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Colloidal Quantum Dot Based, Plasmon Assisted, Nanoscale Laser

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Abstract

The goal of this project is to study the behavior of a quantum confined semiconductor material in the presence of a plasmonic nanostructure. CdSe/CdS "Giant" quantum dots (g-QDs) have been optically characterized and placed within an engineered resonant plasmonic structure. Spectral narrowing and photoluminescence (PL) modulation has been observed from this device. With further cavity refinement, we expect to demonstrate a low power laser with a tunable spectrum.

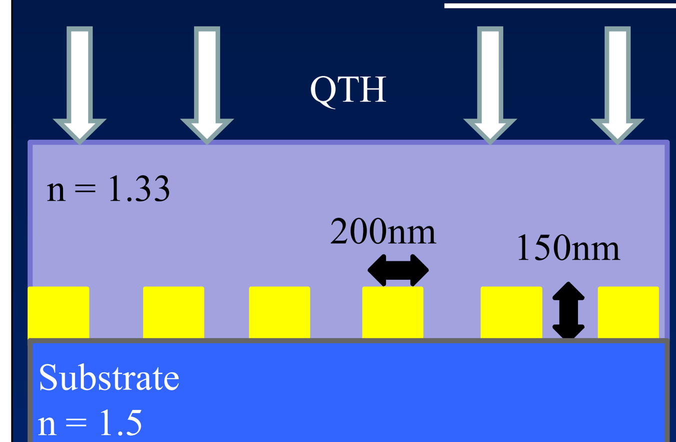
Introduction

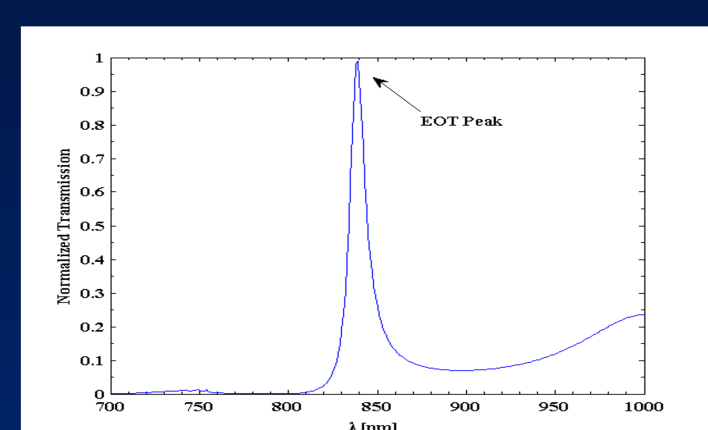
Quantum dots have many unique properties such as:

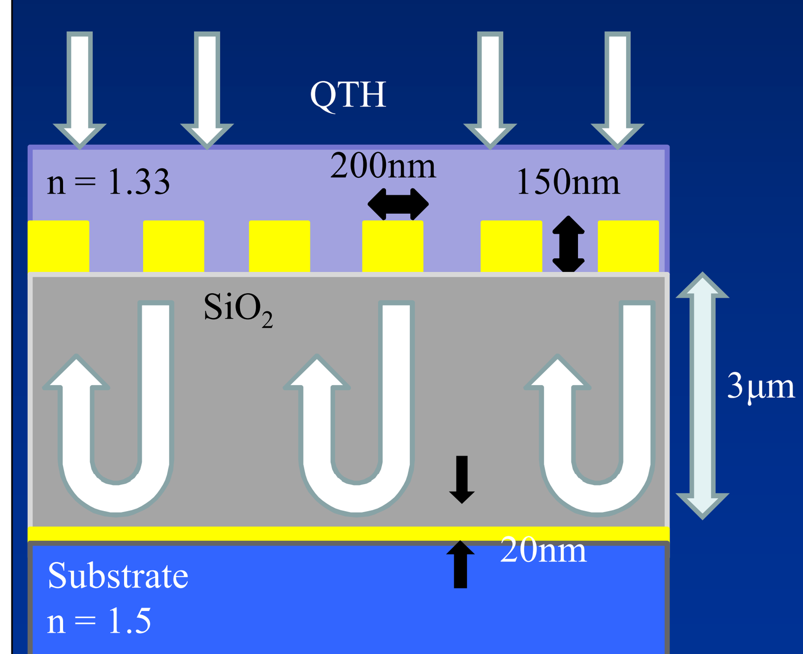
- atomic-like spectra
- ultrahigh charge carrier concentrations
- wide spectral tunability

