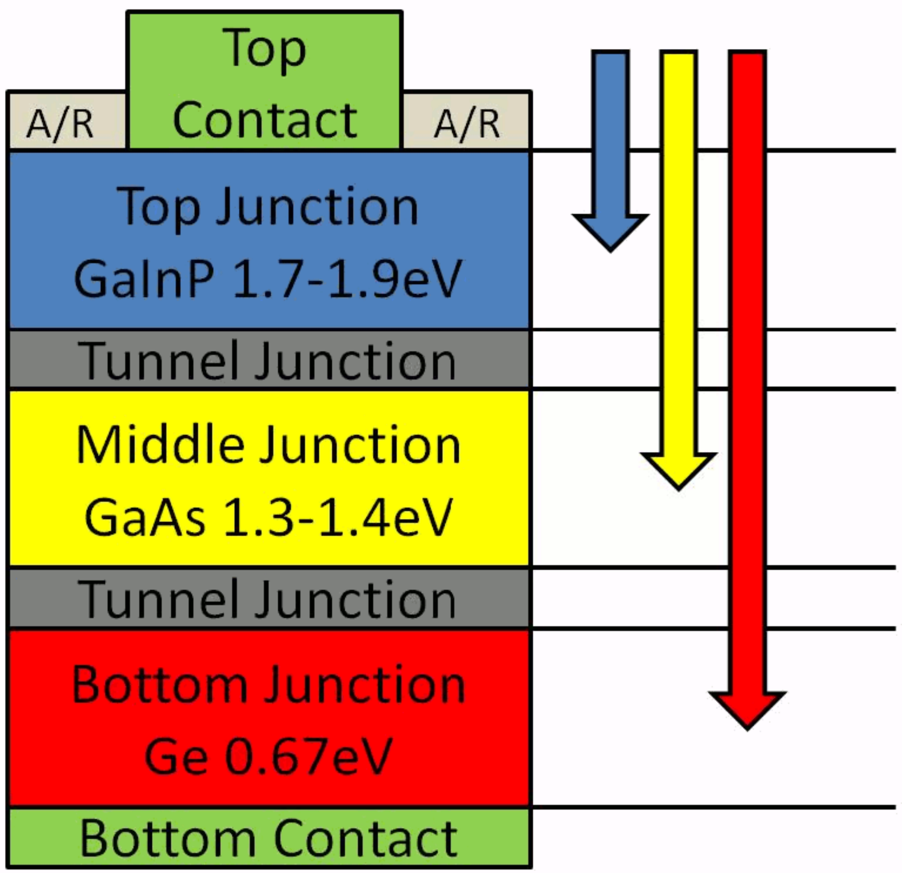
GaInNAs for Space Applications

Mitchell Bredice

Advisor: Dr. Sellers

Multi Junction Solar Cells

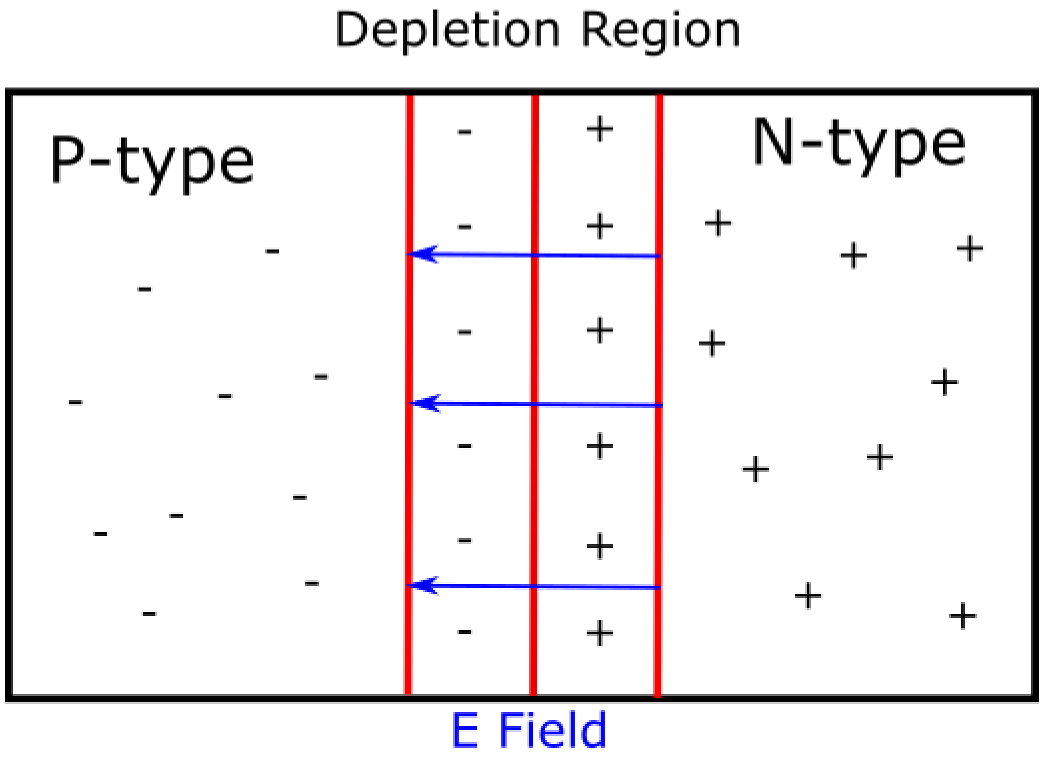
- Predominantly used in space applications
- Use multiple cells in series to absorb more light
- Each additional cell raises the overall efficiency

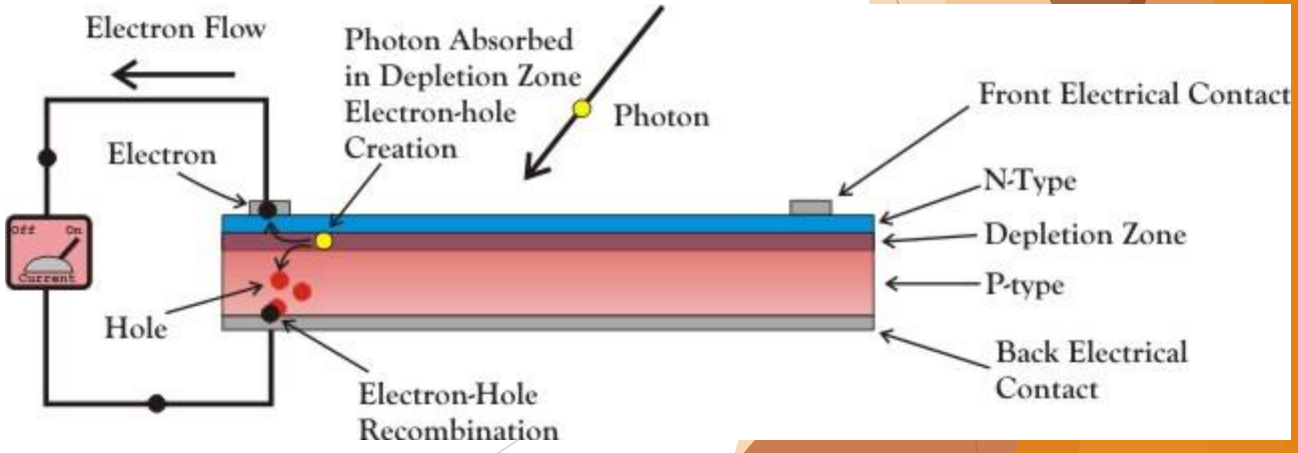


http://large.stanford.edu/courses/2010/ph240/weisse2/

Solar Cells – P-N Junction

- Cells work based on P-N Junction, same as a diode
- Carriers are created in the depletion region
- Electric field of depletion region collects carriers





https://www.imagesco.com/articles/photovoltaic/photovoltaic-pg4.html

Why GaInNAs?

- This material, known as dilute nitrides, have usable properties
- Can be grown on GaAs and lattice matched
- Can have band gap of 1.0 eV
- Could allow for a fourth junction in MJSC’s

Previous Work on GaInNAs

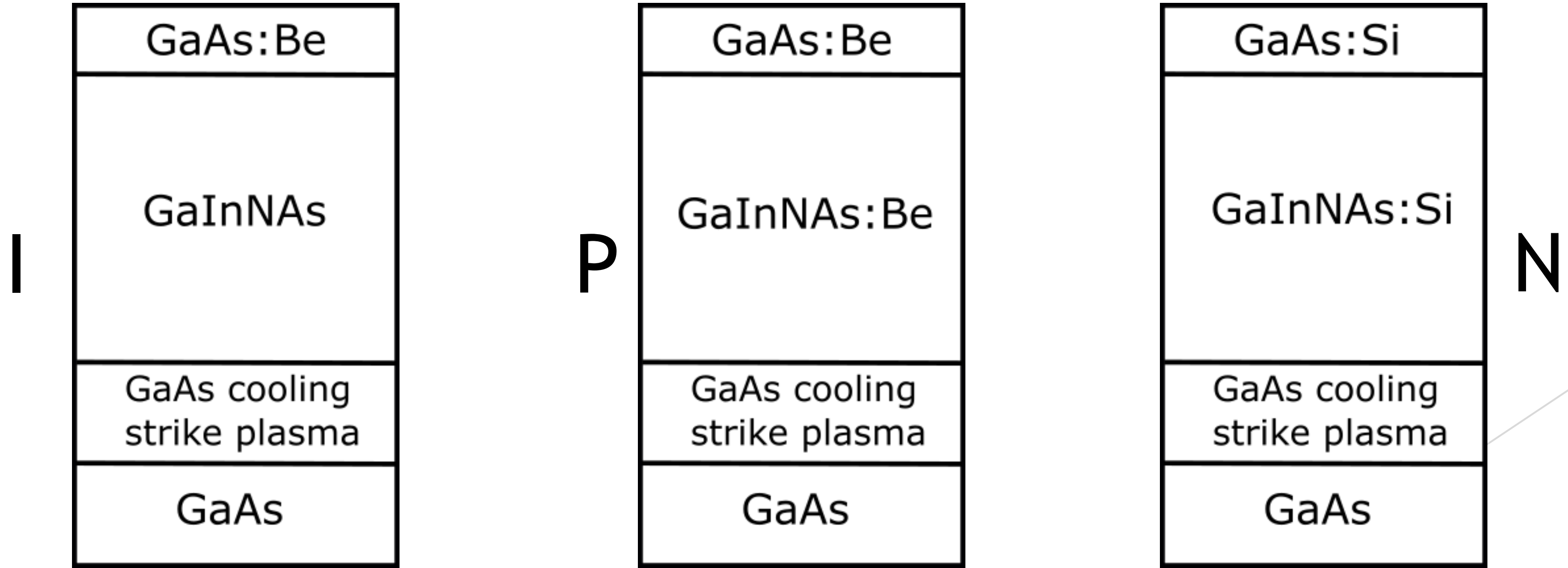
- The Photovoltaic Materials Research group previously found
    - GaInNAs has many defects that inhibit its ability to be used
    - Adding hydrogen into the lattice passivates defects
- This passivation has shown increased performance in solar cells
- But how does hydrogenation affect electrical properties?

