REPORT DOCUMENTATION PAGE

Form Approved
OMB NO. 0704-0188

1. AGENCY USE ONLY (Leave Blank)

2. REPORT DATE
1-25-2005

3. REPORT TYPE AND DATES COVERED
Final Report: 5-1-2000 to 10-31-2004

4. TITLE AND SUBTITLE
A New Bragg Reflector Enhanced UV Solar-Blind Photovoltaic Detector on Si

5. FUNDING NUMBERS
DAAD19-00-1-0171

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8. PERFORMING ORGANIZATION
REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U. S. Army Research Office
P.O. Box 12211
Research Triangle Park, NC 27709-2211

10. SPONSORING / MONITORING
AGENCY REPORT NUMBER

40161.1-EL

11. SUPPLEMENTARY NOTES
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12 a. DISTRIBUTION / AVAILABILITY STATEMENT

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12 b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

The objective of this project is to study MBE growth of PbSrSe with different Sr composition and the potential for detector applications. The PbSrSe material system ranges from UV wide bandgap semiconductor SrSe (3.8e eV) to mid-IR narrow gap semiconductor PbSe (0.26 eV). Therefore it is a very interesting material system to study. During this project, MBE-grown PbSrSe epitaxial layers with Sr composition ranging from 1 to 0 have been successfully demonstrated on Si and BaF_2 substrate. The bandgap energies as well as the refractive indices were determined by optical transmission measurement. A distinct bandgap inversion from the direct to the indirect transition is observed for the first time at $x \sim 0.20$ as the Sr composition increases. *In situ* reflection high energy electron diffraction (RHEED), x-ray diffraction, and optical transmission are used to characterize the epi-layers and show that the material quality is reasonably high. However, doping especially p-type doping for wide gap SrSe is difficult. There is no doping problem for narrow gap small Sr composition PbSrSe materials.

A new concept of growing PbSe-based quantum well materials on [110] orientation was also proposed. Preliminary MBE growth was successful. Future work will be focused on new detector structures on [110] orientation.

14. SUBJECT TERMS

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OR REPORT	18. SECURITY CLASSIFICATION ON THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	**UNCLASSIFIED**	**UNCLASSIFIED**	**UL**

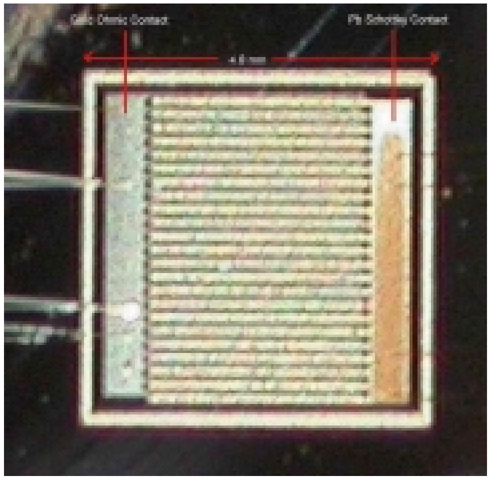
NSN 7540-01-280-5500

Standard Form 298 (Rev.2-89)
Prescribed by ANSI Std. 239-18
298-102

SrSe UV Solar-Blind Photovoltaic Detector on Si

Army Research Office Program (DAAD19-00-1-0171)

PI: Zhisheng Shi, ECE, University of Oklahoma



New Objectives of the Project

Investigation of $Pb_{1-x}Sr_xSe$ in the whole spectra range (x= 0-1). Determine the optical parameters and fabrication of detectors.

