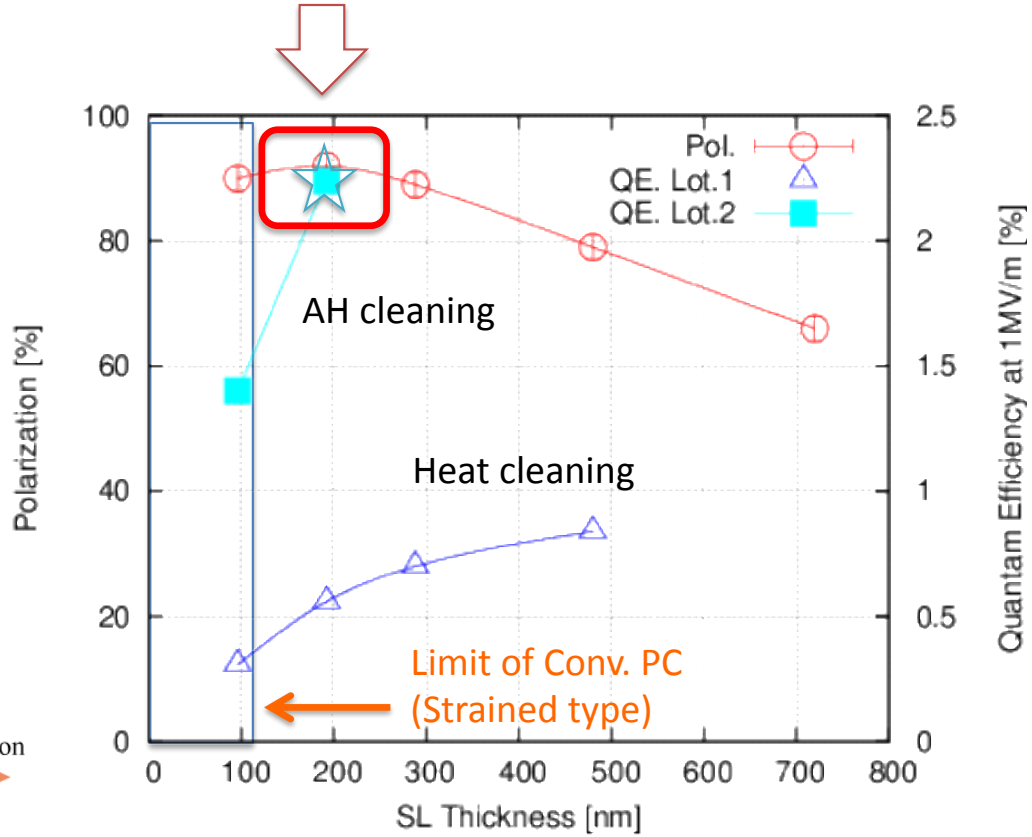
ε : Strain values for each SL layer
L : Thickness period of each SL layer

PES Technologies

- Strain compensated SLSP (X.G. Gin *et al.*)



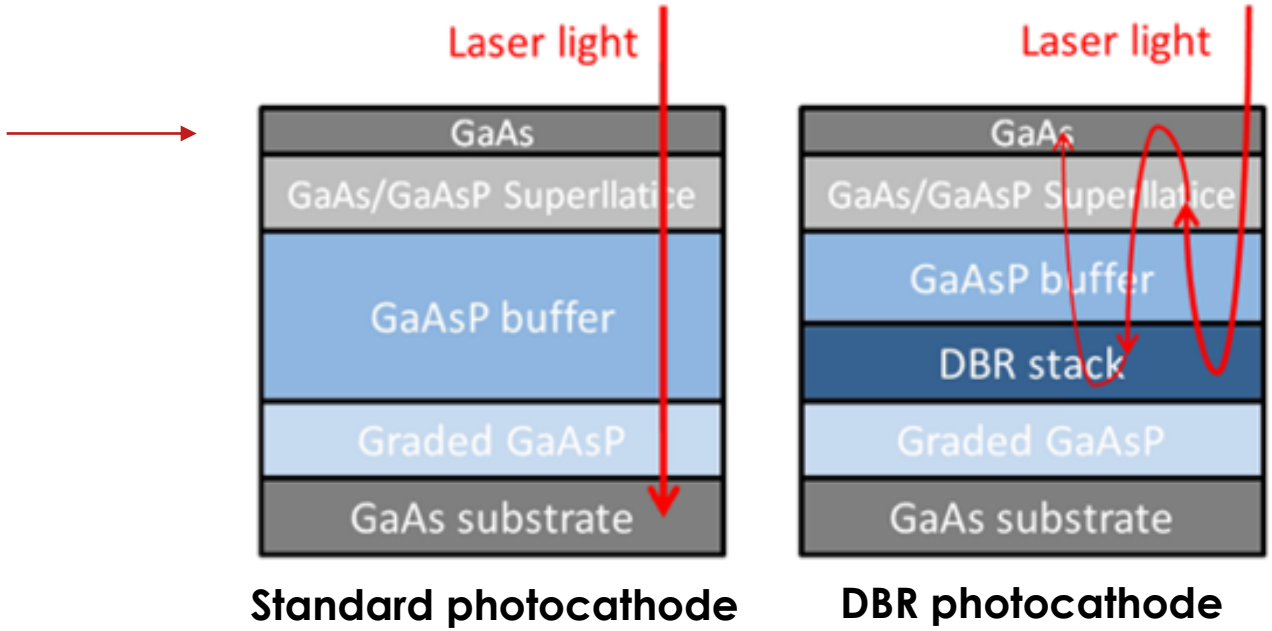




PES Technologies

- Diffracted Bragg Reflector SLSP
  - **Standard Photocathode :** absorption < 5% in the GaAs/GaAsP superlattice
    - Most light passes into the substrate leading to unwanted heating
  - **DBR photocathode** : absorption > 20% in the GaAs/GaAsP superlattice
    - Less light required to make required beam, less light means less heat