Samples

- Three samples were tested
  - One intrinsic, n-type, p-type
- N-type GaInNAs doped with Si
  - N-type means majority carriers are electrons
- P-type GaInNAs doped with Be
  - P-type means majority carriers are holes

Structure

- All grown in 1 μm thick GaAs substrate
- Followed by a 200 nm thick GaAs cooling strike plasma
- Followed by a 2 μm thick GaInNAs layer
    - n-type GaInNAs:Si
    - p-type GaInNas:Be
- Intrinsic and p-type terminated with GaAs:Be cap
- n-type terminated with GaAs:Si cap



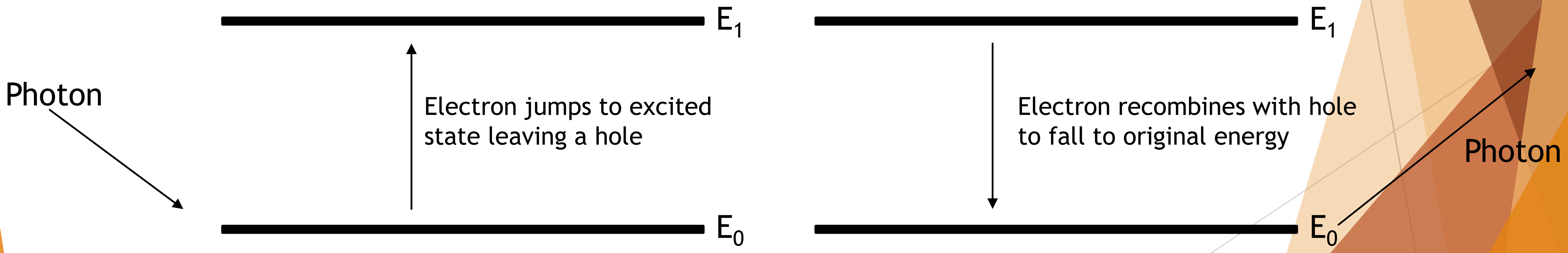
I
GaAs:Be
GaInNAs
GaAs cooling strike plasma
GaAs

P
GaAs:Be
GaInNAs:Be
GaAs cooling strike plasma
GaAs

N
GaAs:Si
GaInNAs:Si
GaAs cooling strike plasma
GaAs

Experimental Techniques - Photoluminescence

- Spectroscopic technique used to investigate defects
- Shine a laser onto sample to create carriers
- Carriers recombine and then emit a photons
- Analyze the resulting spectra



Photon

E_1

E_0

Electron jumps to excited state leaving a hole

E_1

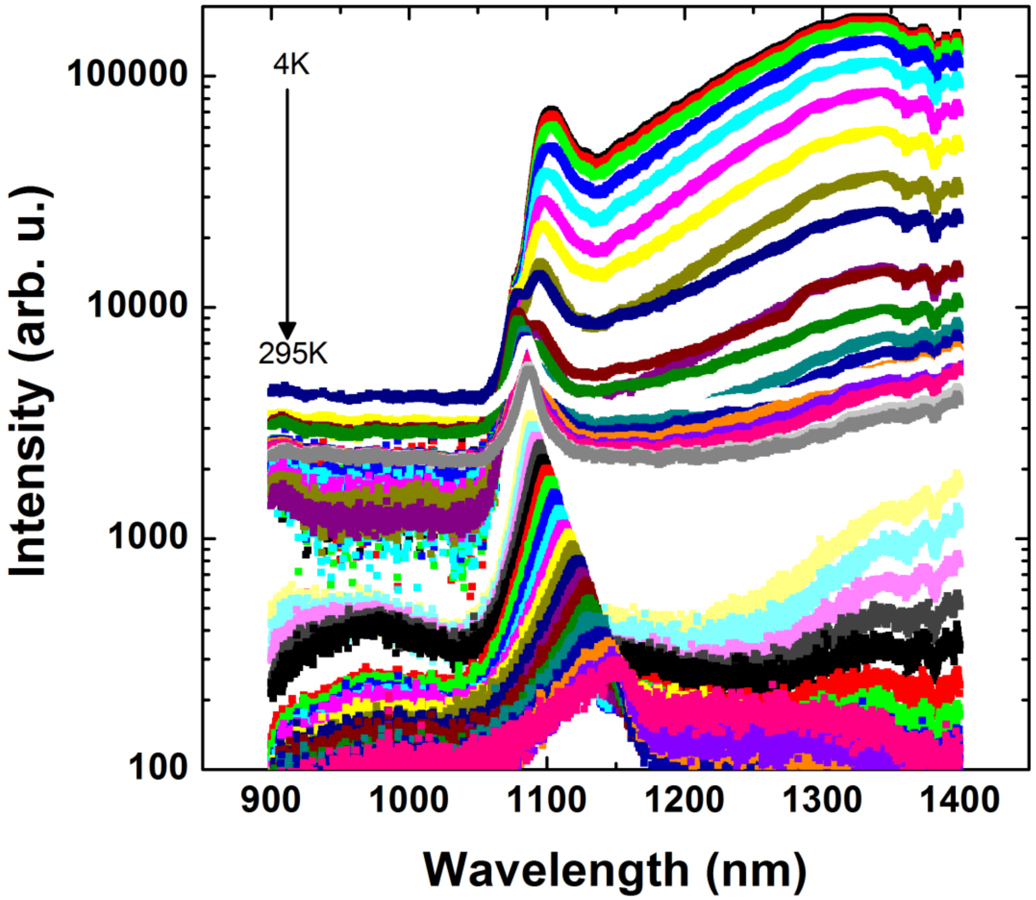
E_0

Electron recombines with hole to fall to original energy

Photon

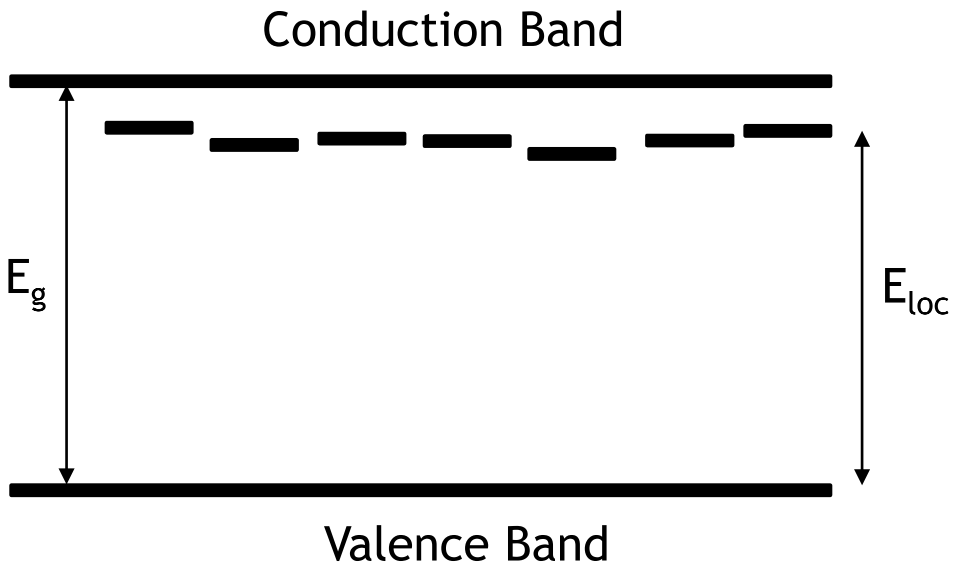
Intrinsic – PL

- Large defect band, dominates at low temperature
- Carrier localization at low temperature
- Peak dominance shifts at 40 K- 45 K



