Growth and Properties of Hg-Based Quantum Well Structures and Superlattices

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An overview of the properties of HgTe-CdTe quantum well structures and superlattices will be presented. These new quantum structures are candidates for use as new LWIR and VLWIR detectors, as well as for other optoelectronic applications. Much as been learned within the past two years about the physics of such structures. The valence band offset has been determined to be ~350 meV, independent of temperature. The occurrence of electron and hole mobilities in excess of 10^5 $cm^2/V \cdot s$ is now understood on the basis of SL band structure calculations. The in-plane and out-of-plane electron and hole effective masses have been measured and interpreted theoretically for HgTe-CdTe superlattices. Controlled substitutional doping of superlattices has recently been achieved at NCSU, and modulation-doped SLs have now been succesfully grown and studied. Most recently, a dramatic lowering of the growth temperature of Hg-based quantum well structures and SLs (to~100 C) has been achieved by means of photoassisted MBE at NCSU. A number of new devices have been fabricated from these doped multilayers.

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GROWTH AND PROPERTIES OF Hg-BASED QUANTUM WELL STRUCTURES & SUPERLATTICES

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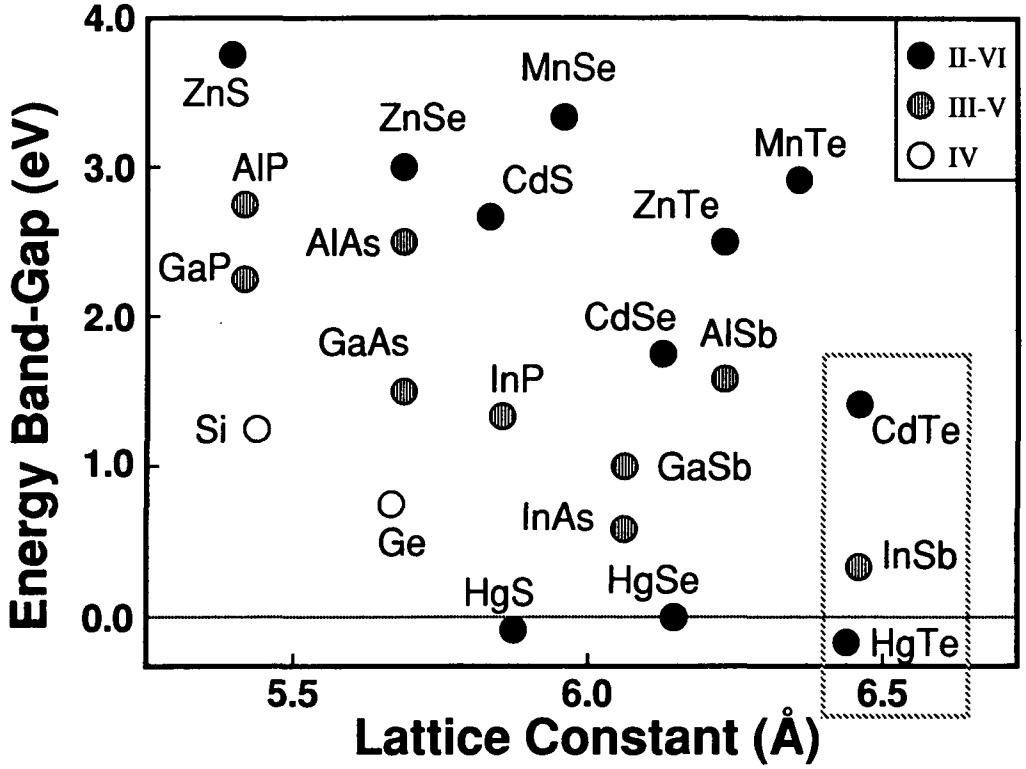
NCSU II-VI SEMICONDUCTOR MBE PROGRAM
Collaborators and Students at NCSU

- **Research Associates**
  - N.C. Giles
  - S. Hwang
  - Z. Yang
  - J. Yu
- **Graduate Students**
  - D. Dreifus
  - J. Han
  - Y. Lansari
  - R. Vaudo
  - R. Reed
- **Technicians**
  - J. Matthews
  - B. Sneed
  - K. Bowers
- **Secretary**
  - T. Hockenberger
- **Undergraduates (4)**

OVERVIEW OF PRESENTATION

- **Photoassisted MBE at NCSU**
  - Experimental Procedures
  - Summary of Materials Properties
- **HgTe-CdTe Superlattices**
  - Growth of VLWIR Structures (18 - 22 μm)
  - Controlled Doping Studies
  - Low Temperature Processing at NCSU
- **Applications**
  - Sources & Detectors
  - Amplifiers & Modulators

ENERGY BAND GAP vs LATTICE CONSTANT OF SELECTED SEMICONDUCTORS

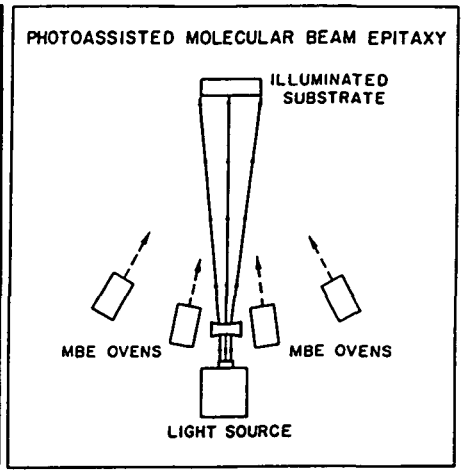


PHOTOASSISTED MOLECULAR BEAM EPITAXY

A New Approach to Controlled Substitutional Doping

R.N. Bicknell, N.C. Giles, and J.F. Schetzina
Appl. Phys. Lett. 49, 1095 (1986)

- A Form of Energy-Assisted Epitaxy
- Growth Temperatures of II-VI Compounds are Low (150 - 350 °C)
- Photons Provide a Source of High Energy, Low Momentum Particles that Bathe the Substrate Surface during Film Growth & Induce Photochemical Reactions
- "Its all done with MIRRORS!!!"



