Near-Infrared Spectroscopy of Nitride Heterostructures

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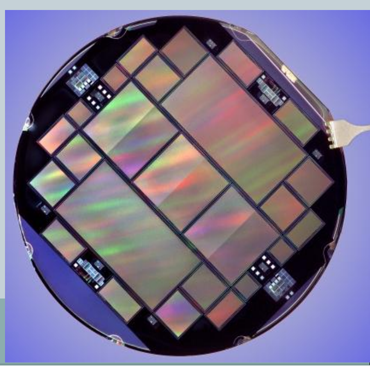
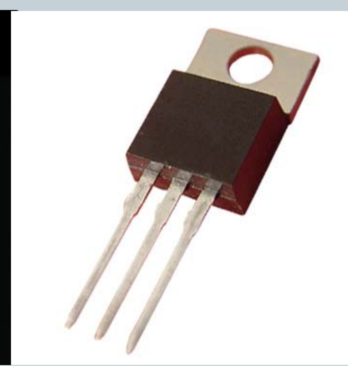
Introduction

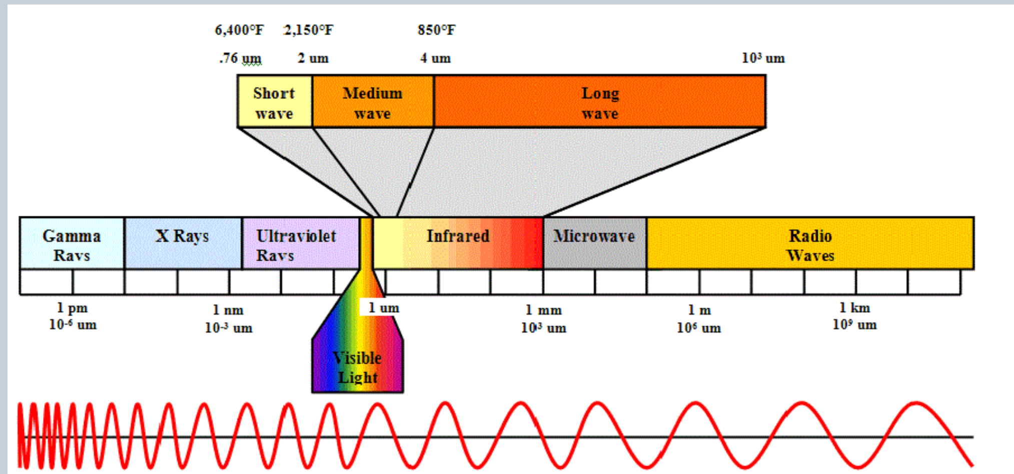
- Experimental Condensed Matter Research
  - Study of large groups of strongly interacting particles such as solids, liquids, plasmas, crystals, superfluids, superconductors
- Optoelectronics
  - Study of the properties of light and its interactions with matter, with emphasis on the development of light sources and detectors
  - Devices: transistors, photodiodes, solar cells, light emitted diodes (LEDs), optical modulators, charge-coupled devices (CCDs), lasers






Goals and Motivation

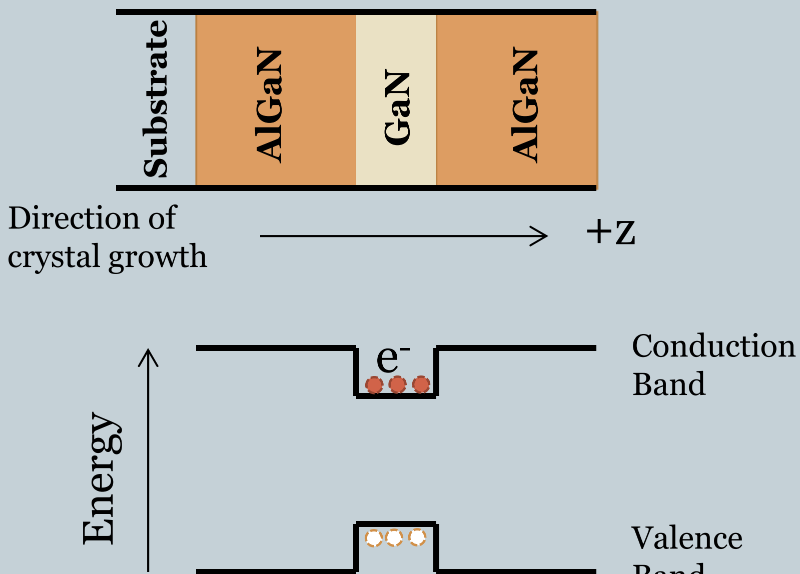
- Compact and efficient light sources in the infrared range
  - Near IR: 0.76 – 1.5 μm
  - Mid IR: 1.5 – 4.0 μm
  - Far IR: 4.0μm – 1mm



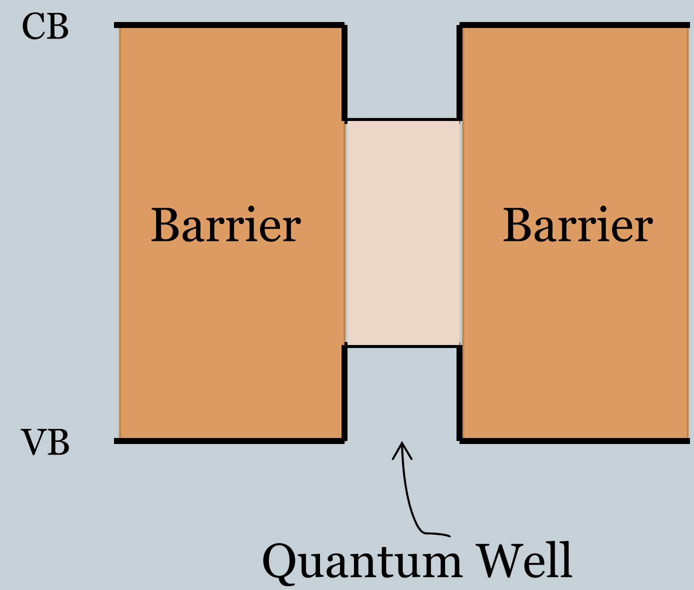
- Longer wavelength = lower energy, so creating light sources is more difficult to achieve than in the visible light range
- My role: Near-infrared absorption measurements of Gallium Nitride samples with various doping characteristics

Semiconductor Quantum Wells

Single Quantum Well

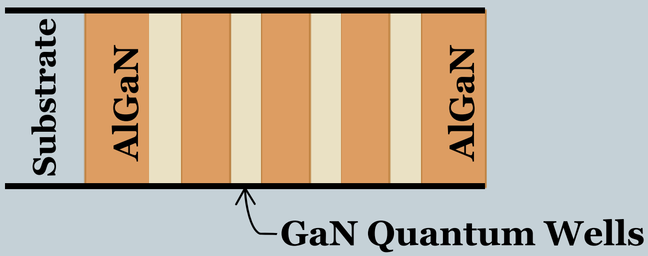


Terminology



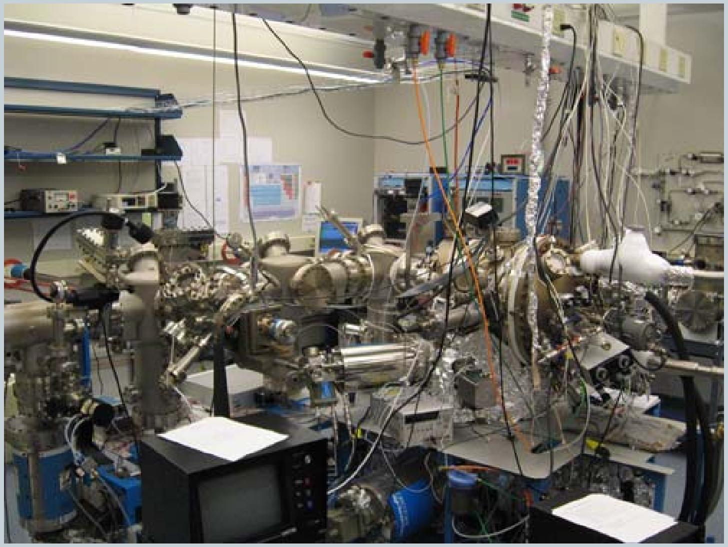
Semiconductor Quantum Wells

Superlattice



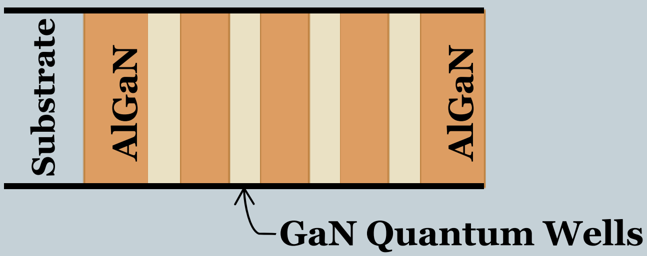
- Size of quantum well determines the energy levels
- Grown by Molecular Beam Epitaxy (MBE) at Birck Nanotechnology Center