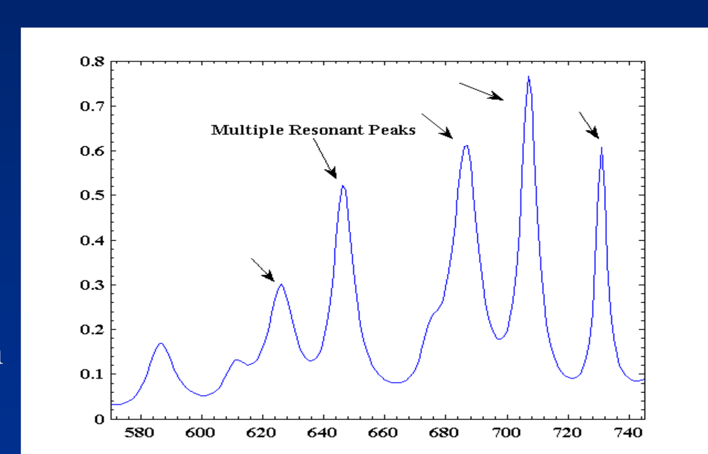
To fully explore these properties, the dynamics of photon-quantum dot interactions in sub-diffraction limit resonant cavities. Light concentration below the diffraction limit is extremely difficult in traditional optical systems. However, nanoscale plasmonic devices have demonstrated this sort of extreme light concentration. Integrating g-QDs into a stable, sub-diffraction plasmonic resonator is a step towards better understanding light-matter interactions in the nanoscale.

Previous Work







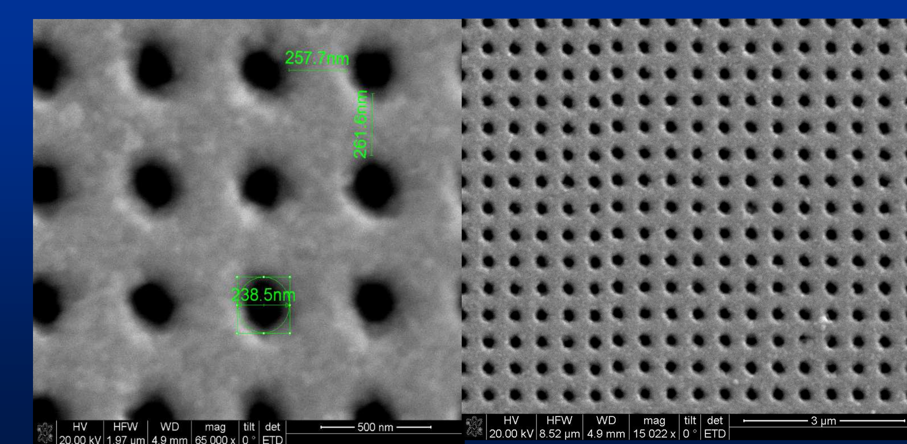


The top device produces an expected peak at 840 nm. This peak indicates extraordinary optical transmission (EOT). However, when this structure is coupled to a dielectric cavity we observe resonant behavior as one would expect from a Fabry-Perot cavity. We theorize the existence of a hybrid plasmonic resonant mode within the coupled structure.

Fabrication

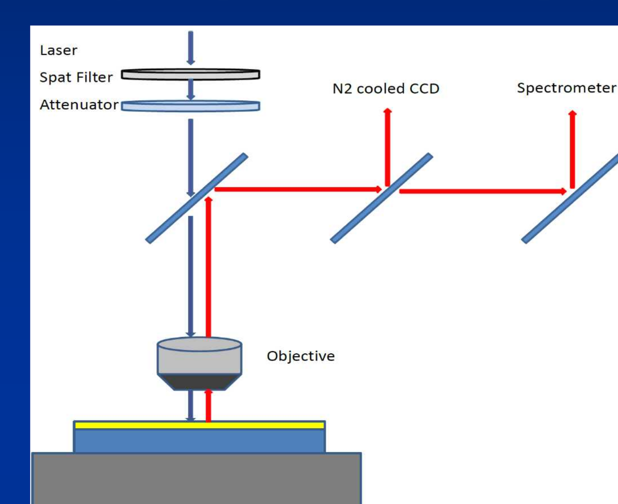
The periodic grating was fabricated using Focused Ion Beam (FIB) milling to create a nanohole array. The final device was achieved through the following:

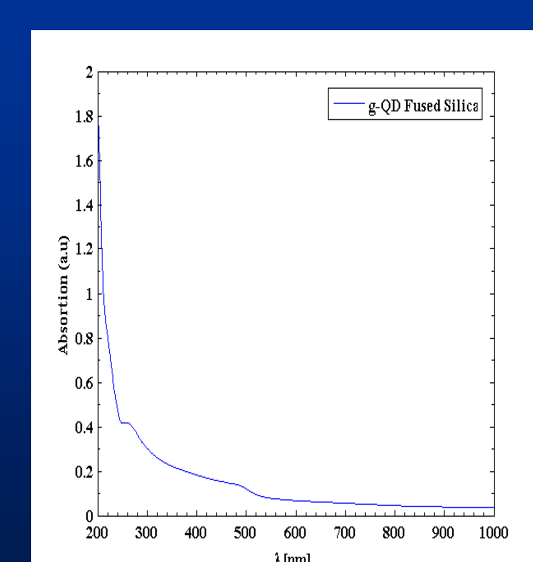
1. 50 Å of Titanium and 1500 Å Gold is evaporated onto the surface of a glass substrate to form a metallic film.
2. The nanohole array was milled into the metallic surface.
3. G-QDs were dissolved in chlorobenzene and mixed with poly(methyl methacrylate) (PMMA) 495 c6 from Microchem. This was then spin-coated at 1000 rpms on the Gold layer creating a quantum dot doped polymer layer.
4. The device was then baked at 110C for 15 minutes to hard bake the polymer.
5. 50 Å of Titanium and 200 Å Gold was evaporated onto the surface to form the top metallic film.



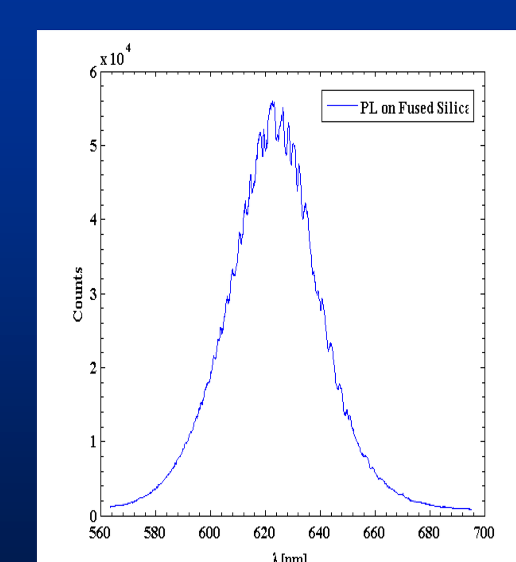
Optical Characterization

In order to observe the contribution of the nanohole array, two devices were fabricated. One was patterned with a nanohole array and the other was not patterned. Resulting PL spectra was experimentally collected via the setup below. Absorption data was collected from a UV-VIS spectrometer (need model#). Both devices show spectral narrowing of the full-width half-max (FWHM) of approximately 10nm although the patterned device displayed a stronger PL modulation.



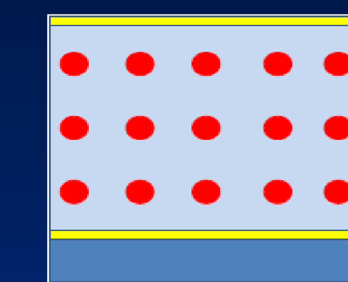


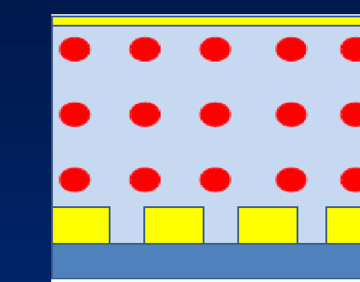
Absorption of g-QDs on fused silica.

