Characterization of quantum confinement in GaAs using photoluminescence spectroscopy

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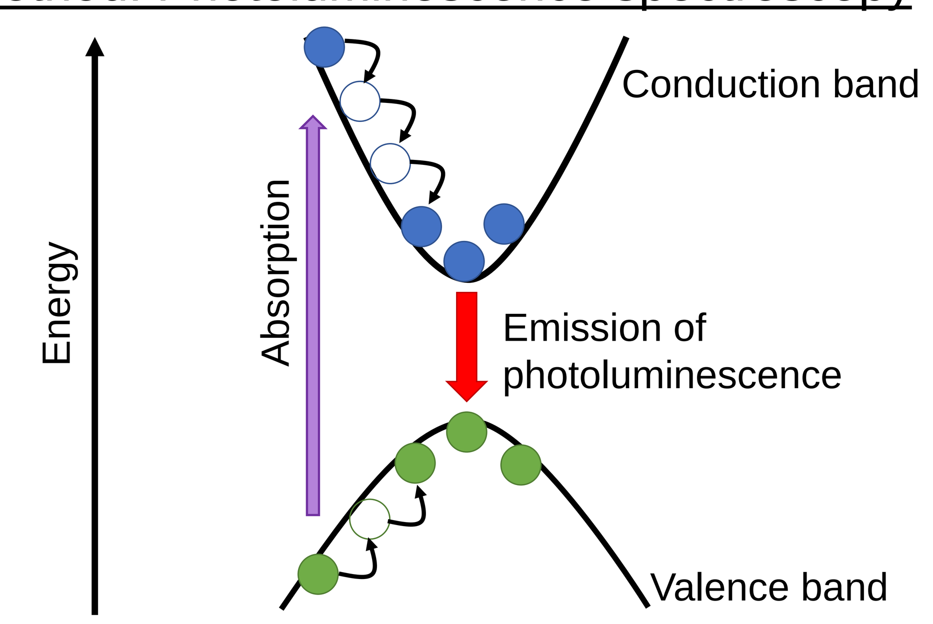
Introduction

- Semiconductors play an important role in many solid state devices including integrated circuits and solar cells.
- To improve performance and tunability, the first step is reliable characterization.
- One tunable parameter is sample thickness.

Method: Photoluminescence spectroscopy



Quantum confinement

- Occurs when the scale of the sample is comparable to that of the de Broglie wavelength of the electrons $\lambda = h/p$.
- As dimensions decrease, the energy of the possible electron states increases.
- Particle in a box model: $E \propto (n/L)^2$ for n, an integer and L, the dimension of the space.

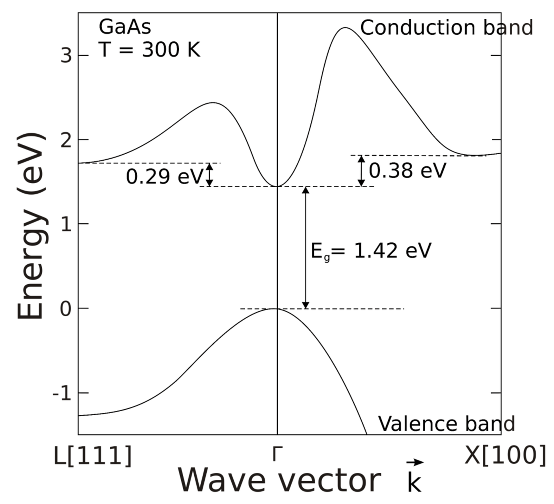
Why GaAs?

- Direct bandgap semiconductor for efficient emission of photoluminescence
- AlGaAs/GaAs heterostructures can be grown to isolate thin GaAs layers: quantum wells.

Sample comparison

3-D: Pure bulk GaAs

300 μm thick



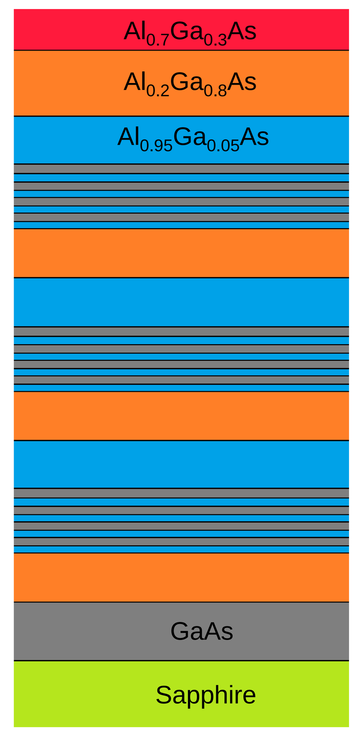
2-D: GaAs quantum well

$Al_{0.7}Ga_{0.3}As$ (etched away)