Heterostructure Growth



Semiconductor Quantum Wells

Superlattice



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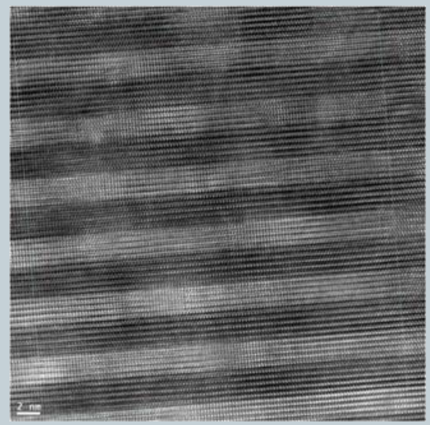
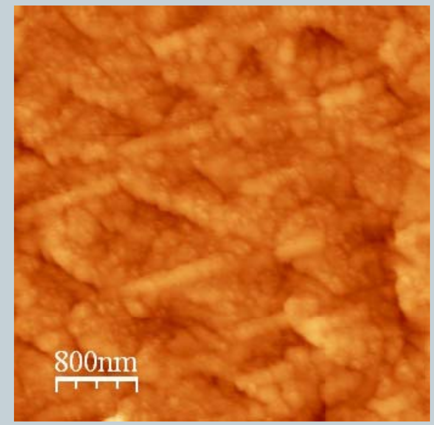
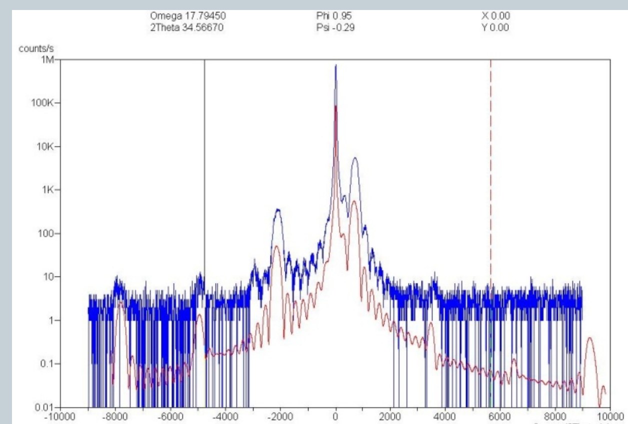
Heterostructure Growth

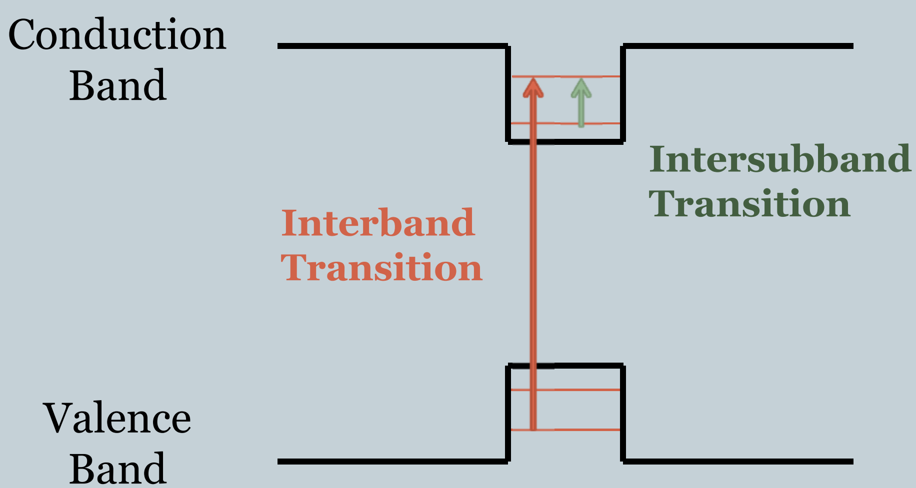






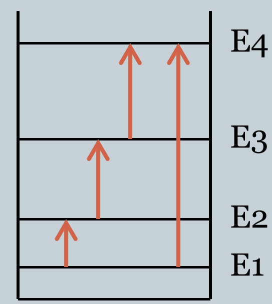
Intersubband Transitions

- Excitations between the levels (or 'subbands') within the quantum wells in the conduction or valence band



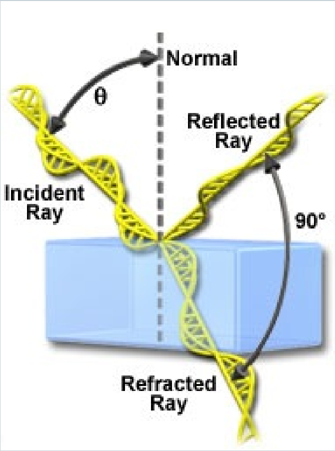
•Intersubband transitions occur at lower energies than interband transitions

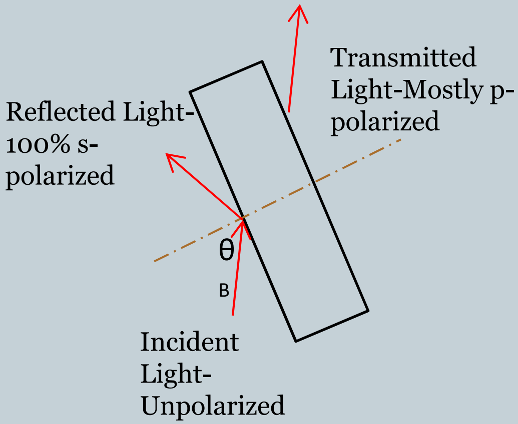
•Levels are quantized and energies are determined by the quantum well depth and thickness

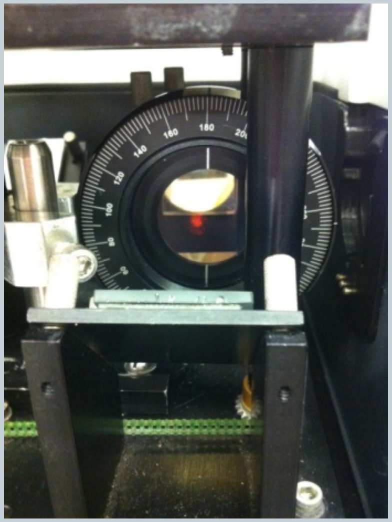


Polarization

- P-polarization: parallel to the plane of incidence
- S-polarization: perpendicular to the plane of incidence
- Selection Rule: there must be a component of the electric field that is perpendicular to the quantum well layers (z-component)
- P-polarization couples with the intersubband transition, since p contains a z-component; s-polarization does not couple
- Brewster's Angle: reflected light is 100% polarized







Quantum Cascade Laser

- Uses quantum confinement to create the necessary population inversion
- Benefits: Ability to be tuned, portability, operation in the terahertz range, higher power than traditional semiconductor lasers
- First demonstrated with Gallium Arsenides
- Conduction band gap makes Gallium Nitrides possible candidates
- Applications: Pollution monitoring, military operations, medical diagnostics

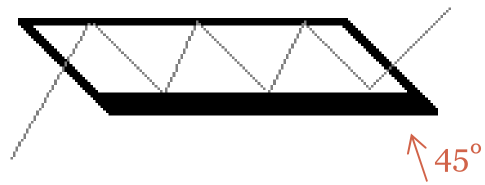
Experimental Process

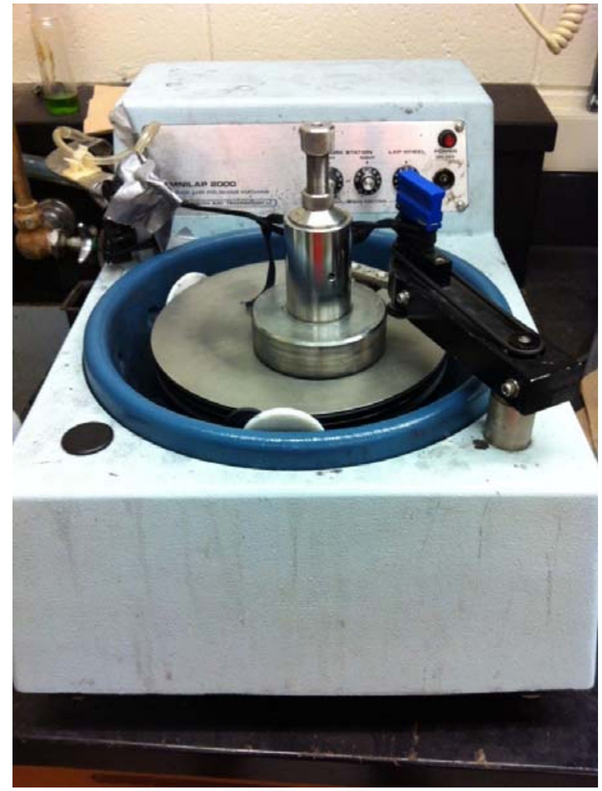
•Single Pass and Multipass Direct Absorption Measurements

