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Optical Characterization of Gallium Arsenide Quantum Dots

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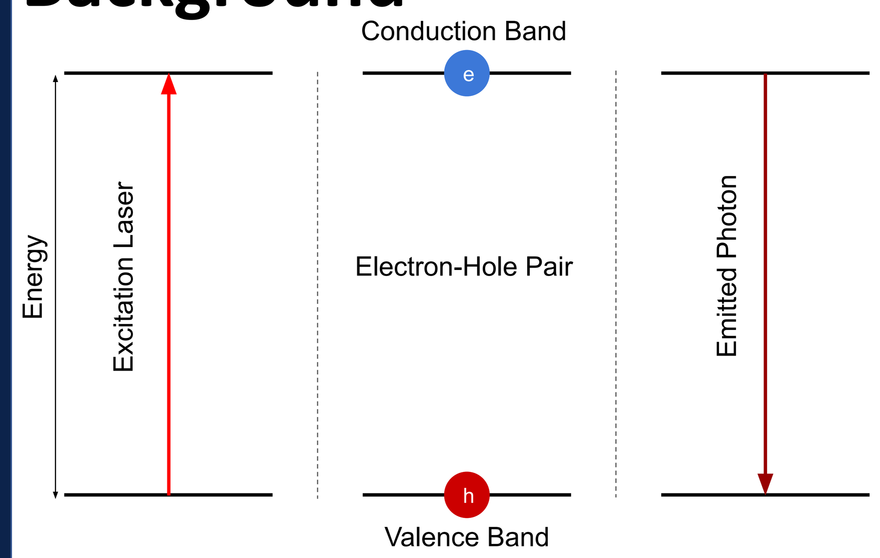
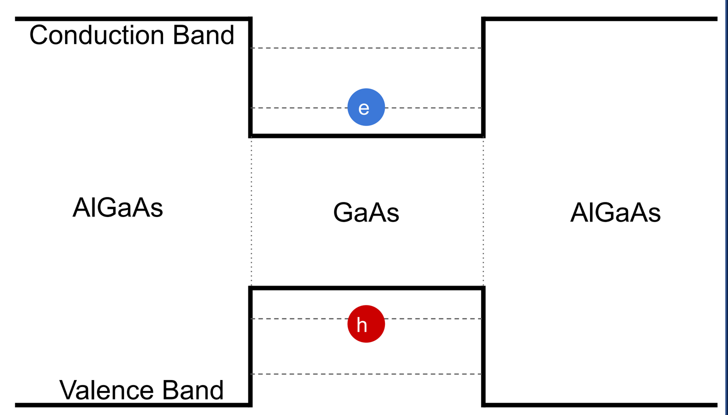
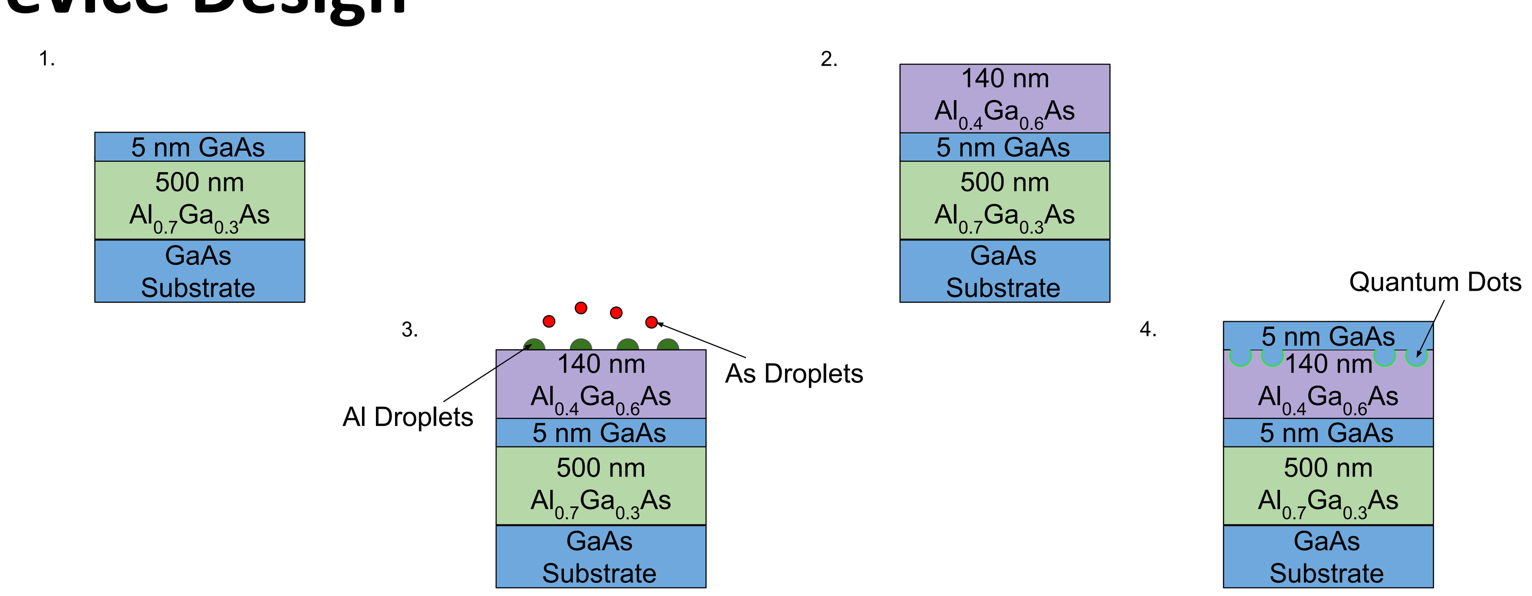
Background