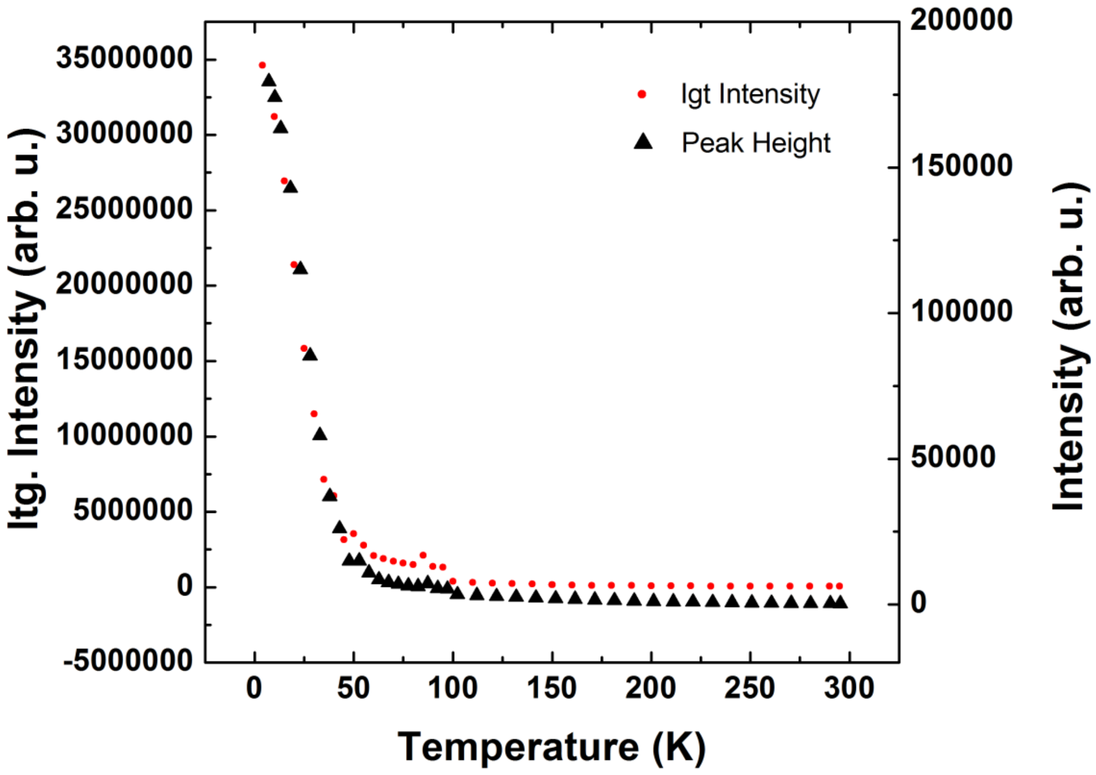
Localized States

- How does this spectra indicate localized states?
- States near band gap due to growth defects



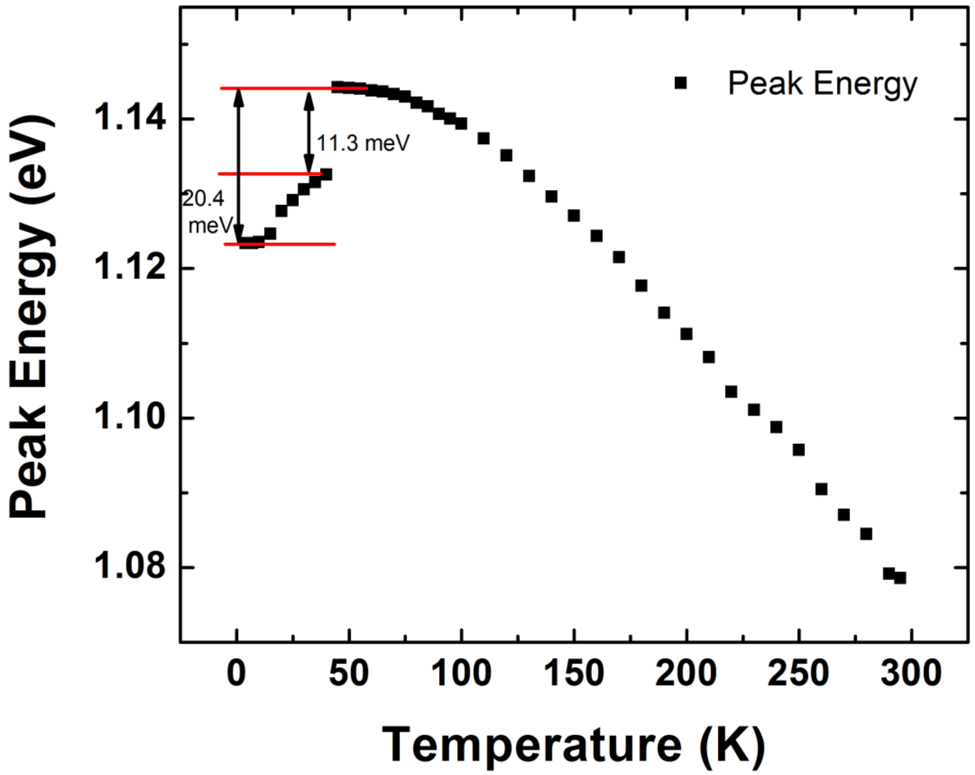
Intrinsic – PL

- Carrier localization at low temperature
- Peak dominance shifts at 45K
- Large quench in intensity, reflects carrier diffusion



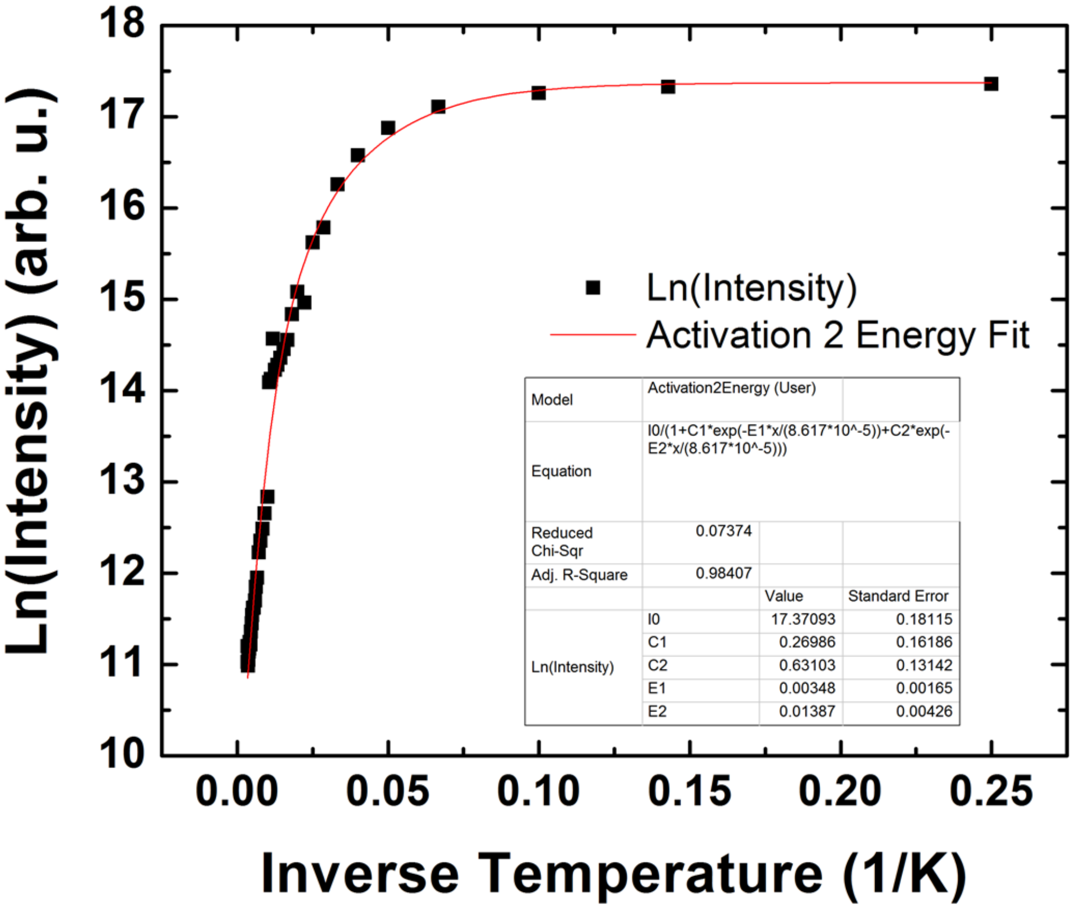
Intrinsic – Peak Energy

- Has S-shape with temperature
- Shift occurs at 45K, reflects the change in peak dominance at 45K
- Shows the typical band gap dependence with temperature after shift