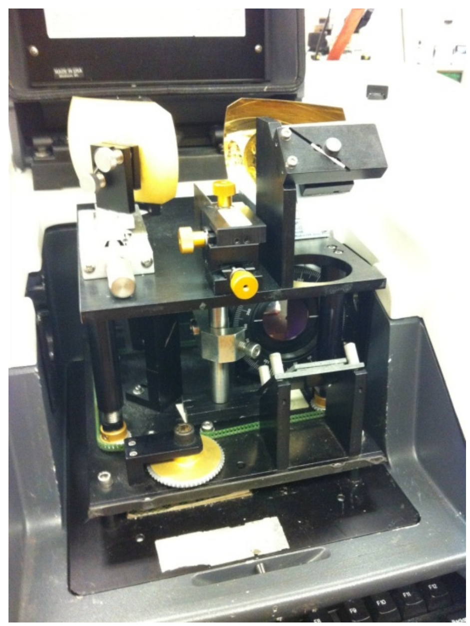
•Polish samples into a multipass waveguide; allows for more interaction with active region

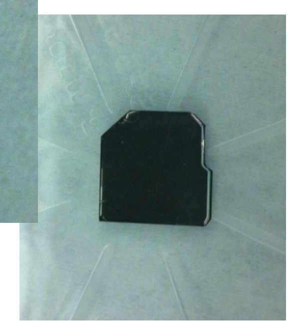
•Create multipass double waveguide to remove boundary conditions

•Align sample in beam condenser









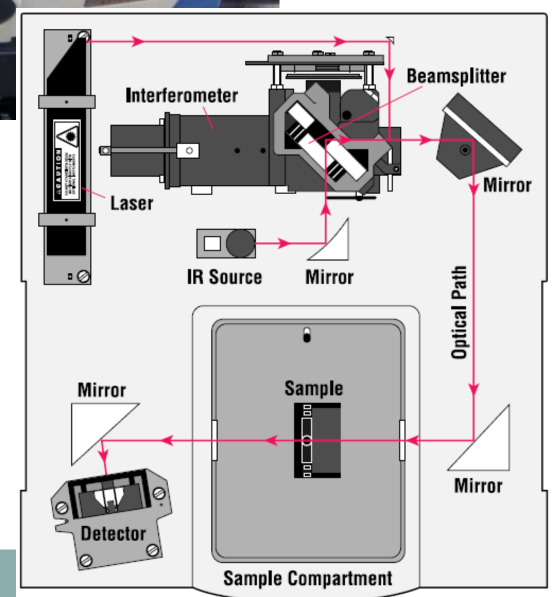
FTIR Spectrometer

- Fourier Transform Infrared
- Type of Michelson Interferometer
- Absorption Measurements from 10,000 - 2,000 wavenumber (cm^{-1}) = 1240meV-250meV = ~1-5 microns

CaF_2 Beamsplitter

InSb Detector

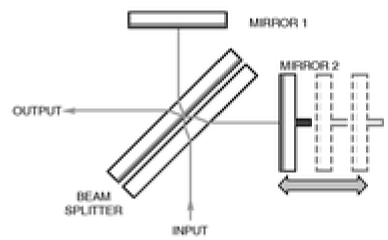
Beam Condenser

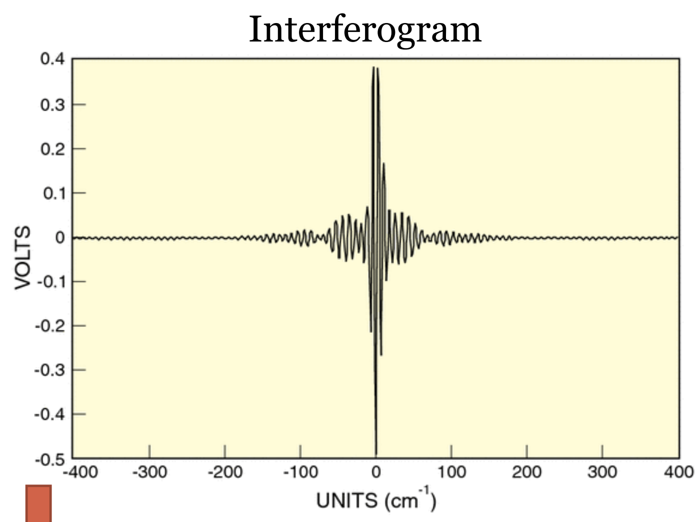


Fourier Analysis

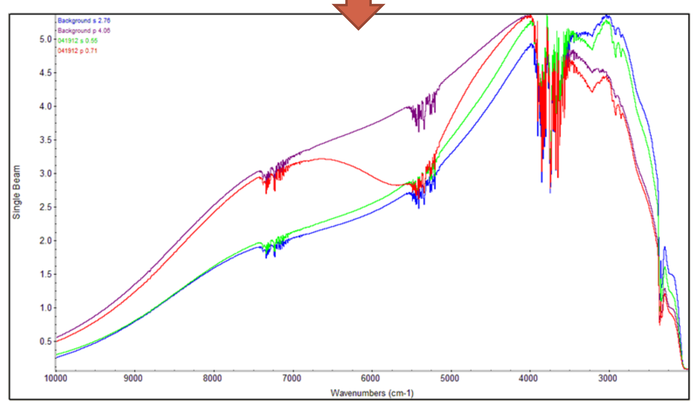
•Premise of Fourier analysis is that any curve can be formed by a superposition of periodic sine waves

•Computer calculates the Fourier transform of the interferogram and displays the spectra

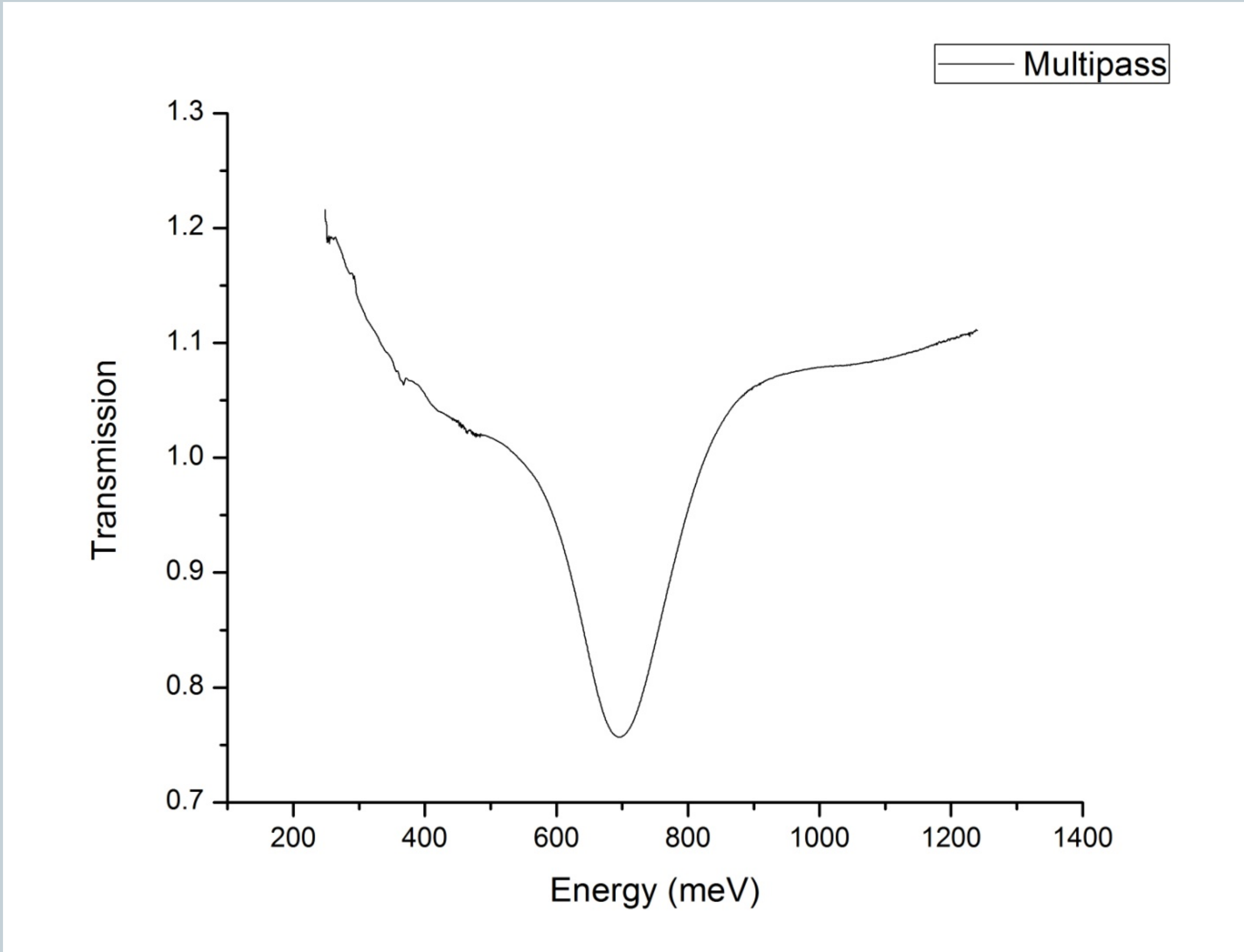




$$F(k) = \mathcal{F}_x[f(x)](k) = \int_{-\infty}^{\infty} f(x)\, e^{-2\pi i k x}\, dx$$