$Al_{0.2}Ga_{0.8}As$	56 nm
$Al_{0.95}Ga_{0.05}As$	40 nm
GaAs	7 nm
$Al_{0.95}Ga_{0.05}As$	3 nm
$Al_{0.2}Ga_{0.8}As$	40 nm

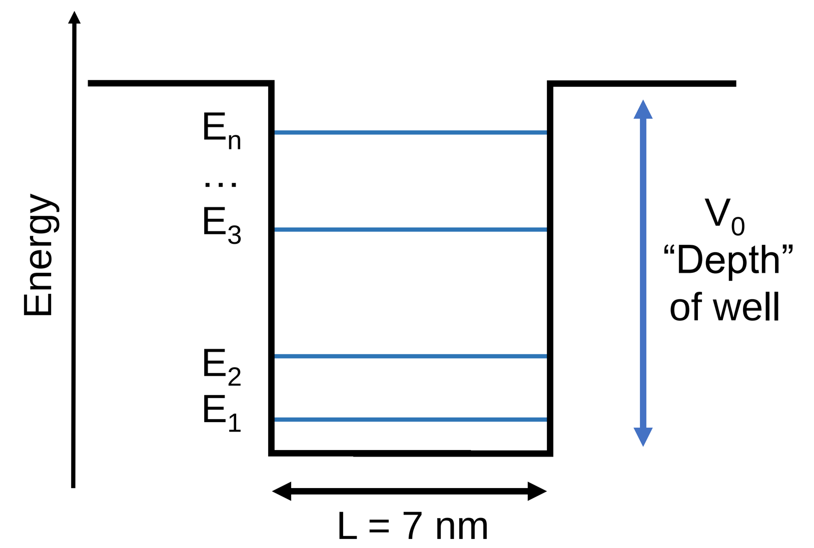
×4 ×3

GaAs substrate, mounted on sapphire



Results

Photoluminescence collected at room temperature

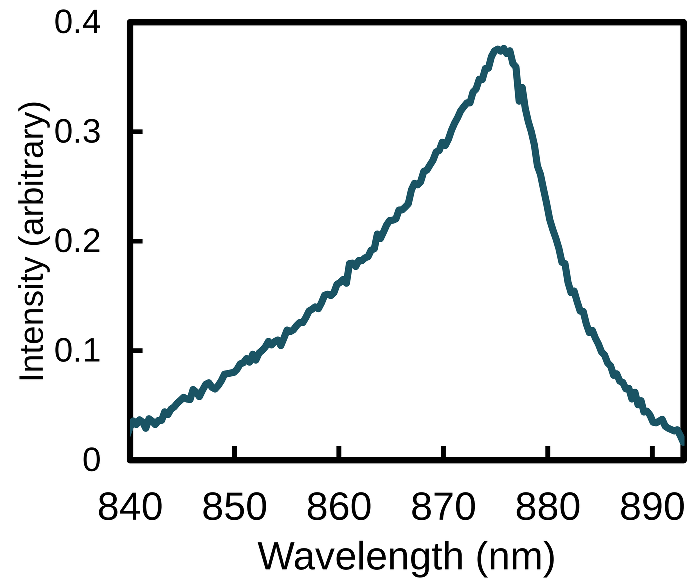


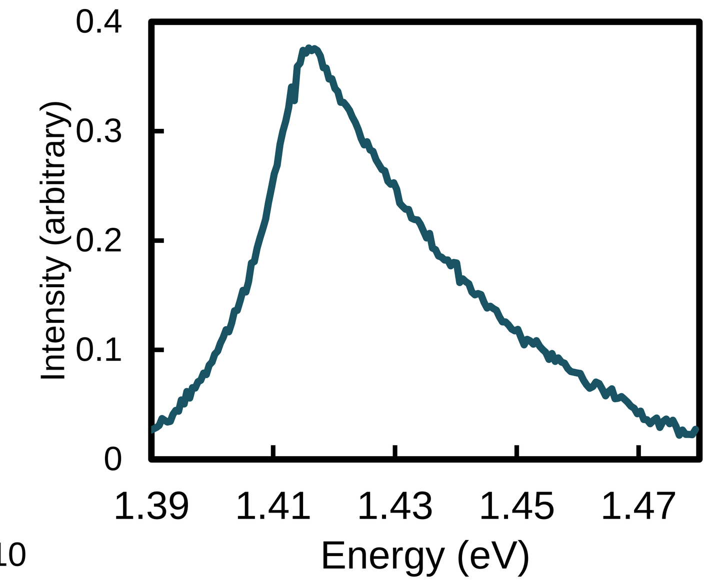
- Discrete energy levels E_j in quantum well
- Approximation: $V_0 = \infty$