Activation Energy Fit - Intrinsic

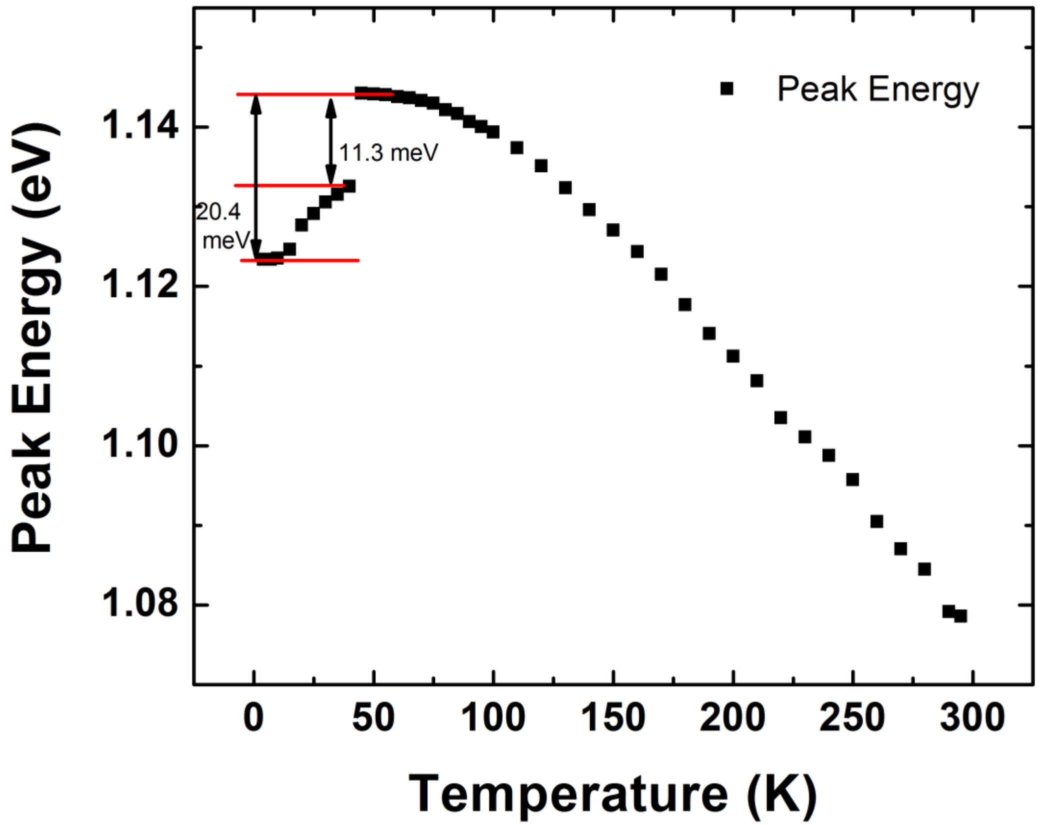
- $\frac{I_0}{1+C_1 e^{-E_1 x/(8.617 * 10^{-5})}+C_2 e^{-E_2 x/(8.617*10^{-5})}}$
- Two energy values were fitted, 3.48 meV and 13.87 meV
- 3.48 meV translates to ~40K



Model	Activation2Energy (User)		
Equation	I0/(1+C1*exp(-E1*x/(8.617*10^-5))+C2*exp(-E2*x/(8.617*10^-5)))		
Reduced Chi-Sqr	0.07374		
Adj. R-Square	0.98407		
		Value	Standard Error
Ln(Intensity)	I0	17.37093	0.18115
	C1	0.26986	0.16186
	C2	0.63103	0.13142
	E1	0.00348	0.00165
	E2	0.01387	0.00426

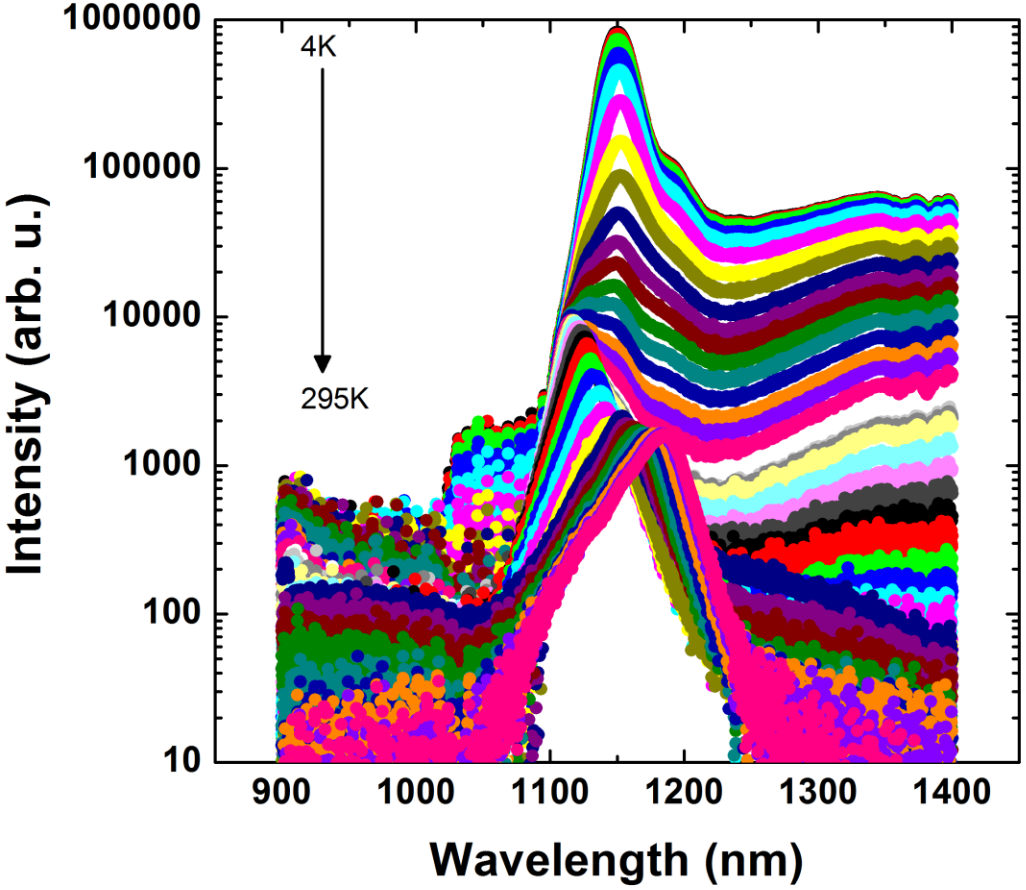
Activation Energy Fit - Intrinsic

- $\frac{I_0}{1+C_1 e^{-E_1 x/(8.617 * 10^{-5})}+C_2 e^{-E_2 x/(8.617*10^{-5})}}$
- Two energy values were fitted, 3.48 meV and 13.87 meV
- 3.48 meV translates to ~40K
- 13.87 meV could reference the difference in energy of localized states and band gap



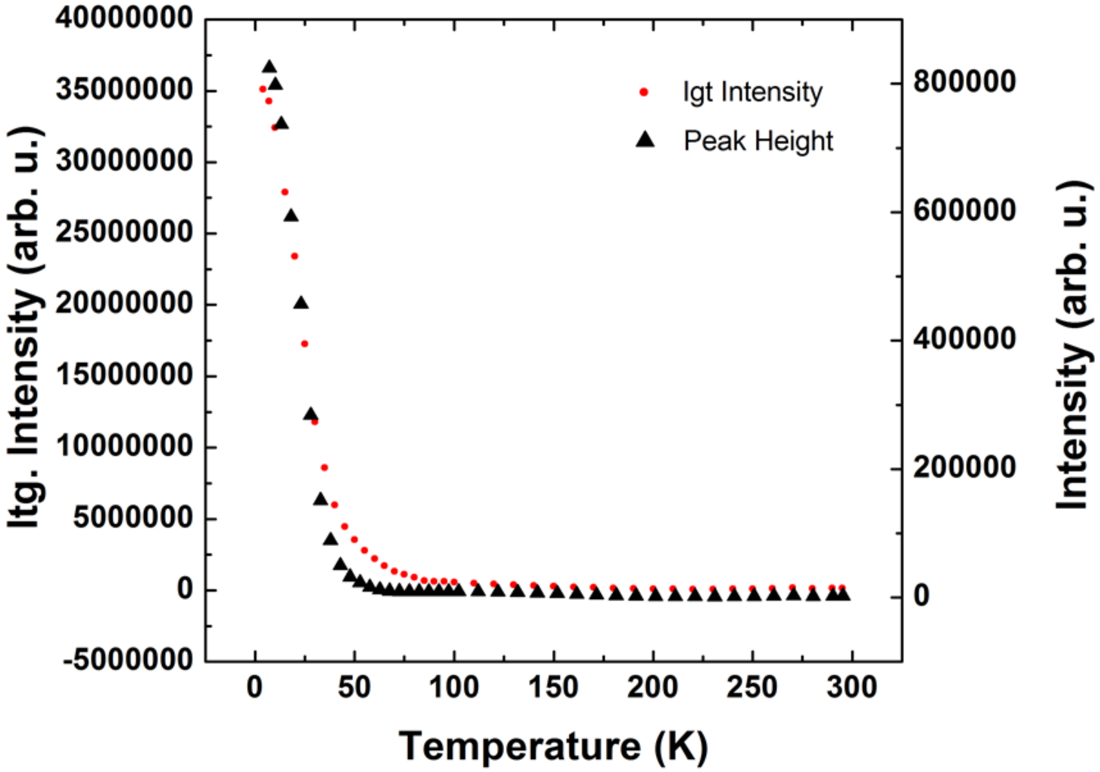
N-type - PL

- Large defect band at low temperatures
- Carrier localization at low temperatures
- Peak dominance shifts at 70 K
- Shoulder-Peak energy difference, 22.9 meV



