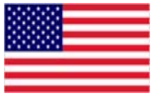
NIR, MWIR and LWIR Quantum Well Infrared Photodetector using Interband and Intersubband Transitions

Fabio Durante P. Alves (ITA – Brazil)



G. Karunasiri and N. Hanson (NPS – USA)

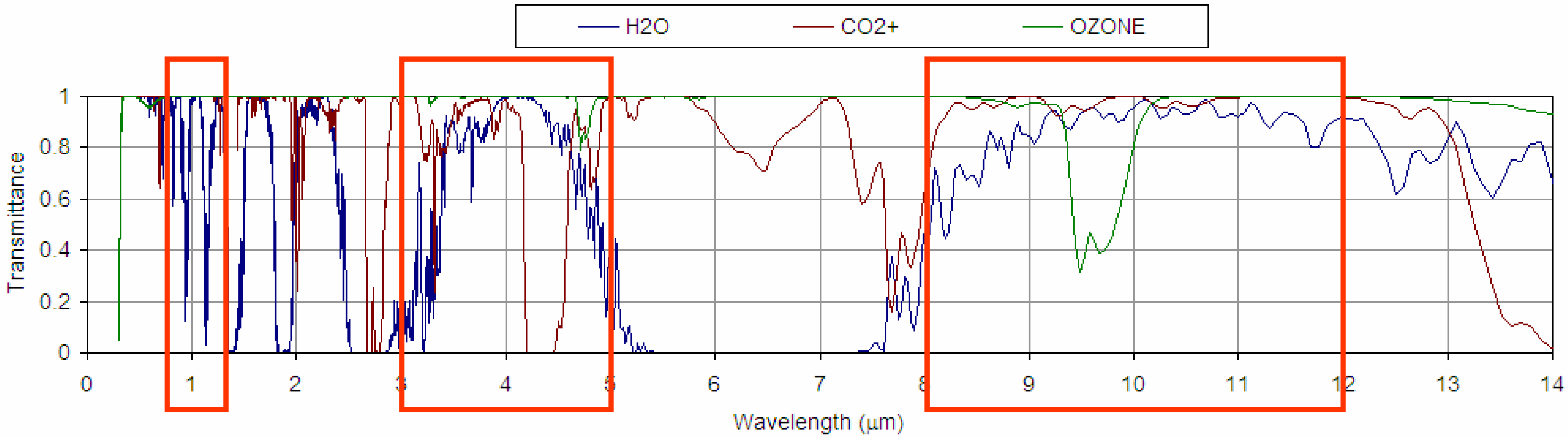
M. Byloos, H. C. Liu, A. Bezinger
and M. Buchanan (NRC – Canada)

Motivation

λ ~ 8 – 12 μm

λ ~ 3 – 5 μm

λ ~ 0.8 – 1.2 μm

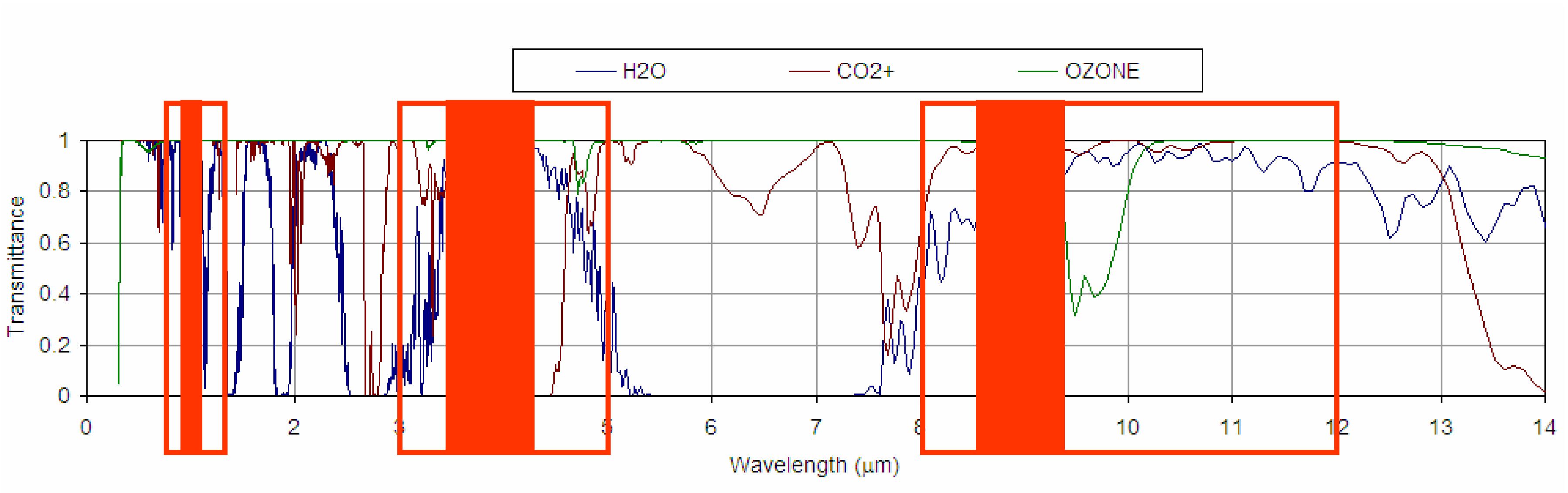


Motivation

LWIR - $\Delta\lambda \sim 1\ \mu m$

MWIR - $\Delta\lambda \sim 1\ \mu m$

NIR - $\Delta\lambda \sim 0.1\ \mu m$



Purpose

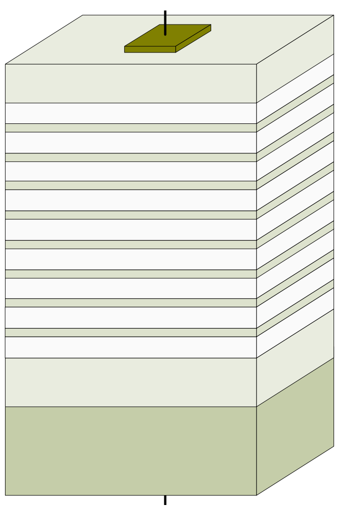
To investigate the feasibility of a *QWIP capable to detect* ***simultaneously*** *3 different IR bands within the wavelengths intervals of 0.8 - 1.2 μm, 3.0 - 5.0 μm and 8.0 - 12.0 μm*.