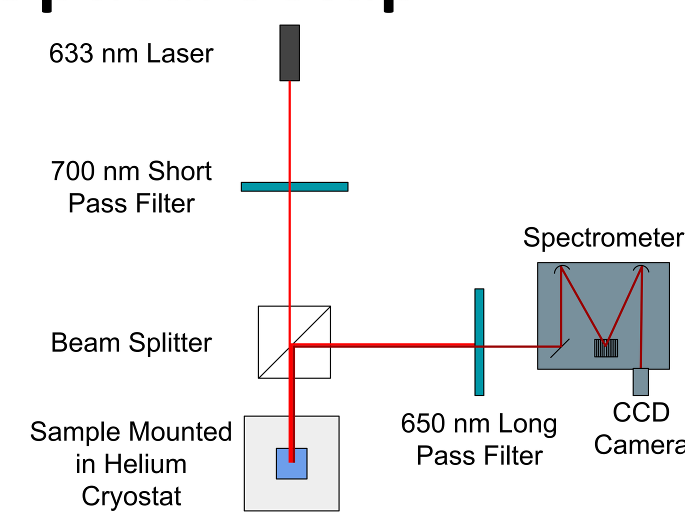
- An excitation laser can be used to move a two-level system to an excited state.
- When this occurs, an electron-hole pair is formed.
- The electron occupies the conduction band, and the hole occupies the valence band.
- The system quickly decays back to the ground state releasing its stored energy as a photon.
- Photons formed in this way are called exciton emissions.
- Gallium Arsenide (GaAs) Quantum Dots are semiconductor devices made using GaAs and Aluminum Gallium Arsenide (AlGaAs).
- The band gap difference between the AlGasAs and GaAs creates low-energy, trapped electron states.
- These states are similar to two-level systems allowing for the creation of single photons.
- An important first step for optical characterization of quantum dots is photoluminescence spectroscopy (PL).
- This technique measures the energies of emitted photons, and allows us to select suitable samples for future measurements.

Device Design



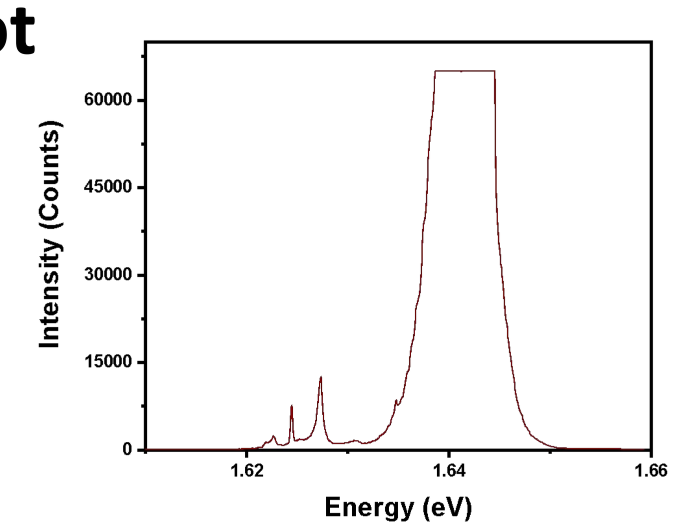
- 500 nm of AlGaAs, made up of 0.7 Aluminium (Al) and 0.3 Gallium (Ga), was grown on a GaAs substrate and capped by a 5 nm layer of GaAs.
- A 140 nm AlGaAs layer, made up of 0.4 Al and 0.6 Ga, was grown on the GaAs cap.
- Al droplets were deposited on the device, and Arsenic (As) droplets were sprayed onto the Al.
- As a result, small holes, called nanoholes were drilled. These nanoholes were filled with a 5 nm top layer of GaAs, creating GaAs quantum dots.
- Varying growth conditions changed the energies of photons emitted by the quantum dots.
- All samples were fabricated at Sandia National Laboratories by Sadhvikas Addamane