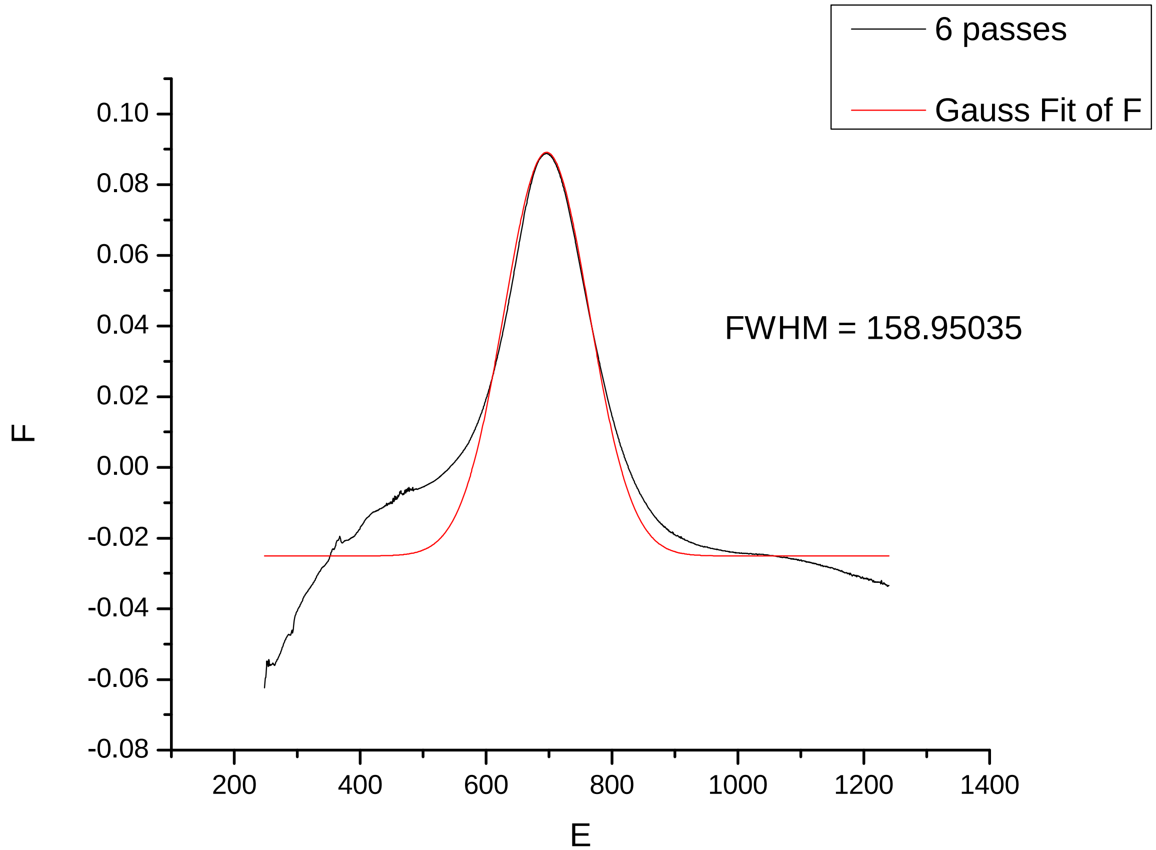
Sample Data



Multipass
1.3
1.2
1.1
1.0
0.9
0.8
0.7
Transmission
200
400
600
800
1000
1200
1400
Energy (meV)

Final Analysis

- C, M, N, and θ determined by experimental design and sample size
- T = Transmission
- α_{2D} = Absorption
- M= Length/ Thickness of Sample = Number of Passes



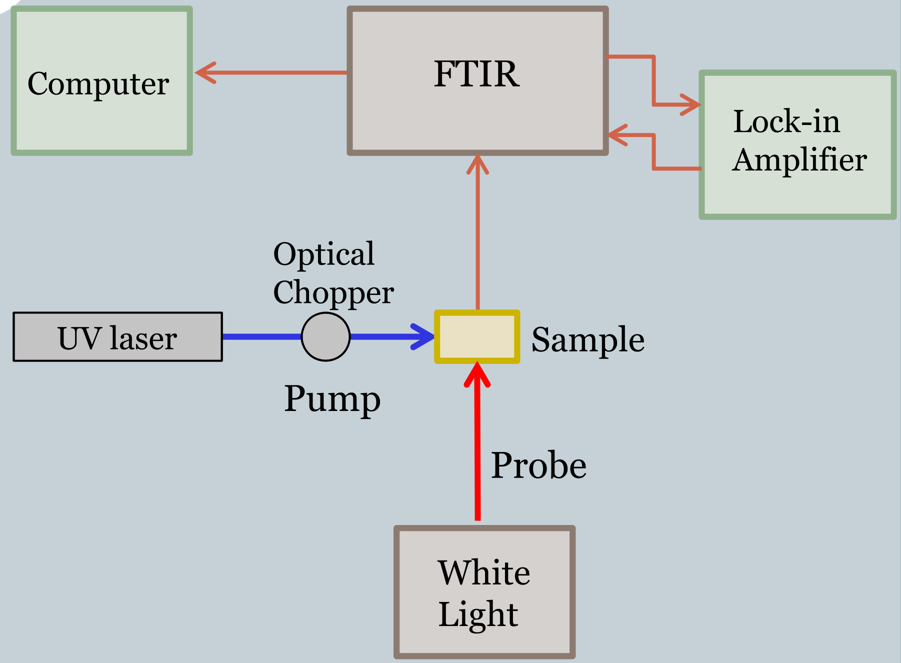
$$T \cong \exp(-C*M*N*\alpha_{2D} *\sin^2\theta/\cos\theta)$$

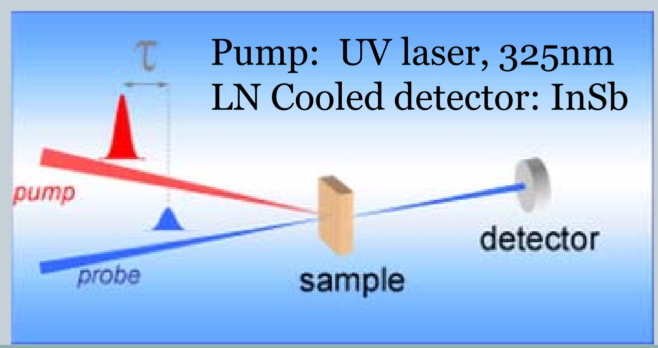
Photoinduced Absorption

- Method is suitable for observing peaks which may not be clearly defined in the direct absorption spectra

- HeCd laser is used to excite the sample

- Laser is optically chopped and measurement is taken as a step scan with the use of a lock-in amplifier