SUBSTITUTIONAL DOPING OF II-VI SEMICONDUCTORS
Major Long-Term Problems

- **Poor Quality Bulk Crystals & Substrates**
- **Large Dislocation Densities**
- **Large Densities of Native Defects**
- **Low Percentage of Dopant Activation**
- **Compensation Effects Often Dominate**
- **Poor Electrical Properties - Low Mobilities**
- **Inferior Optical Properties - Deep Levels**

PHOTOASSISTED MOLECULAR BEAM EPITAXY

Microscopic Mechanisms

- Conversion of Surface Molecules into Atoms
- Photochemical Changes in Atomic Bonding
- Enhancement of Surface Mobility of Atoms
- Photochemical Activation of Dopant Atoms
- Modification of Stoichiometry of Growth Surface

PHOTOASSISTED MOLECULAR BEAM EPITAXY

MBE Film Growth Systems at NCSU

SYSTEMS DESIGNED AND CONSTRUCTED AT NCSU

- Custom Features for II-VI Materials
- Cost Effective

MBE FACILITIES

- Three Hg-Compatible Systems
- One System for Wide Gap II-VIs
- Special Hg Sources (NCSU)
- Two-Zoned Furnaces (NCSU)
- Computer-Controlled Shutters
- Spectra Physics Argon Ion Laser

PHOTOASSISTED MOLECULAR BEAM EPITAXY

WIDE-BAND-GAP & NARROW-BAND-GAP II-VIs

MATERIALS GROWN		PROPERTIES
CdTe:In	CdMnTe:In	• Controlled Doping
CdTe:Sb	CdMnTe:Sb	• High Carrier Mobilities
CdTe:As	HgCdTe	• Narrow Rocking Curves
CdMnTe-CdTe Superlattices		• Bright Photoluminescence
HgTe-CdTe Superlattices		• p-n Junctions Fabricated
Modulation-Doped HgCdTe		• FETs Fabricated

HgTe-CdTe SUPERLATTICES

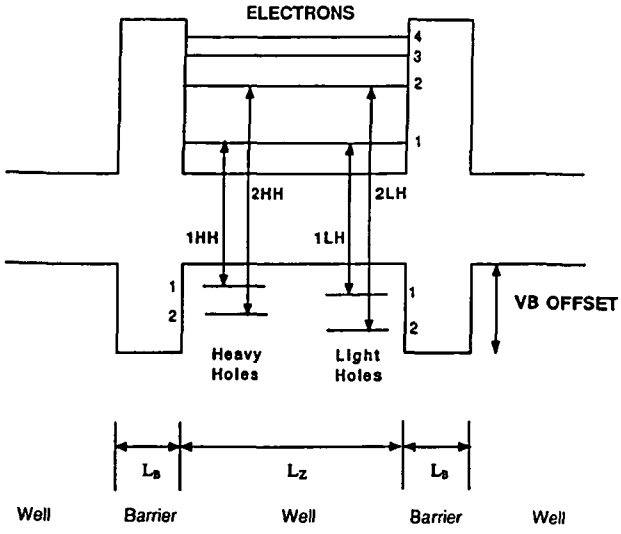
Growth Parameters

SUBSTRATE:		(100) CdZnTe
SUBSTRATE TEMPERATURE:		150 °C
		140 °C (Photoassisted)
T_{In} :		400-475 °C
T_{As}:		220 °C
Hg FLUX:		1.5 X10^{-4} Torr
DEPOSITION RATE:		1-3 Å/sec
LAYER THICKNESSES:		
	HgTe	32-160 Å
	CdTe	26-102 Å