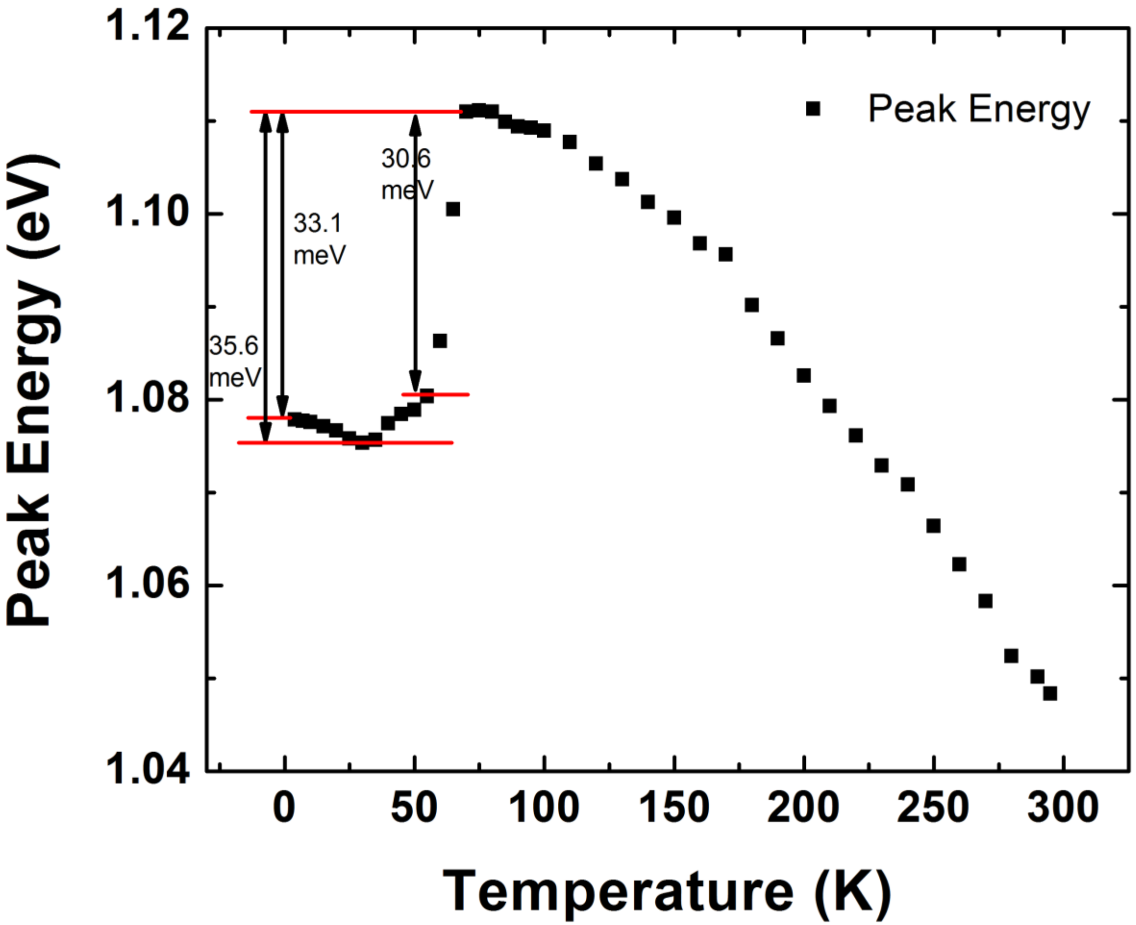
N-type - PL

- Carrier localization at low temperatures
- Peak dominance shifts at 70 K
- Large quench in intensity reflects carrier diffusion



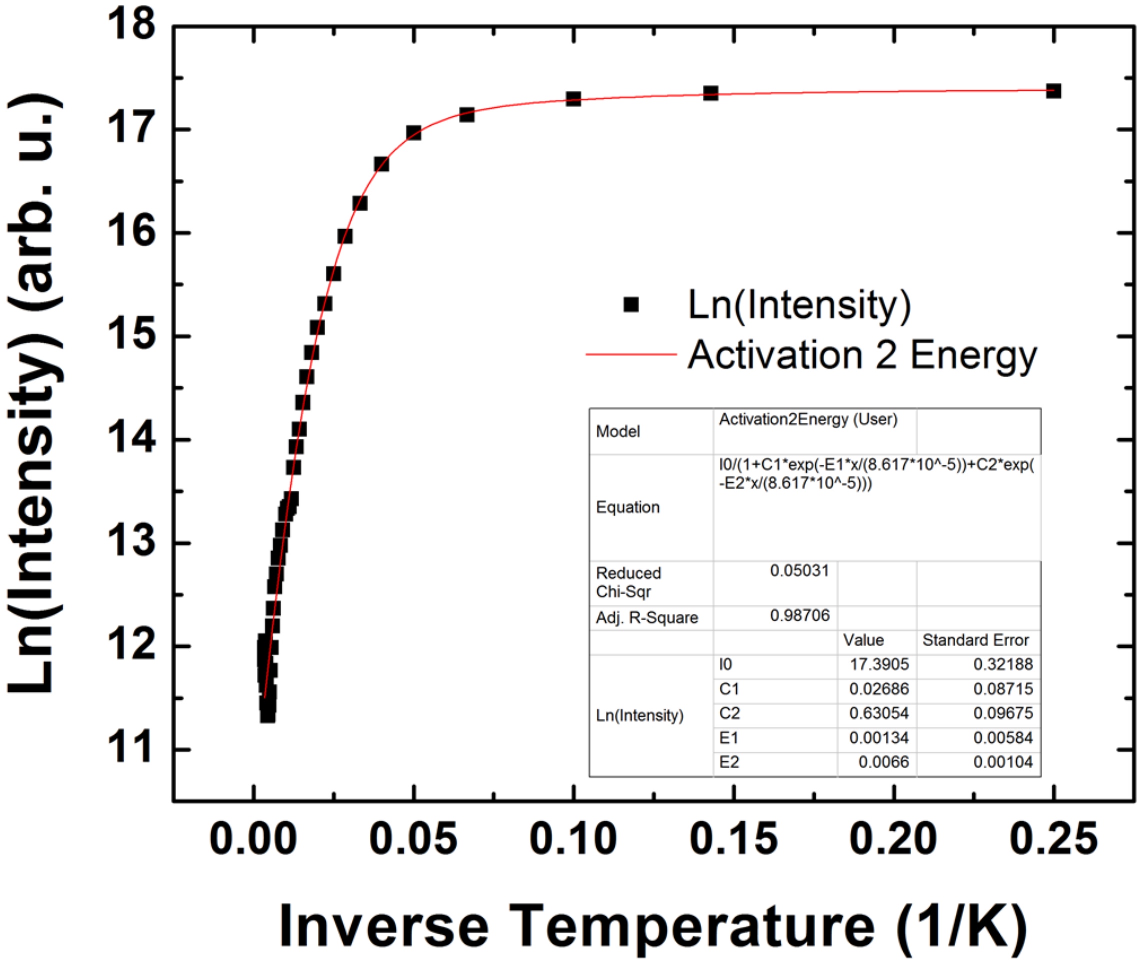
N-type – Peak Energy

- Shows S-shaped dependence
- Reflects change in PL dominance at 70K
- Two processes occur



Activation Energy Fit – n-type

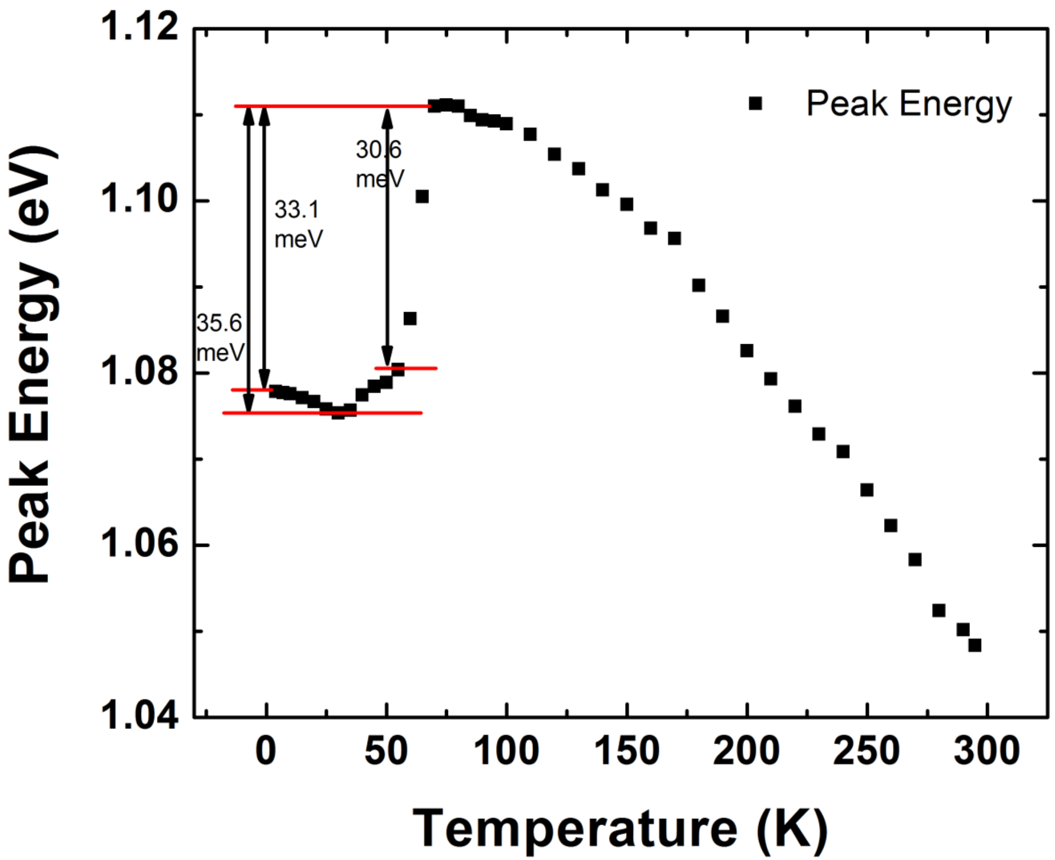
- $\frac{I_0}{1+C_1 e^{-E_1 x/(8.617*10^{-5})}+C_2 e^{-E_2 x/(8.617*10^{-5})}}$
- Two energies fit, 1.34 meV and 6.6 meV
- 6.6 meV translates to ~76 K
- 1.34 meV translates to ~15 K



