GaAsSb/AlGaAsP Superlattice Polarized Electron Source

Contract # DE-SC0009516

Principal Investigator: Yiqiao Chen, SVT Associates, MN 55344

Collaborator: DoE Jefferson Lab

DoE SBIR/STTR Exchange Meeting

Aug 6-7, 2015, Gaithersburg, Maryland

SVT Associates, Inc.

SVT Associates Company Overview

Founded in 1993 as Molecular Beam Epitaxy (MBE) equipment provider

- Originated from Perkin Elmer Physical Electronics MBE Group
- One of today's leading MBE suppliers by continual product development
- Over 160 MBE systems now in the field

- Strong UHV hardware, epitaxial growth, and thin film expertise
- Technology Driven Company
  - >30% employees are PhD scientists (currently 30 employees total)
  - Key engineers > 25 years experience in MBE and UHV technology
- Diverse system product line spanning Molecular Beam Epitaxy (MBE), Thin Film Deposition (i.e. ALD, PVD, PLD and Solar), and In-situ Thin Film Monitoring
- Only MBE Company with System, Components, Process, In-situ Monitoring Expertise with our own Applications Laboratory and Characterization Facility

SVT Facilities and Capabilities

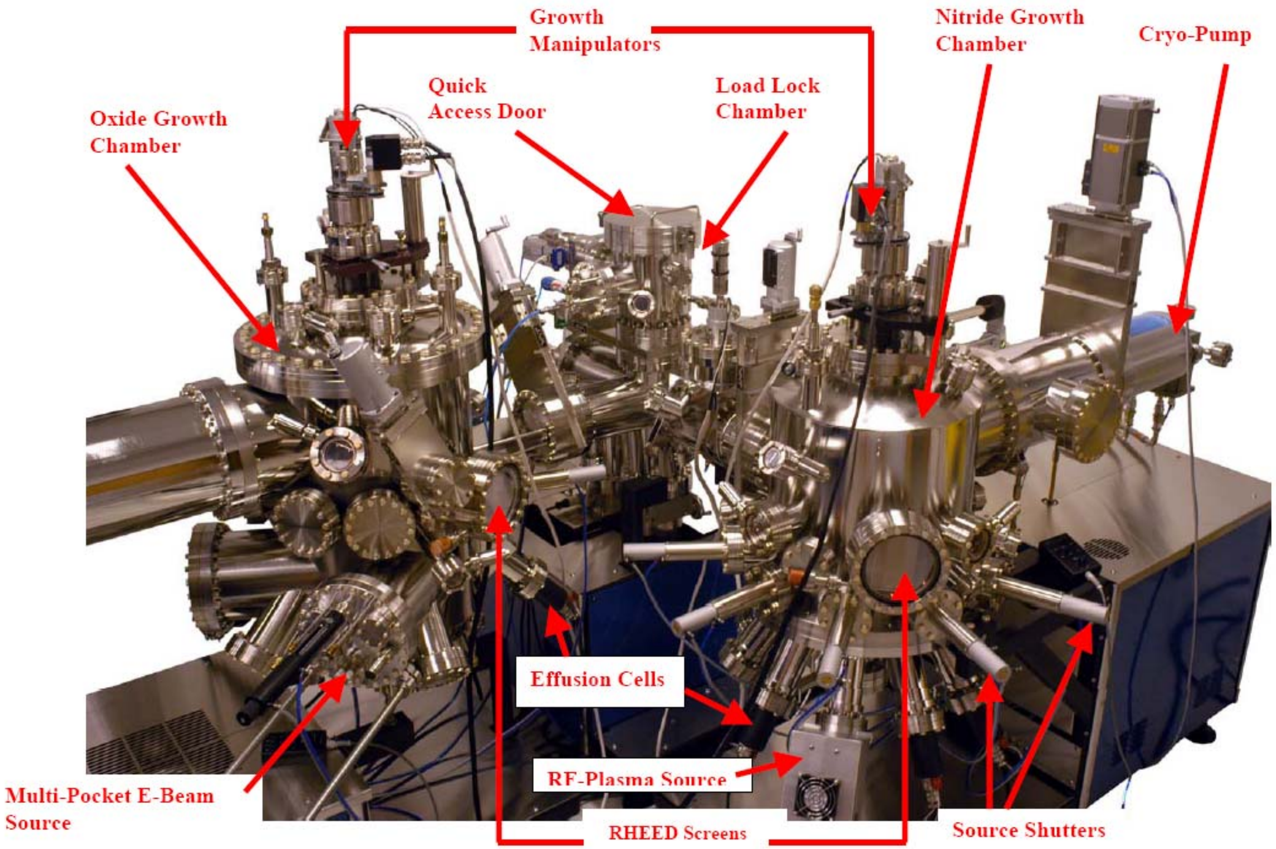
- Material deposition systems: MBE PLD, ALD

Established know-how:
8 Applications Laboratory MBE systems producing world class epitaxial growth, feeding requirements back to equipment designers

- Complete semiconductor material characterization facility: HR-XRD, FTIR, Hall, Low-temp probe station, Semiconductor parameter analyzer, ellipsometer.