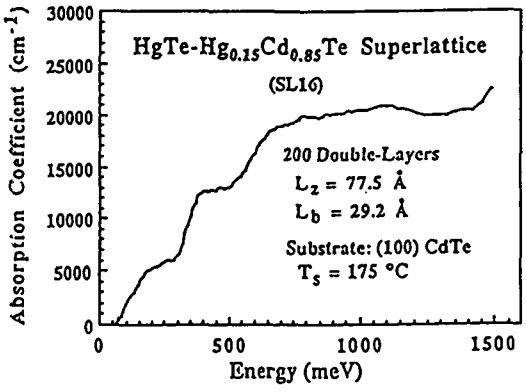
Hg Te-CdTe SUPERLATTICES

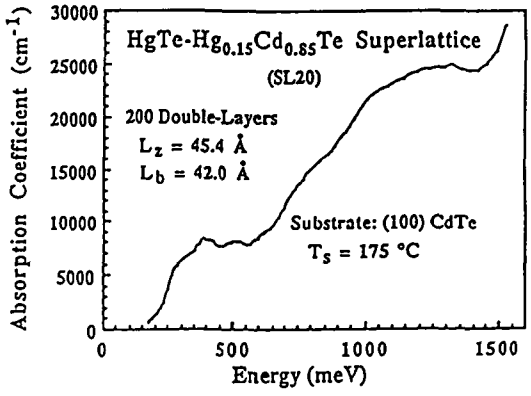
Designation of Electronic Transitions

QUANTUM TRANSITIONS IN MULTILAYERS



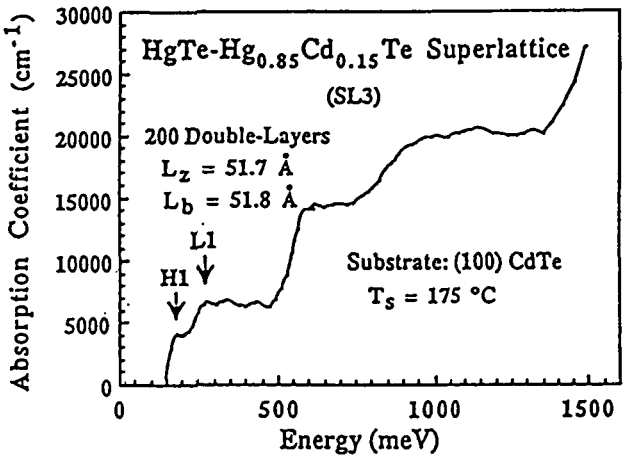
Optical Properties

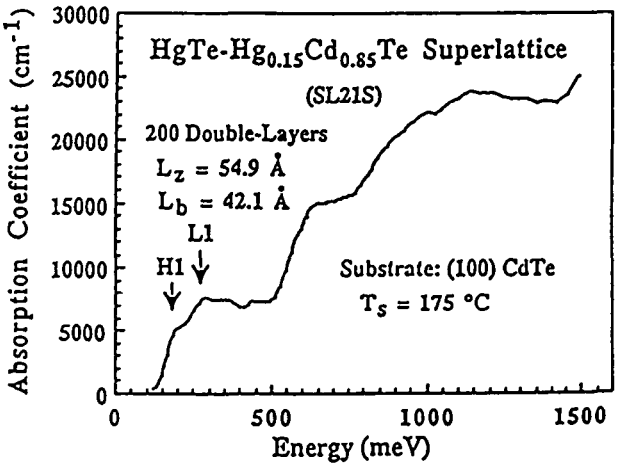




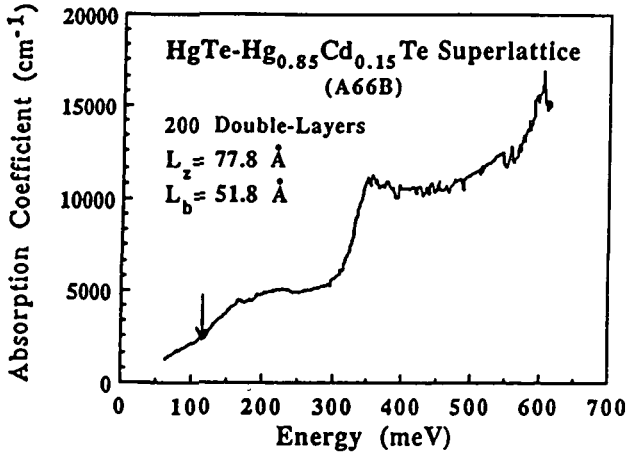
HgTe-CdTe SUPERLATTICES

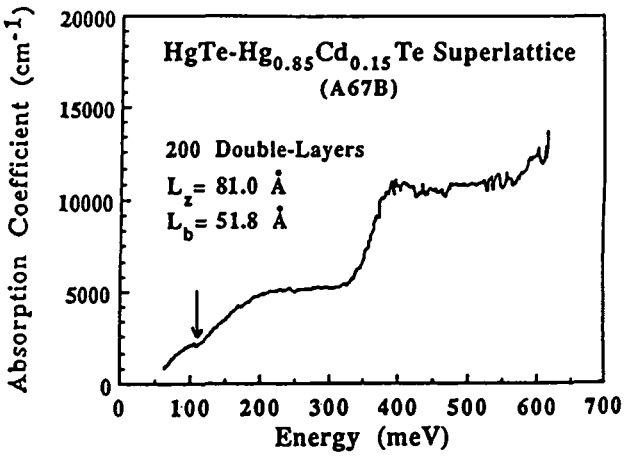
Optical Properties