Model	Activation2Energy (User)		
Equation	I0/(1+C1*exp(-E1*x/(8.617*10^-5))+C2*exp(-E2*x/(8.617*10^-5)))		
Reduced Chi-Sqr	0.05031		
Adj. R-Square	0.98706		
		Value	Standard Error
Ln(Intensity)	I0	17.3905	0.32188
	C1	0.02686	0.08715
	C2	0.63054	0.09675
	E1	0.00134	0.00584
	E2	0.0066	0.00104

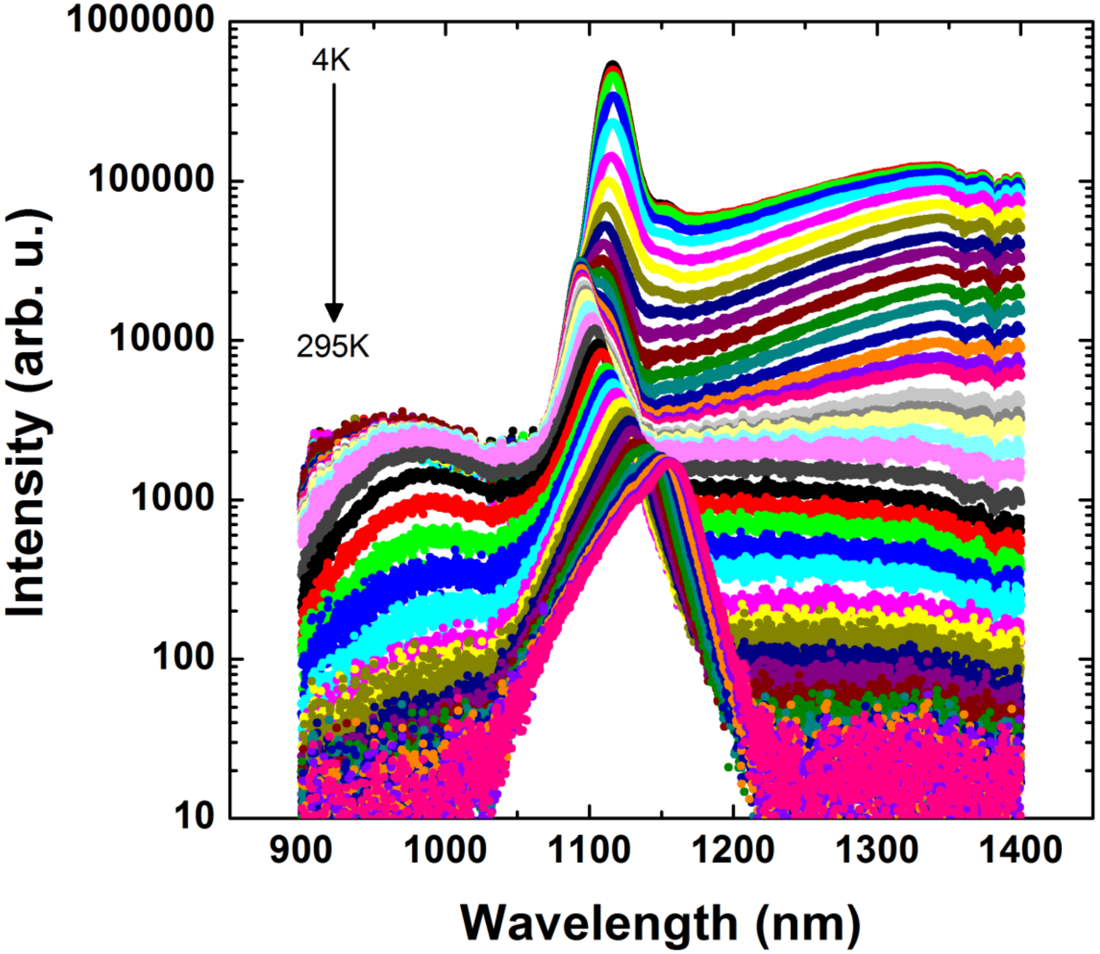
Activation Energy Fit – n-type

- $\frac{I_0}{1+C_1 e^{-E_1 x/(8.617 * 10^{-5})}+C_2 e^{-E_2 x/(8.617*10^{-5})}}$
- Two energies fit, 1.34 meV and 6.6 meV
- 6.6 meV translates to ~76 K
  - Close to where the peak transition occurs
- 1.34 meV translates to ~15 K
  - Possibly first dip in Peak energy



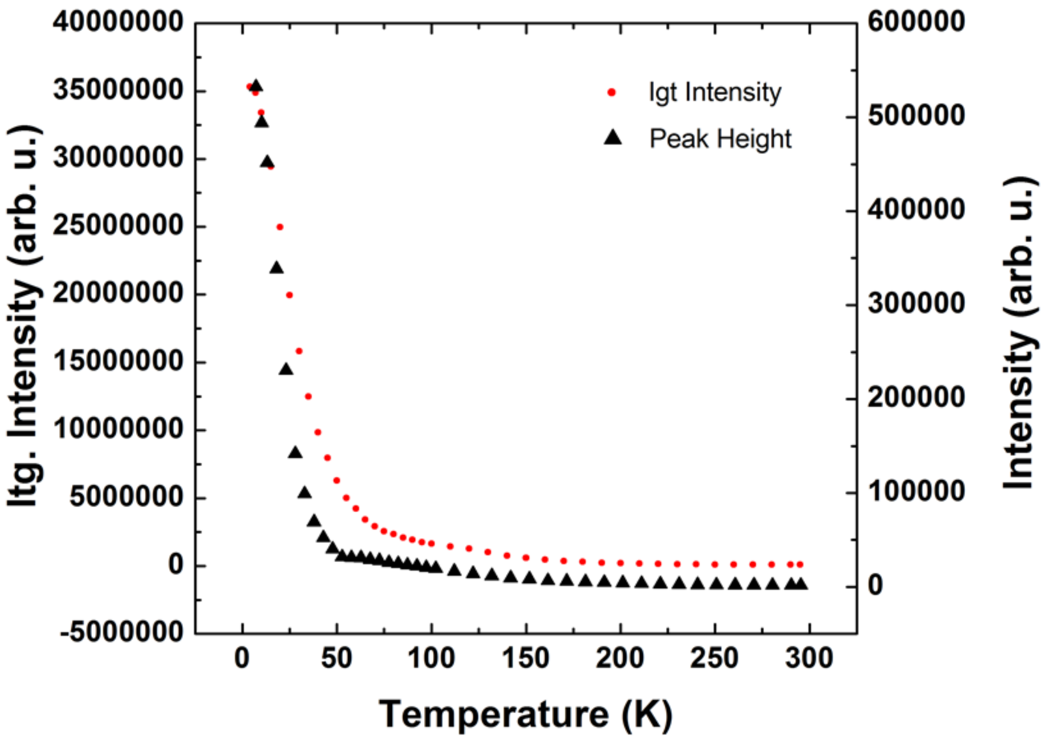
P-type – PL

- Large defect band at low temperatures
- Carrier localization at low temperatures
- Peak dominance shifts at 50 K – 55 K
- Shoulder-Peak energy difference 18.11 meV



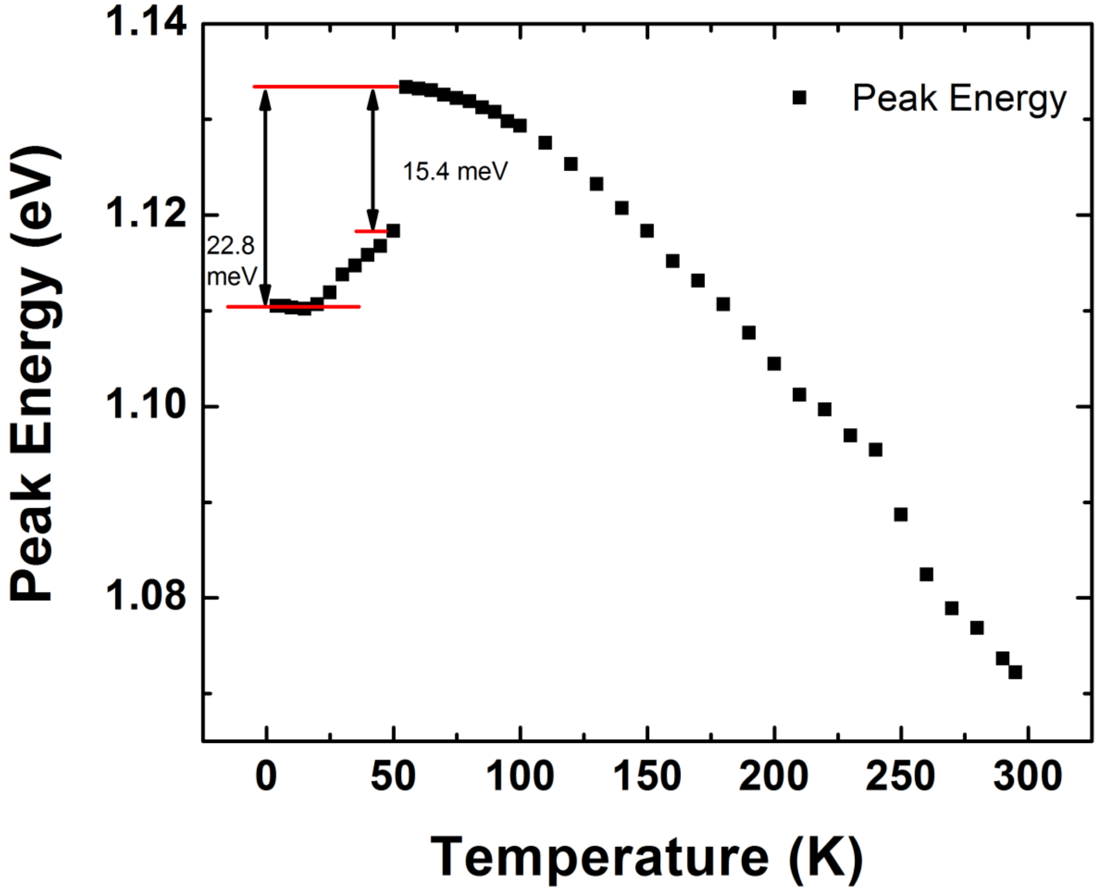
P-type – PL

- Carrier localization at low temperatures
- Peak dominance shifts at 50 K – 55 K
- Large quench in intensity