- Device Fabrication

Class-100 clean room, ICP dry etcher.



Dual Oxide - Nitride MBE

SVT Associates, Inc.

Engines for Thin Film Innovation

Semiconductors Research at SVT

- US government, industrial research grants, and internal programs
- Established research collaboration with many universities: Illinois, North Carolina State, Florida, Stanford ...
- Highly technically oriented, PhD scientists & engineers
- > 100 book chapters, publications and presentations
- Significant Antimonide, Nitride and ZnO accomplishments
  - High power HEMT & MOSHEMT
  - Commercialized solar blind UV detector products
  - High efficiency photocathode
  - Innovative LED utilizing Quantum Structures
  - New mid Infrared Laser and Photodiode
  - Rainbow colored MgZnCdO

Program Overview

Program title: GaAsSb/AlGaAsP Superlattice High-Polarization Electron Source

Ultimate goal:

cw polarized electron sources with >80% polarization and >10 mA beam current

SVT-70%

- Photocathode Modeling/Design
- Material Growth

JLab-30%

- Photocathode Testing

Present Applications:

- DoE needs: high energy accelerators
- Spintronics

Potential Applications:

- Surface analysis
- Quantum computing
- Magnetic imaging

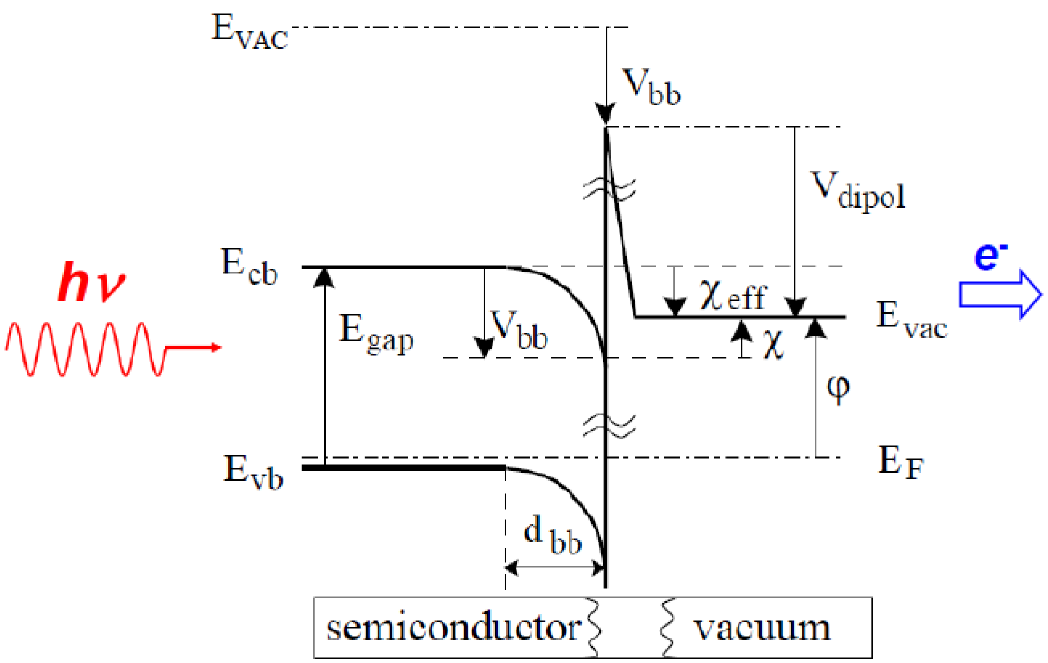
SVT Associates, Inc.

Photocathode - General Properties

Photons → free electrons in vacuum

1. **Optical absorption**
2. **Electron transport to surface**
3. **Escape from surface to vacuum (NEA)**