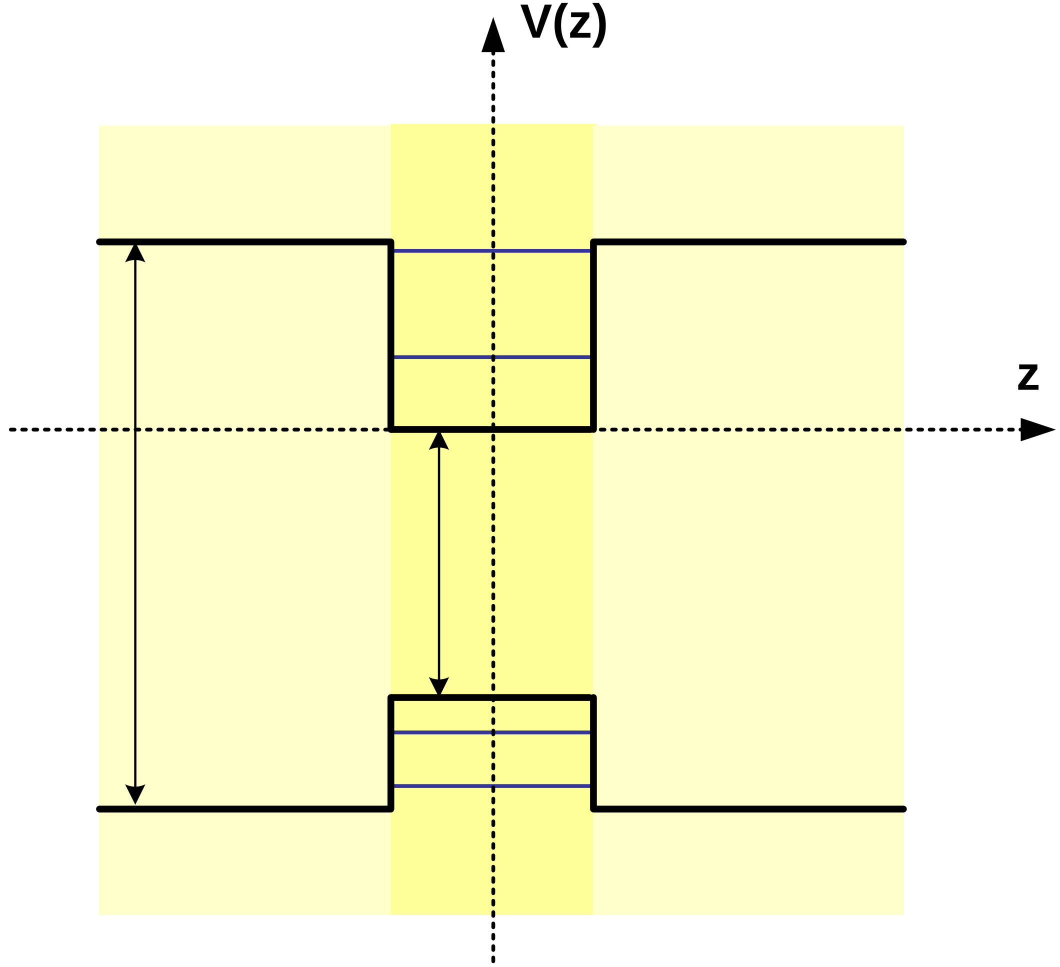
Outline

- QWIP Design
- Experimental Results
- Future work

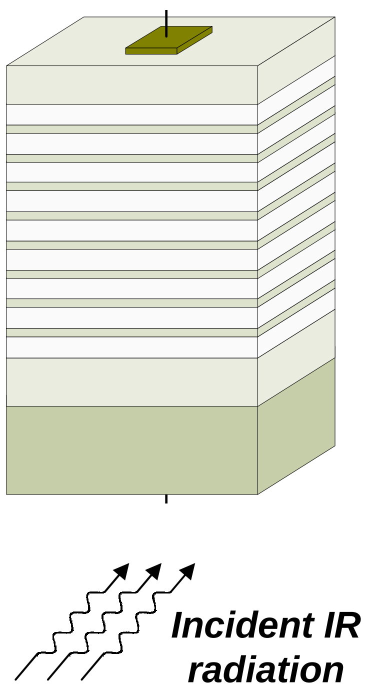
Design and Modeling Considerations

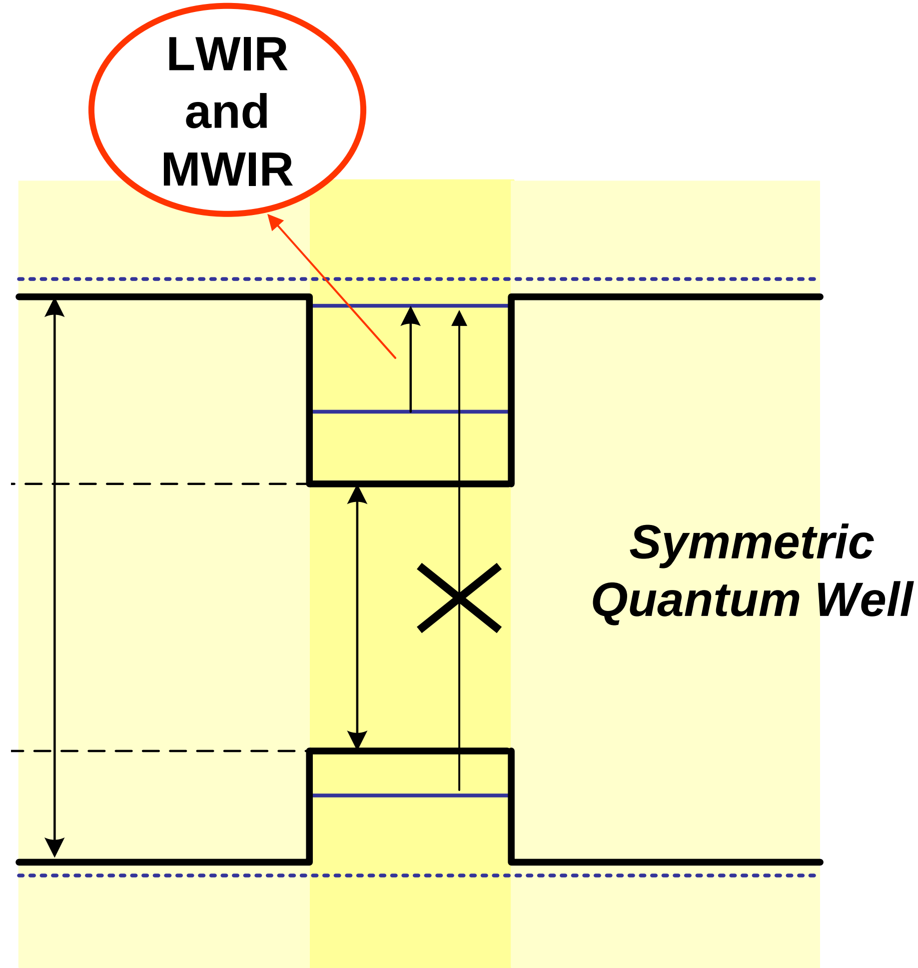
Quantum Wells



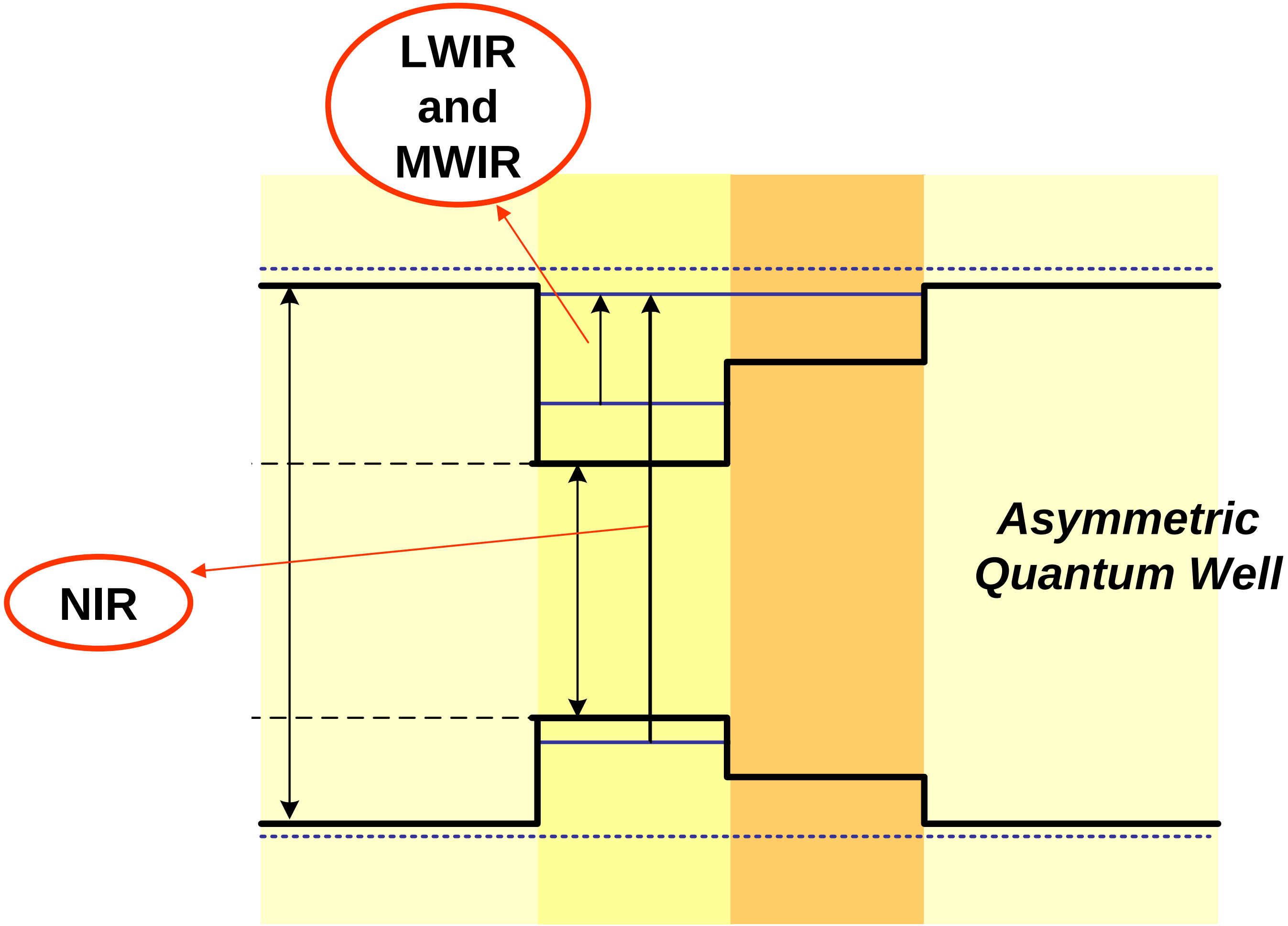


MWIR and LWIR



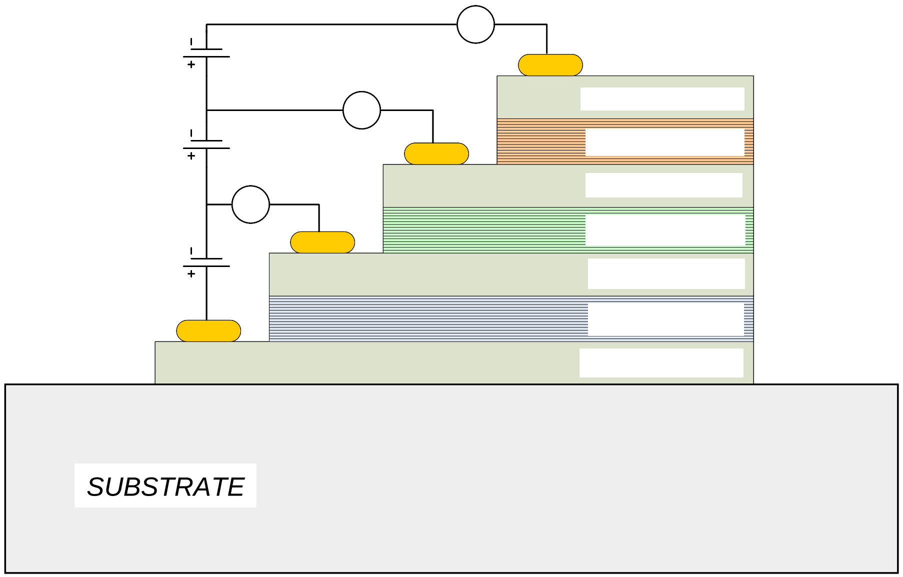


Semiconductor Heterostructure

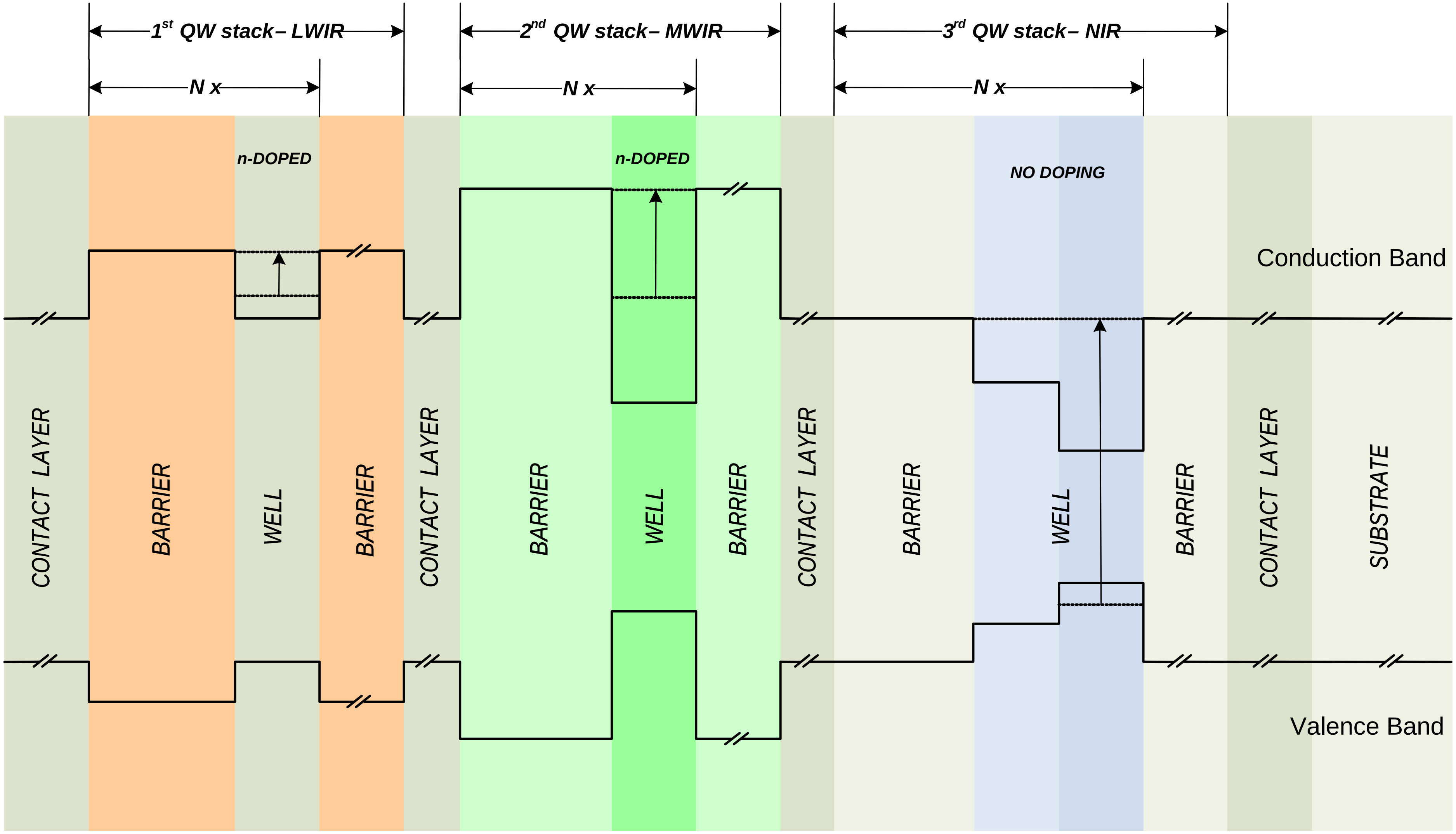


Semiconductor Heterostructure

To have the capability to detect simultaneously three different IR bands, with independent readouts, we employed a configuration with three different stacks of quantum wells formed by alloys of GaAs, AlGaAs and InGaAs, separated by heavily doped GaAs contact layers.