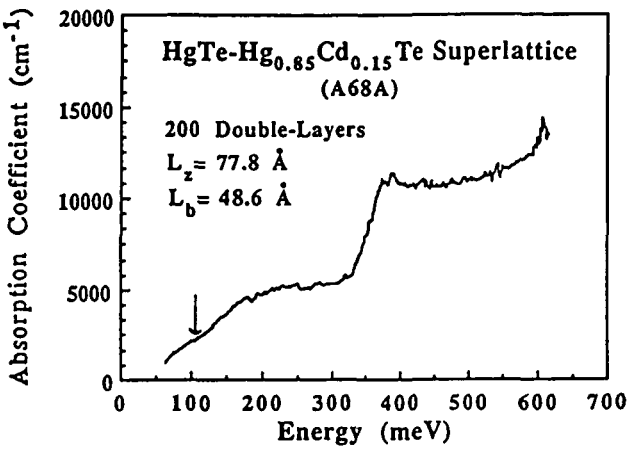
Optical Properties: VLWIR Structures

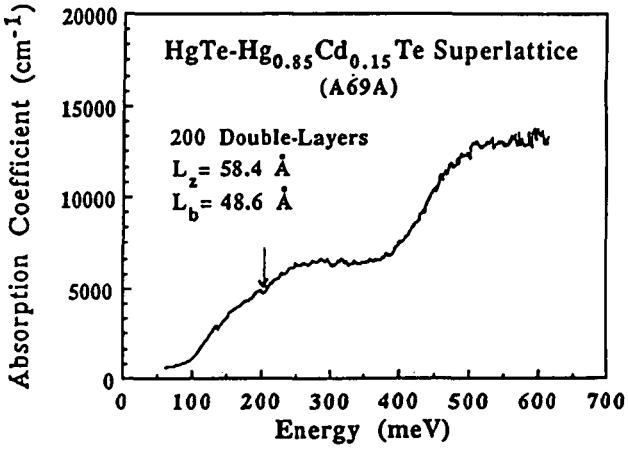


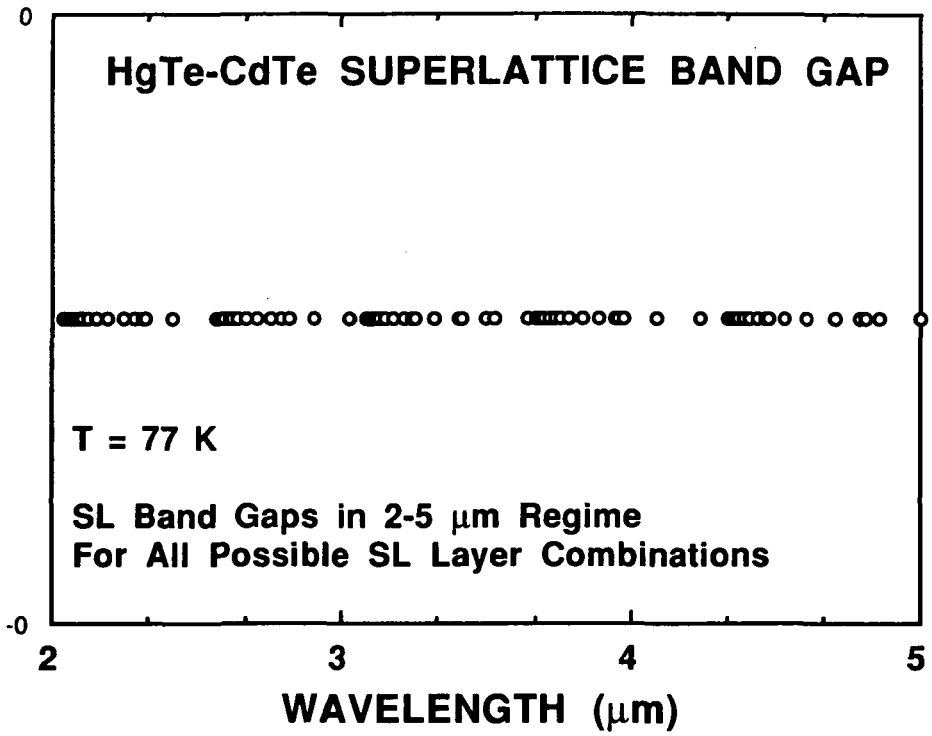


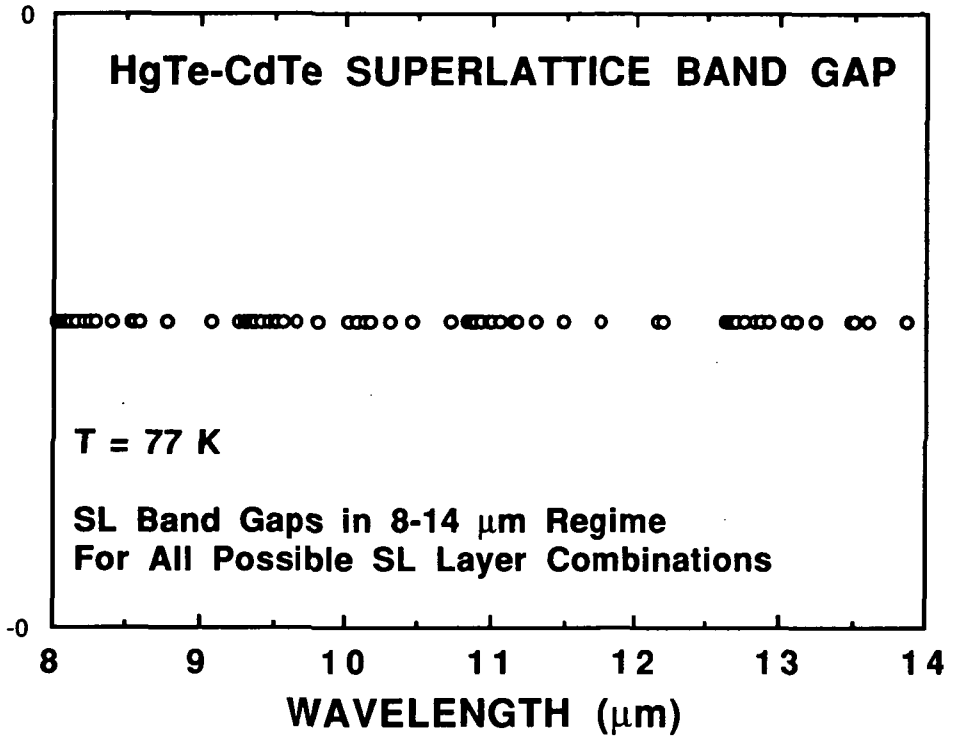
HgTe-CdTe SUPERLATTICES

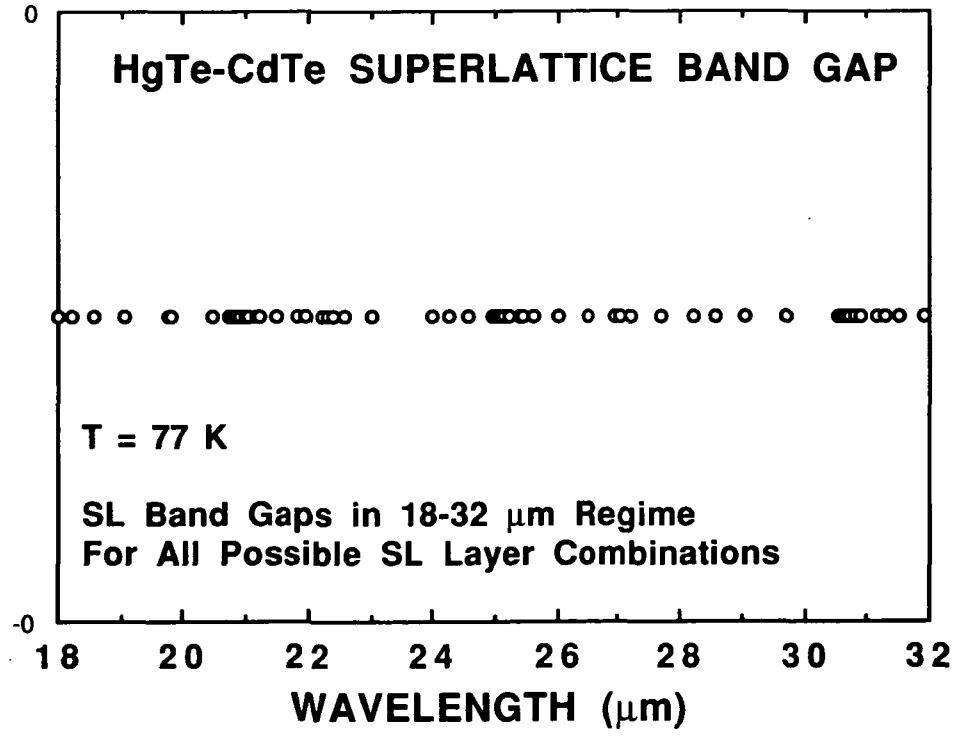
Optical Properties: VLWIR Structures

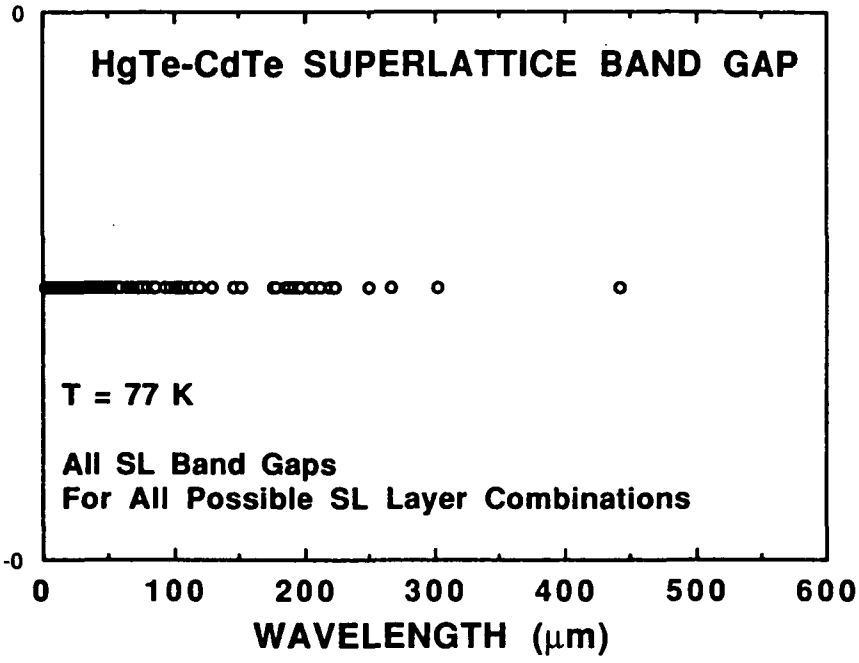







HgTe-CdTe SUPERLATTICE BAND GAP
T = 77 K