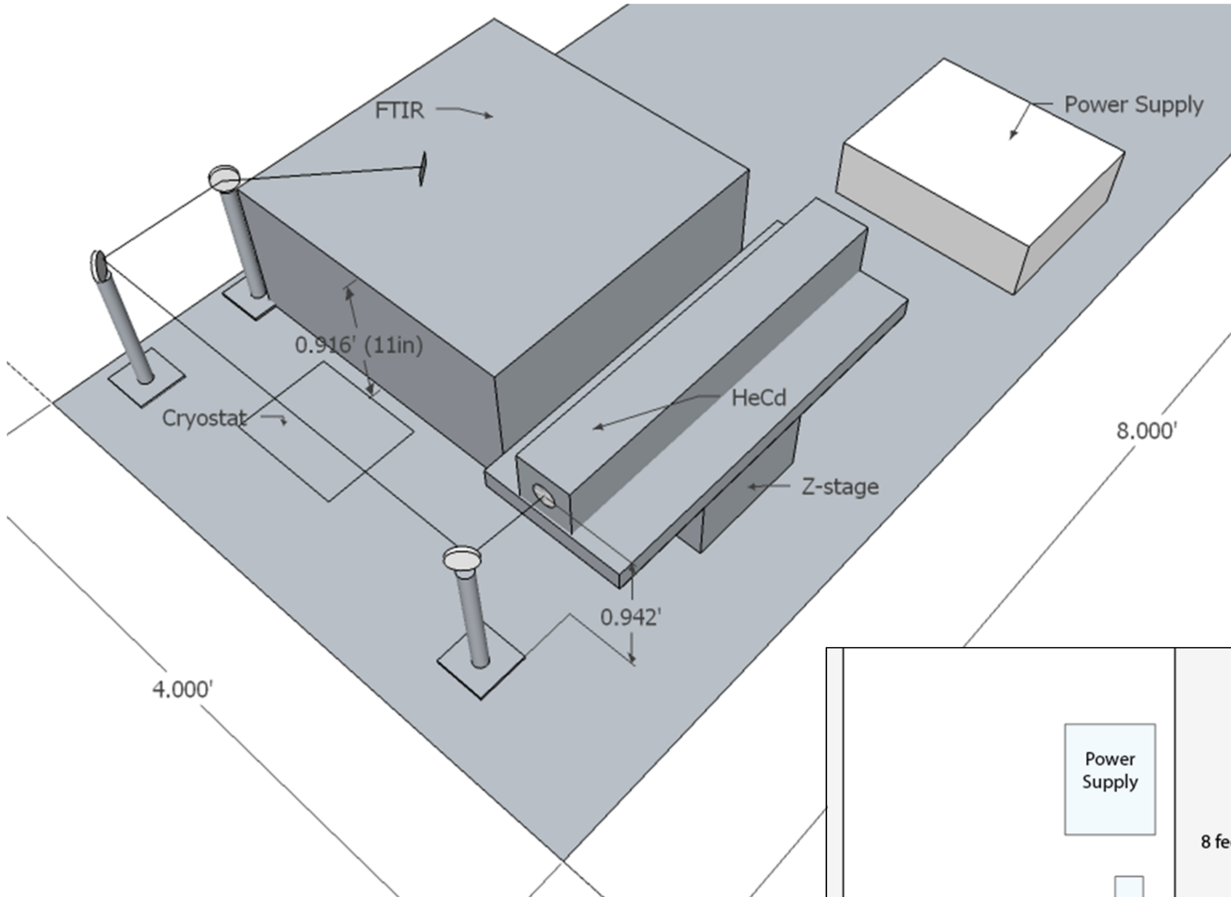


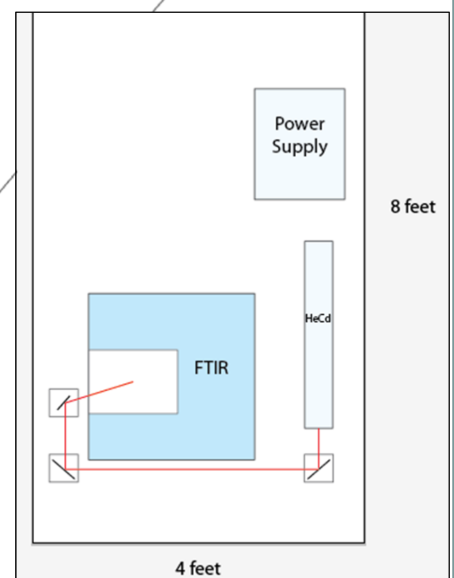
-Beam Initial Diameter=0.3mm

-Beam Divergence = 2.0mrad

-Beam Diameter at Sample = 3.1 mm

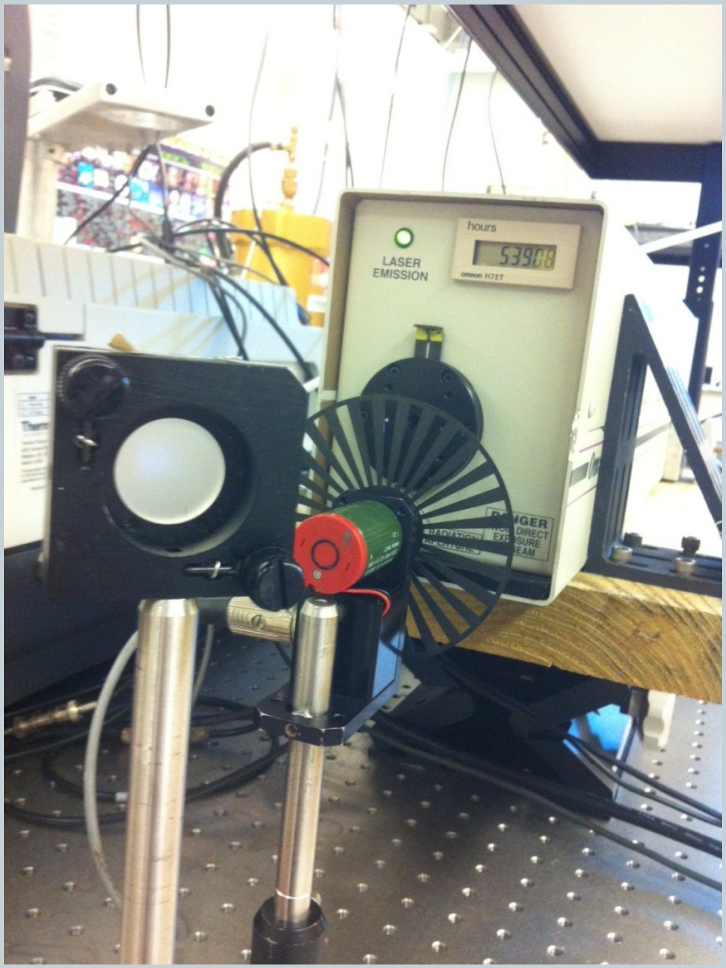
-Mirrors optimized for 325nm wavelength

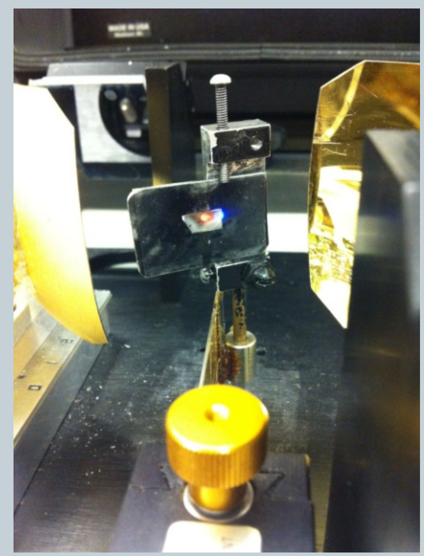




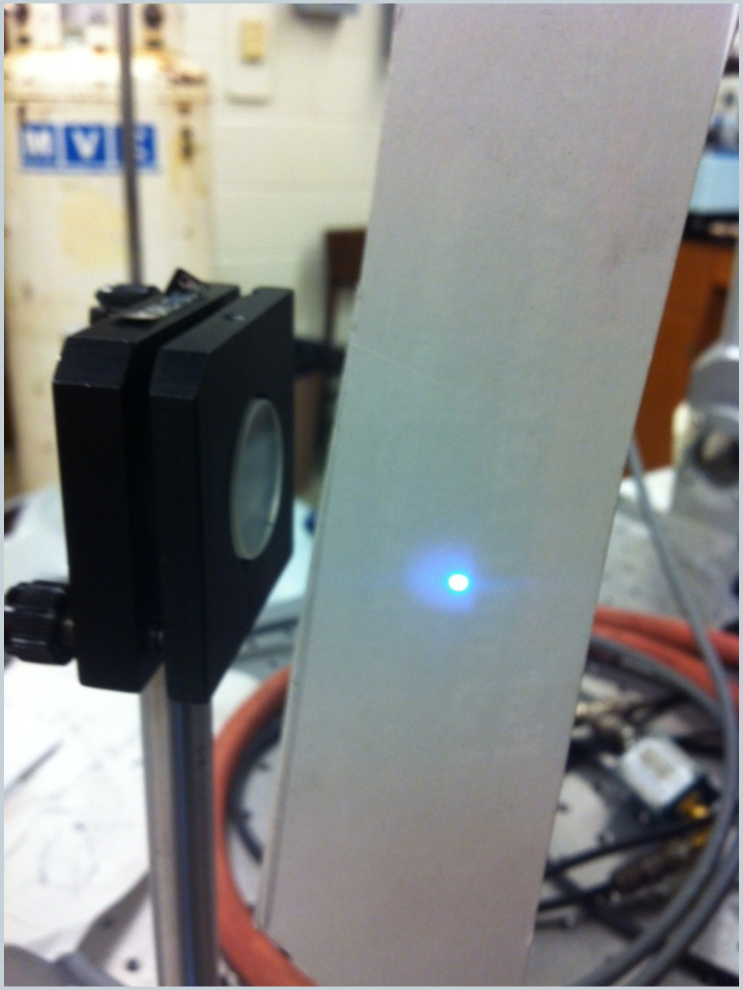