Design and Modeling Considerations



Design and Modeling Considerations

The barriers were made large to have uncoupled quantum wells in all stacks;

The quantum wells for each stack were computed independently;

The electron wavefunctions in the heterostructure were computed using the effective mass approximation for the one-dimensional potential profile along the growth direction;

The band non-parobolicity effects were considered;

The strain due to the difference in lattice constants between GaAs or AlGaAs and InGaAs crystal layers was not taken into account;

For the valence band, the heavy and light hole bands were represented using average negative effective masses, mhh and mlh, respectively;

One-dimensional time independent Schrödinger's Equation

$$-\frac{\hbar^2}{2}\frac{\partial}{\partial z}\frac{1}{m^*(z)}\frac{\partial}{\partial z}\psi(z)+V(z)\psi(z)=E\psi(z)$$

One-dimensional time independent Schrödinger's Equation

$$-\frac{\hbar^2}{2}\frac{\partial}{\partial z}\frac{1}{m^*(z)}\frac{\partial}{\partial z}\psi(z)+V(z)\psi(z)=E\psi(z)$$

Potential Profile

Poisson equation

$$\nabla^2 V_\rho = -\frac{\rho}{\varepsilon}$$

$$V_b(z) = -qFz$$

External electric field potential

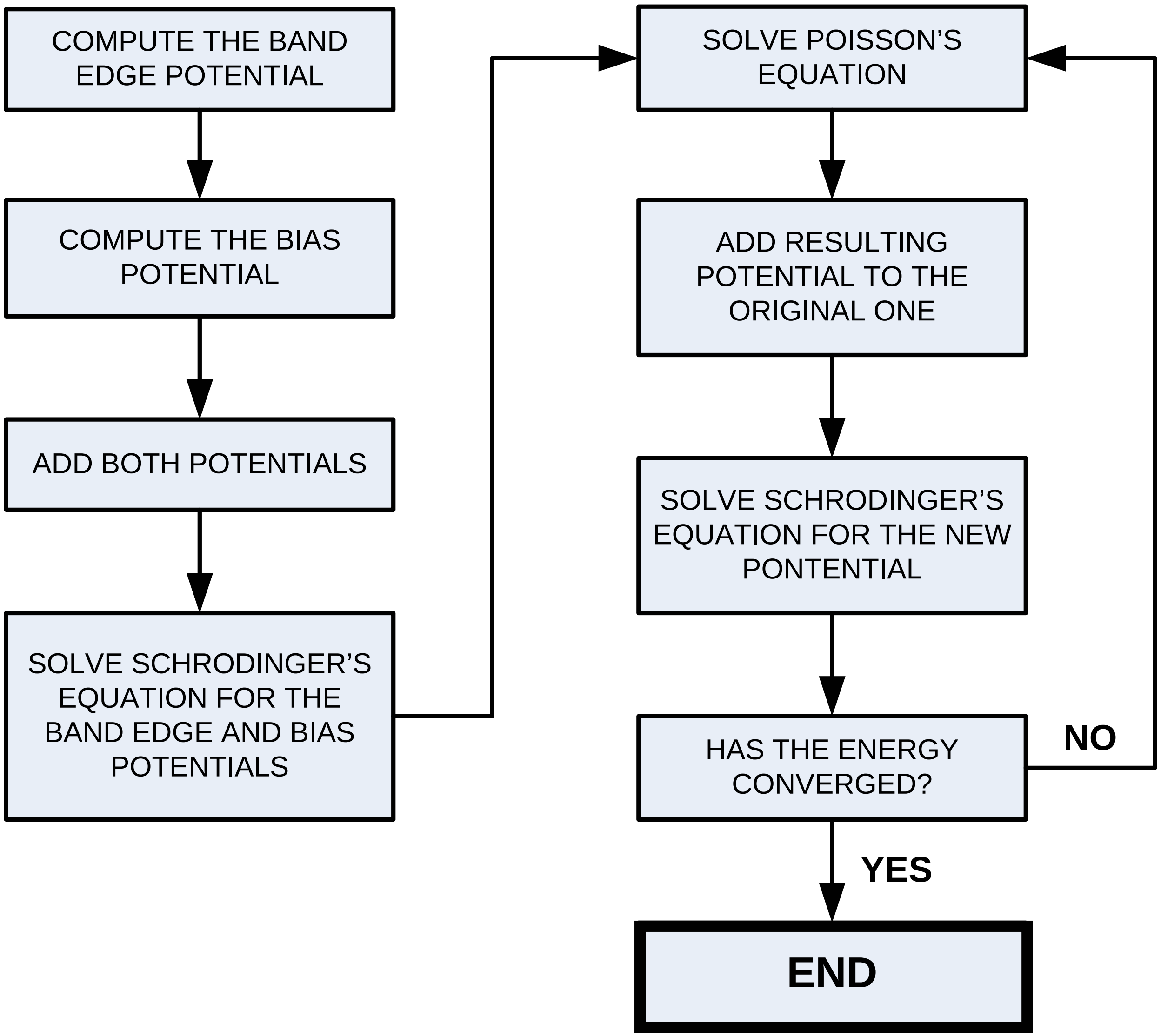
Charge distribution potential

$$V(z) = V_e(z) + V_b(z) + V_\rho(z)$$

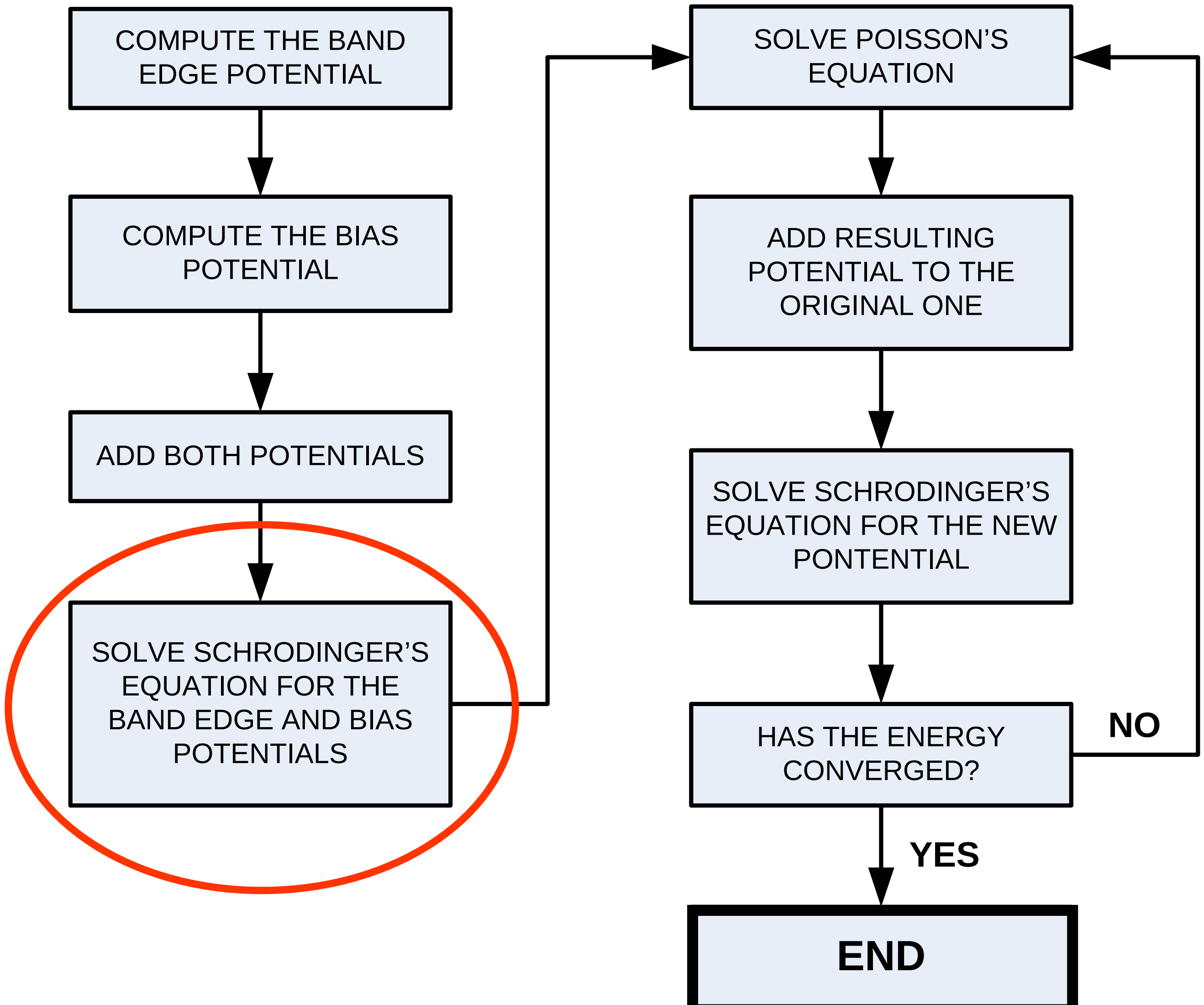
Bandedge potential

$$V_b(z) = (E_{g,n+1} - E_{g,n})\delta_{n,n+1}$$

Self-Consistent Schrödinger-Poisson Solution



Self-Consistent Schrödinger-Poisson Solution



Shooting Method

$$\frac{\psi(z+\delta z)}{m^*(z+\delta z/2)} = \left\{\frac{2(\delta z)^2}{\hbar^2}[V(z)-E] + \frac{1}{m^*(z+\delta z/2)} + \frac{1}{m^*(z-\delta z/2)}\right\}\psi(z) - \frac{\psi(z-\delta z)}{m^*(z-\delta z/2)}$$

- Knowing two values of the wavefunction, $\psi(z-\delta z)$, $\psi(z)$
- The third point can be predicted → $\psi(z+\delta z)$

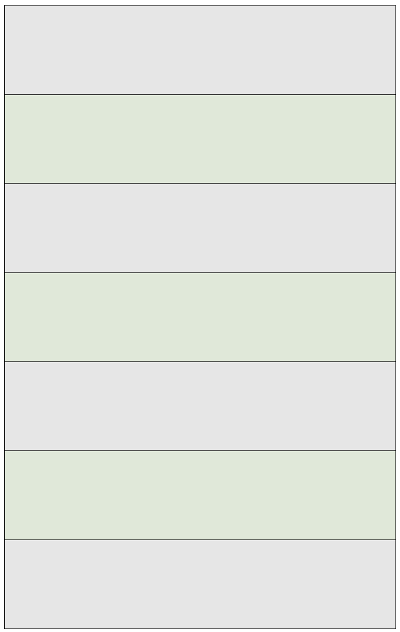
Using the new point together with its predecessor, a fourth point can be calculated and so on. Hence the wavefunction can be deduced for any particular energy value.