SL Band Gaps in 8-14 μm Regime
For All Possible SL Layer Combinations
0
-0
8
9
10
11
12
13
14
WAVELENGTH (μm)


HgTe-CdTe SUPERLATTICE BAND GAP
T = 77 K
SL Band Gaps in 18-32 μm Regime
For All Possible SL Layer Combinations
0
-0
18
20
22
24
26
28
30
32
WAVELENGTH (μm)

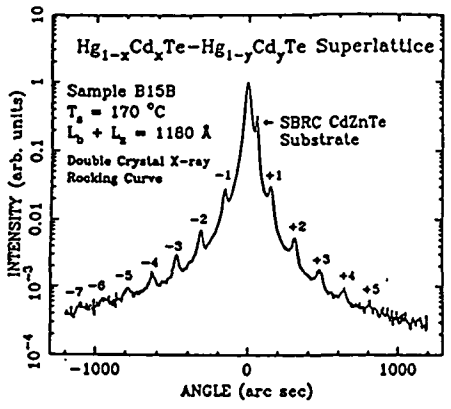


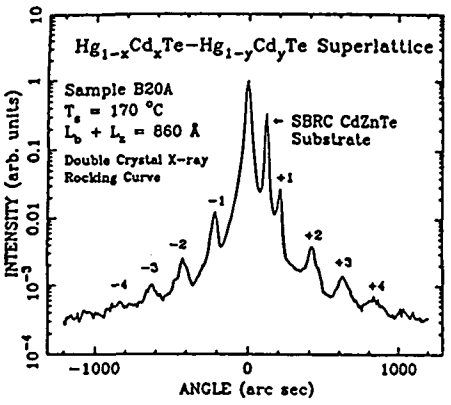
Vertical Cross-Section TEM Photo
of Modulation Doped HgCdTe