Approach

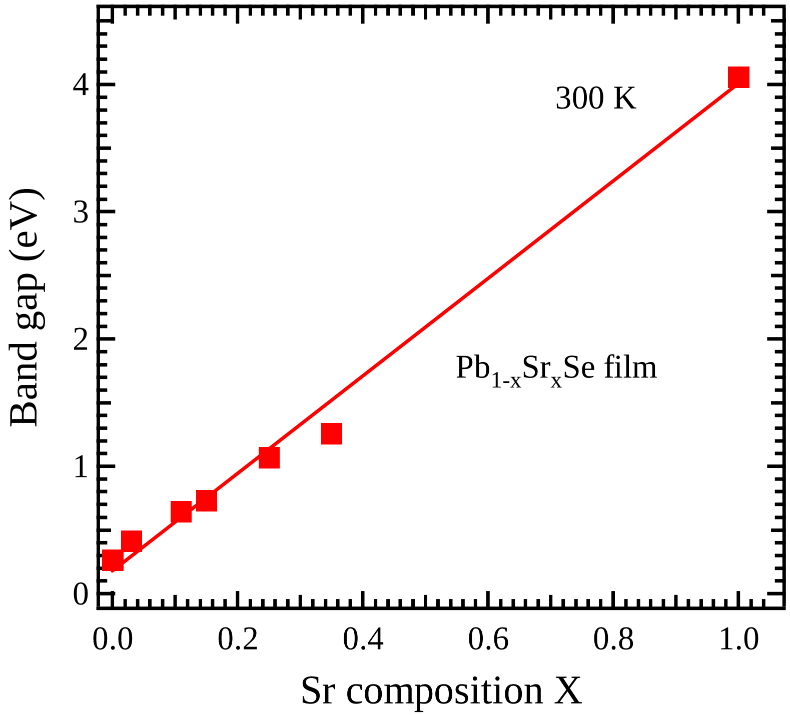
- MBE growth of thin-film PbSrSe on BaF_2 and Si substrates
- Determine basic material parameters
- Develop processing technologies

Highlights of Current Findings

- Monocrystalline $Pb_{1-x}Sr_xSe$ film growth in the whole spectra range (x=0-1)
- Temperature Dependent E_g , absorption coefficients and refractive indices determined for the first time
- Direct to indirect band transition observed for the first time.

Applications PbSrSe Material

- **UV – Mid-IR detector**
- **RF/Microwave/Millimeter-wave Technology**



Advantages of $Pb_{1-x}Sr_xSe$

- Huge wavelength coverage
  - multi-wavelength detection
- Good material quality on Si
  - integration with Si readout
- Low temperature growth
  - ROIC could withstand