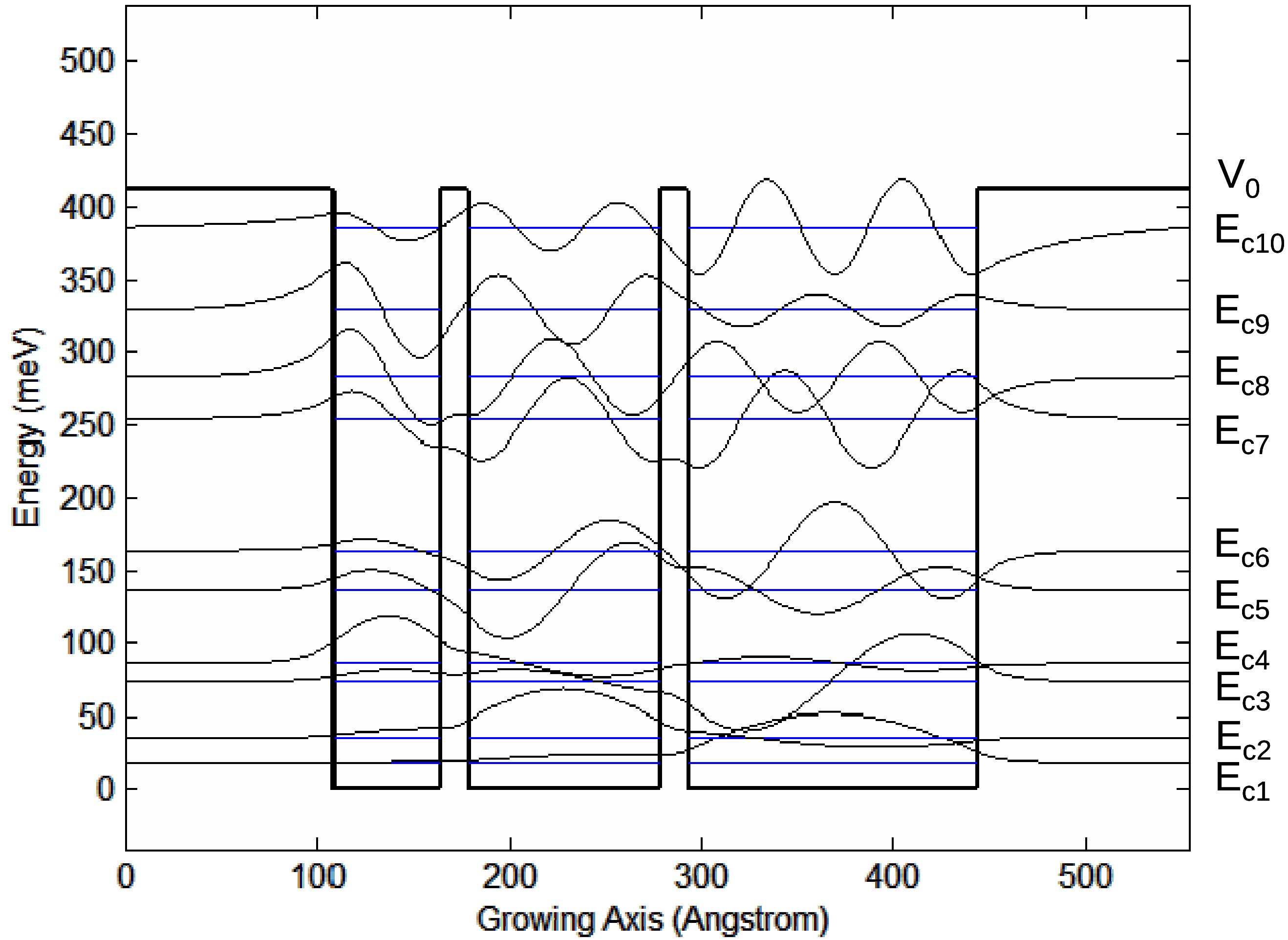
P. Harrison, *Quantum Wells, Wires and Dots: Theoretical and Computational Physics*, John Wiley & Sons Inc., New York, 2001.

- Multiple layer structures
- Handle arbitrary potential profiles
- Efficient to compute biased structures
- Suitable to be used in self-consistent solutions

- Convergence problems with wide barriers
- Computationally expensive

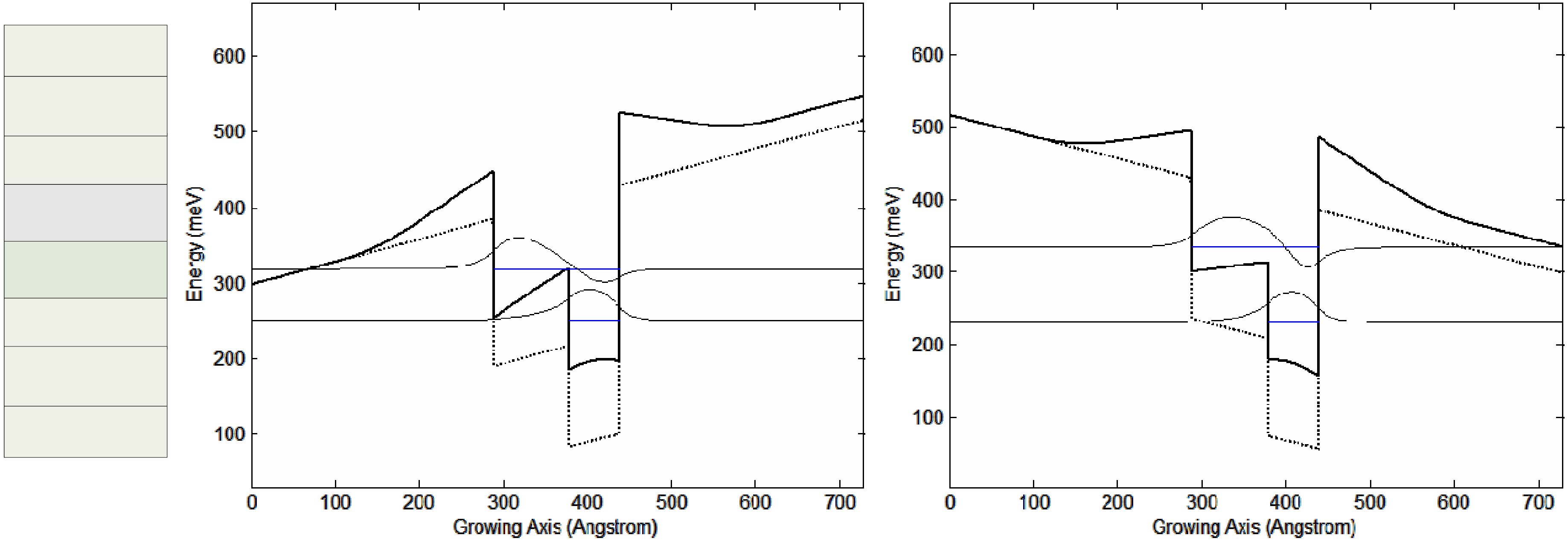
Shooting Method





Clayton L. Workman, "Intersubband Transitions in Strained InGaAs Quantum Well for Multi-color Infrared Detector Applications," PhD Thesis, University of Arkansas, 2000.

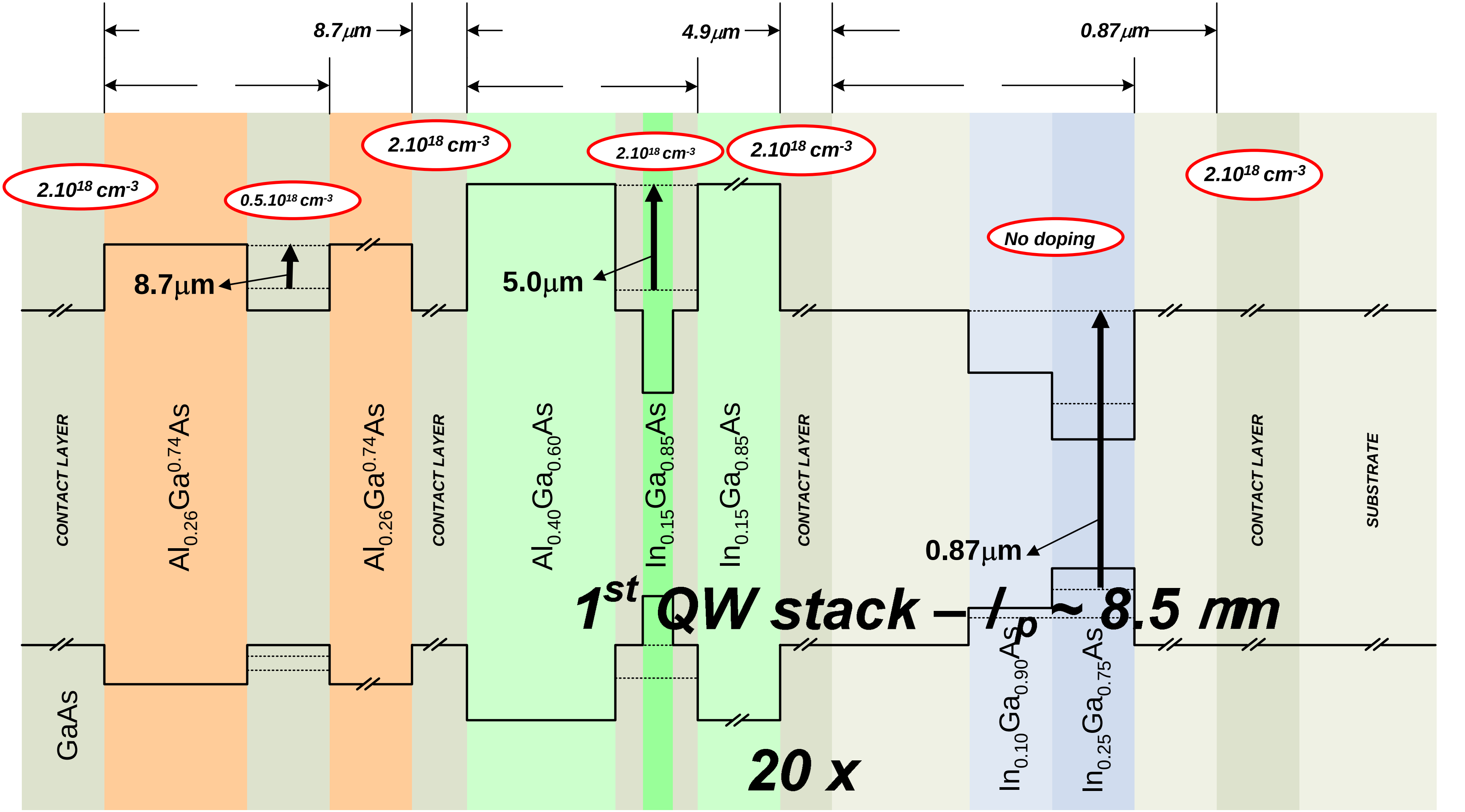
Self-Consistent Schrödinger-Poisson Solution



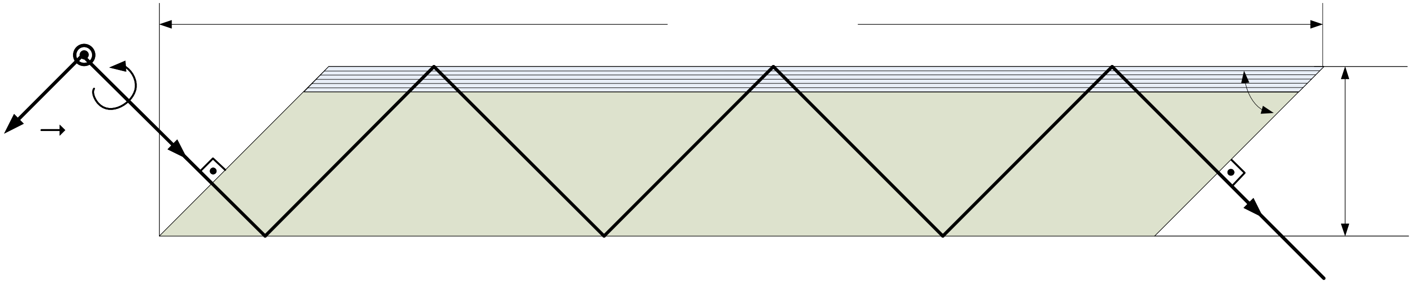
F.Y. Huang et al, *Appl. Phys. Lett.*, 63, 1669(1993)