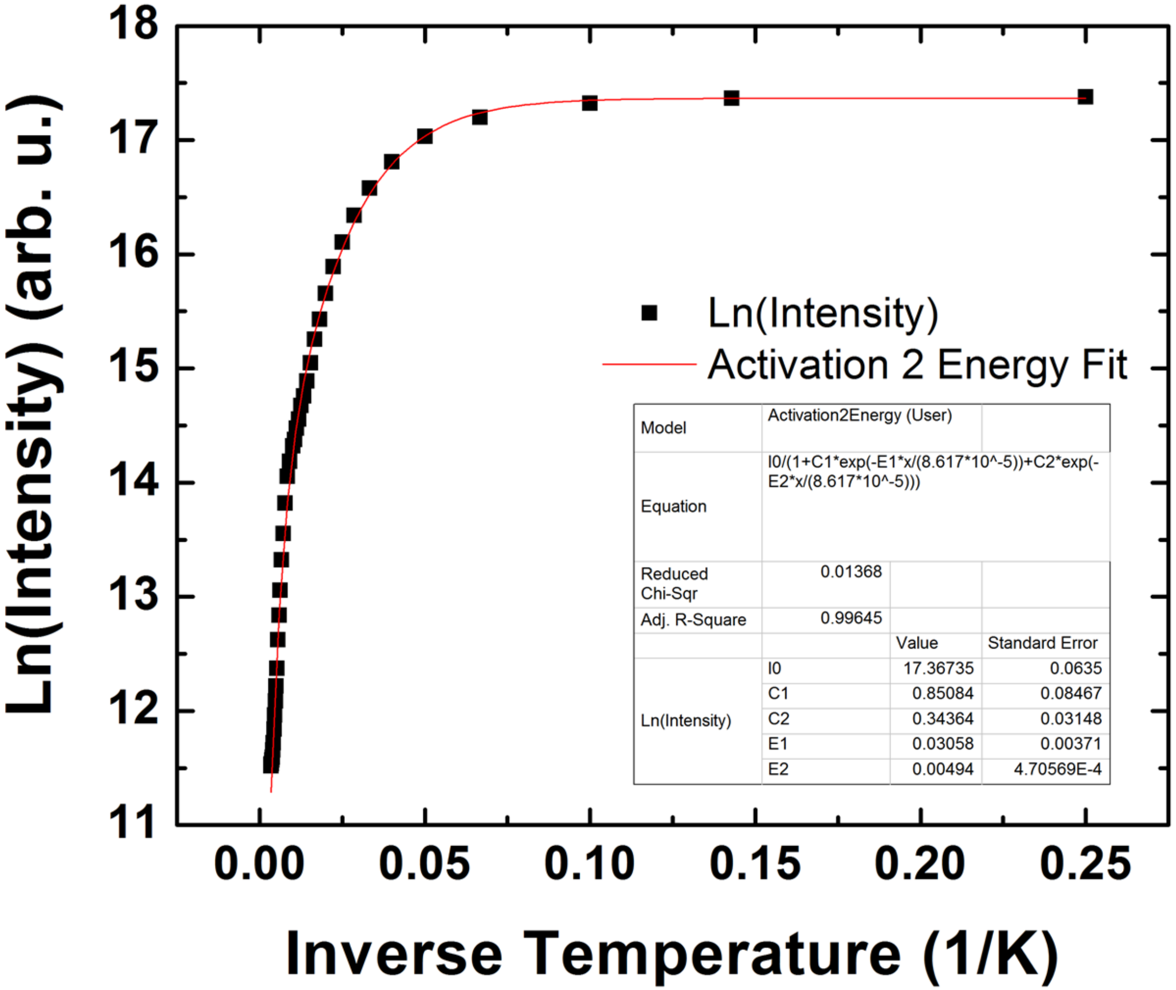
P-type – Peak Energy

- S-shaped dependence as observed in previous samples
- Shift in peak energy reflects shift in peak dominance at 55K



Activation Energy Fit – p-type

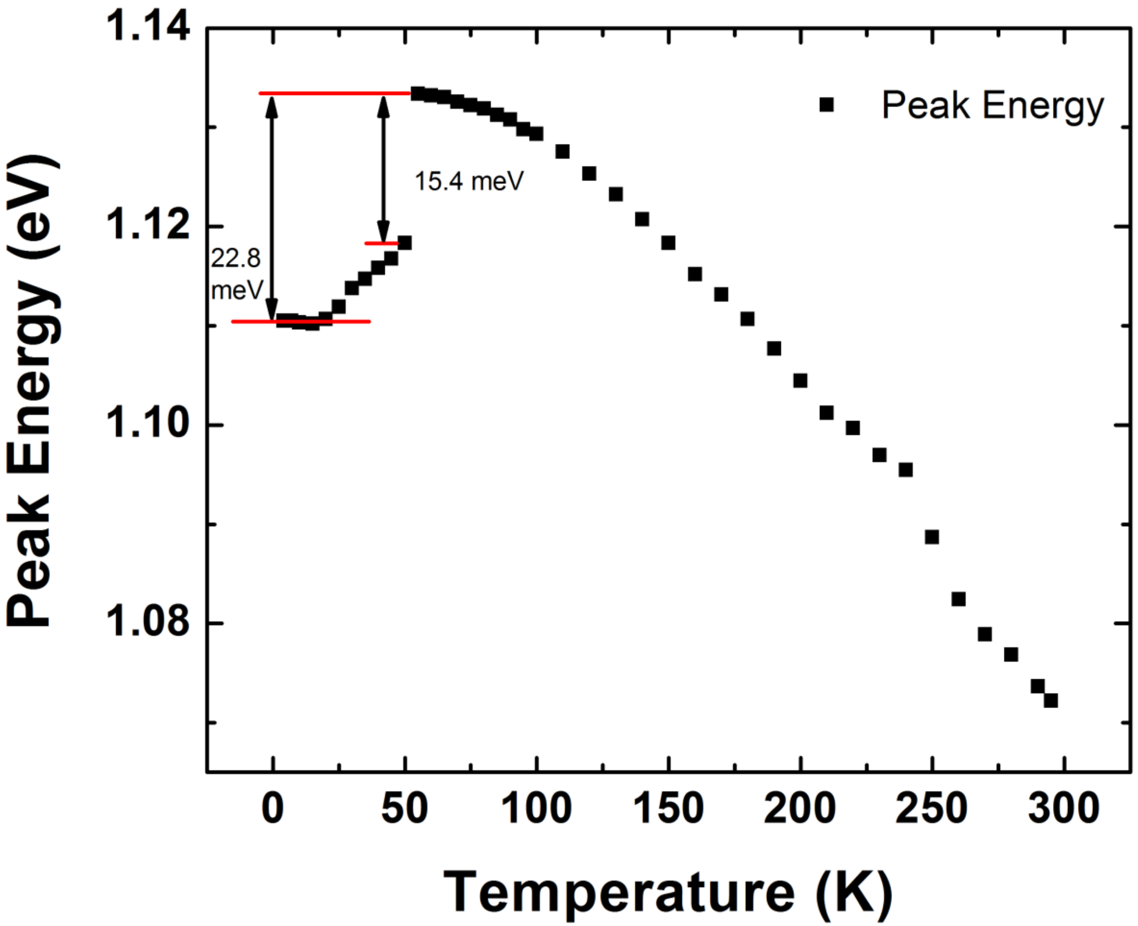
- $\frac{I_0}{1+C_1e^{-E_1x/(8.617\,*\,10^{-5})}+C_2e^{-E_2x/(8.617*10^{-5})}}$
- Two energies fit, 30.58 meV and 4.94 meV
- 4.94 meV translates to ~57 K



Model	Activation2Energy (User)		
Equation	I0/(1+C1*exp(-E1*x/(8.617*10^-5))+C2*exp(-E2*x/(8.617*10^-5)))		
Reduced Chi-Sqr	0.01368		
Adj. R-Square	0.99645		
		Value	Standard Error
Ln(Intensity)	I0	17.36735	0.0635
	C1	0.85084	0.08467
	C2	0.34364	0.03148
	E1	0.03058	0.00371
	E2	0.00494	4.70569E-4

