NDnano Undergraduate Research Fellowship (NURF)
2014 Project Summary

1. **Student name**: Anuj Kumar

2. **Faculty mentor name**: Prof. Alexander Mintairov

3. **Project title**: Simulations of InP/AlInAs quantum dot band structures, and the stabilization and optimization of laser power using feedback control system

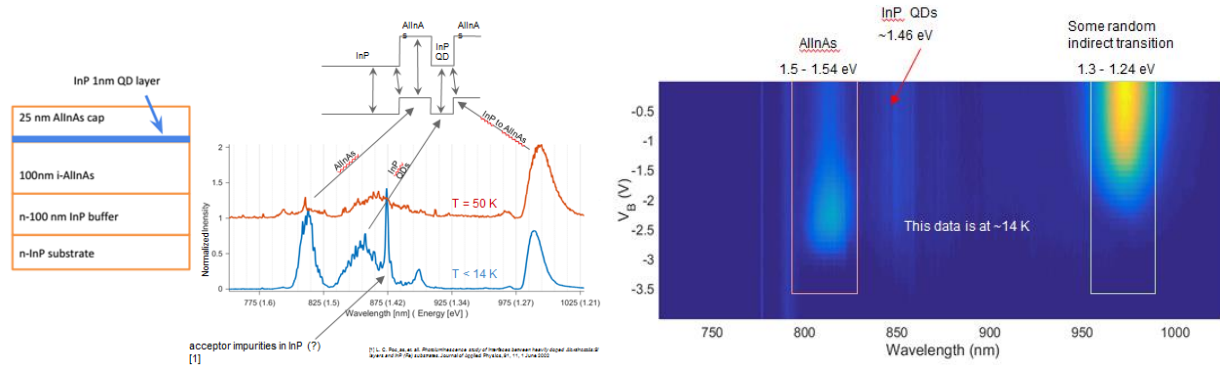4. **Briefly describe any new skills you acquired during your summer research**:
I learnt how to measure the temperature dependent susceptibility and Hall mobility of semiconductor heterostructures; I learnt how to establish high vacuum conditions for 4 K temperature measurements; and I learnt how to use *nextnanomat* software for the simulation of quantum-dot band structures simulations, as well as how to attribute those ideal simulations to real-world experiment values. For the stabilization and optimization of the laser output power, I learnt how to program a Raspberry Pi in Python/C and link it to a computer running LabVIEW. In addition, I became adept at programming in MATLAB, Python, and LabVIEW.

5. **Briefly share a practical application/end use of your research**:
The fundamental understanding of the quantum dots (QDs) in our samples will allow us to better understand the capabilities of such systems, one such application being the identification of states suitable for quantum computing using the electrons confined in the dots. Also, optimizing the power output of the laser will help towards reducing errors, and understanding these systems better.
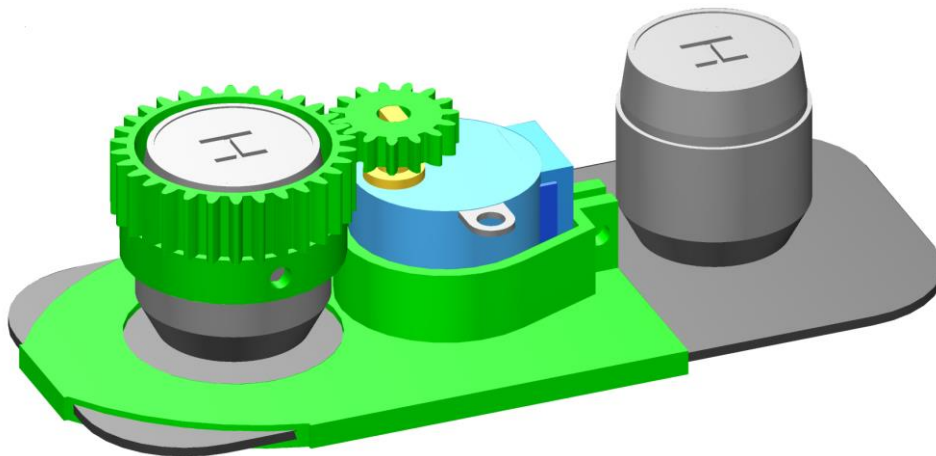
Begin two-paragraph project summary here:
A QD is a zero-dimensional semiconductor that is small enough to exhibit quantum mechanical phenomena. The electronic properties of these materials are intermediate between those of bulk semiconductors and of discrete molecules; this means that the electrons in a QD have discrete energy levels, and bind in a way similar to that of atomic nuclei in a molecule. The Nano-Optics lab group had already measured the experimental photoluminescence emission spectra of their QDs at various temperatures. My primary goal was to use the software packages *nextnanomat* and Prof. Greg Snider's *1D Poisson Simulator* to simulate the band structures of the QDs to help understand the emission peaks of their spectra. Both of these software packages solve for the eigenstates of a potential profile using the 1D Schrodinger's equation and incorporate Poisson's current model, which allows for a voltage bias to be applied to the sample. The experimental spectra of an InP/AlInAs QD structure showed peaks at three different wavelengths, which is suggestive of some indirect band transition. Using the software packages, I was able to theoretically calculate three emission lines; however, one of the lines appeared 100 meV away from the experimental line. I also took the Hall mobility, susceptibility, and various resistance readings on our two other samples, GaN/AlN quantum wells, at temperatures of 15 K, 50 K, 150 K, and room temperature. The temperature-dependency curves of the mobility were as expected from the sample.

The image on the left is the spectra depicting the peaks with their wavelengths, and what transitions we think they are supposed to come from. The one on the right shows the experimental reading.

The other part of my project consisted of optimizing the power output of the Coherent Mira 900 Basic femtosecond pulse laser. This required controlling one of the mirrors inside of the laser, in very minute steps, something unattainable by human hand. Also, the maximum power of the laser varied with time implying that somebody had to continuously keep adjusting the mirror to keep the laser at maximum power. To improve upon this, I collaborated with Prof. Mintairov's graduate student James Kapaldo to use a stepper motor to control the mirror. We used a raspberry pi to control the stepper motor; so, this led me to learn and become adept at using a raspberry pi. For this to work, I had to connect the lab's Windows XP computer, using LabVIEW to read in laser power, to the raspberry pi to relay the power reading so that the pi could act on it. This was one of the primary difficulties in getting this to work, as LabVIEW and the raspberry pi are not made to communicate through standard means. Accomplishing this was one of my major milestones. In addition I learnt how to use James' 3D printer to print parts, like gears etc., to connect the stepper motor to the knob controlling the mirror in the laser. I then implemented a local hill climbing procedure in Python on the raspberry pi to get the laser to maximum power and keep it there. Local hill climbing works, because from previous experience we know that the power output in the laser doesn't have any local maxima.

This image shows the setup we made with the 3D printer to connect the stepper motor to the knob on the laser.

Publications (papers/posters/presentations): I have written a longer summary report of my work this summer by August, including various simulations I did and how they changed with various parameters, which can be requested at akumar3@nd.edu.