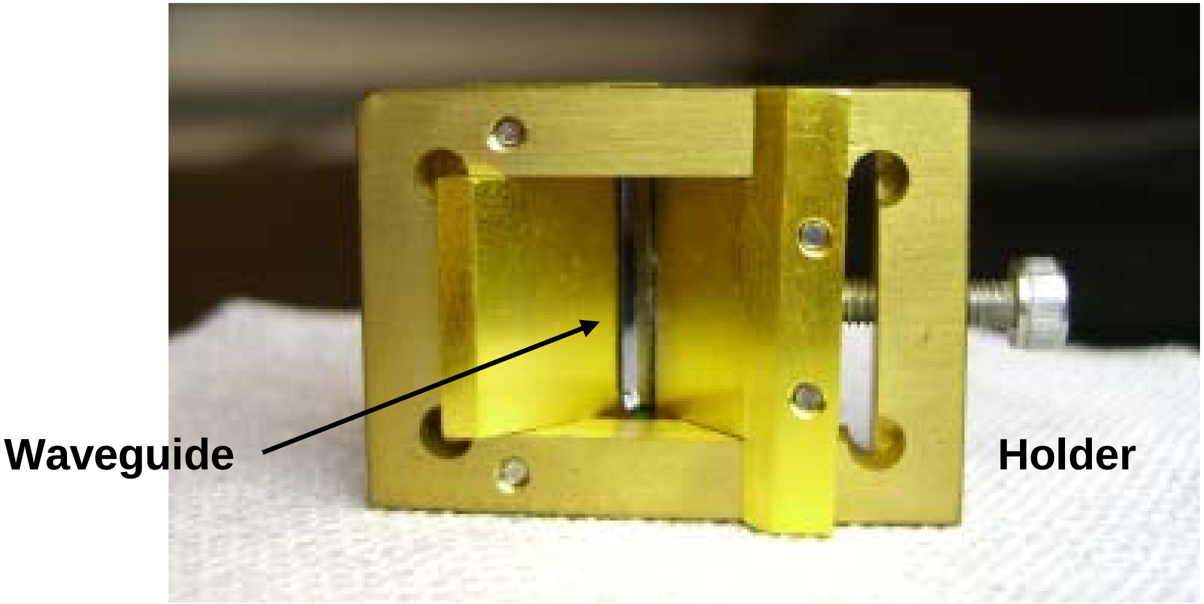
Wafer Structure

Strained InGaAs/GaAs/AlGaAs

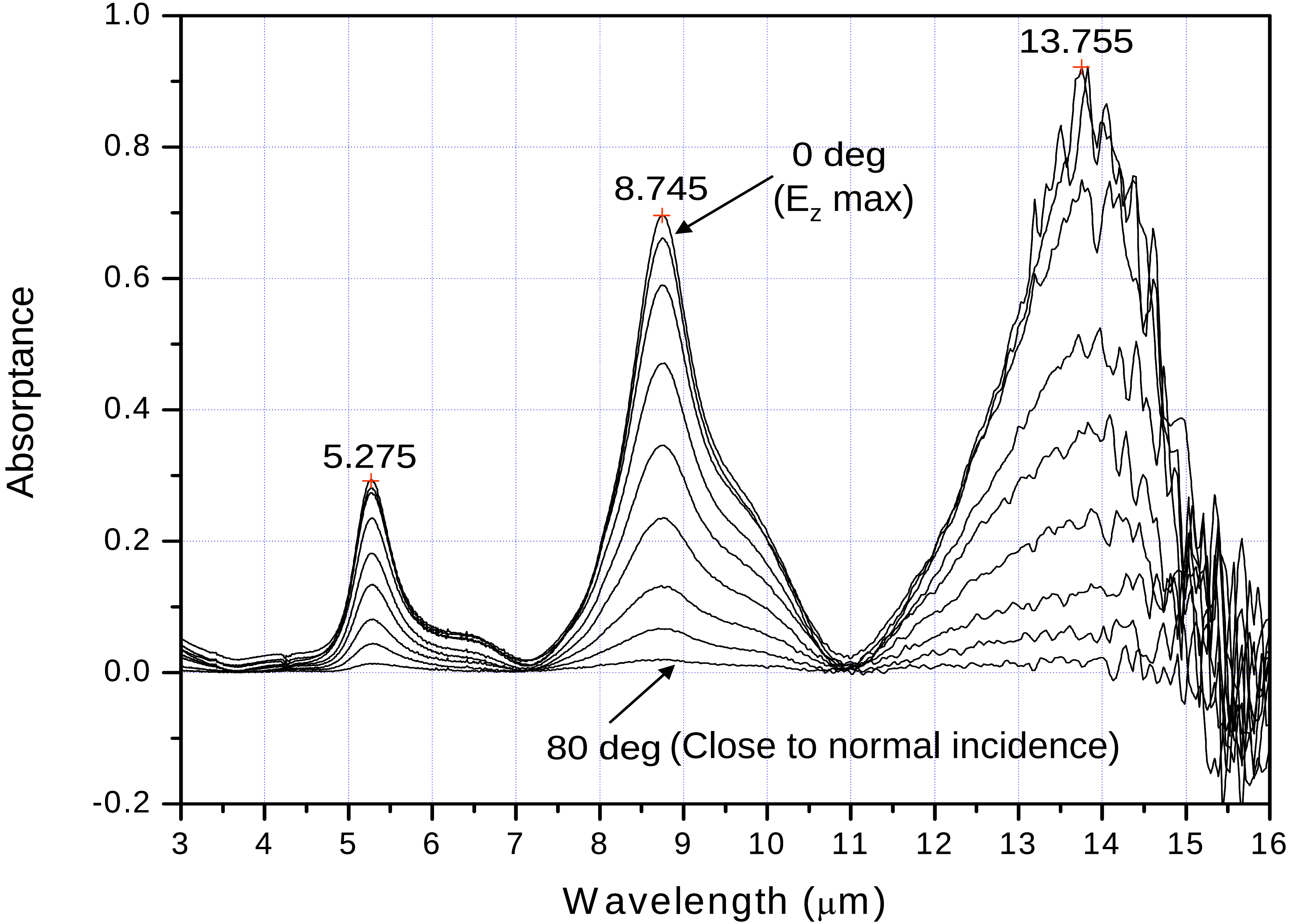


Experimental Results

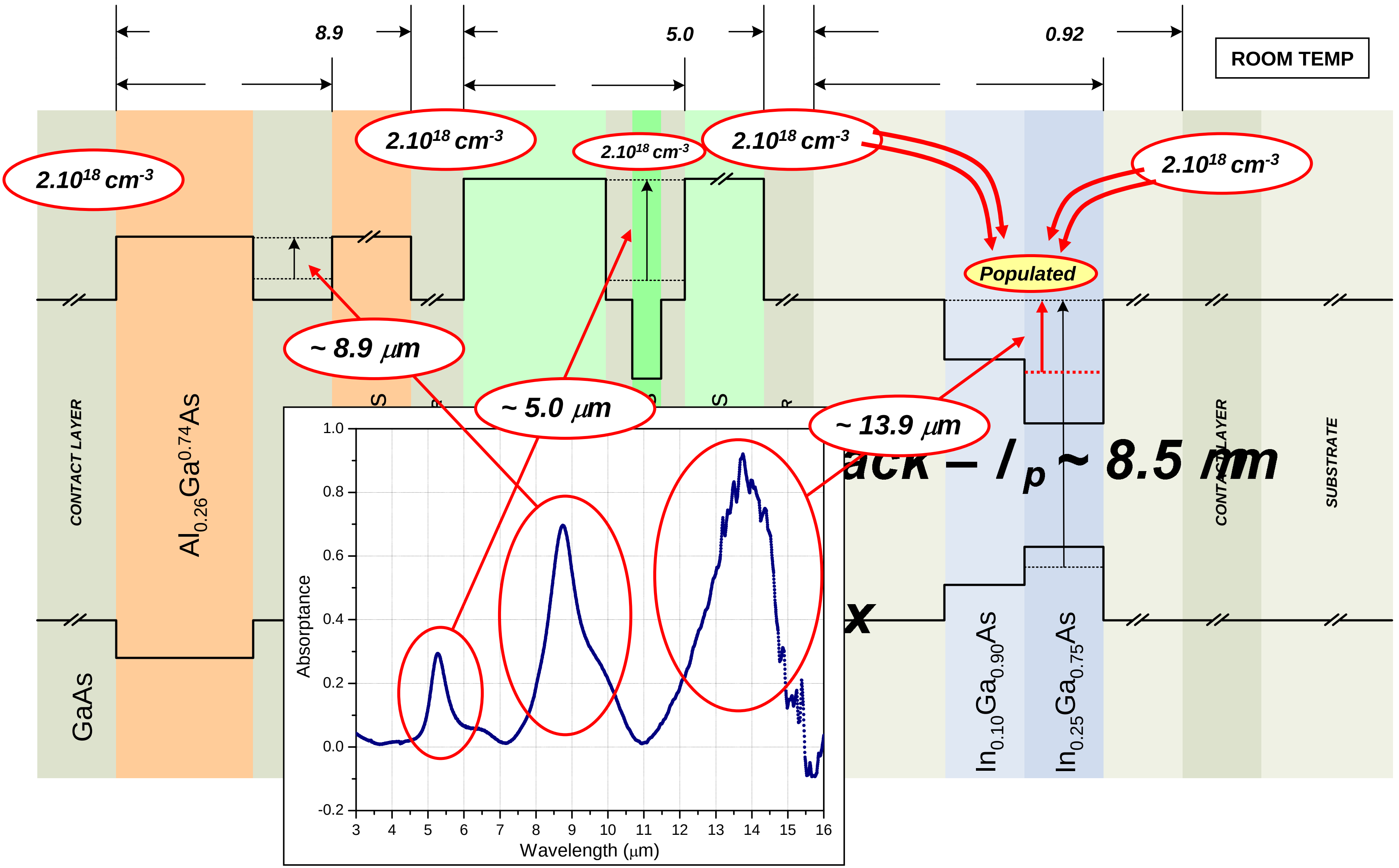


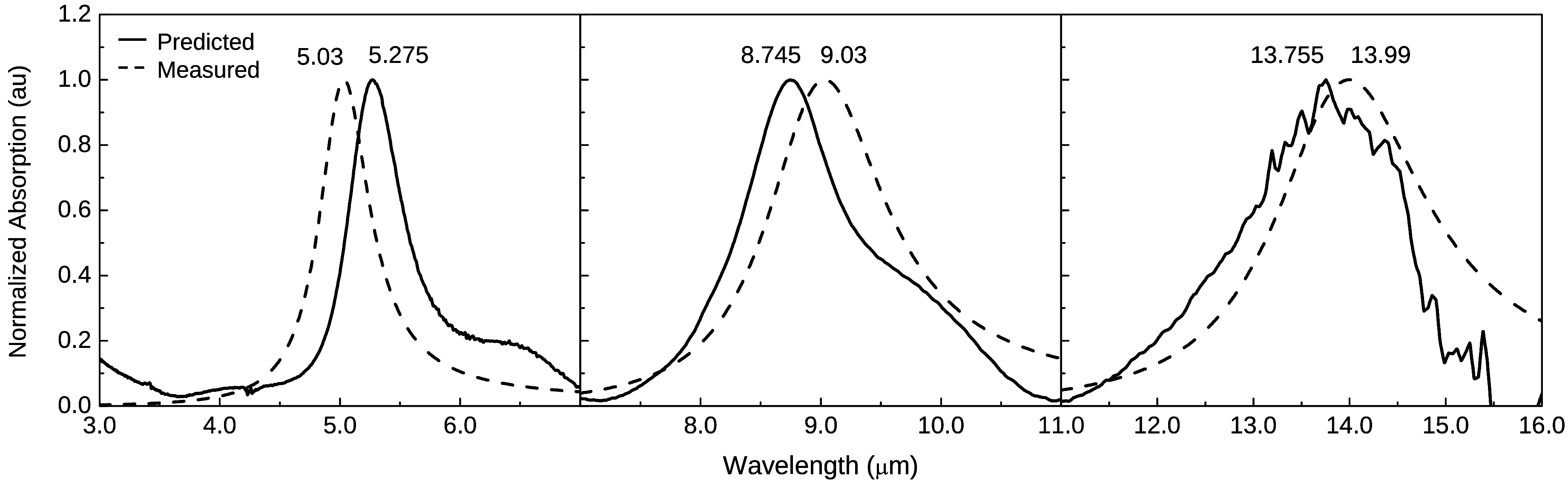


Waveguide configuration


13.755
8.745
0 deg
(E$_z$ max)
5.275
80 deg (Close to normal incidence)
Absorptance
Wavelength (μm)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