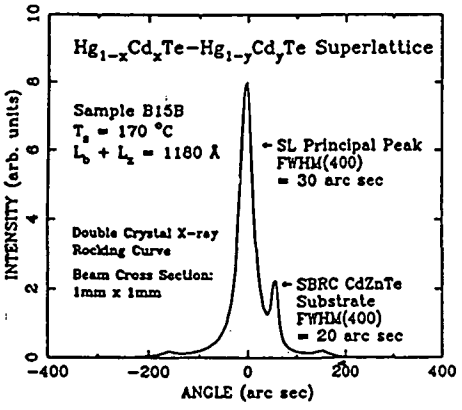
N. Otsuka, Purdue University

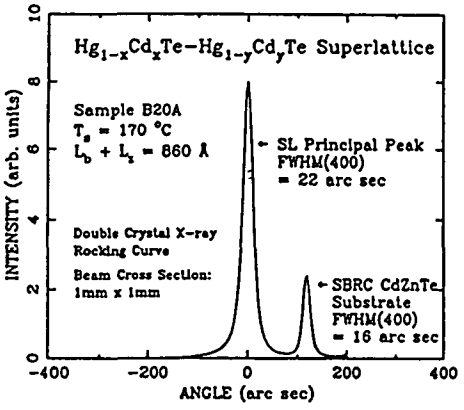
HgTe-CdTe SUPERLATTICES

Structural Properties: X-Ray Diffraction

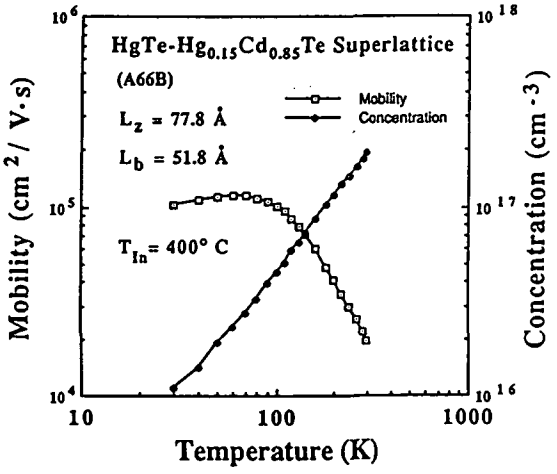


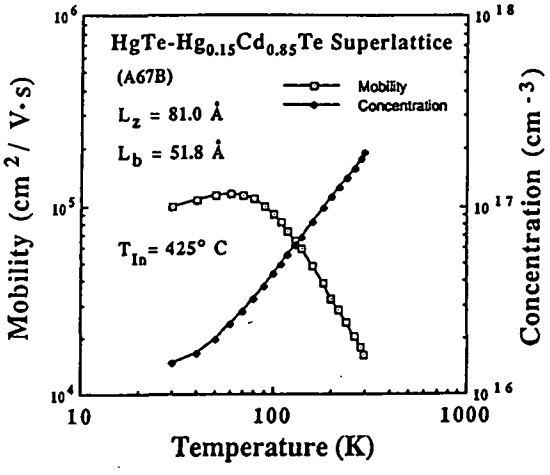






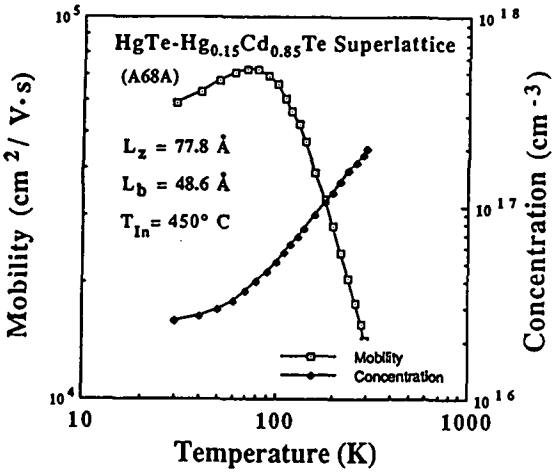
Substitutional Doping: n-Type (Indium)

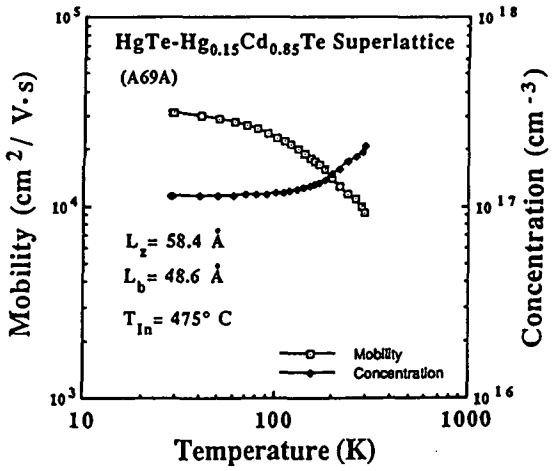




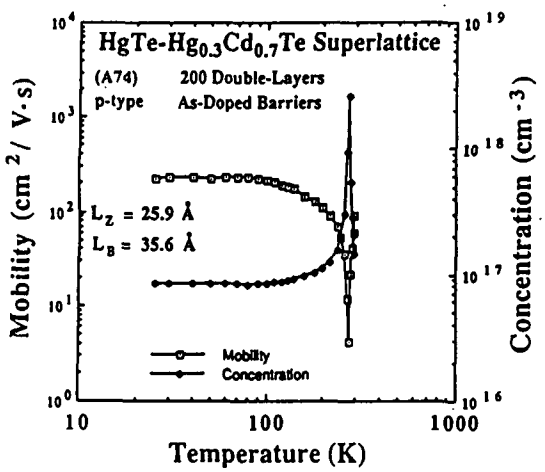
HgTe-CdTe SUPERLATTICES

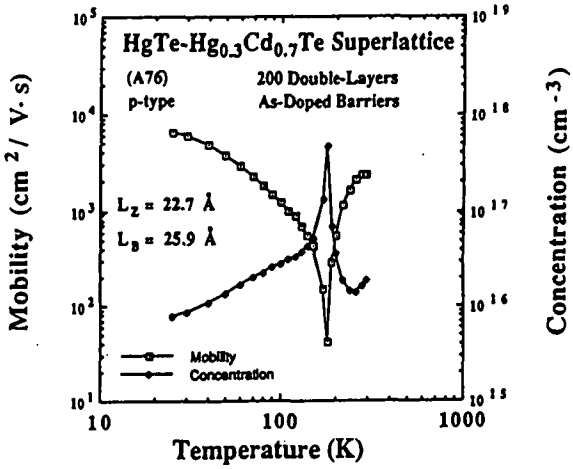
Substitutional Doping: n-Type (Indium)





Substitutional Doping: p-Type (Arsenic)