- Ground state energy E_1 is increased by ΔE relative to unconfined ground state, with

$$\Delta E = \frac{\hbar^2}{2m^*}\left(\frac{\pi}{L}\right)^2 = 0.12\ \text{eV} \quad [1]$$

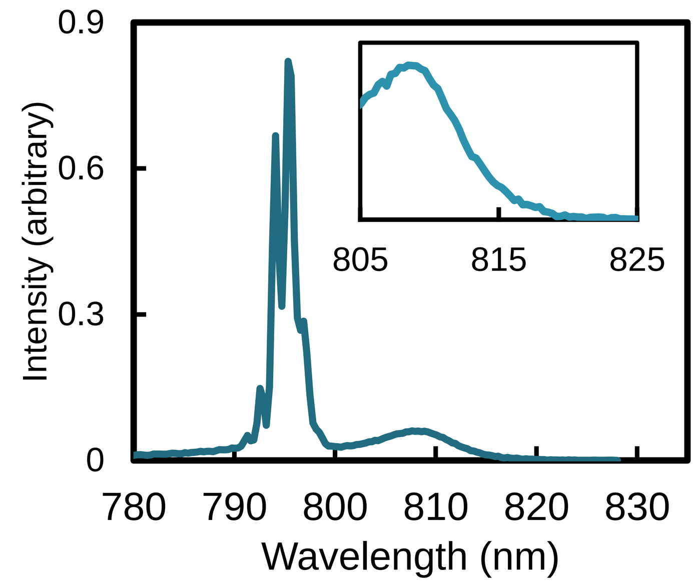
where $m^* = 0.063m_0$ is the effective mass of a confined electron.

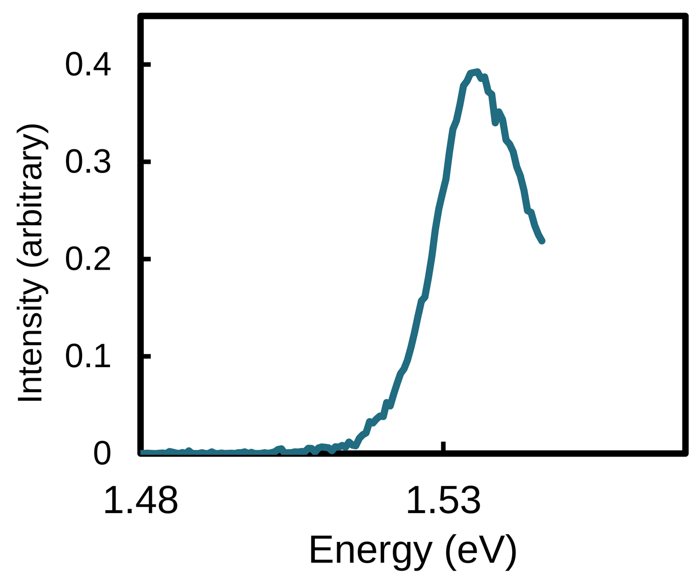
3-D Excitation beam: 80 mW @ λ = 820 nm, Resolution Δλ = 0.3 nm