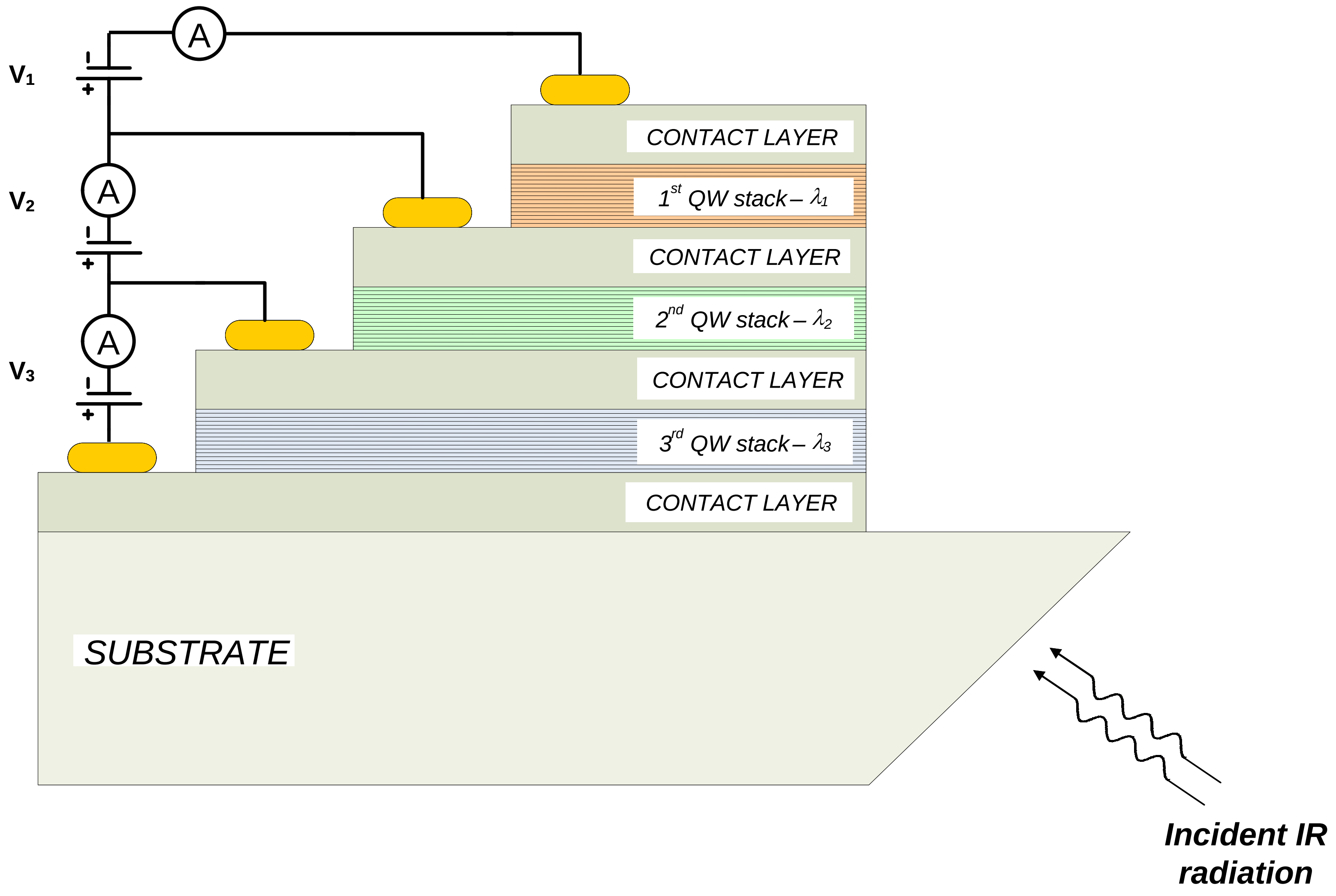
Experimental Results *Intersubband Absorption Measurements*

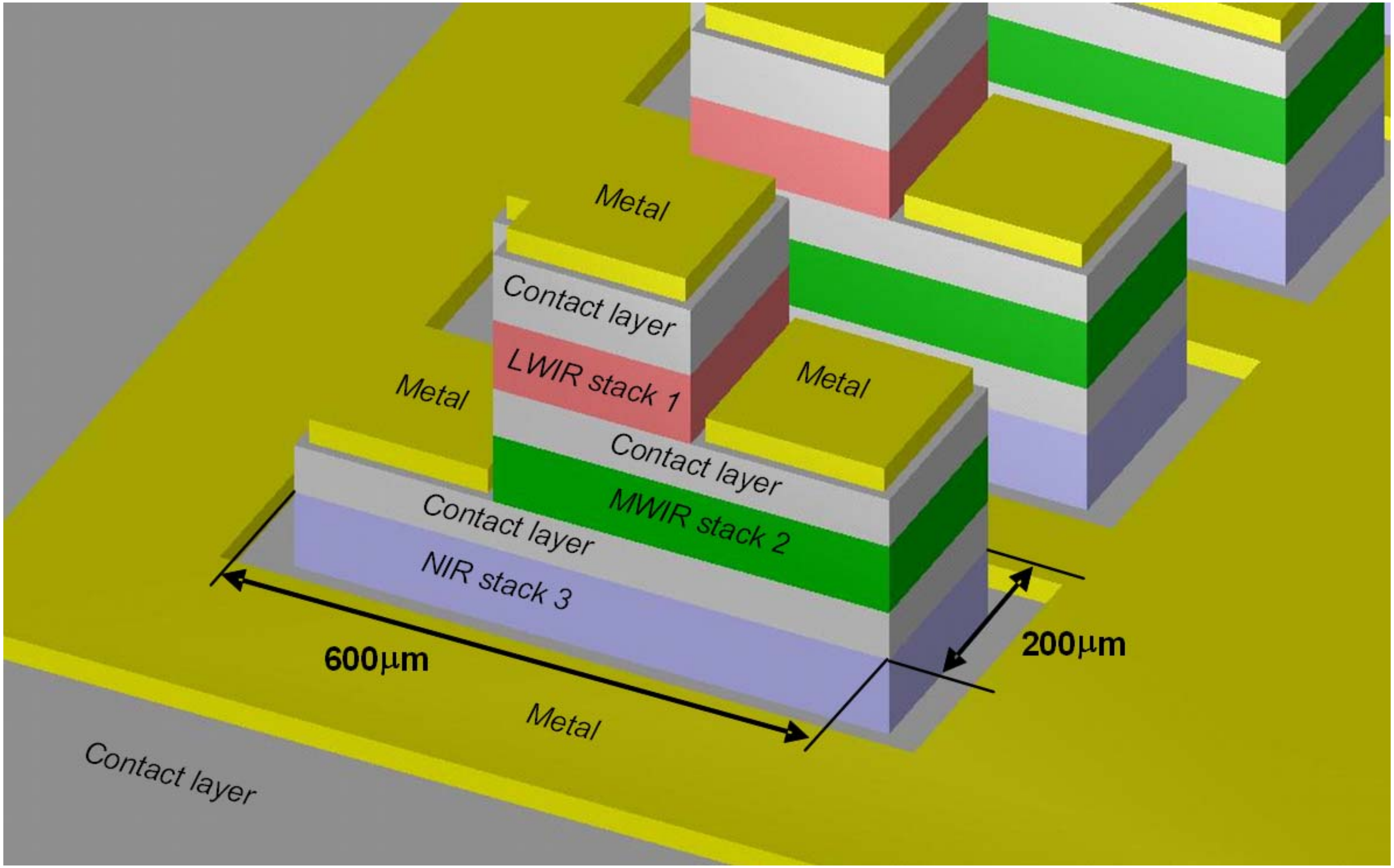




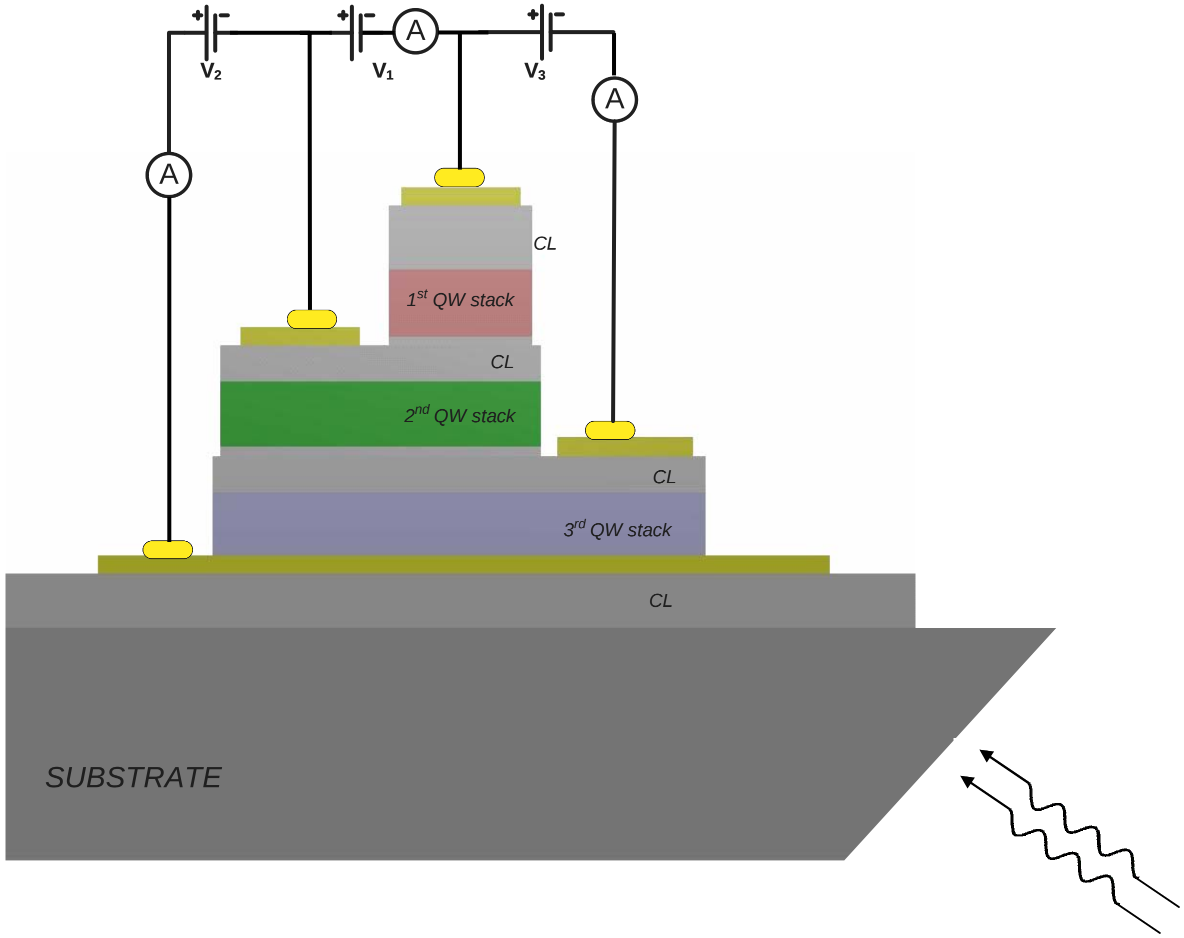
Predicted
Measured
5.03
5.275
8.745
9.03
13.755
13.99
Normalized Absorption (au)
Wavelength (μm)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
3.0
4.0
5.0
6.0
8.0
9.0
10.0
11.0
12.0
13.0
14.0
15.0
16.0

