The Setup, Design, and Implementation of a Photoluminescence Experiment on Quantum Wells

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Introduction

This summer, I completed my first internship at the University of Colorado at Boulder via the CU Research Experience for Undergraduates program. I worked in JILA, in a lab run by Dr. Steve Cundiff. My goals for the summer and for the program were to get an older model Ti:Sapphire laser functional and optimized by aligning its cavity, to create an experimental setup designed for completing photoluminescence experiments, to integrate the Ti:Sapphire laser into the setup, and to begin running experiments on samples such as quantum dots and quantum wells. The overall purpose of the work I did this summer in the Cundiff lab was to create the aforementioned setup so that it may be used by others in the future for various photoluminescence experiments. The majority of the work I did during the CU REU program consisted of implementing a birefringent filter into the Ti:Sapphire laser, and aligning and optimizing the cavity. Within the past few weeks I have set up the experiment, integrated the laser into the setup and have been running the experiment on a quantum well, searching for a photoluminescence signal as per the intent of the experiment.

In this paper, I will outline the methods through which I aligned and optimized the Ti:Sapphire laser while integrating the birefringent filter, I will describe and explain my experimental setup, and I will discuss the results I have gotten thus far.

Getting the Ti:Sapphire Laser Functional

When I began the REU program, my first goal was to take a Titanium Sapphire laser from the eighties, which had become unaligned, and get it up and running. This included coupling a Coherent® Verdi V-5 pump laser into the Ti:Sapphire cavity in order to create infrared fluorescence and eventually lasing. The Verdi V-5 is a diode-pumped solid-state frequency-doubled

Neodymium Vanadate [Nd:YVO$_4$] laser which emits a green beam of Λ 532 nm with output power ranging from 0.01 – 5.5 W. However, before I could begin alignment, there were steps taken to get the laser correctly set up.

First of all, I had to move the Verdi laser – whose components include the controller, the chiller, and the laser head – from a laminar flow isolation table to a regular lab table. From there, the next step was figuring out a way to cool not only the Verdi laser, but also the Ti:Sapph laser; this is because both lasers will fluctuate in output performance if their gain mediums are not kept at constant temperature. This was done using swagelocks and T pipe-joints to split the input and output lines of the chiller for the Verdi laser so that they also ran into the Ti:Sapph input/output lines.

After successfully cooling both laser cavities, the next step in the process was to decide in which way to align the Ti:Sapphire cavity. In its original form, this laser was set up as a ring cavity, which is exemplified by Figure 1.
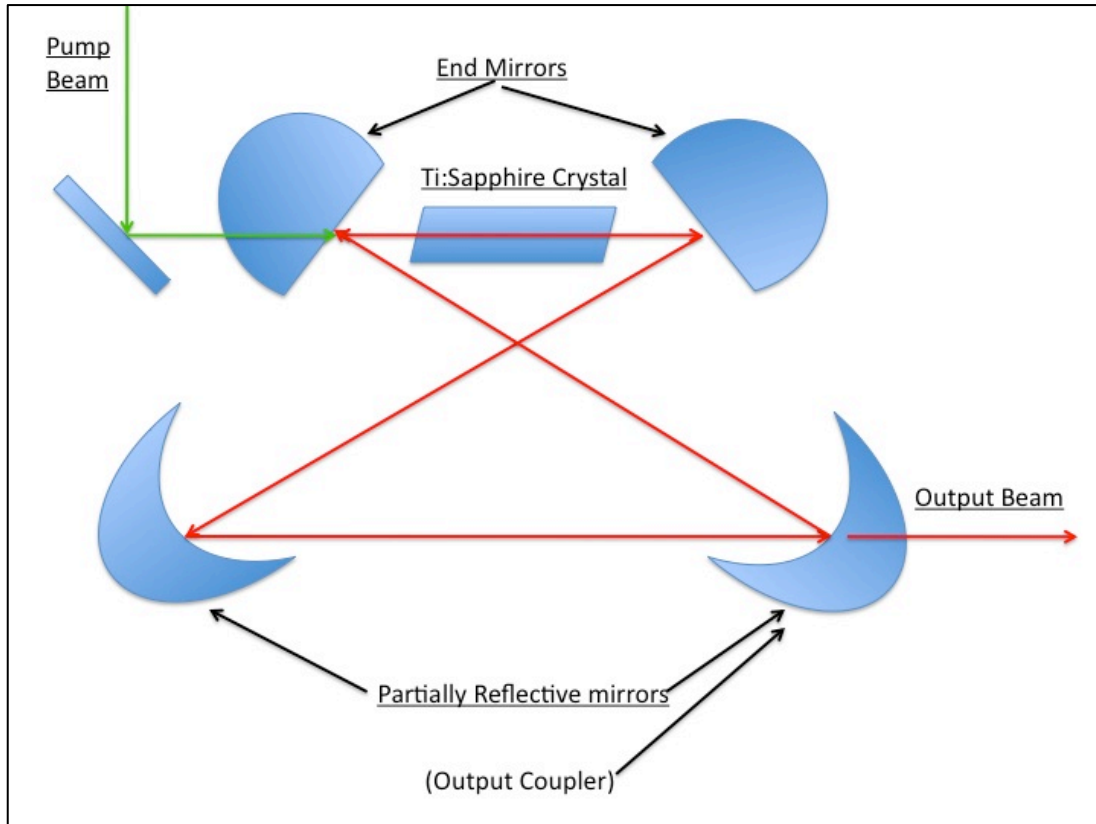
The advantage to having a ring cavity is that, when using something like the birefringent filter I used in my laser, single-wavelength operation can be achieved; this is done through imposing different losses upon the two different directions of possible propagation, which effectively selects the beam to go in one direction [1]. These types of cavities also have the advantage of being more easily mode locked than other types of cavities.

