Instrumentation and experiments on novel quantum effects in semiconductor optics

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Light is a tool for studying matter due to the interaction of different colors or wavelengths depending on the properties of matter. For the summer, we assembled an optical spectroscopy set-up necessary for probing semiconductor microcavity polaritons with light. The system had to provide accurate readings of the spectral response of the semiconductor samples which tend to have low contrast between signal and background noise. The samples were designed to have certain resonance energies due to quantum wells and optical cavity structure. By exciting them with light of specific wavelengths, we can determine if the spectral response agrees with the design specifications.

We put together a spectroscopy set-up to measure the reflectivity and emission spectra of the layered semiconductors. The spectroscopy set-up used a monochromator to take input from a broadband light source and disperse the light into separate wavelengths so that a single one may be selected. The selected wavelength was reflected off the sample, and by rotating the grating within the monochromator, different wavelengths of light can be used to excite or probe the sample. To best characterize the sample, a pair of silicon detectors were used to make minimal noise measurements of the reflections. One detector measured the reflection off a sample while another measured the incident light. Subtracting the signal of one detector from the other removes common noise. Furthermore, a lock-in amplifier took the signals from the detectors to isolate the low signal from a noisy background. A lock-in employs phase sensitive detection by multiplying a modulated signal with a reference at the same frequency. As a result, the noise is averaged to zero while the signal that is in phase to the reference frequency adds up. An optical chopper was placed outside the monochromator to modulate the selected wavelength of light. Thus, the combination of a pair of photodetectors, a lock-in amplifier and chopper were employed to produce precise measurements.

For ease and speed of measurements, an Arduino Uno microcontroller was used to automate the system. It served as an interface between the stepper motor for the monochromator’s grating, the lock-in and the computer. By telling the computer what wavelengths were being put out by the monochromator, the Arduino informed the computer when to take data from the lock-in through its GPIB connection. The computer could then tell the stepper motor to move to the next wavelength. Thus, whole spectra could be produced by entering the data acquisition routine to the computer.

The spectroscopy setup was tested with GaAs/AlGaAs and CdZnSe/ZnSe dielectric mirrors and quantum well samples from the University of Pittsburgh and the National Renewable Energy Laboratory. By placing maximum resistance and no voltage bias on the photodetectors, and running the lock-in at a relatively high time constant, the system produced spectra containing extremely little noise. The results were compared to simulations run based on the design of the samples and they closely matched. The system efficiently produced clean signals and may be used for future spectral characterization of new microcavity samples.

Through the experience, I learned research techniques such as spectroscopy and low signal detection methods which have applications in the study of semiconductors. Additionally, I gained programming experience with simulations by using the shooting method. Further programming experience was gained through automation.