Devices Configuration

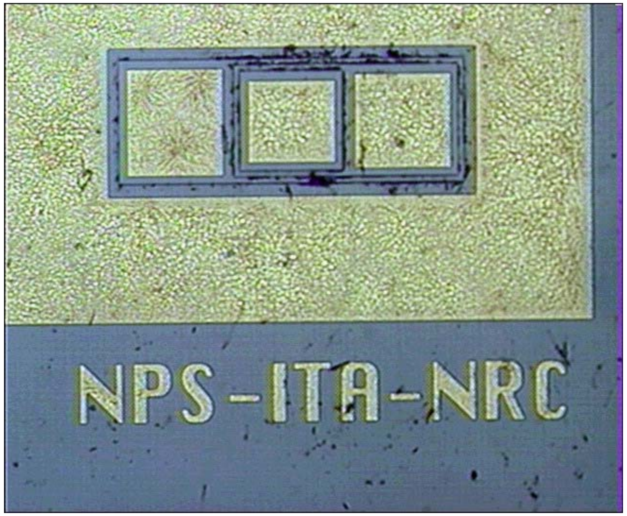


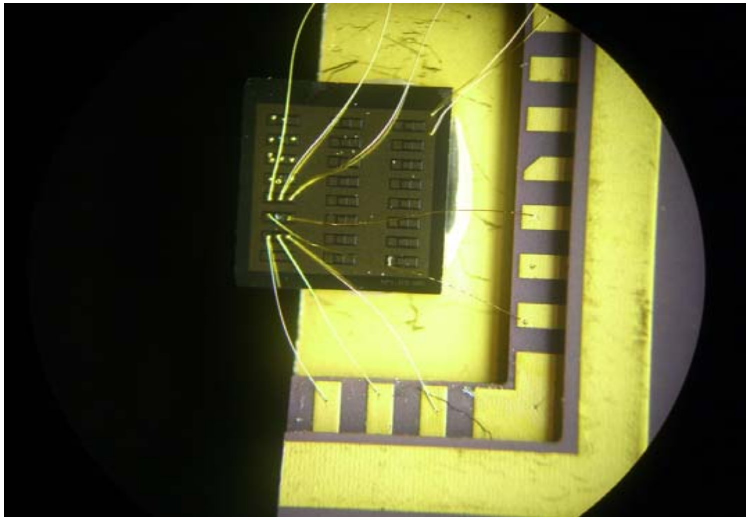


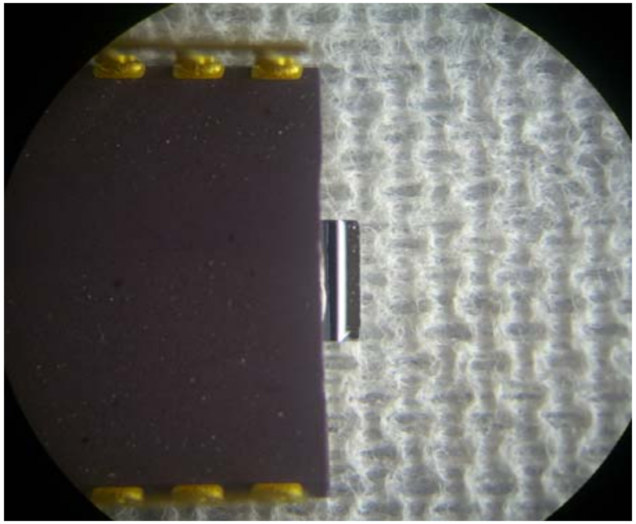
Metal
Contact layer
LWIR stack 1
Metal
Metal
Contact layer
MWIR stack 2
Contact layer
NIR stack 3
600µm
200µm
Metal
Contact layer