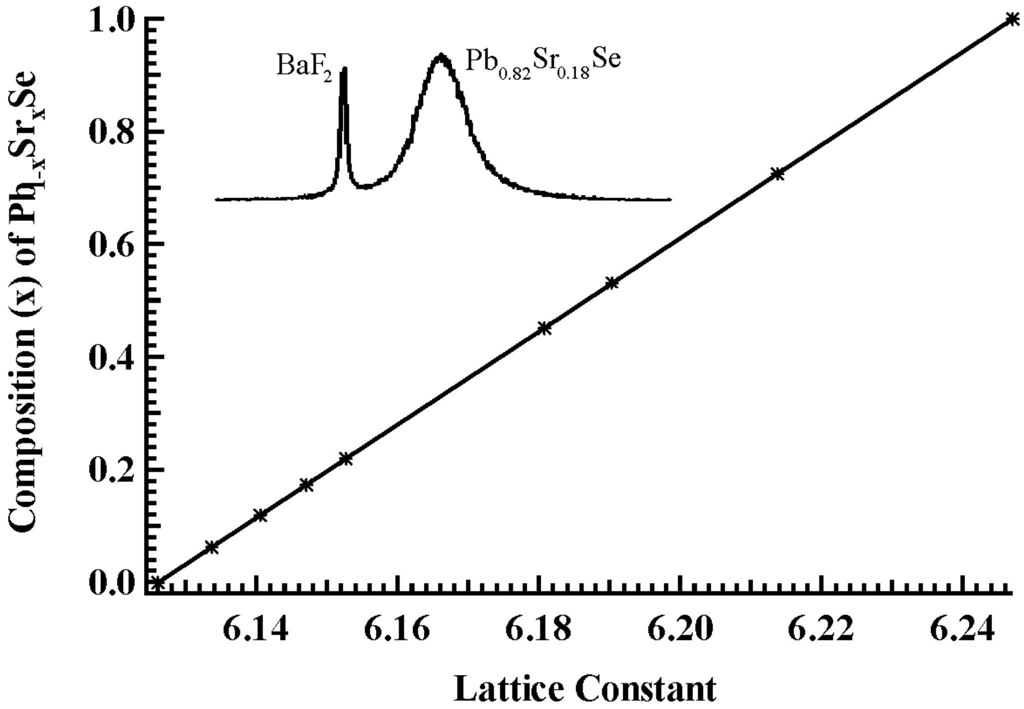
Some Related Material Parameters

Materials	Crystal structure	Melting Point (ºC)	Lattice constant (Å)	α (10-6 K-1)	Bandgap Energy (eV)
SrSe	Cubic (NaCl)	1600	6.22*	NA	3.94* (indirect) 4.18* (direct)
PbSe	Cubic (NaCl)		6.124*	19.4	0.265*
SrS	Cubic	2226	6.02	NA	4.7
Si	Diamond		5.43095	2.6	1.124
CaF_2	Cubic (CaF_2)		5.464	19.2	12.1
BaF_2	Cubic (CaF_2)		6.20	19.8	10.4

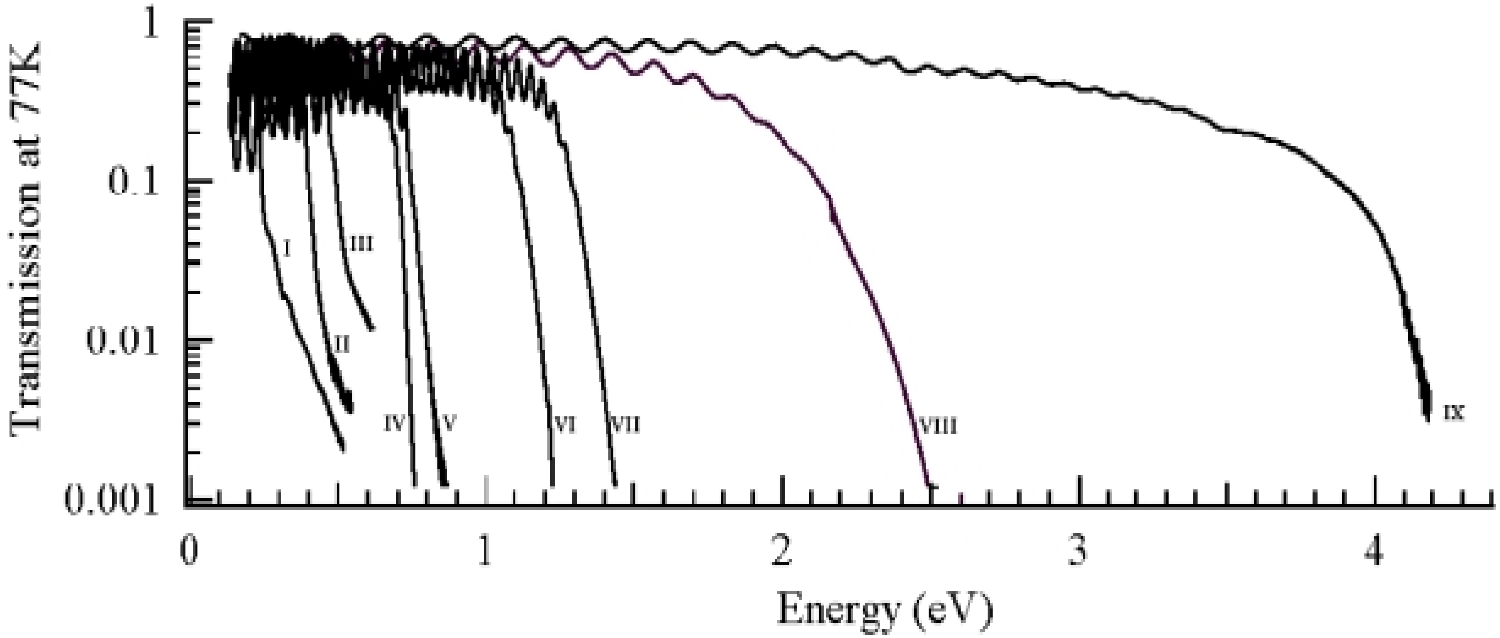
*** Data determined in our Lab**

CaF_2 is nearly lattice matched to Si and thermal expansion matched to PbSe - an ideal buffer layer between Si and epi-layer to reduce dislocation and avoid cracking