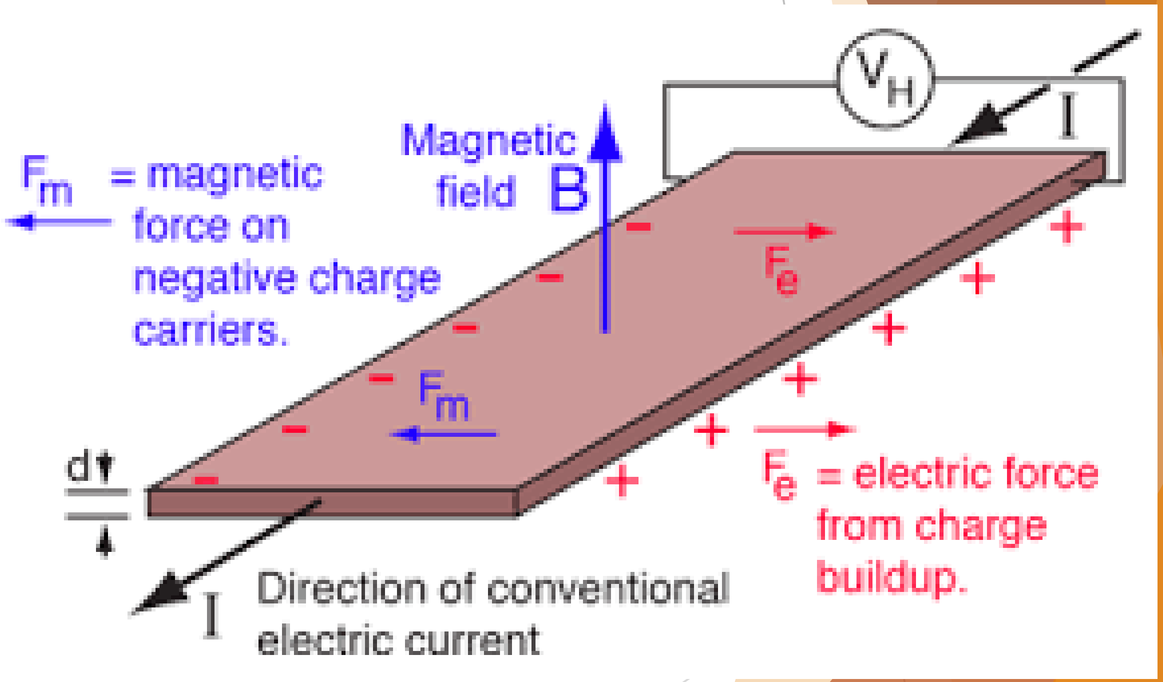
Activation Energy Fit – p-type

- $\frac{I_0}{1+C_1 e^{-E_1 x/(8.617 * 10^{-5})}+C_2 e^{-E_2 x/(8.617*10^{-5})}}$
- Two energies fit, 30.58 meV and 4.94 meV
- 4.94 meV translates to ~57 K
- Close to where peak energy transition occurs



Experimental Techniques - Hall Effect

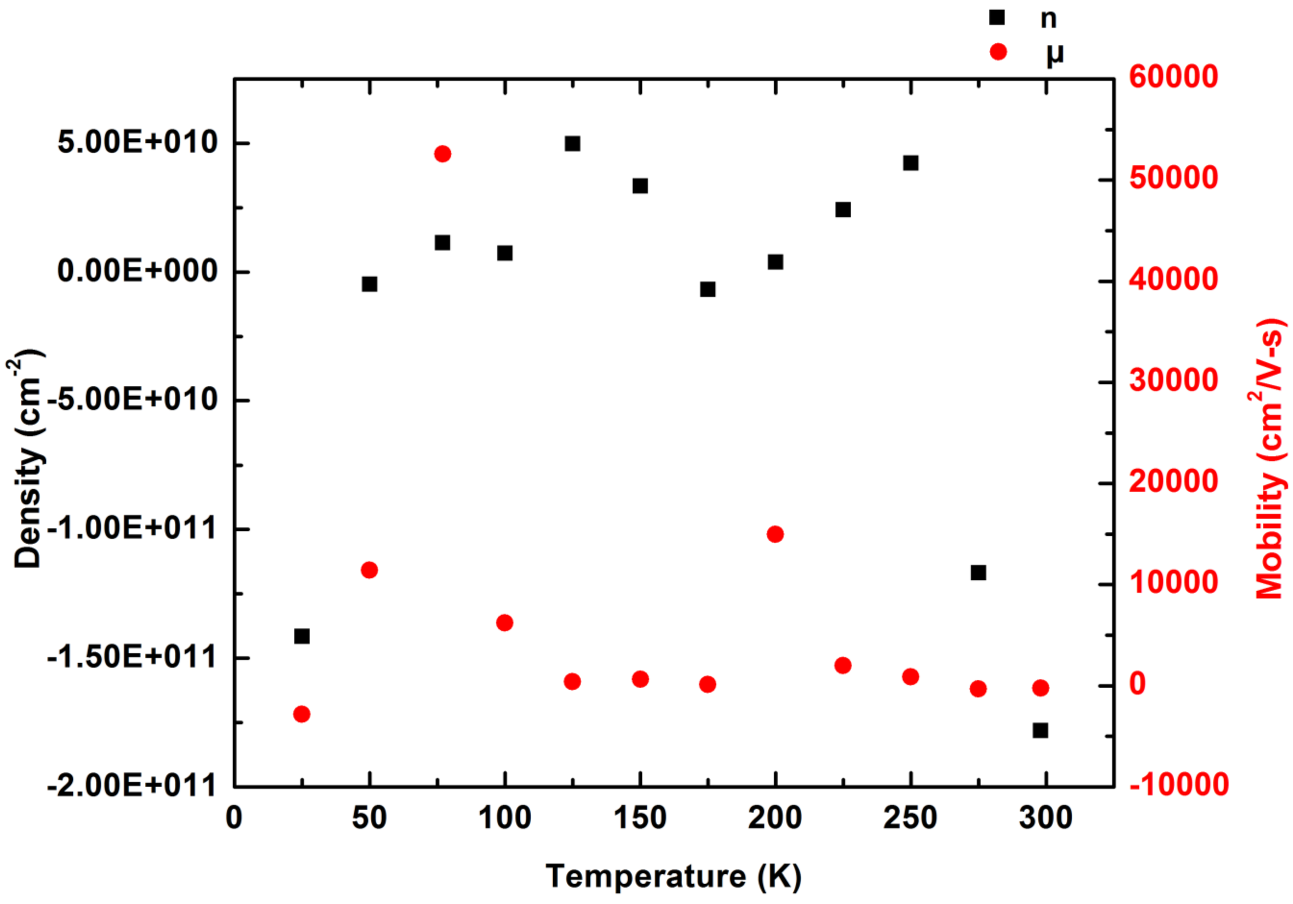
- Application of Lorentz Force
- Bends charge carriers in the semiconductor
- This then creates an electric field, in the transverse direction
- The electric field then produces the Hall Voltage



http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/Hall.html

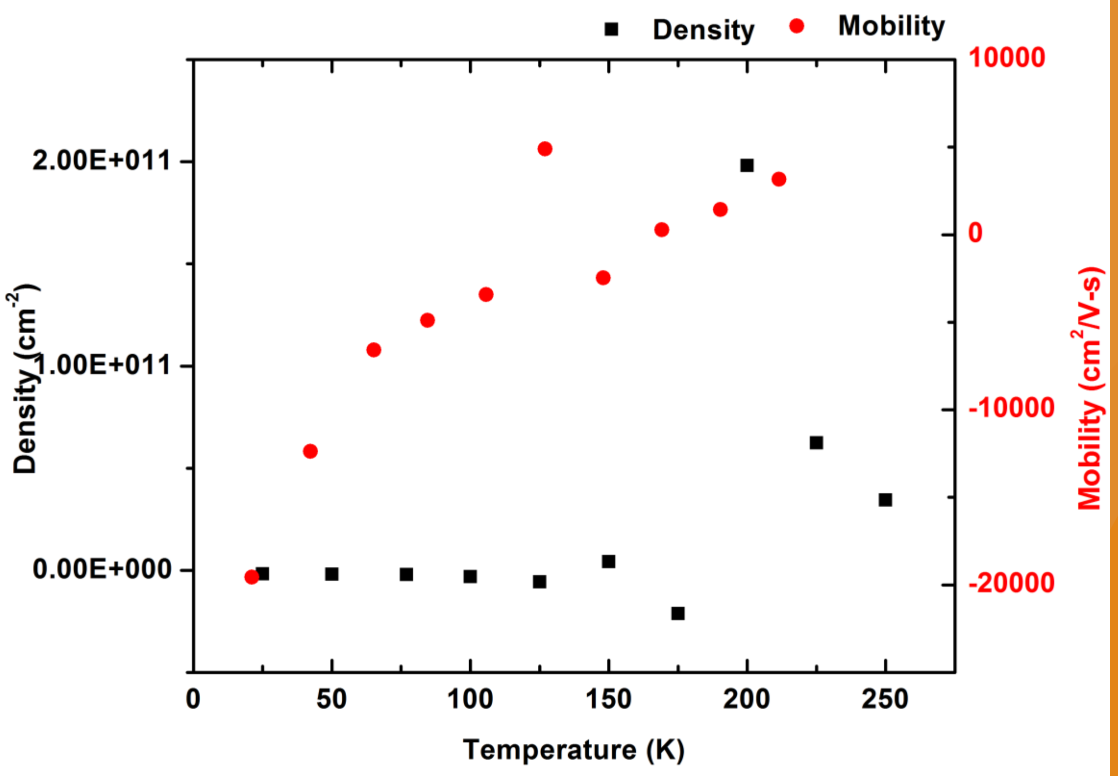
Intrinsic - Hall

- Negative density indicates p-type, positive n-type
- Hall signal is very noisy
- Think we are only probing surface



N-type - Hall

- Negative density indicates p-type, positive n-type
- Density appears to be zero due to large difference in order of magnitudes
- Hall signal is very noisy
- Think we are only probing surface



Future Plans

- Etch cap off of samples and perform Hall measurements
- Perform PL and Hall measurements on hydrogenated samples
- Compare to find hydrogenation’s effect on electrical properties