Two aspects of emitted electrons in polarized photocathode: density and spins

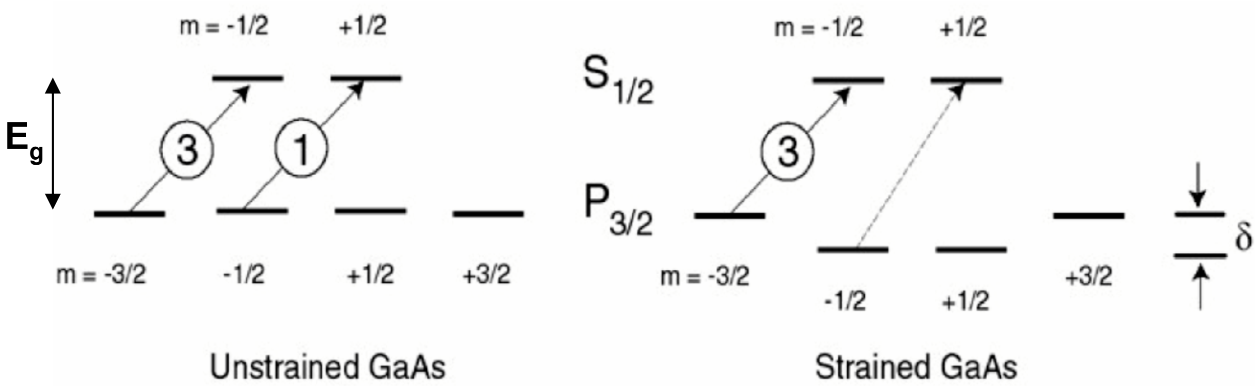


Improvement:
1. increase QE
2. increase polarization

Basics of polarized electron photocathode

Semiconductor: suitable material for polarized photocathodes

Non-zero transition matrix elements for semiconductors under circular-polarized light illumination



50% polarization **100% polarization**

Strained SL : highest polarization (HH-LH splitting further increased due to the quantum confinement by SL)

Initial polarization: $P_0 = (n_\uparrow - n_\downarrow)/(n_\uparrow + n_\downarrow)$

SVT Associates, Inc.

Why Sb-based SL?

Existing structures in literature

1. InGaAs/AlGaAs (strained well),70-80%, QE~0.7%
2. GaAs/GaAsP (strained well), 92%, measured, QE~1%
3. GaAs/AlInGaAs (strained barrier), 91%
4. AlInGaAs/GaAsP (strain-balanced), 84%
5. AlInGaAs/AlGaAs (strained well), 92% with QE~0.85%

} All HH-LH splittings<95meV

$GaAs/GaAs_{0.64}P_{0.36}$ SL:

Best overall performance thus far, HH-LH splitting δ~92 meV

$GaAs_{0.85}Sb_{0.15}/Al_{0.25}GaAsP_{0.15}$ SL:

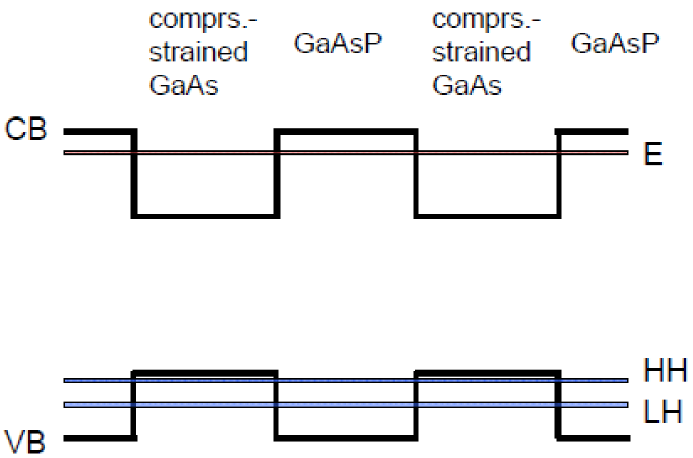
•highest VB offset ⟹ Highest HH-LH splitting: δ>150 meV resulting in highest initial polarization and larger tolerance to γ
•Dislocation-free SL material since no strain relaxed layer required, boost QE
•No need to grow very thick metamorphic buffer (5-10 µm), cost-effective

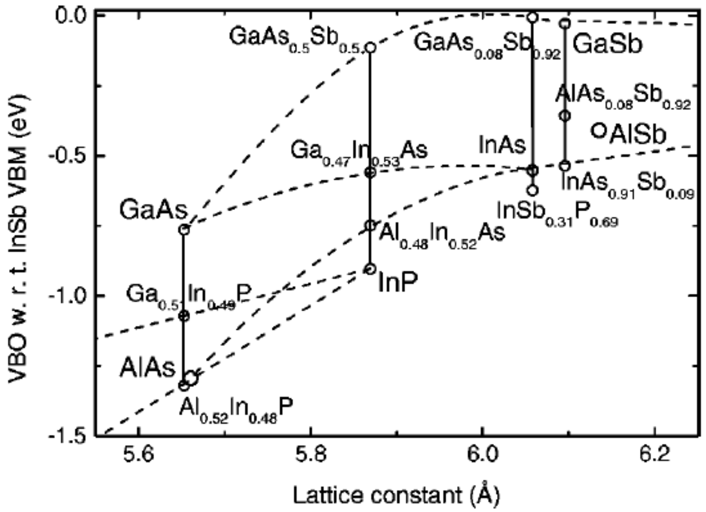
GaAsSb/AlGaAsP SL Photocathode – High Polarization and High QE

SVT Associates, Inc.