Laser Setup

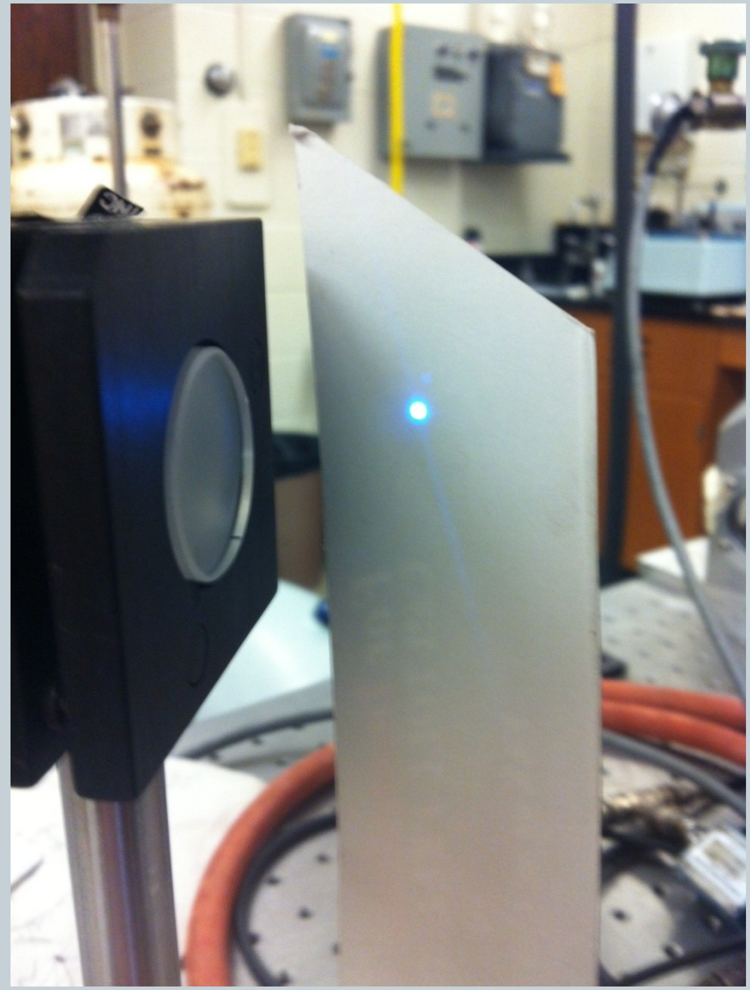
Installation





Installation





Data

DIRECT AND PHOTOINDUCED ABSORPTION MEASUREMENTS

092811

101711

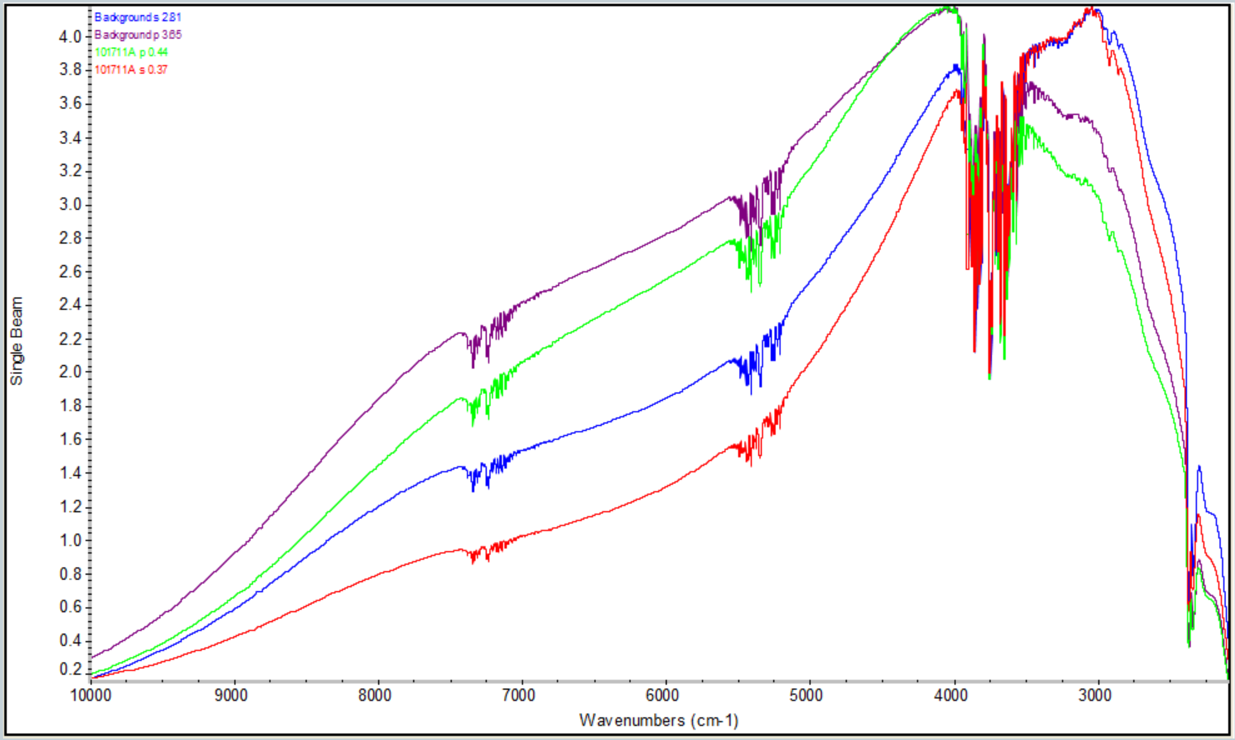
102411

041912

060512

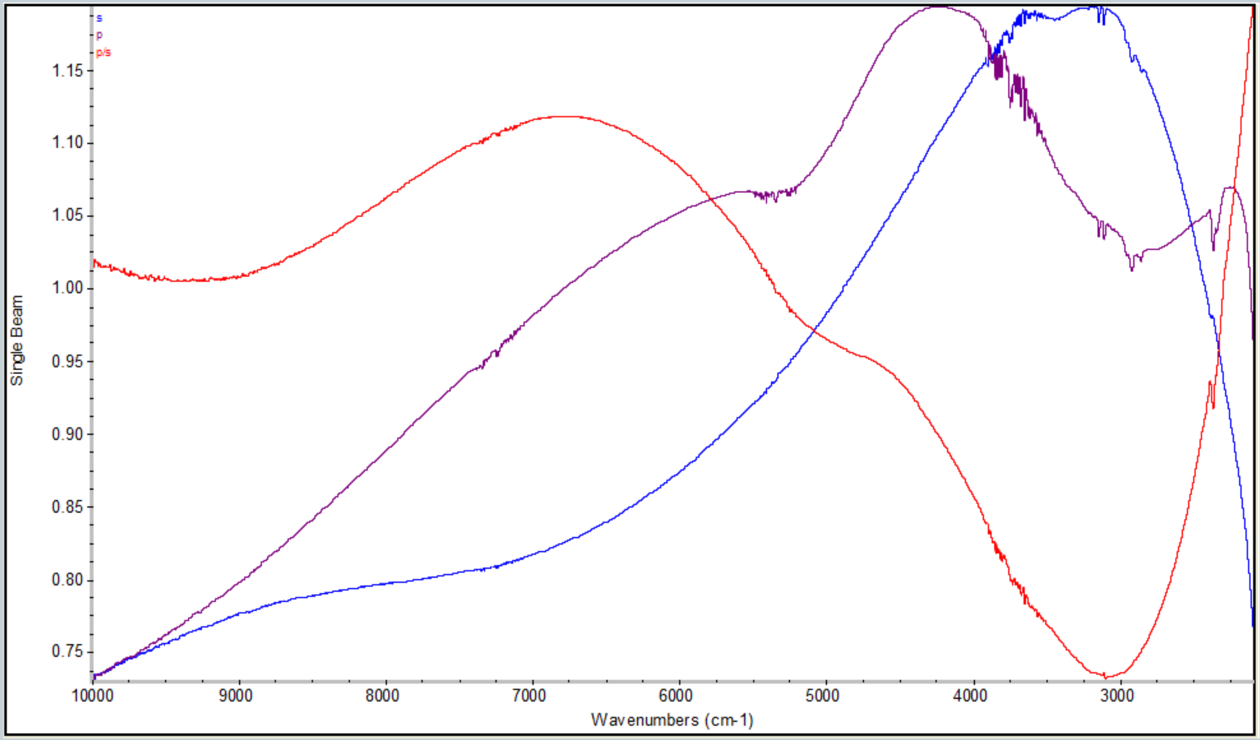
060612

101711



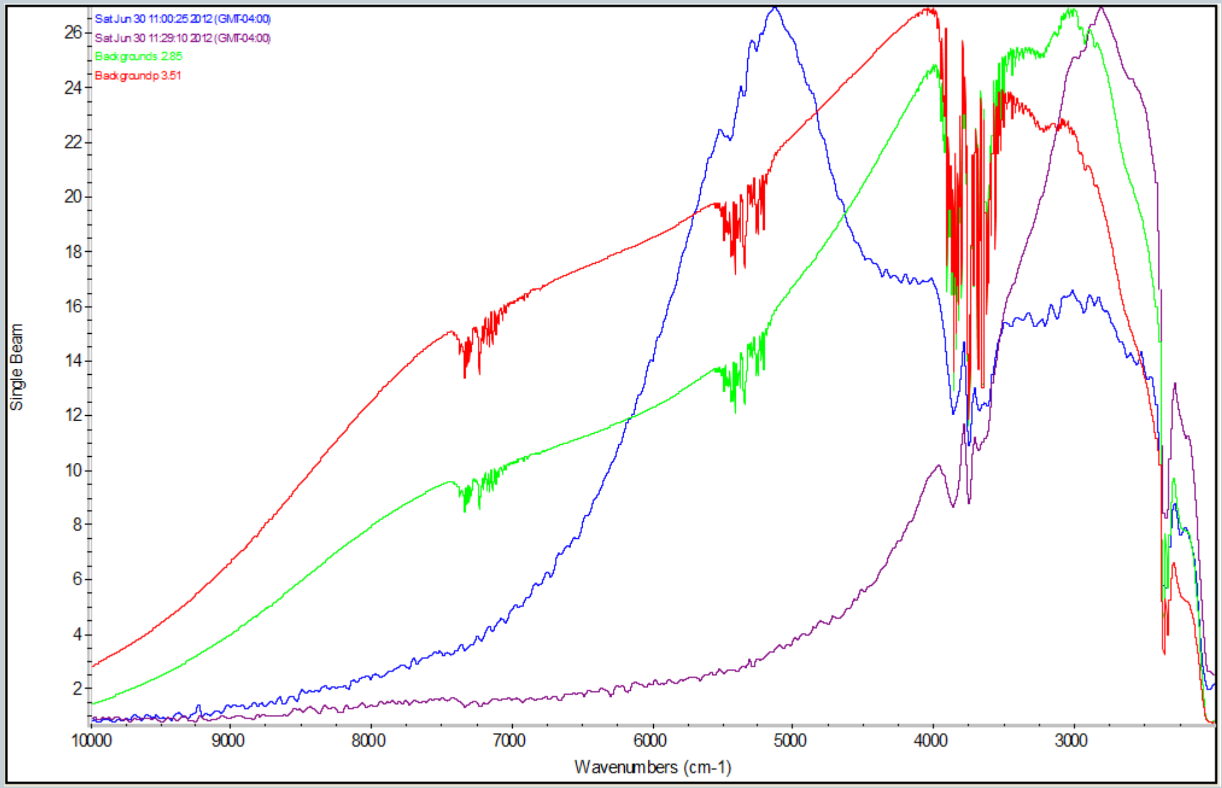