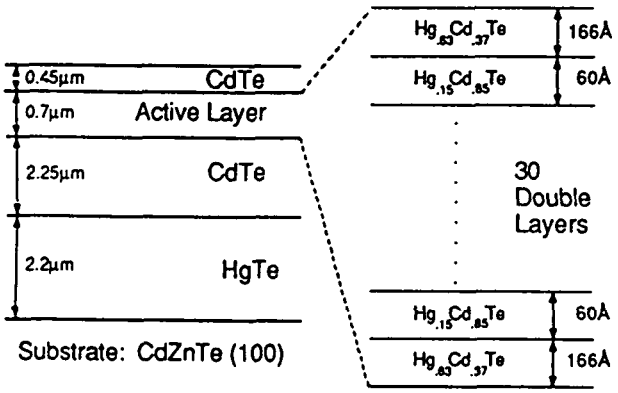


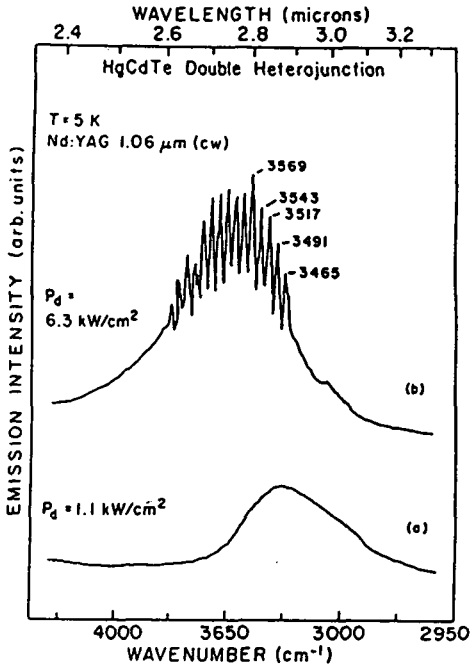


HgCdTe-CdTe SUPERLATTICES

Stimulated Emission

HgCdTe Double Heterojunction

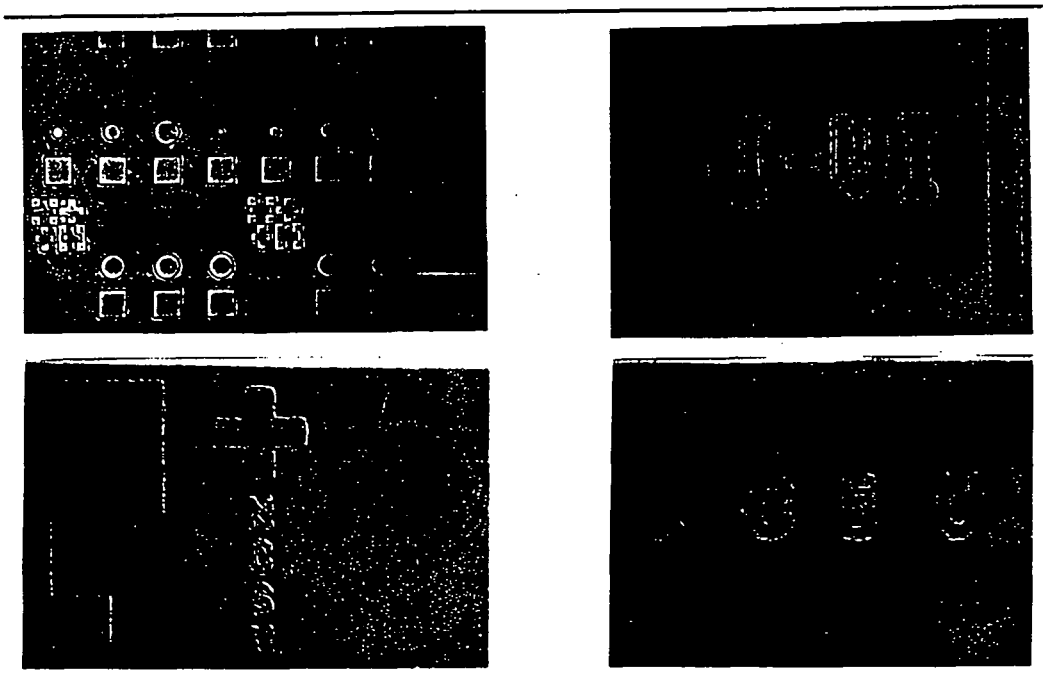




DARPA

Selective-Area Epitaxy of HgTe-CdTe Superlattices

NCSU



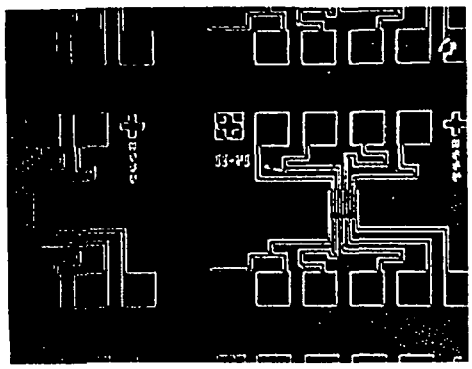
DARPA

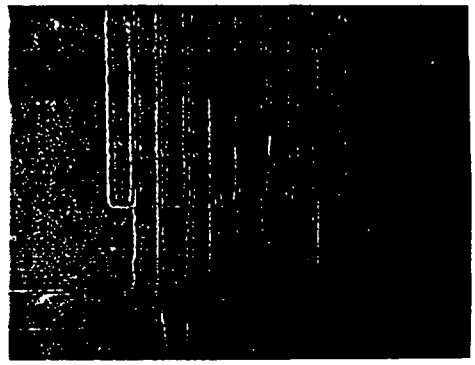
Selective-Area Epitaxy of HgTe-CdTe Superlattices