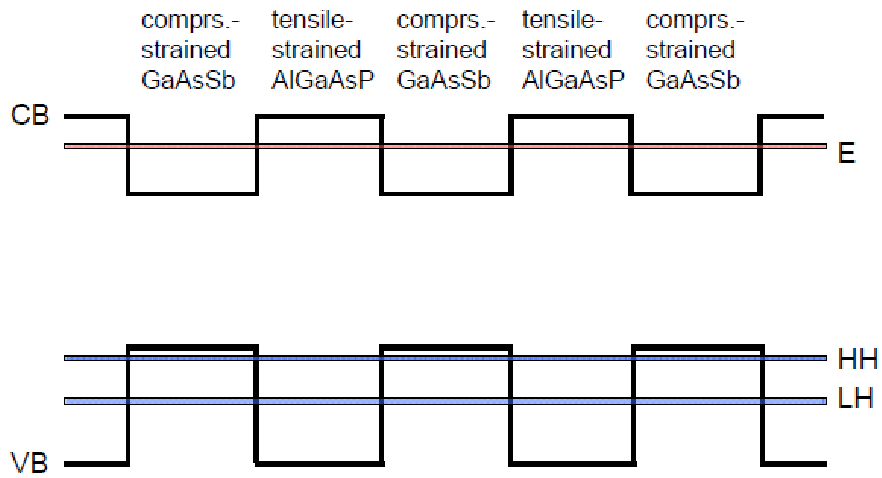
Very High VB offset in GaAsSb/AlGaAs Heterostructure