- Multipass sample of 101711 (AlGaN/GaN)
- Direct absorption

101711



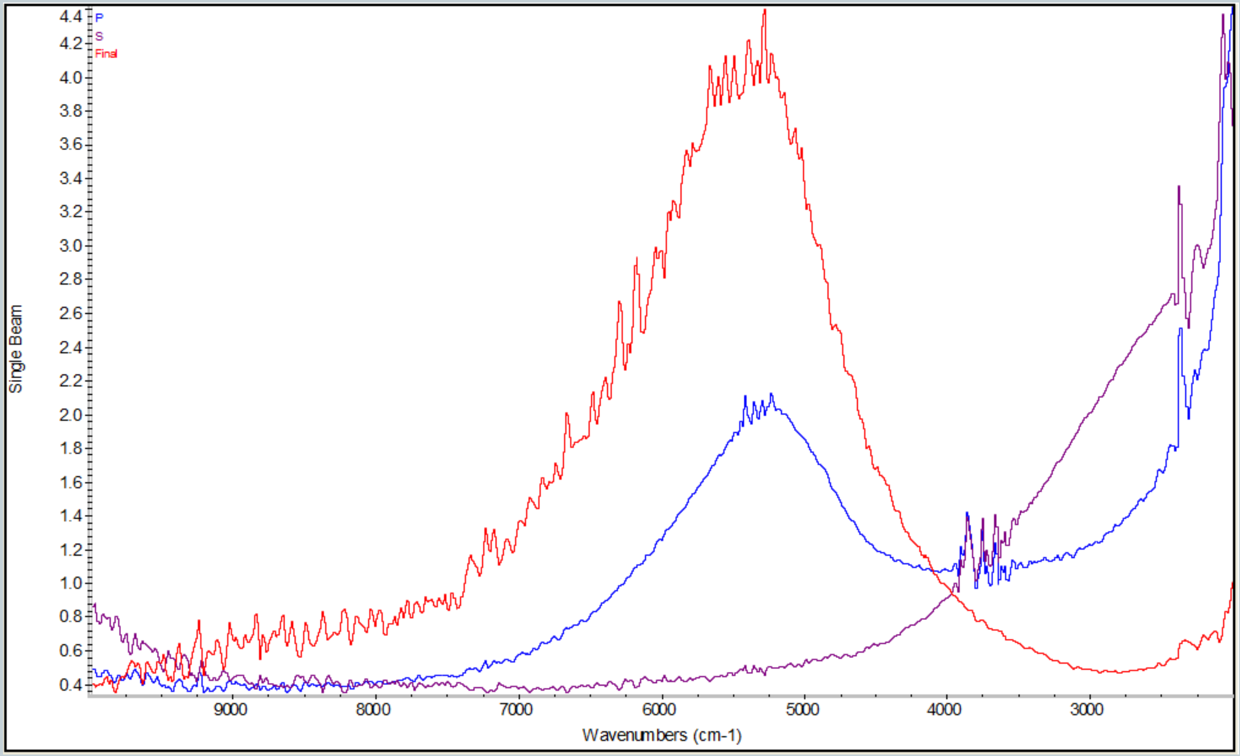
- Multipass sample of 101711 (AlGaN/GaN)
- Direct absorption spectral math

101711- PIA



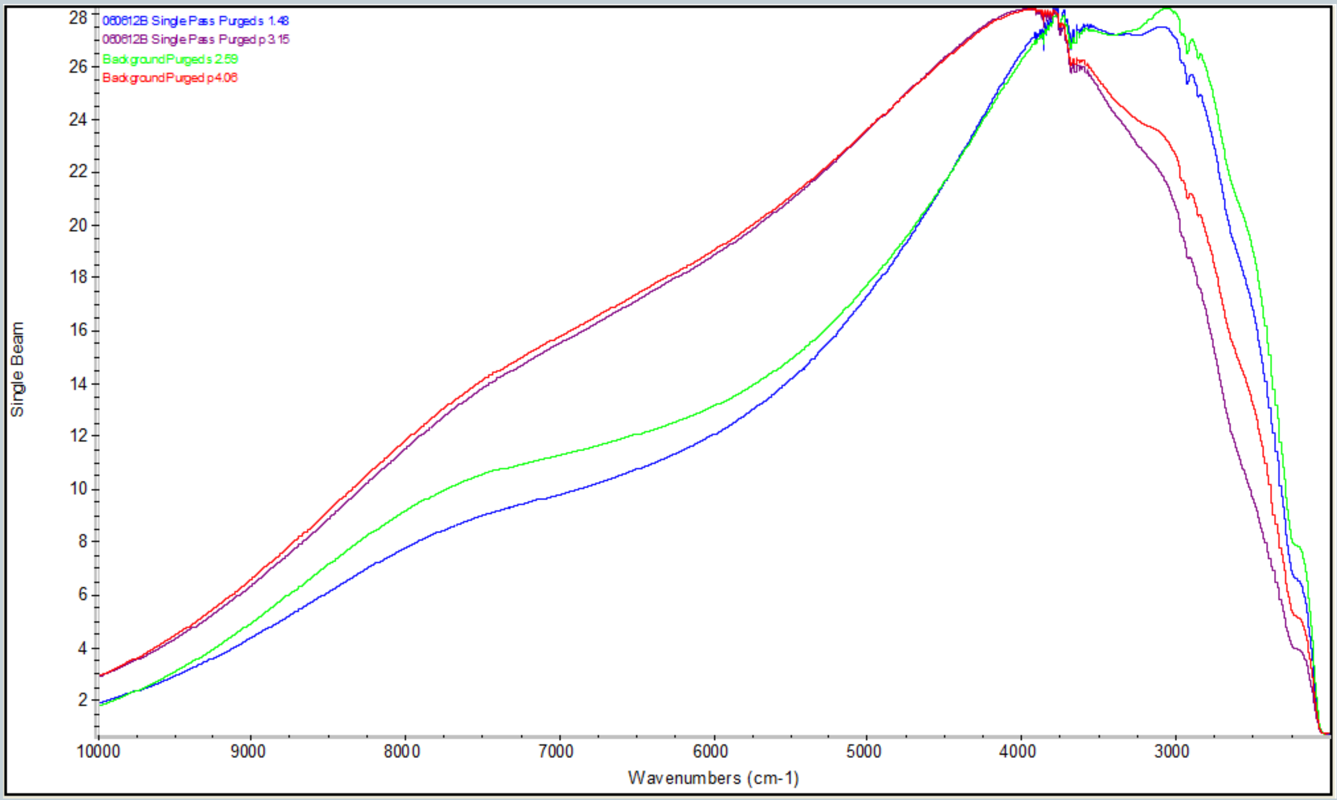
- Multipass sample of 101711 (AlGaN/GaN)
- Photoinduced absorption