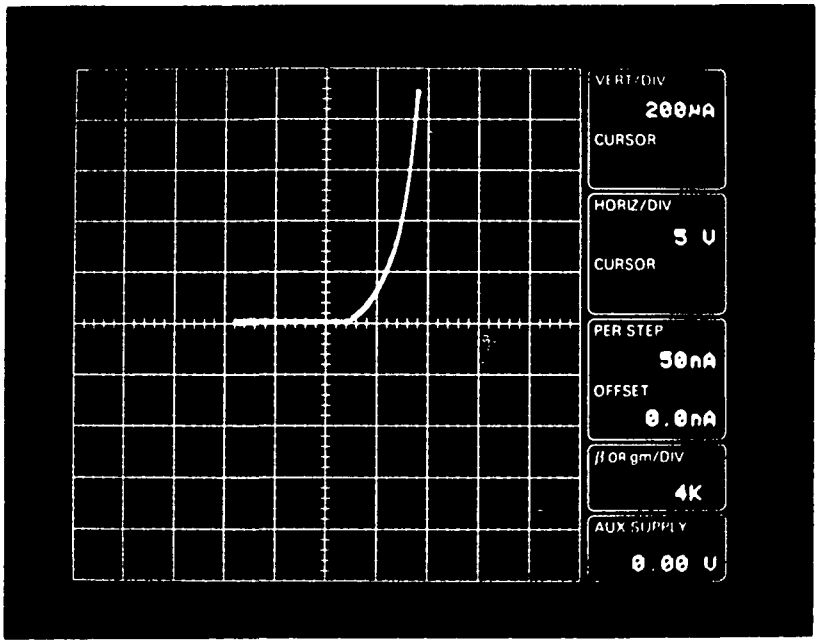
NCSU

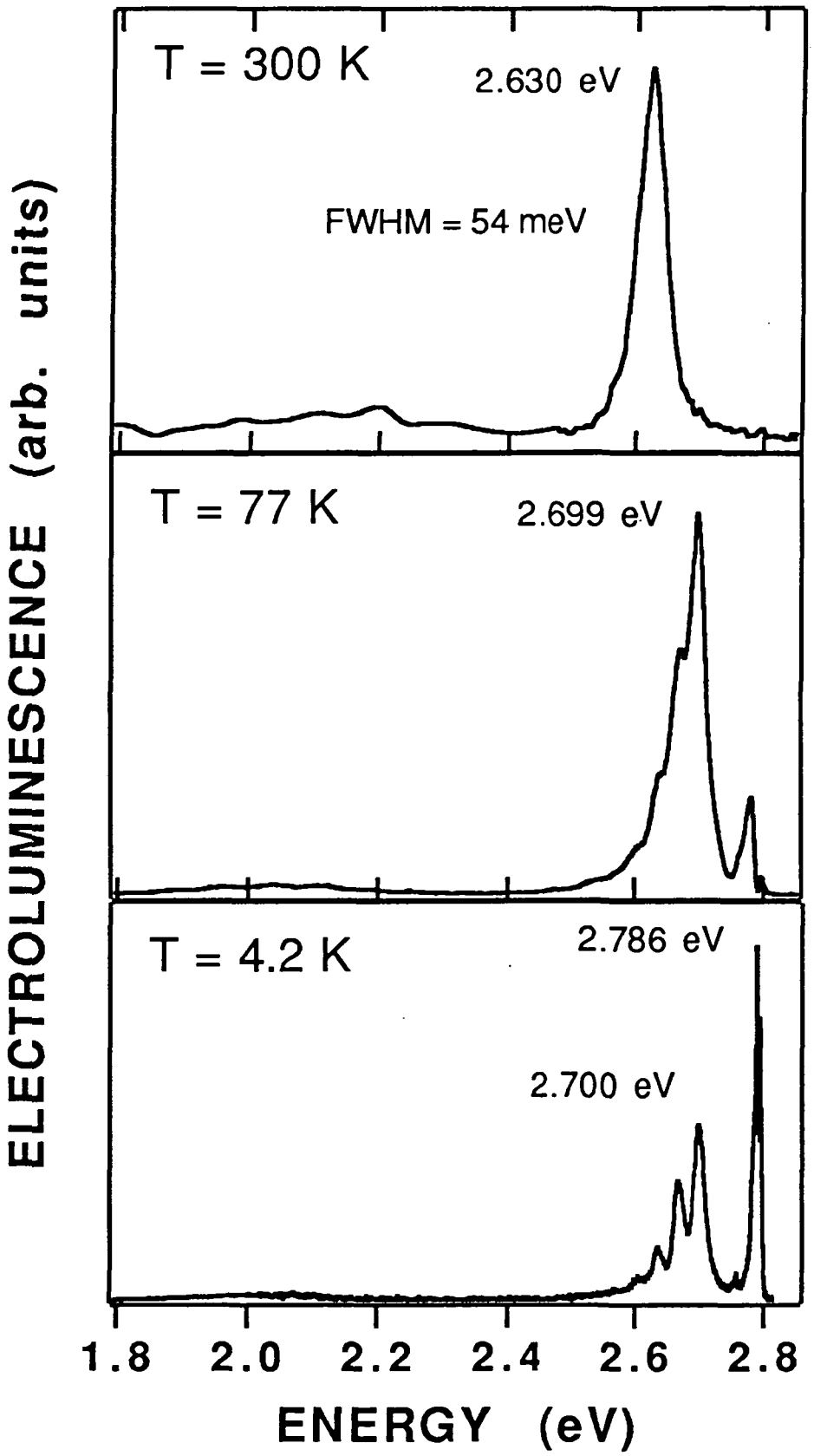
Growth Parameters: CdZnTe Substrates, Ts = 150 °C,

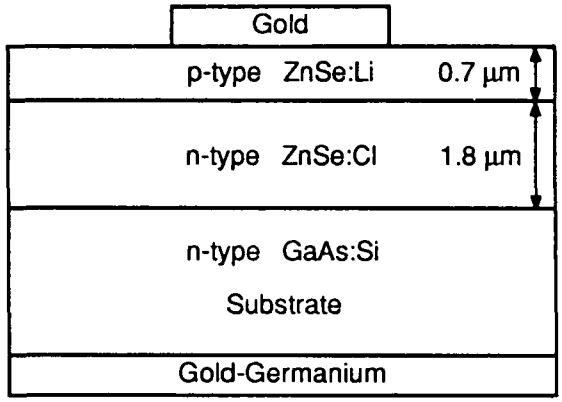
Applications: Multicolored Sources and/or Detectors;
Optical Waveguides; Light Modulators

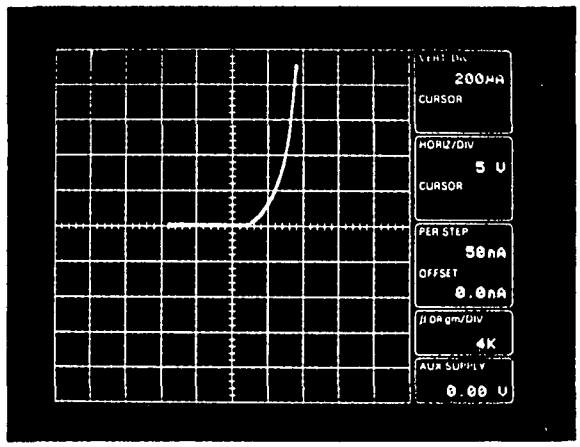







T = 300 K
2.630 eV
FWHM = 54 meV
T = 77 K
2.699 eV
T = 4.2 K
2.786 eV
2.700 eV
ELECTROLUMINESCENCE (arb. units)
1.8
2.0
2.2
2.4
2.6
2.8
ENERGY (eV)





HgTe-CdTe SUPERLATTICES

Summary of Properties

- AN INTERESTING INFRARED QUANTUM STRUCTURE
- SUPERLATTICE HAS MANY DIFFERENT STATES WHICH EXHIBIT VERY DIFFERENT PROPERTIES
- A VARIABLE BAND GAP STRUCTURE AS PREDICTED
- EXHIBITS LARGE ABSORPTION IN INFRARED REGION
- EXCELLENT ELECTRICAL PROPERTIES
- EXCELLENT STRUCTURAL PROPERTIES
- SHORT MINORITY CARRIER LIFETIMES (10 - 20 ns)
- DETECTOR APPLICATIONS: VLWIR REGION (18 - 24 µm)