Optical Setup



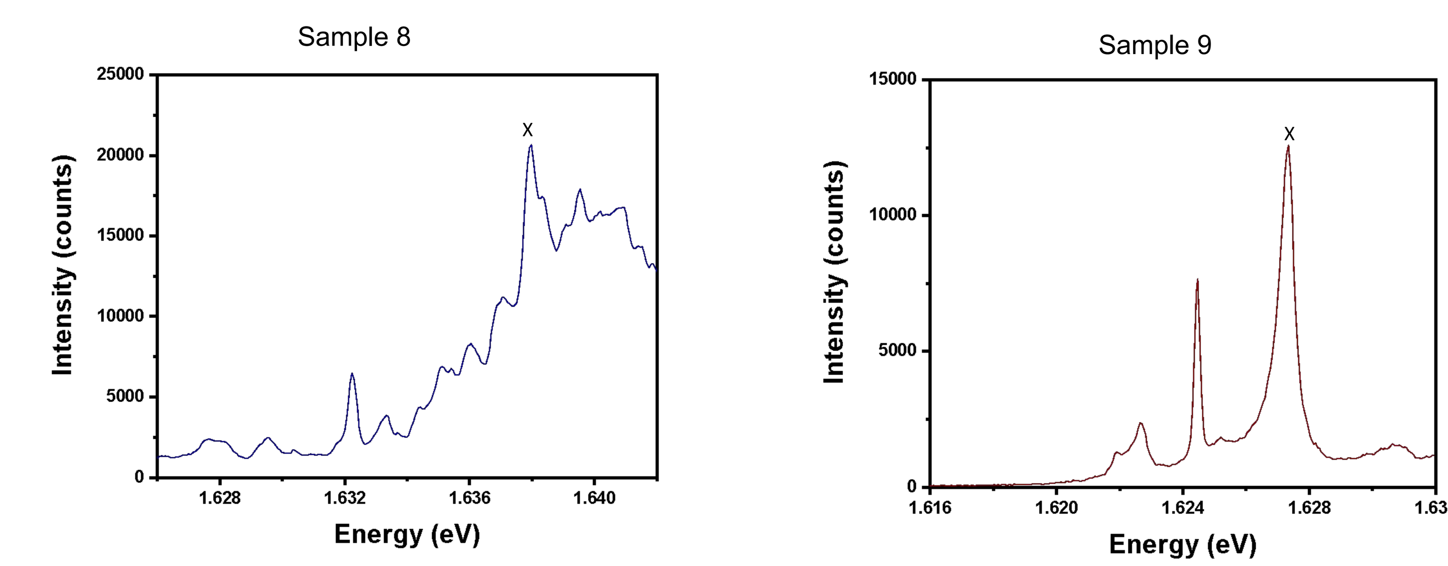
- Samples were held at 9 K in a helium cryostat and were excited by a red (633 nm) laser.
- The laser was passed through a 700 nm short pass filter before reaching and exciting the sample.
- The excitation signal and reflected laser were directed by a beam splitter through a 650 nm long pass filter, which blocked the reflected laser light.
- The signal passed through the filter and into a spectrometer, which used a charge coupled device (CCD) camera to measure the emission energies.

Photoluminescence Spectrum From Single Quantum Dot



- A photoluminescence spectrum taken from a single quantum dot.
- The high intensity peak centered at 1.64 eV corresponds to the quantum well created by the 5 nm GaAs layer.
- The lower intensity peaks with lower energy are emissions from the quantum dot.