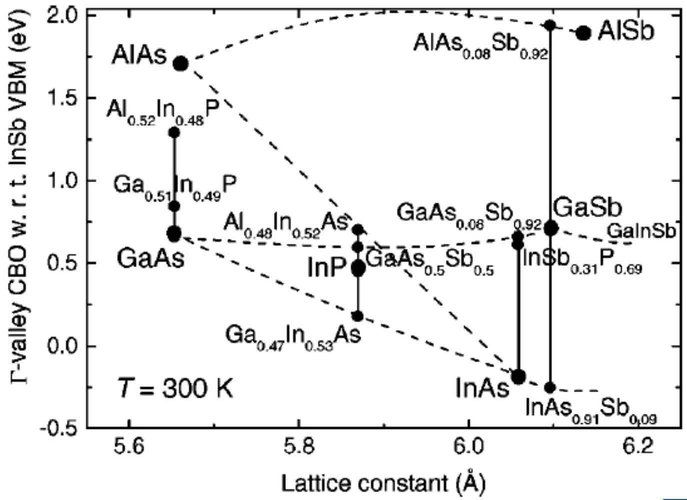
GaAs/GaAsP SL





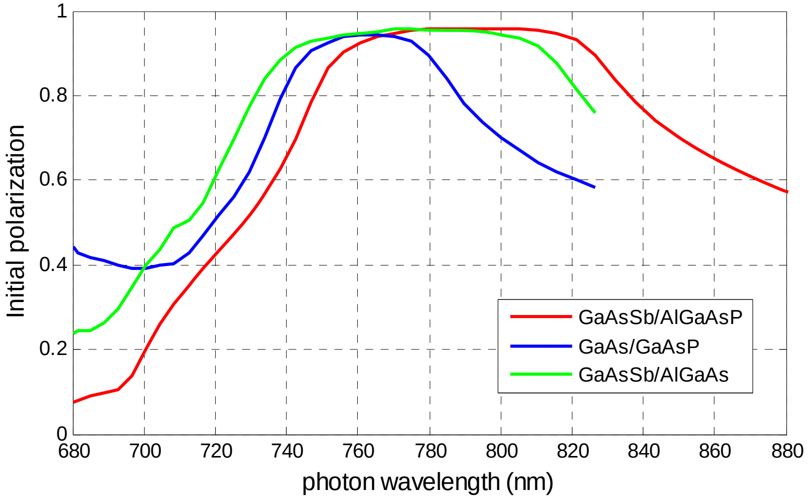
GaAsSb/AlGaAsP SL



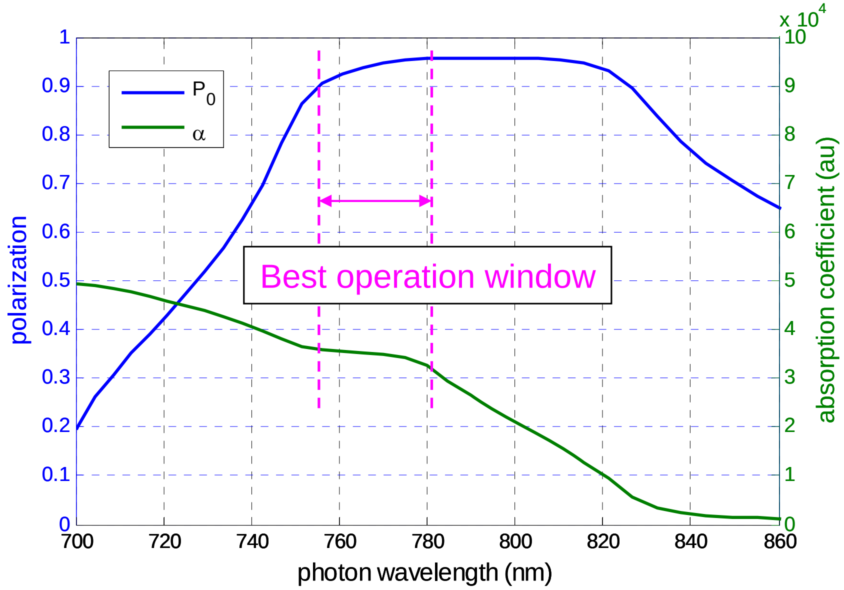


SVT Associates, Inc.

GaAsSb/AlGaAsP SL: wider high P_0 range and larger tolerance to γ



Comparison of the initial polarization of photocathodes based on $GaAs_{0.85}Sb_{0.15}$/ $Al_{0.25}Ga_{0.75}As_{0.85}P_{0.15}$ SL, GaAs/ $GaAs_{0.67}P_{0.33}$ SL and $GaAs_{0.85}Sb_{0.15}$/ $Al_{0.4}Ga_{0.6}As$ on GaAs substrate. Line spreading width γ=10 meV is used for all three.



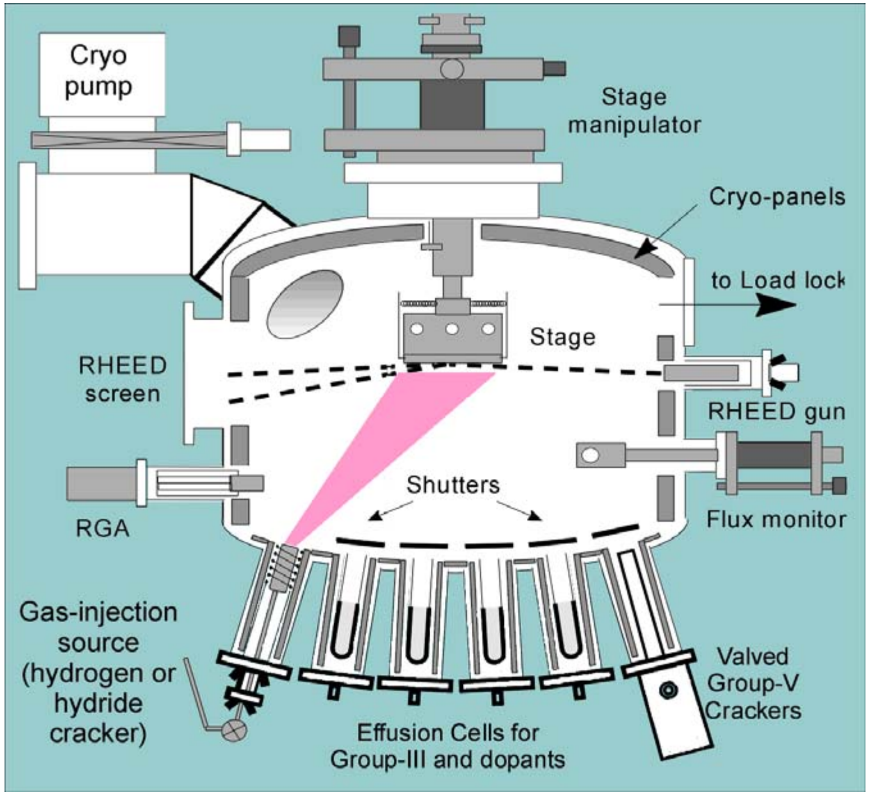
Calculated absorption coefficient and initial polarization for $GaAs_{0.85}Sb_{0.15}$ (6ML) / $Al_{0.25}Ga_{0.75}As_{0.85}P_{0.15}$ (14ML) SL on GaAs substrate.

Broadening of band, γ : $\delta(\omega_{nn'}(\vec{k}_{\|}, k_z) - \omega) \rightarrow \frac{1}{\pi} \mathrm{Im} \frac{1}{\omega - \omega_{nn'}(\vec{k}_{\|}, k_z) - i\gamma}$

SVT Associates, Inc.