2-D Excitation beam: 9 mW @ λ = 785 nm, Resolution Δλ = 0.4 nm

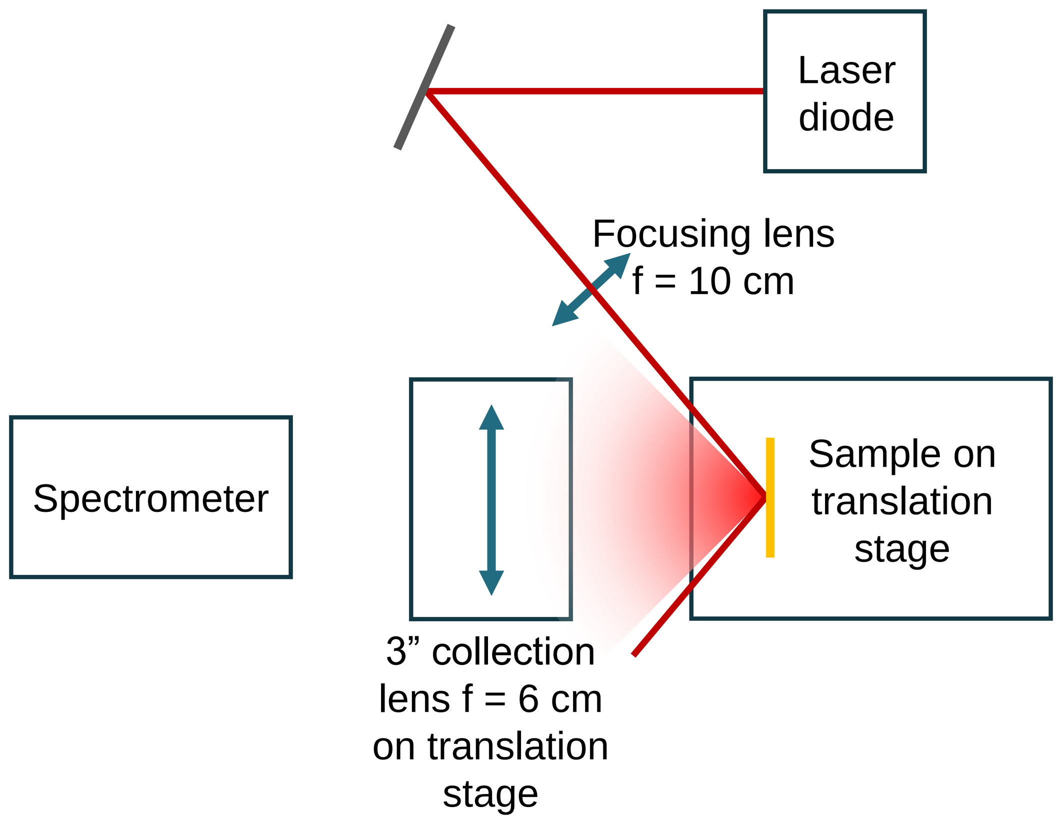


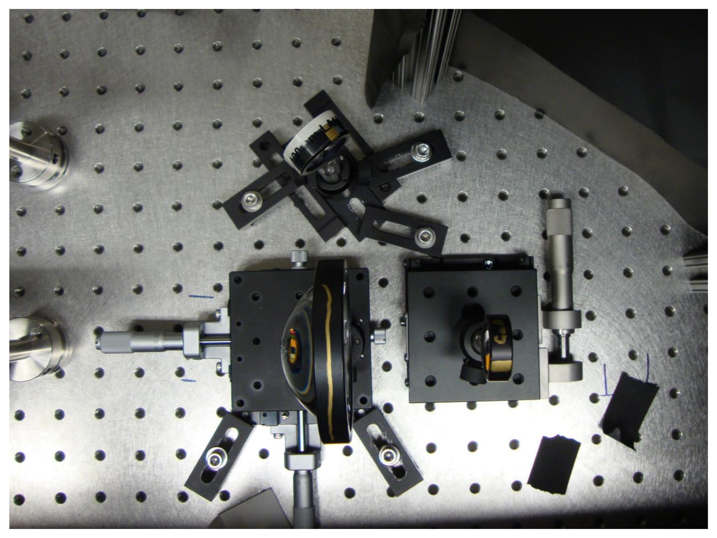


[1] M. Cardona, P. Yu, *Fundamentals of Semiconductors*, Springer, 2010

Experiment

- Sample is excited using a laser diode
- Photoluminescence and scattered diode light are collected using a 3" lens and spectrally resolved





Conclusion and future research

At room temperature, bandgap shifts from 1.42 eV to 1.54 eV due to quantum confinement. This agrees with the infinite potential well model.

Future projects

- Investigate temperature dependence of bandgap in 2-D and 3-D samples.
- Perform measurements at cryogenic temperatures to observe electron-hole pairs known as excitons
- Use existing set-up to characterize new samples

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