Composition vs. lattice constant for $Pb_{1-x}Sr_xSe$ determined by X-ray



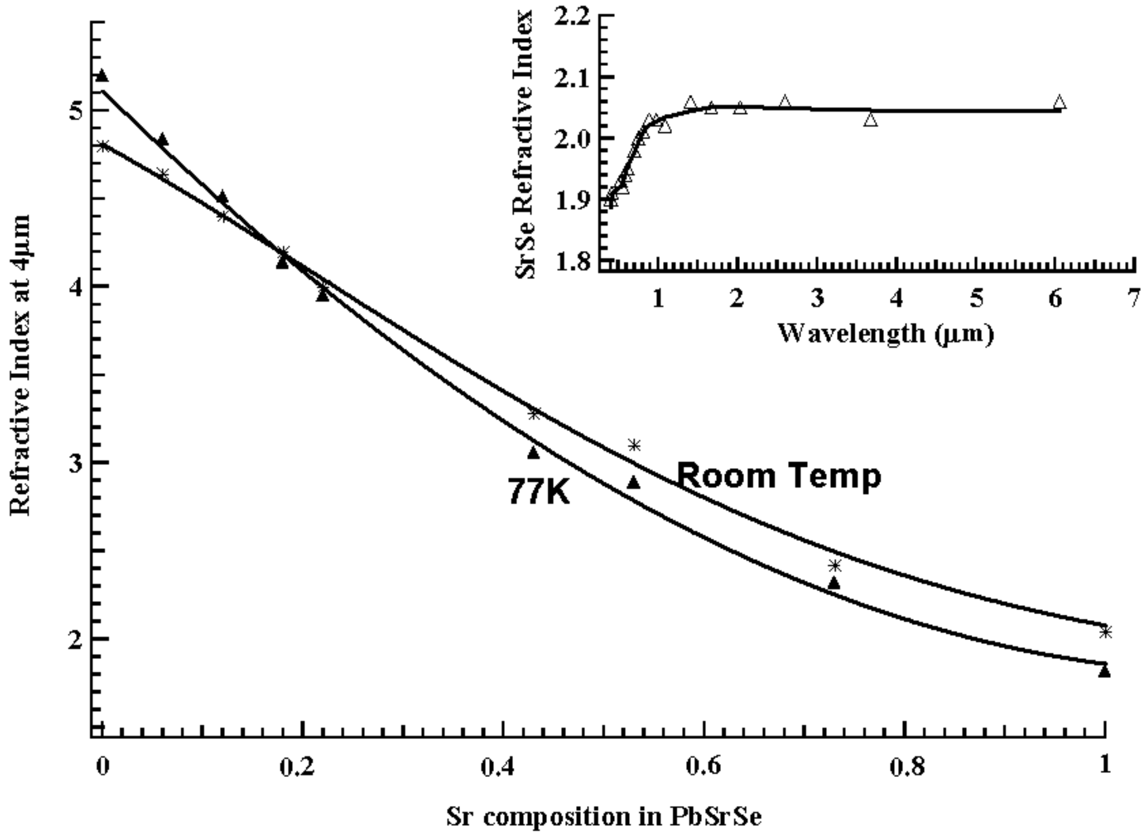
Direct to Indirect Band gap Transition



Transmission curves for $Pb_{1-x}Sr_xSe$ at 77K plotted in logarithmic scale. (I): PbSe, (II): $Pb_{0.94}Sr_{0.06}Se$, (III): $Pb_{0.88}Sr_{0.12}Se$, (IV): $Pb_{0.72}Sr_{0.18}Se$, (V): $Pb_{0.78}Sr_{0.22}Se$, (VI): $Pb_{0.57}Sr_{0.43}Se$, (VII): $Pb_{1-0.47}Sr_{0.53}Se$, (VIII): $Pb_{0.27}Sr_{0.73}Se$, (IX): SrSe.

