Optical measurement of polariton strong coupling in semiconductor microcavities

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In a semiconductor, excitons form when electrons are excited from the valence band to the conduction band, leaving behind a “hole” in the valence band which has charge opposite that of the electron. When the electron and hole bind together, the resulting quasiparticle is known as an exciton. If one traps light within a semiconductor optical microcavity, the photons from the light can strongly couple with the excitons to form *polaritons*. These polaritons are well known to exhibit exotic behaviors such as superfluidity and Bose-Einstein condensation. Polaritons exist in one of two energy states; polaritons of the lower energy state are known as lower polaritons while those existing in the higher energy state are known as upper polaritons. Lower polaritons are very easy to observe; however, with polariton samples that have very long lifetimes, the upper polariton line-width narrows beyond the resolution of ordinary detectors. Our project attempts to find this upper polariton energy signature using various methods.

The first method used was reflection spectroscopy in which a white light source, which spans a flat intensity from 750 to 900 nanometers, is used to determine the energies of the upper and lower polaritons. In this method, the light which is reflected off the sample is sent through a spectrometer. The intensity of the reflected light as a function of wavelength is then recorded in an intensified CCD camera. In theory, the upper and lower polaritons will absorb light corresponding to its energy which shows as a dip in the reflectivity spectrum. By changing the position of the sample off which the light reflects and image processing the data, we were able to clearly show what the lower polariton energies are at every region on the sample. Unfortunately, however, this method did not allow us to see the upper polariton, but it allowed us to find the lower polariton and create a well-based calculation of where the upper polariton should be located on this particular sample.

Another method we used is a technique known as differential reflectivity, developed in the summer of 2015 by Prof. Balili and Matthew Link at Calvin College. In this method, a laser beam is split, half of the beam going clean through to a sensor, the other half being reflected off our semiconductor microcavity sample to another sensor. The difference between the readings of these two sensors would be amplified and recorded using a lock-in amplifier, and we would repeat this process across the whole sample. We would scan the sample several times, changing the wavelength of the laser within the range of the expected resonance of the upper polariton with each spatial scan. The results would then give the reflectivity as a function of the wavelength.

Finally, the other method which gave us clearer results is known as photoluminescent excitation spectroscopy (PLE). We scanned a continuously tunable laser across the range over which the upper polariton was predicted to be by our calculations while looking at the intensity of the lower polariton. The position of the upper polariton corresponds to the wavelength at which the intensity of the lower polariton is at its maximum. The intensity of the lower polariton is recorded with an intensified CCD camera.

To date, we are still analyzing our latest PLE data of which we are confident will show a signature of the upper polariton energies. Although we are still generating our final results, I know I have already personally gained many useful skills and knowledge. Through this project, I have learned how to better write programs for scientific use both in controlling equipment and analyzing data. In addition, I've been able to gain a better understanding of certain aspects of quantum mechanics by being exposed to it in a lab setting.