However, despite the ring cavity being highly efficient, I realized when beginning to align the Ti:Sapphire laser that it would be much easier to set the cavity up as a simple optical cavity, which can be seen in Figure 2.
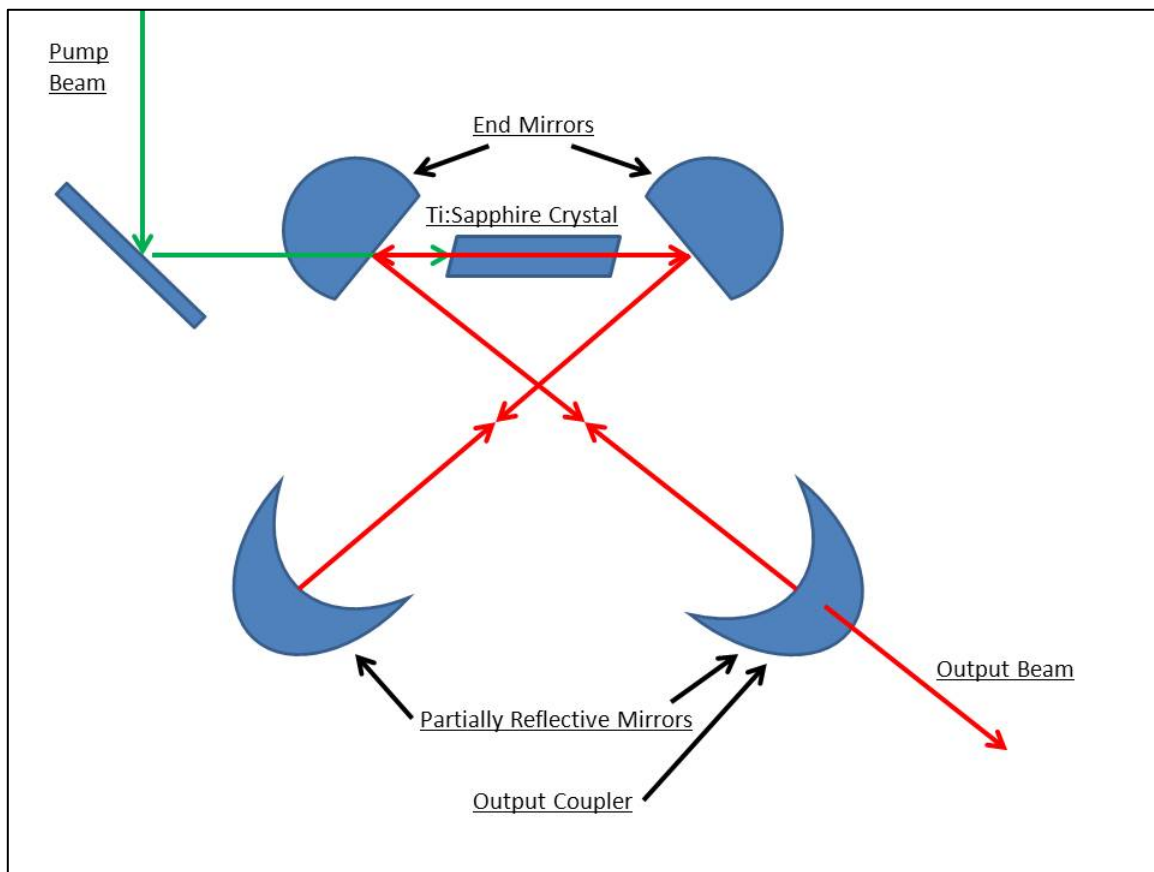

Figure 2: A simple optical cavity. The beam propagates from an end mirror to a partially reflective mirror, back in on itself, and repeats the same pattern with the other end mirror/partially reflective mirror.