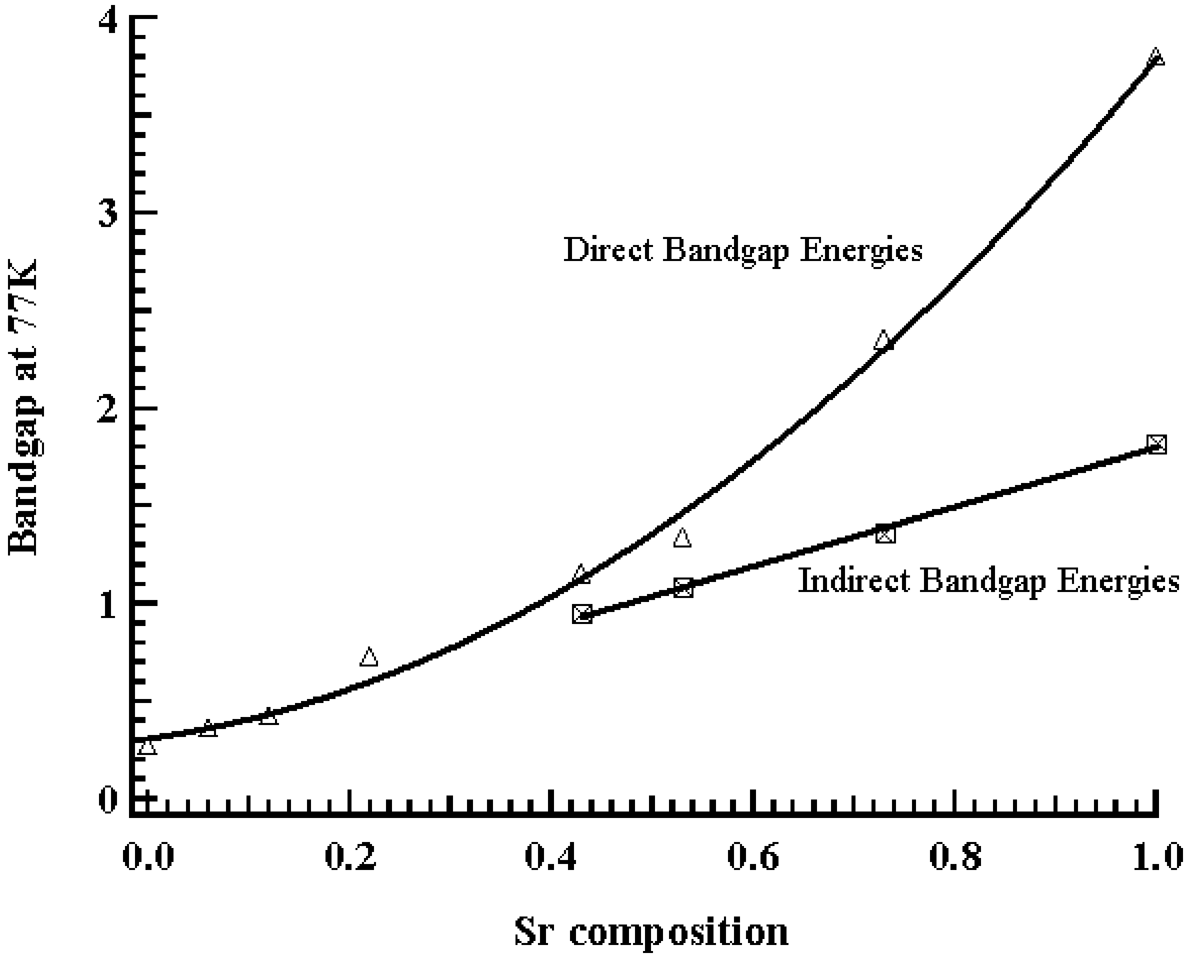
Direct to Indirect band transition appears at x~0.2