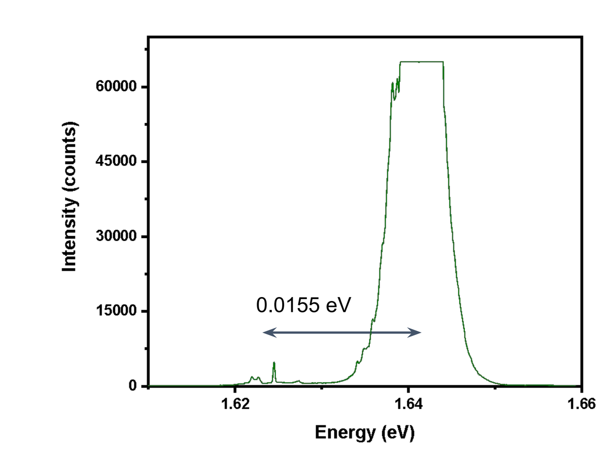
Emission Peaks



- Photoluminescence data was collected from several quantum dots across two samples: sample 8 and sample 9.
- Exciton emissions were identified as high intensity peaks, labeled X. Lower intensity peaks correspond to charged exciton emissions.
- Sample 8 had exciton emissions with an average energy of 1.6323 ± 0.0032 eV, and Sample 9 had exciton emissions with an average energy of 1.6267 ± 0.0016 eV.

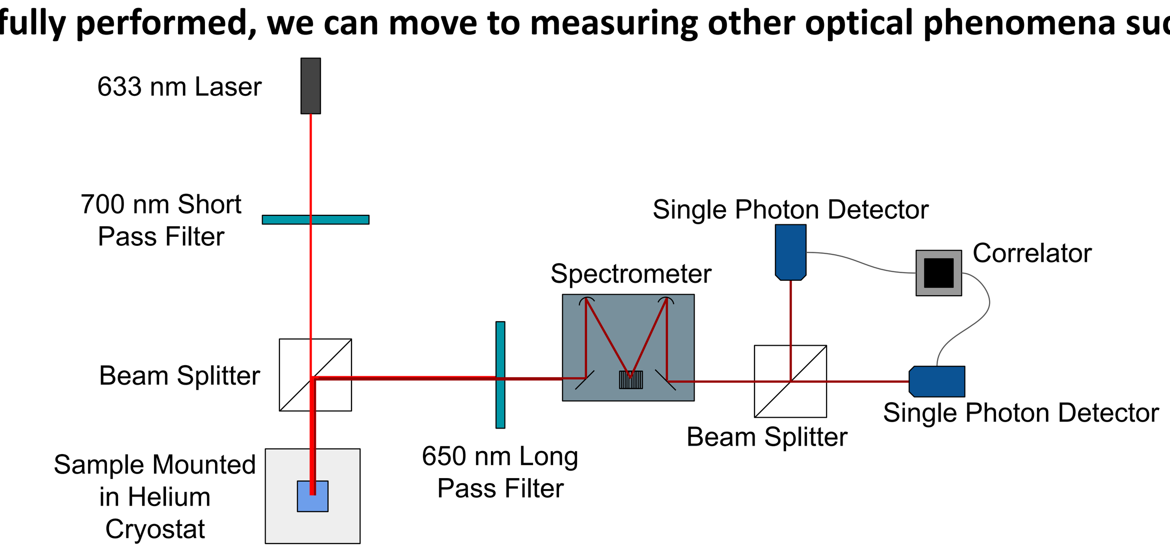
Conclusions

- Sample 9 hosted quantum dots whose exciton emissions had significantly lower energy than those of sample 8.
- This means that the emissions from quantum dots on sample 9 are separated from the high intensity quantum well.
- Therefore, future measurements should be performed on these quantum dots.



Future Directions

- The immediate next step is to perform an antibunching measurements on quantum dots from sample 9 to determine if these quantum dots emit a single photon per excitation cycle.
- These measurements employ a similar optical setup to photoluminescence measurements, but after reaching the spectrometer, emissions from quantum dots are split into two time correlated single photon detectors.
- If the probability of both detectors firing at the same time is measured to be 0, then these quantum dots are single photon emitters.
- After antibunching measurements are successfully performed, we can move to measuring other optical phenomena such as Rabi oscillations or the Hong-Oh-Mandel effect.



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