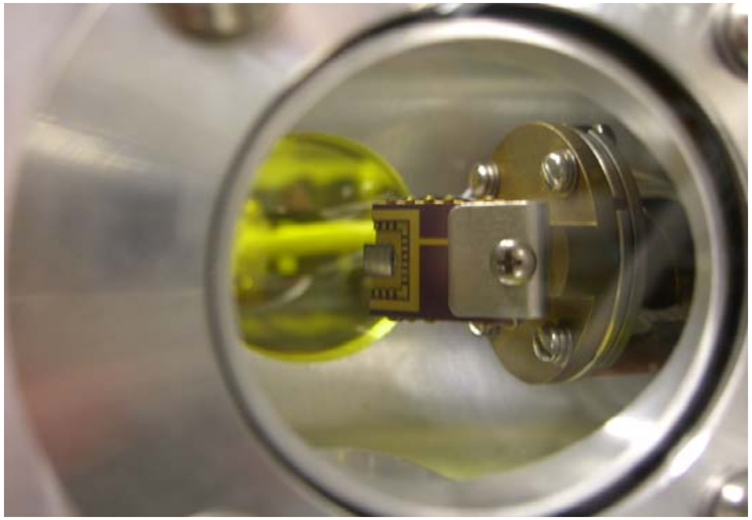


V2
V1
V3
A
A
A
CL
1st QW stack
CL
2nd QW stack
CL
3rd QW stack
CL
SUBSTRATE


NPS-ITA-NRC

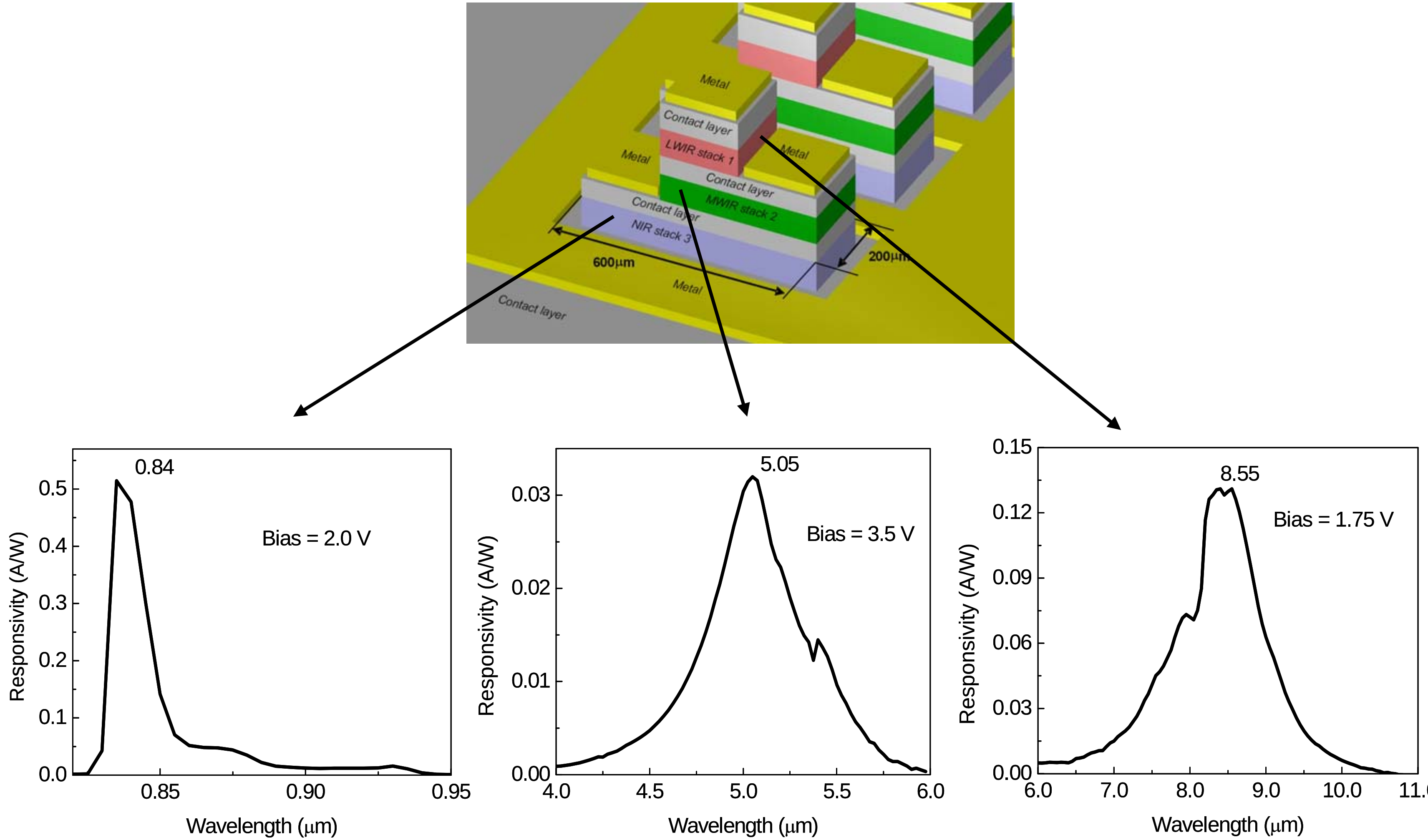


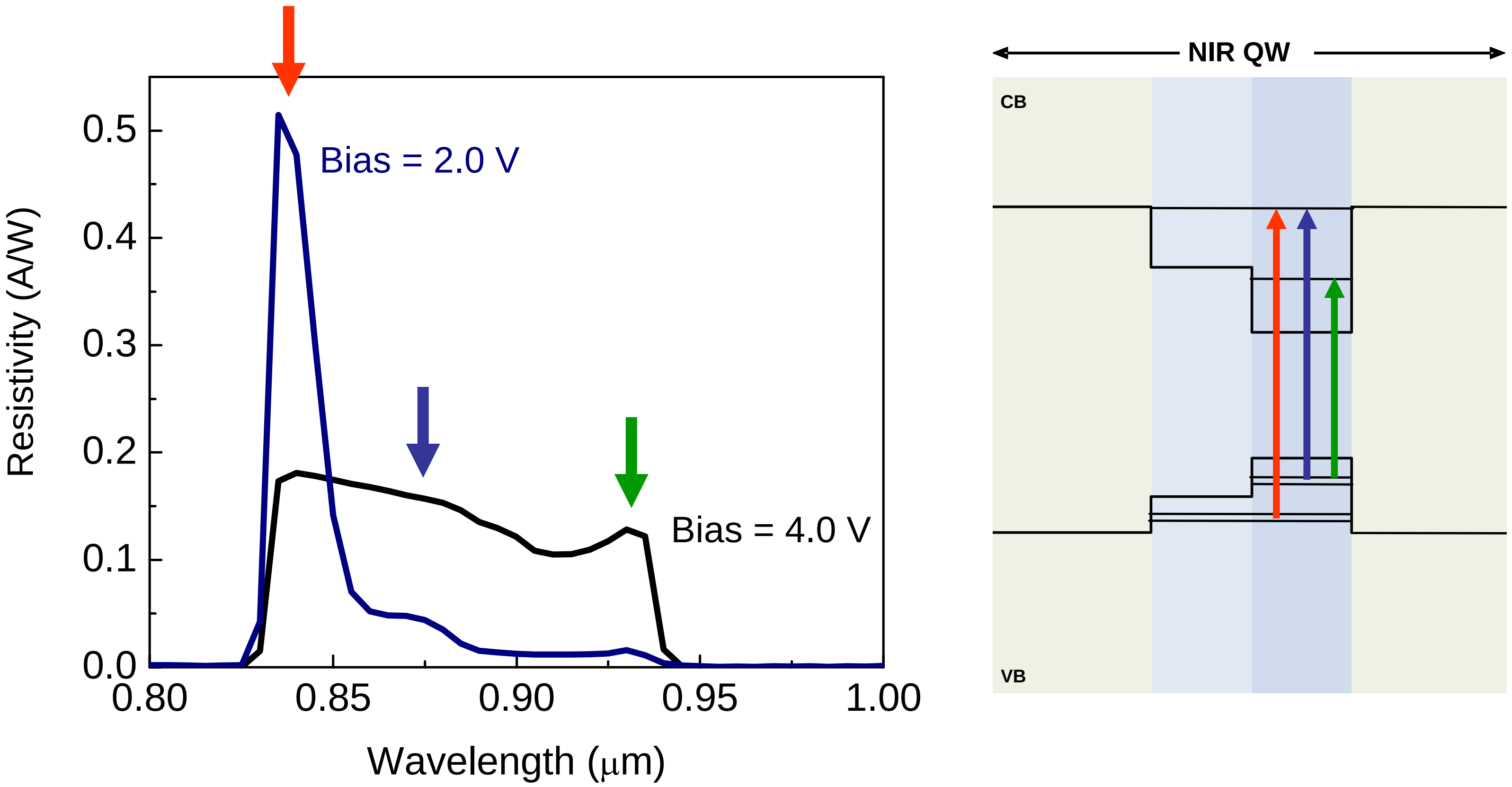




Experimental Results

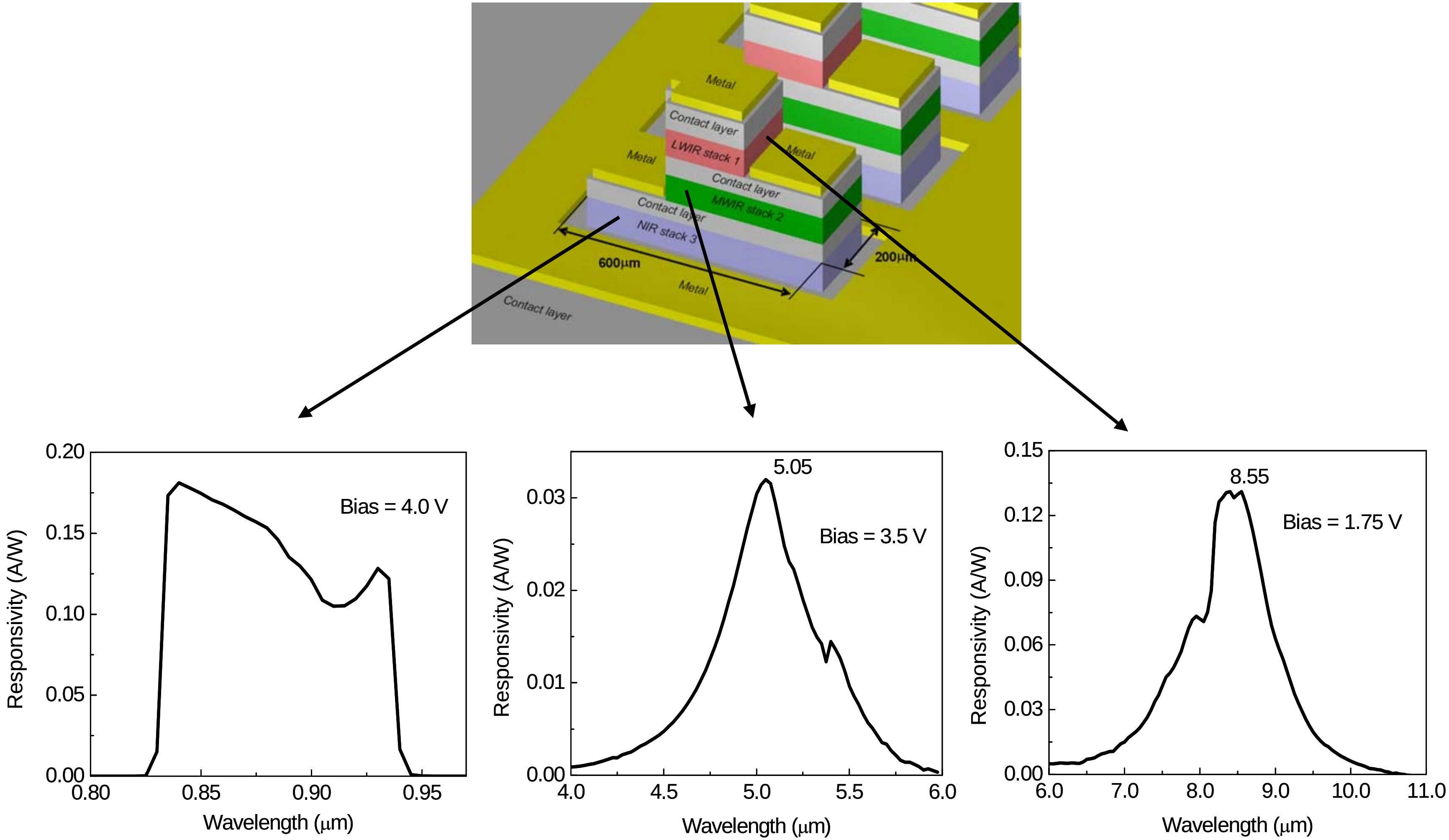
Responsivity Measurements





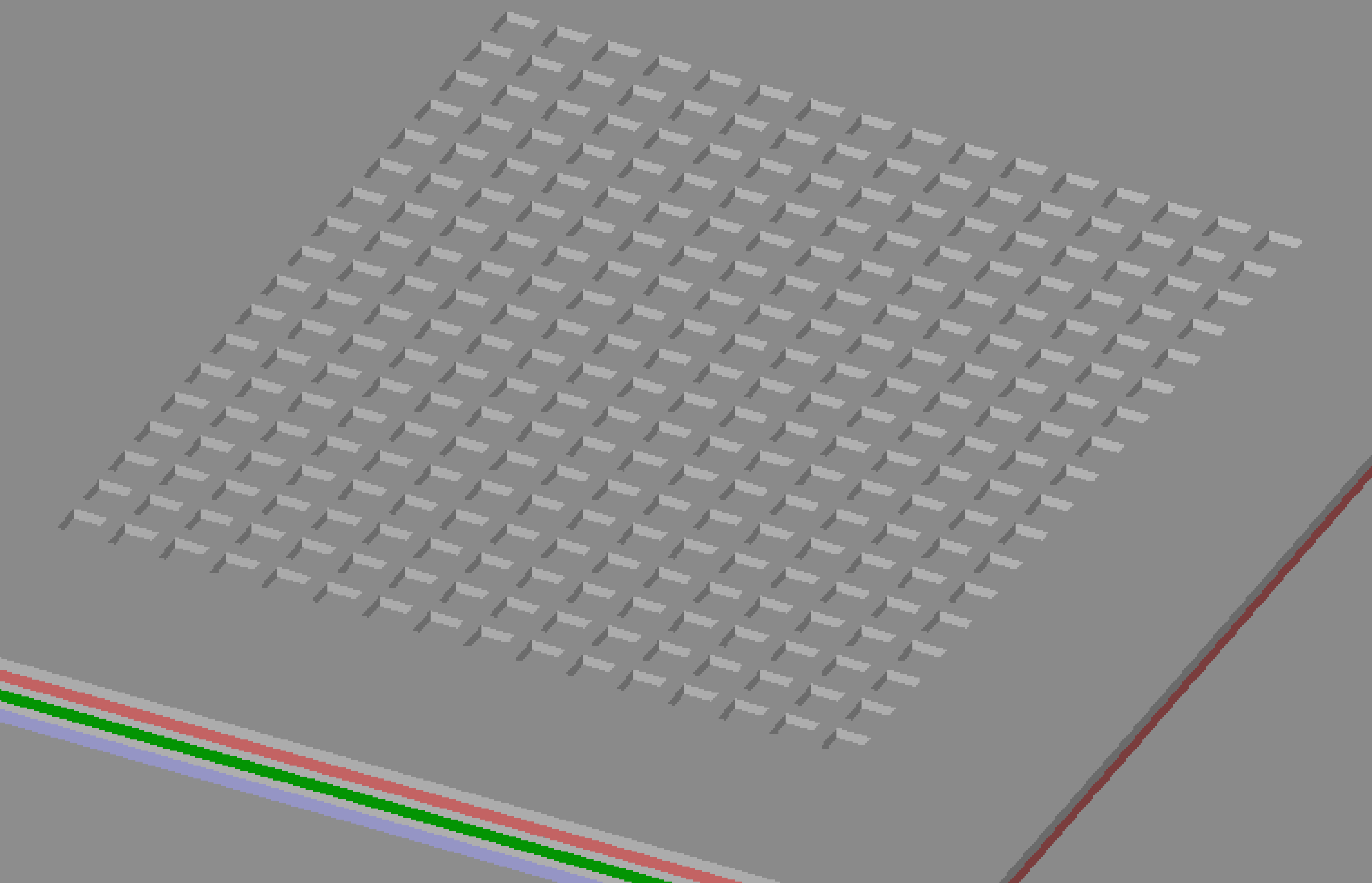
Resistivity (A/W)
0.0
0.1
0.2
0.3
0.4
0.5
0.80
0.85
0.90
0.95
1.00
Wavelength (μm)
Bias = 2.0 V
Bias = 4.0 V
NIR QW
CB
VB

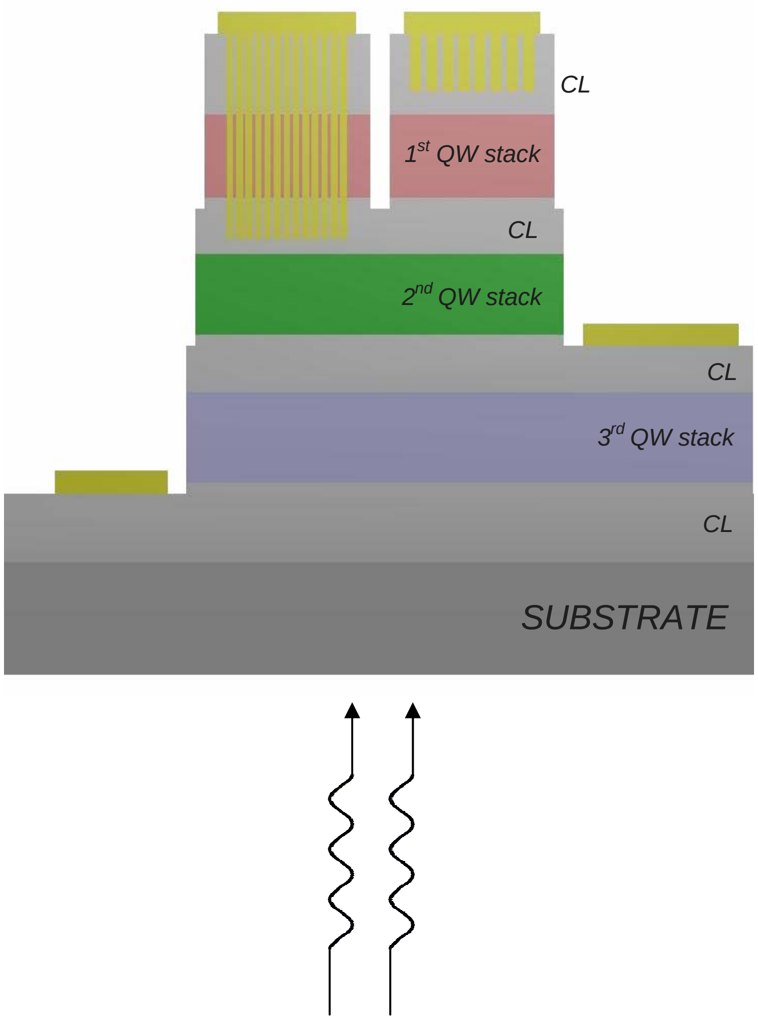
Responsivity Measurements



Future Work

Optical Coupling





Normal incidence detector

Summary

A near-, mid- and long-infrared photodetector with separate readouts was fabricated using interband and intersubband transitions in a quantum well structure.

The measured absorption and photocurrent data show a good agreement with the simplified model develop for the design of the quantum well structure.

The photocurrent spectroscopy measurements demonstrate the possibility of detection of widely separated wavelength bands using interband and intersubband transitions in quantum wells.

Finally, this approach presents a great potentiality in designing detectors to sense specific emission signatures.

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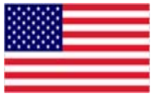

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