Refractive Indices



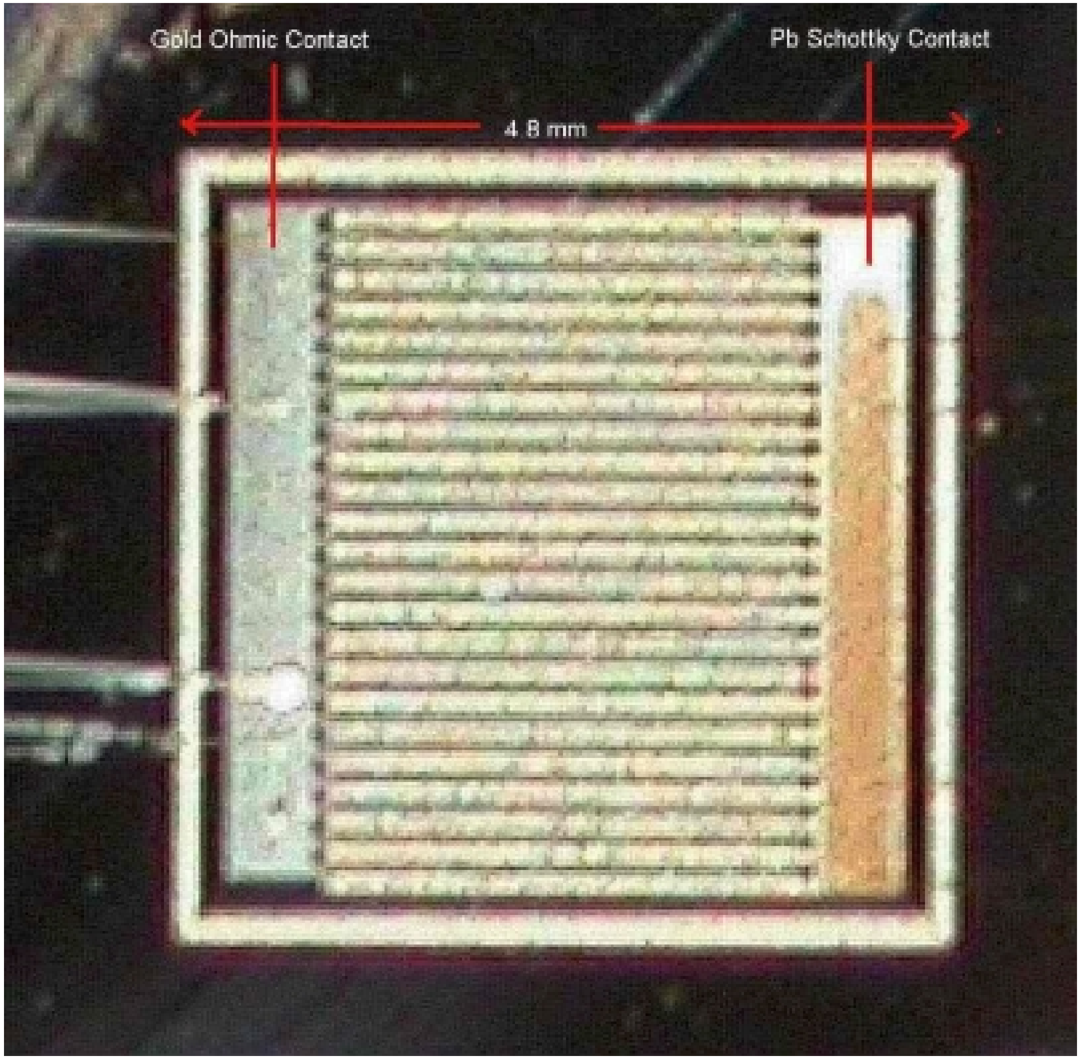
Refractive index of $Pb_{1-x}Sr_xSe$ for different compositions (x), at 77K and at room temperature. Insert in the figure is the refractive index of SrSe at 77K