101711- PIA



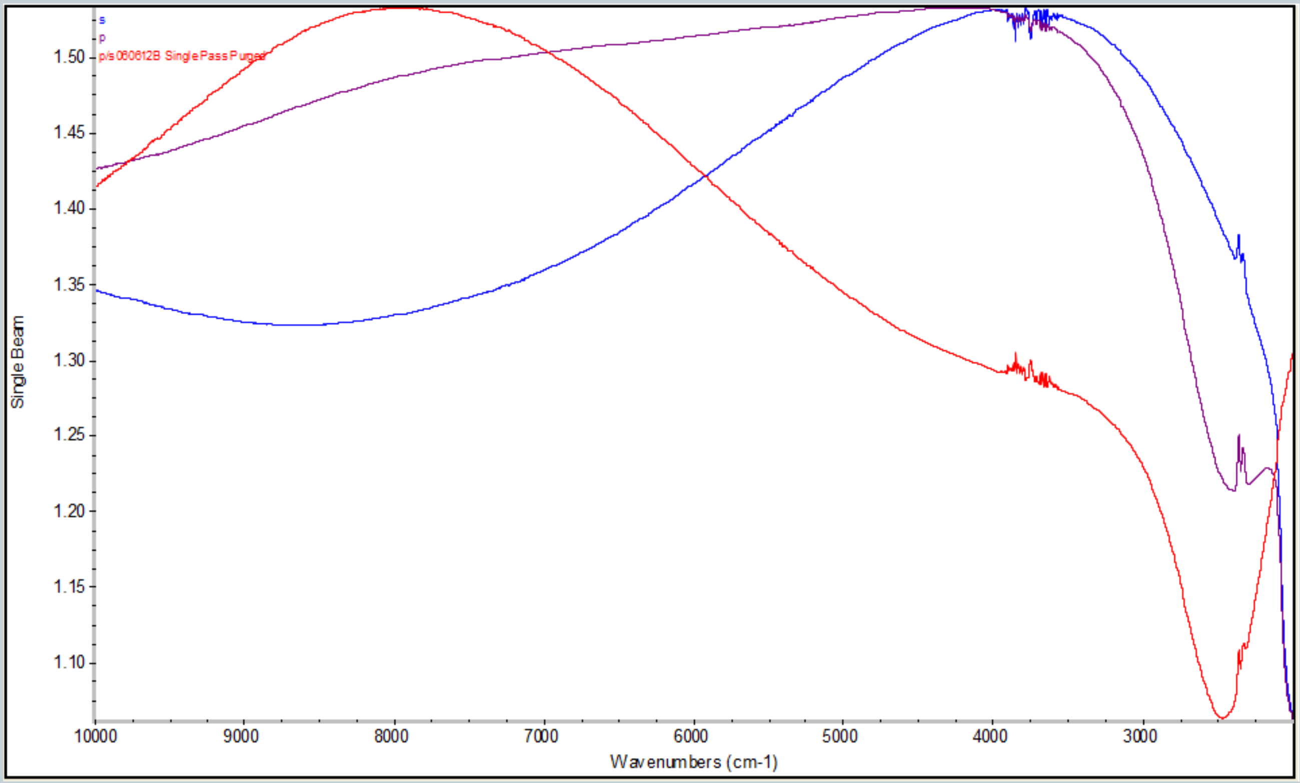
•Multipass sample of 101711 (AlGaN/GaN)
•Photoinduced absorption spectral math

060612



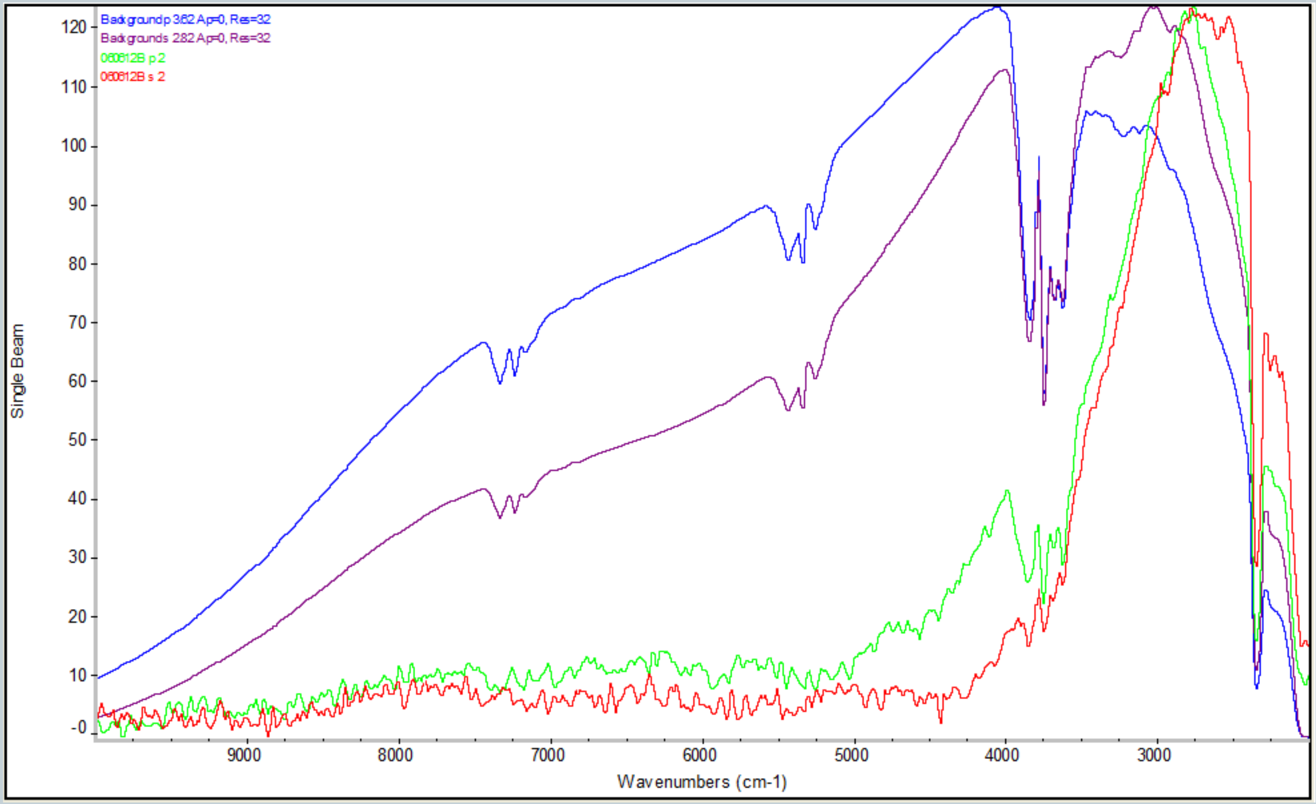
- Single pass sample of 060612 (InAlN/GaN)
- Direct absorption
- Purged

060612



- Single pass sample of 060612 (InAlN/GaN)
- Direct absorption spectral math
- Purged

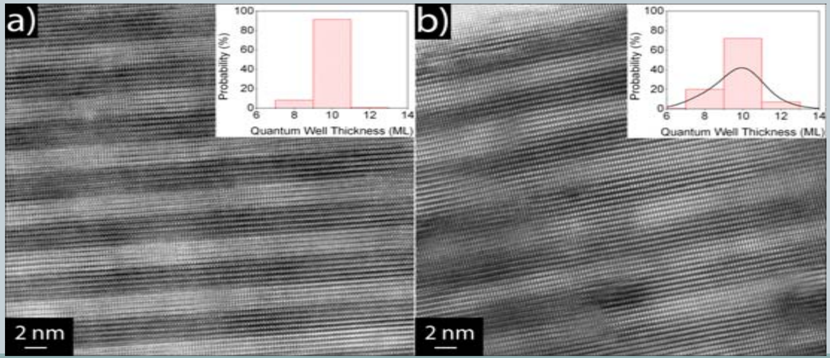
060612-PIA



- Single pass sample of 060612 (InAlN/GaN)
- Photoinduced absorption

Analysis

- From these absorption spectra we can find the transition energies and the widths of the peaks
- This information can then be compared with theoretical predictions in the literature, and we can identify materials parameters including the conduction band offset, polarization field, and structural information about interface roughness
- Useful in the design of optical devices



Thank You!

Works Cited

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