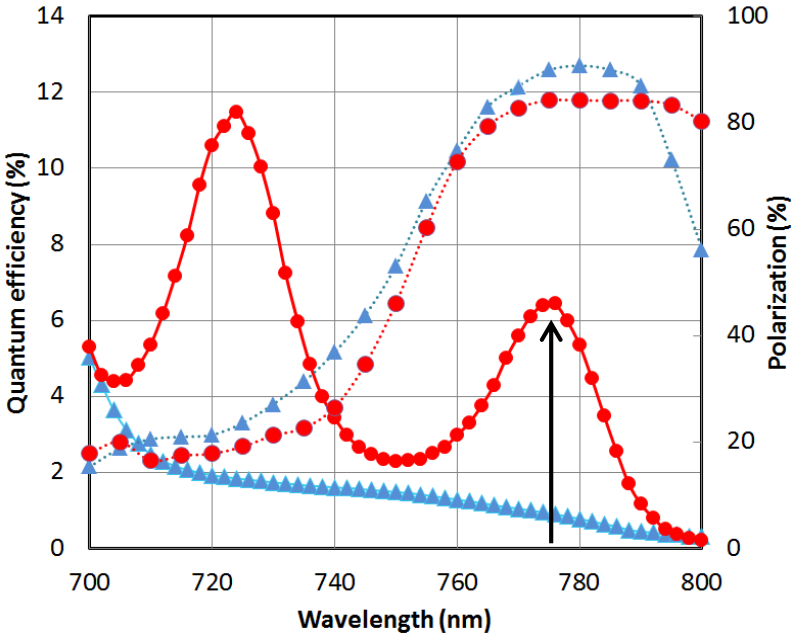
Spin polarized excitation layer



PES Technologies

- Diffracted Bragg Reflector SLSP

W. Liu, S. Zhang, M. Stutzman, M. Poelker, Y. Chen, W. Lu, and A. Moy, Appl. Phys. Lett. **109**, 252104 (2016)



- ➢ DBR strained-superlattice
  - **QE = 6.4%**
  - Polarization = 84%
- ➢ Standard strained-superlattice
  - QE ~1 %
  - Polarization ~90 %

- The highest reported QE of any high polarization photocathode
- Candidate for EIC, polarized positrons
- U.S. DOE SBIR partnership

Cathode	Lab	P(%)	QE (%)	FOM (P^2QE)
GaAs-GaAsP	SLAC/SVT	86	1.2	0.89
AlInGaAs-AlGaAs	St. Petersburg	92	0.85	0.72
GaAs-GaAsP	Nagoya	92	1.6	1.35
GaAs-GaAsP/DBR	JLab/SVT	84	6.4	4.52

PES Technologies

- Long rick history for high polarization photcathodes
  - Breakthroughs first in academic setting
  - Lessons learned moved to commercial semiconductor vendors (US)
- Breaking the 50% theoretical limit (P > 80%, QE ~ 0.1%)
  - Maruyama et al at Univ. California Berkeley InGaAs/GaAs P>70%
  - Soon after demonstrations at Nagoya University (Japan) and St. Petersburg Technical University (Russia)
- Solving the QE crisis (strained superlattice GaAs)
  - Thin-layer pairs solved strain relaxation, yielding P >80% & QE~1%
  - SLAC, Nagoya, St. Petersburg all pioneered the superlattice
- Commercial vendors
  - SLAC teamed up with vendors in DOE SBIR/STTR program
  - SPIRE/Bandwidth Semicondutor => strained GaAs by MOCVD
  - SVT Associates => superlattice by MBE
  - Very reliable performance

PES Technologies

- Present commercial perspective
  - After SLAC repurposed as Light Source JLab teamed up with SVT
  - They later produced the distributed Bragg reflector with QE ~ 6%
  - Unfortunately, SVT no long sells this material or plans future R&D
- The challenge now is to restore a source of photocathodes !!!
- It is a global challenge:
  - US
    - In FY21 two new 2-year R&D projects are funded
      - **JLab/BNL/Old Dominion University** – test growth process of superlattice by MOCVD and compare to MBE quality
      - **JLab/Univ. California Santa Barbara** – test CBE (chemical beam epitaxy) as alternative to using hazardous solid/gaseous phosphorous of MBE
      - **Euclid Techlabs** has partnered with BNL/Jlab/universities in polarized photocathode R&D, and is proposing to envision a superlattice production facility for EIC, JLab, others…
    - Partner with photocathode workshops (Snowmass, P3, PSTP)
  - Japan
    - What is status of R&D, plans for SuperKEK-B and strain compensated SLSP?
  - Europe
    - What is status of R&D, plans for MESA, Darmstadt, CERN?