Cooled shutter for As/P/Sb material system

- As and P very volatile -> unwanted P into GaAsSb
- Instant flux shut off of P by cooled shutter -> sharp SL interfaces



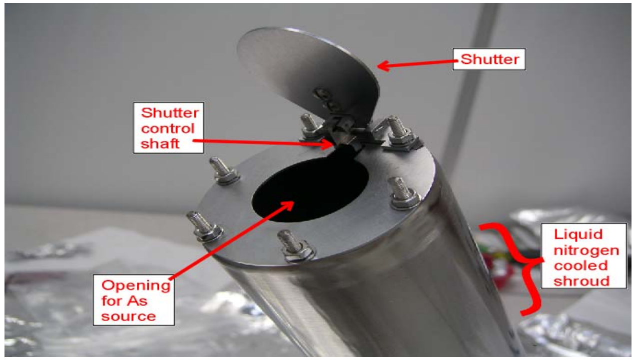
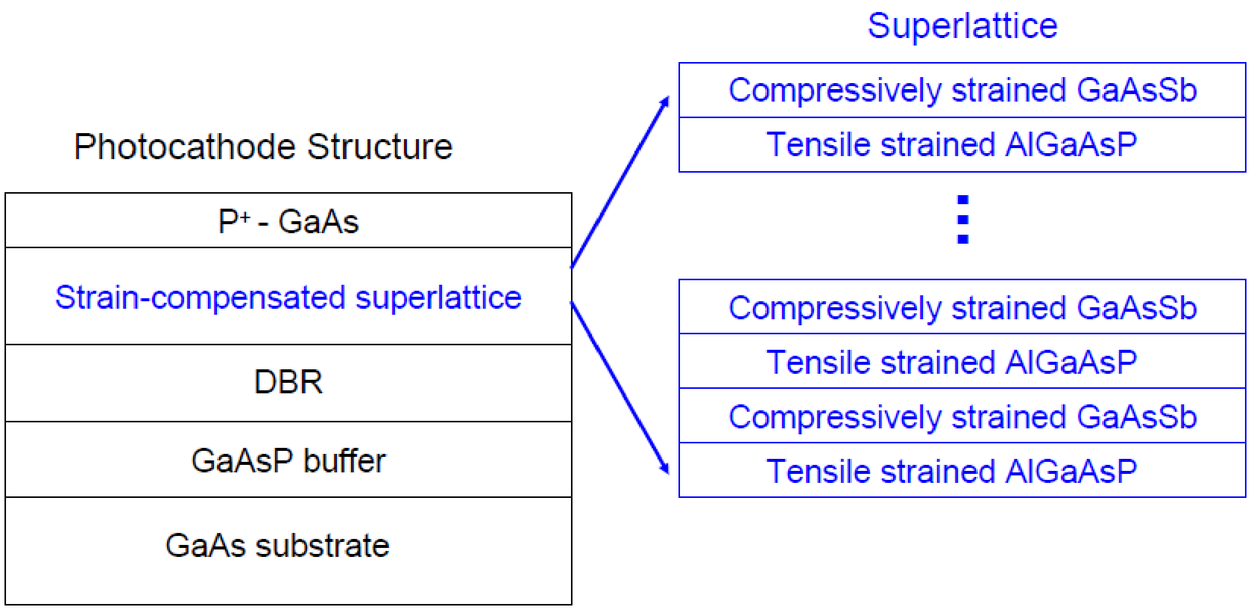


Photo of the output end of the independently cooled shroud/shutter assembly for phosphorus flux abatement. The shutter can change states in a sub-second time scale.

SVT Associates, Inc.

