UNIVERSITY OF NOTRE DAME
NDnano
CENTER FOR NANO SCIENCE AND TECHNOLOGY

ND*nano* Undergraduate Research Fellowship (NURF)
2012 Project Summary

Student name: Kyle McCall
Faculty mentor name: Professor Alexander Mintairov
Project title: Emission Dynamics of Electronic Molecules

Briefly describe any new skills you acquired during your summer research:
I took photoluminescence measurements of various kinds, including controlling the temperature of the system and placing a voltage on the sample. I measured the emission dynamics of quantum dots using time-resolved fluorescence, which examined how the photo-excitation signals from the quantum dots decayed in time. I worked on pulling and setting up fibers with tuning forks suitable for near-field scanning optical microscopy (NSOM). I used these to study the topography and NSOM images of a quantum dot sample and some optical cavity samples. I learned basic Matlab programming and how to create reports in LaTeX. I took the Physics machine shop safety course so I can use the shop, and I also took the cleanroom training and learned to safely use the HF fume hood.

Please briefly share a practical application/end use of your research:
The fundamental understanding of these quantum dots will allow us to better understand the capabilities of such systems, one possible application would be the identification of states suitable for quantum computing using the electrons confined in the dots.

Begin two-paragraph project summary here:

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Quantum dots (QDs) are semiconductor structures which allow confined electrons and form a platform for various nano-electronics and nano-optics applications. This means that the electrons in QDs are bound together and that they interact in a way similar to the behavior of atomic nuclei in a molecule. This confinement and the Pauli Exclusion Principle mean that the energy levels of the electrons in a particular quantum dot are quantized, which gives us a way of studying the structure using the energy levels of the electrons. These energy levels can be determined using photoexcitation, so photoluminescence measurements give a way to study these systems. The long-term goal of the lab is to use the photoluminescence measurements and near-field scanning optical microscopy to analyze the structure and states of individual quantum dots, which would then lead to a better understanding of this system and the interactions of the bound electrons. This summer's project goal was to lay the groundwork for such analysis, taking many kinds of measurements with the current set of samples to decide which ones to study further and better understand what sort of data to expect from each type of measurement.

I started by taking a series of photoluminescence measurements of our 17 samples at both cold (liquid helium-cooled) and warm temperatures. These measurements were base measurements, meant to introduce the lab set-up to me and to identify the most promising samples for further analysis. I then collaborated with Prof. Mintairov's graduate student James Kapaldo to help him write a graphical user interface (GUI) in Matlab which would collect the data and give specific options for viewing, analyzing and comparing the spectra collected. James processed one of the best samples so that contacts could be placed on its surface and underside. This allowed for a voltage bias to be applied to the sample to analyze how the spectra changed under a potential, and we took cold measurements of the sample varying the bias. The spectra became stronger under positive bias, and decayed with negative potential, which corresponds to increasing and decreasing the energy and number of electrons in the QDs. This sample was also used to take temperature-dependent measurements, which showed that the thermal energy of the substrate interfered with the electrons in the dots, and the signal decayed as temperature increased. Time-resolved fluorescence measurements of this sample were also taken at cold temperature, which gave a first look at how the emission signal from the QDs decayed in time from a pulsed laser. I took the physics machine shop safety course and can now use the shop to make parts for the lab, and I also took cleanroom training with the HF hood to etch some fibers for a collaborator of Prof Mintairov's. I practiced pulling fibers to get good tips and gluing tuning forks and fibers for use in NSOM measurements, and worked on using the

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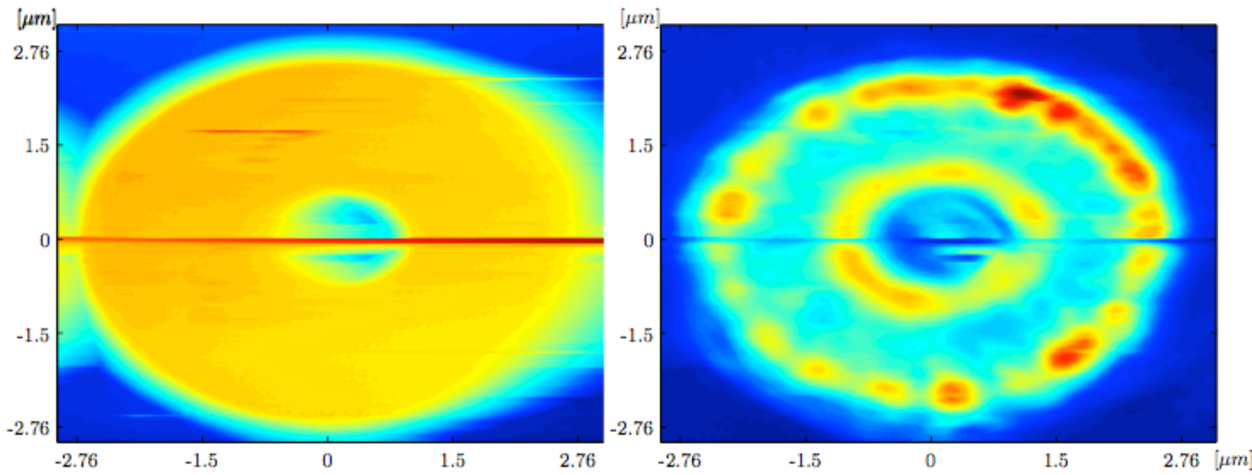
microcontroller to safely approach the samples without crashing the fiber tip. The NSOM set-up yields micro-photoluminescence measurements as well as topographical data, and the software also combines the two signals using a germanium detector to get a surface map of the spectral signal strength for a given wavelength. I took these kinds of measurements for one of our quantum dot samples, as well as a sample of optical cavities which is being studied for its whispering gallery modes.



(a) Topography

(b) NSOM

The image on the left is a topographical view of an optical cavity, and the right image is an NSOM image of the same sample, showing where the intensity of the photoexcitation signal was greatest. The colors are relative heights in (a) and relative intensity in (b), where red is high and blue is low.

Publications (papers/posters/presentations): I have written a longer summary report of my work this summer, with example data for each measurement and more detail about the lab set-up, which can be requested at kmccall2@nd.edu.