Bandgap Energies Of PbSrSe

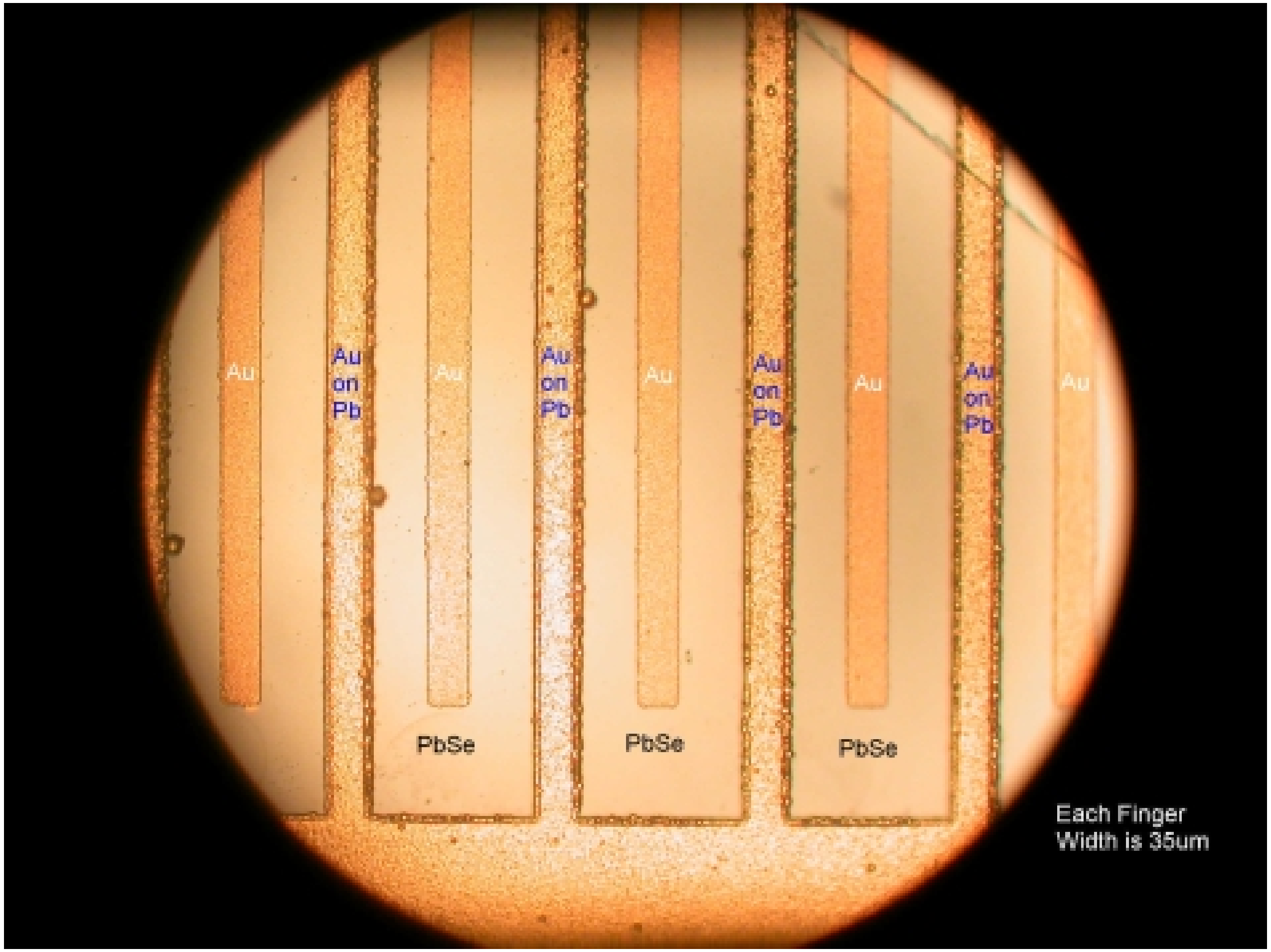


Direct and Indirect bandgap energies of $Pb_{1-x}Sr_xSe$ at 77K for different compositions