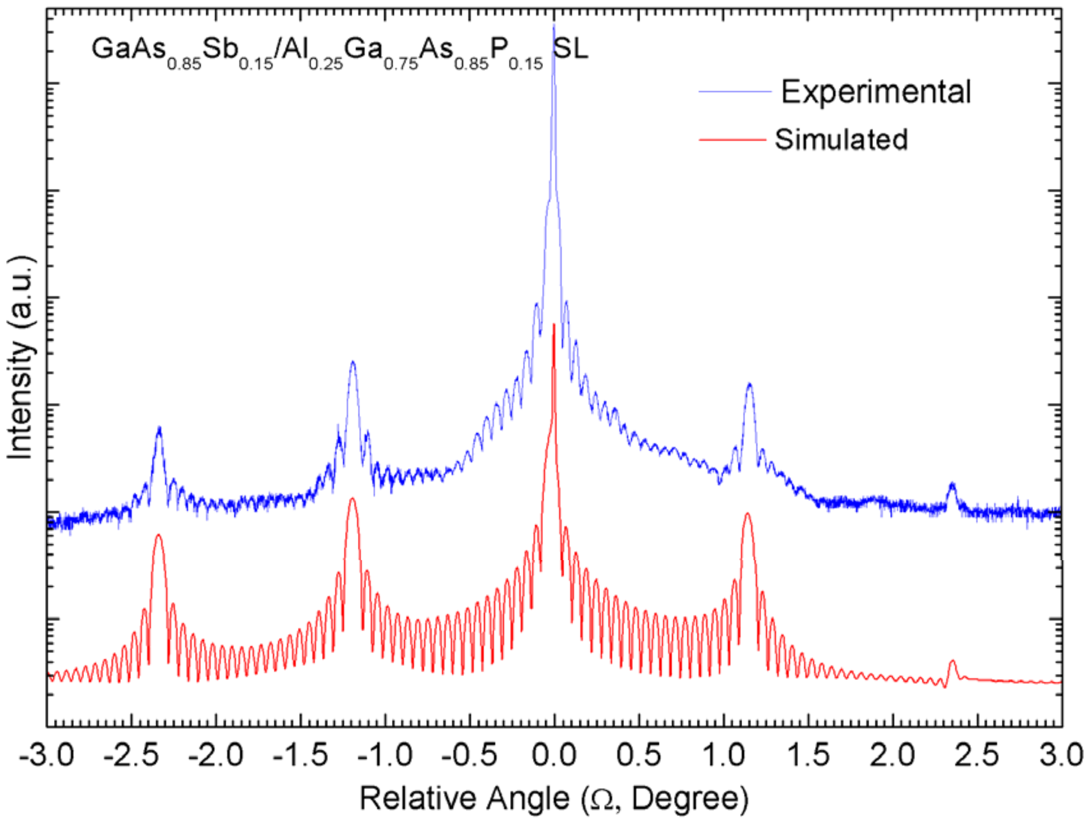
Key benefits of proposed approaches

- Improved polarization by large HH-LH splitting.
- Significantly improved material quality and thicker SL absorber region boosting QE by fully strain-compensated GaAsSb/AlGaAsP SL.
- An effective InAlP/InGaP DBR structure on a GaAs substrate to enhance QE through more efficient photon absorption.
- Cooled shutter approach to improve interface quality of GaAsSb/AlGaAsP SLs.



SVT Associates, Inc.

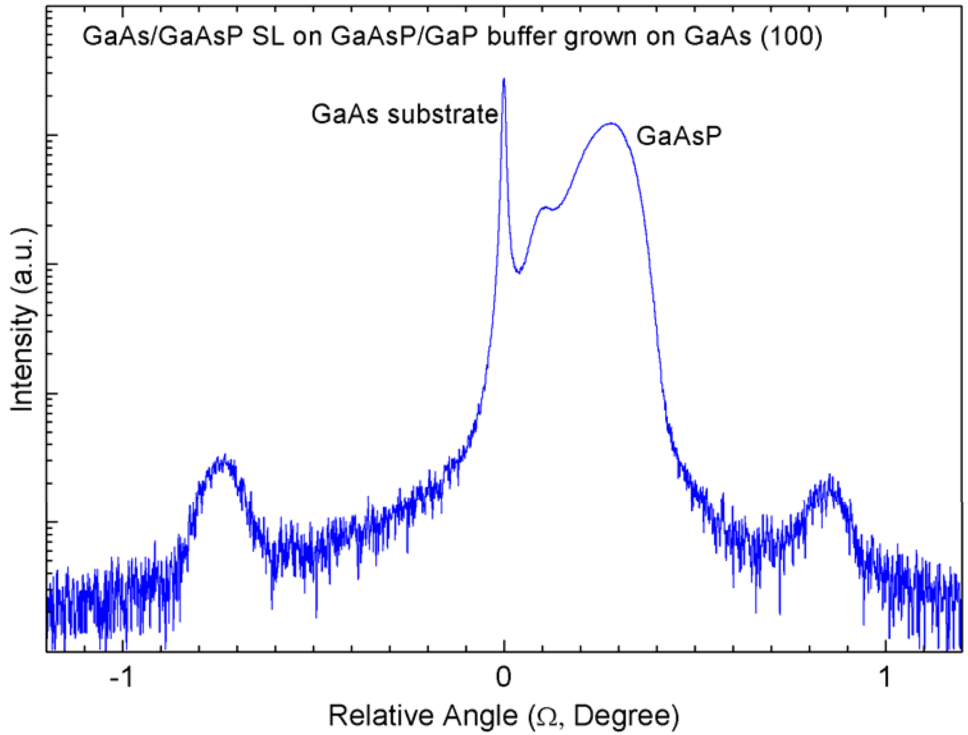
High-quality GaAsSb/AlGaAsP SL material achieved



Measured and simulated XRD rocking curves for a $GaAs_{0.85}Sb_{0.15}$/ $Al_{0.25}Ga_{0.75}As_{0.85}P_{0.15}$ SL structure grown on GaAs.