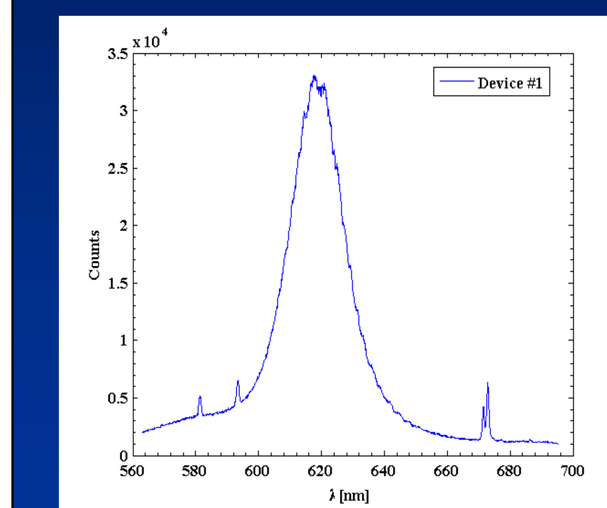


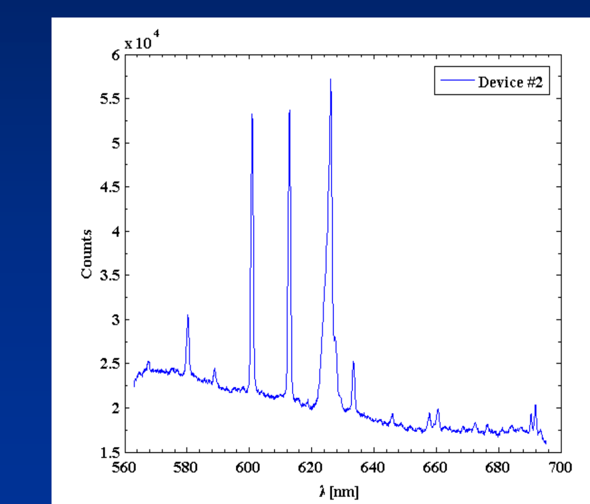
PL of g-QDs on fused silica.

Results



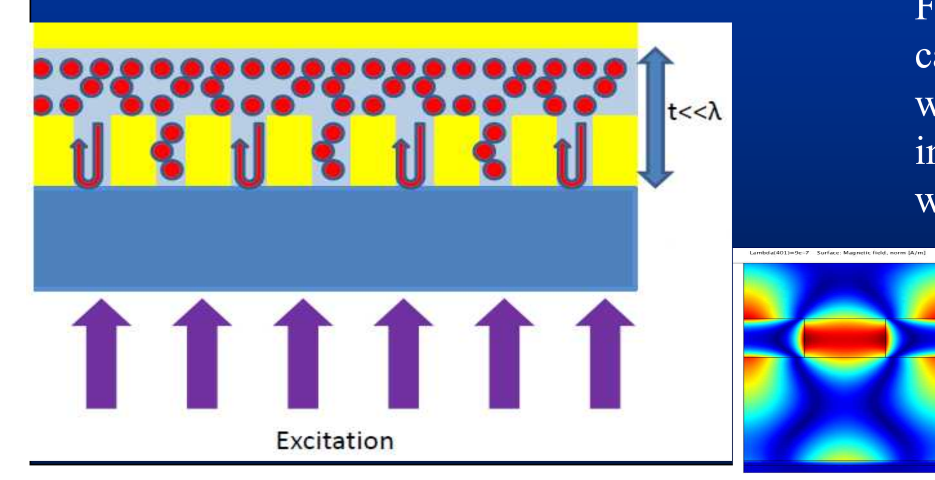






Strong PL modulation is observed when g-QDs interact with the nanohole array device. This is attributed to the unique spectral properties of the hybrid plasmon mode.

Future Work



Further optimization of a plasmonic cavity much smaller than the emitted wavelength continues. Simulations indicate a high field concentration within this type of cavity.

Summary

- We have integrated g-QDs into a plasmonic cavity by dispersing quantum dots in PMMA.
- Experimental results show spectral narrowing and modulation of the PL signal.
- Further optimization of the plasmonic cavity is required to achieve lasing in a sub-diffraction limit scale cavity. At this time, simulation results are encouraging.

Affiliation

Jayson Briscoe, PhD Candidate – Klipsch School of Electrical Engineering, New Mexico State University. Expected graduation date: 8/2013. Presentation date – 08/02/2012

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