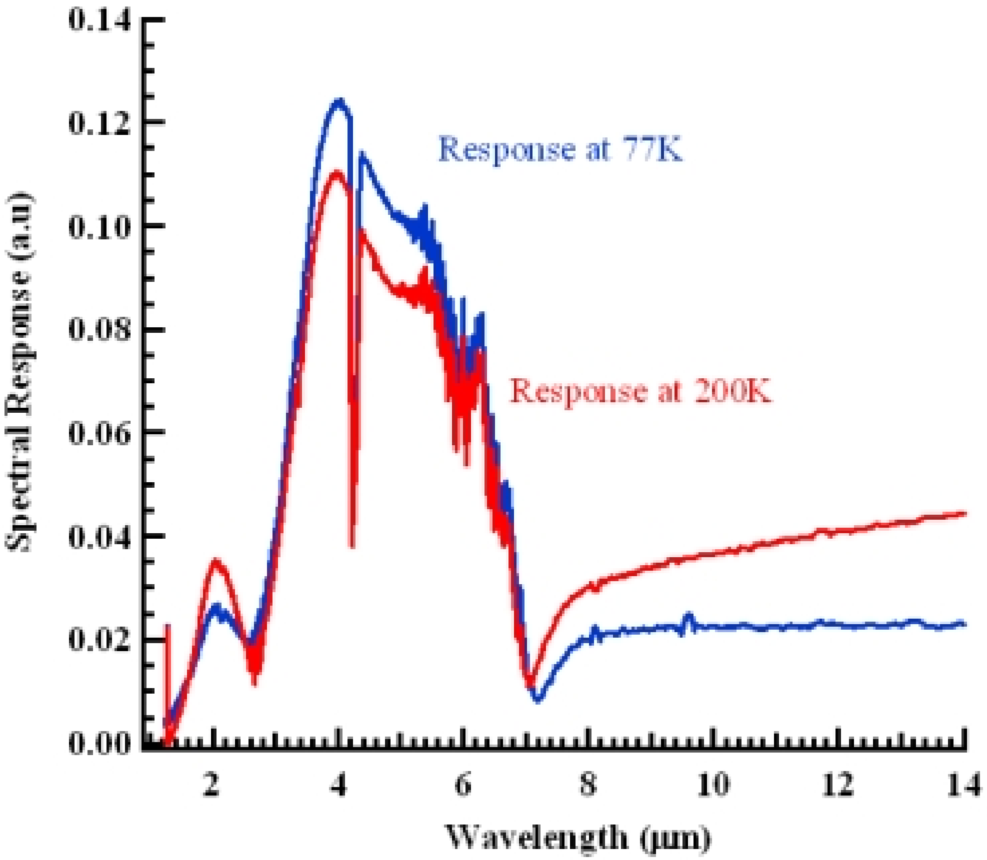
PbSe Schottky contact photovoltaic detector



Au and Pb Finger contacts



Spectra response



Spectra response of PbSe detector at 77K and 200K. The center dip is due to CO_2 absorption.

The shoulder noises around 6 mm are caused by water absorption.

Future Work

Further Development of Detector Processing

- Passivation using BaF_2
- Reduction of backgroup carrier concentration

P-N Junction Mid-IR Detector

Resonant Cavity Enhanced Mid-IR Detector

Detector Array On Si

Paper published

1) A. Majumdar, H. Z. Xu, F. Zhao, J. C. Keay, L. Jayasinghe, S. Khosravani, X. Lu, V. Kelkar, and Z. Shi, “Bandgap energies and refractive indices of $Pb_{1-x}Sr_{x}Se$”, J. Appl. Phys., **95,** 939(2004)

2) F. Zhao, H. Wu, A. Majumdar and Z. Shi,“Continuous wave optically pumped lead-salt mid-infrared quantum-well vertical-cavity surface-emitting lasers”, Appl. Phys. Lett., **83**, 5129 (2003).

3) A. Majumdar, H.Z. Xu, F. Zhao, L. Jayasinghe, S. Khosravani, X. Lu, V. Kelkar, Z. Shi, “Bandgap Energies and Refractive Indices of $Pb_{1-x}Sr_xSe$”, MRS Proceedings, Symposium I “Optoelectronics of Group-IV-Based Materials”, Editors: Tom Gregorkiewicz, Robert G. Elliman, Philippe M. Fauchet, James A. Hutchby, Volume 770, I7.9.

Graduate Students Supported

1) Mr. Shahriar Khosravani (Ph.D candidate, graduated in 2003)
2) Mr. Tao Zheng, (Transferred to computer Science department)
3) Mr. Vishal Kelkar (MS candidate, graduated in 2003)
4) Swathi Bondili (MS candidate, expected to graduate in May 2005)
5) Shikha Jain (PhD candidate, started in August 2004)