Recent progress on GaAs/GaAsP photocathodes

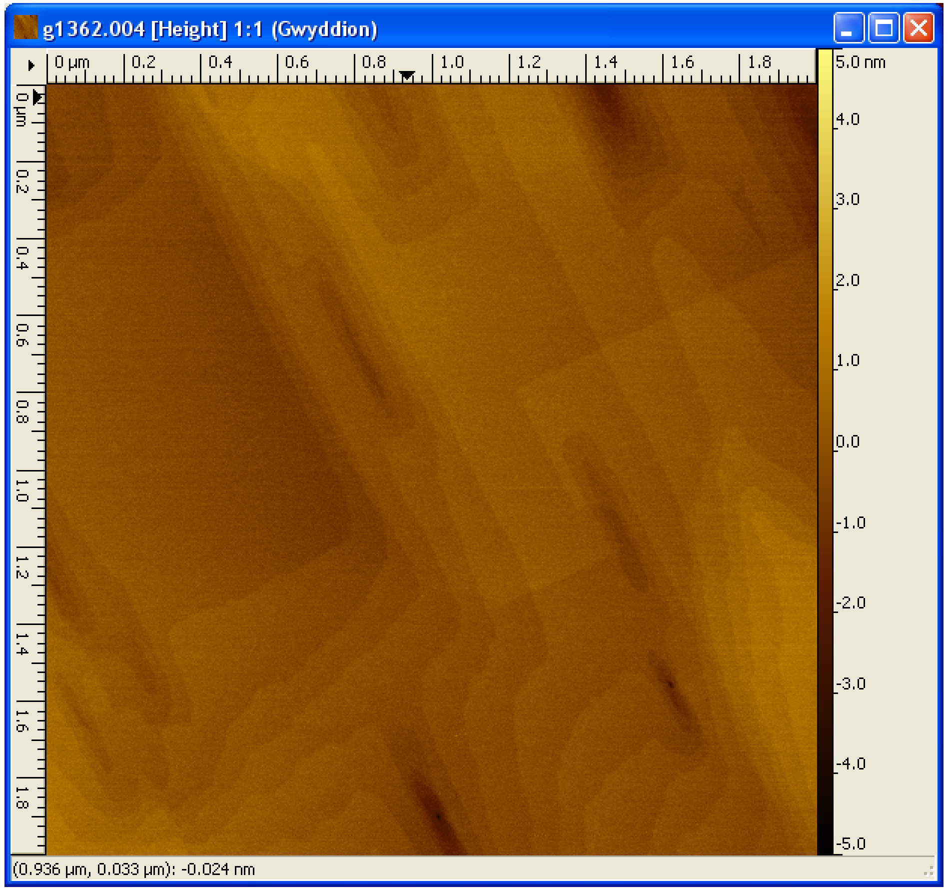
- Novel thin (~50nm) GaP buffer instead of thick (~5000nm) graded GaAsP buffer.
- Fast relaxation of GaP on GaAs.
- Direct growth of GaAsP on GaP; no graded GaAsP required.
- Structurally high quality GaAs/GaAsP SL achieved.

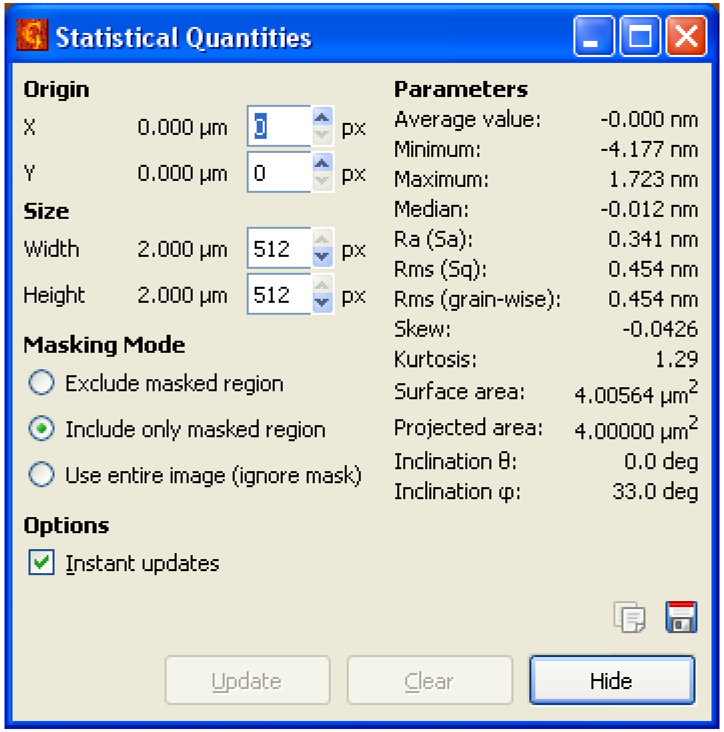


High-resolution X-ray diffraction curve for GaAs/GaAsP SL grown on GaP/GaAs.

SVT Associates, Inc.

AFM picture for GaAs/GaAsP SL grown on GaP/GaAs





SVT Associates, Inc.

Summary

Progress

- SL structure design and DBR design completed
- Equipment upgrade completed (P pumping system, dedicated MBE P/Sb system)
- MBE growth of GaAsSb/AlGaAsP SL performed, encouraging initial material result
- Delay due to cryo-shroud leakage; leakage fixed and maintenance completed.

Next step

- Optimization of MBE growth of GaAsSb/AlGaAsP SLs
- MBE growth and optical testing of DBRs
- MBE growth of GaAsSb/AlGaAsP SL photocathodes
- Device fabrication and testing (JLab)