The reasoning for being able to set up the cavity in this way was, for one, so that the alignment of the cavity would be much easier and more efficient. Also, with the BRF being put into the cavity, single frequency operation could be achieved just as with a ring cavity.

I began alignment of the laser by creating a card with a small hole in it, and using an Infrared Viewer to see how close the small amount of fluorescence coming through the hole was to reflecting back in on itself; once the small bright spot seen on the card was made – via adjusting the partially reflective mirror – to go back into the hole, then that leg of the cavity was close to alignment. I did this for both legs of the cavity, iterating back and forth until both seemed visually close to alignment. Then, I put a power meter into the path of the light allowed through the output coupler and adjusted the PR mirrors to optimize that power until lasing could be seen.

At this point, I began implementing the birefringent filter into my cavity. The first step in doing this was finding out the Brewster's angle and placing the BRF at that angle with respect to the beam and the normal of the birefringent crystal surface. To find this angle, I found out the indices of refraction of the [calcite] crystal (1.49 – 1.66) and the air (1.0003), and used Snell's law, Brewster's law, and the Fresnel equation: $\theta_B = \arctan\left(\frac{n_2}{n_1}\right)$, where n is the index of refraction. Once I knew the Brewster's angle, I needed a way to mount the filter, so I created a mount out of spare optics parts that functioned in the same way a manufactured mount for such a filter would. The mount needed to not only screw into the table, but also to hold the BRF at 90°. Below are images of the mount I created (right), juxtaposed with a manufacturer's mount.
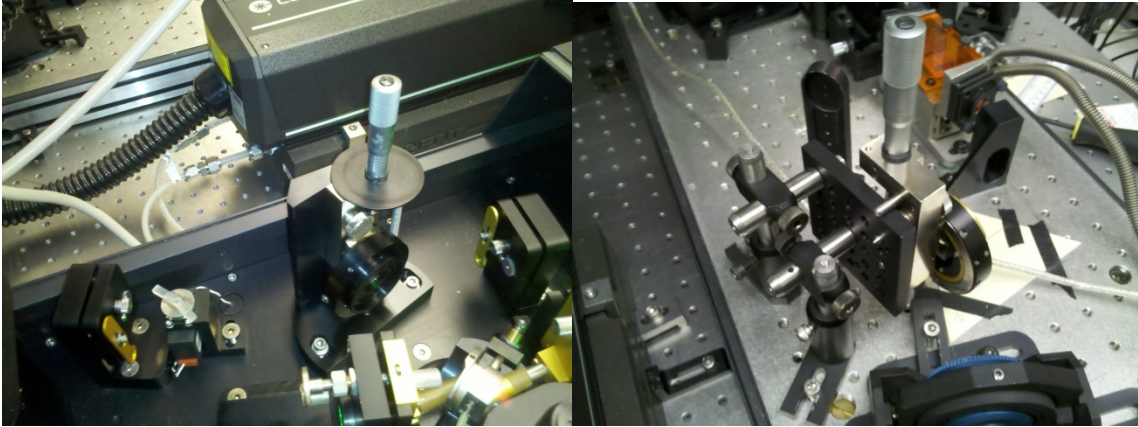
I then placed the BRF into the cavity, using an IR-sensitive card to check the reflection of the beam off of the surface of the crystal in order to most accurately place the mount at the Brewster's angle. Once the mount was integrated into the cavity, I optimized the power of the output beam. I used a power meter, and adjusted the beam path using a method called "walking up the beam"; this is where one knob of a mirror is adjusted until the maximum power output is seen, and then the corresponding knob of the other mirror is adjusted until another maximum is seen. In this way, the same parameter of the beam path is being adjusted for both mirrors, and the beam is effectively moved along the same angular direction of propagation towards optimal alignment.

Once the laser had been optimized, I had to characterize the BRF. The purpose of doing so was to see how tuning the BRF affected the output of the beam, and to find the optimal tuning range of the filter. When I characterized the filter using an optical spectrum analyzer, I saw a repeating pattern of wavelength variation; tuning the filter in one direction would steadily increase the output wavelength, until multiple frequency operation could be seen, and after which the pattern would start over. I then found which of these tunable regions would allow for the highest variation in frequency while also giving the highest output power.
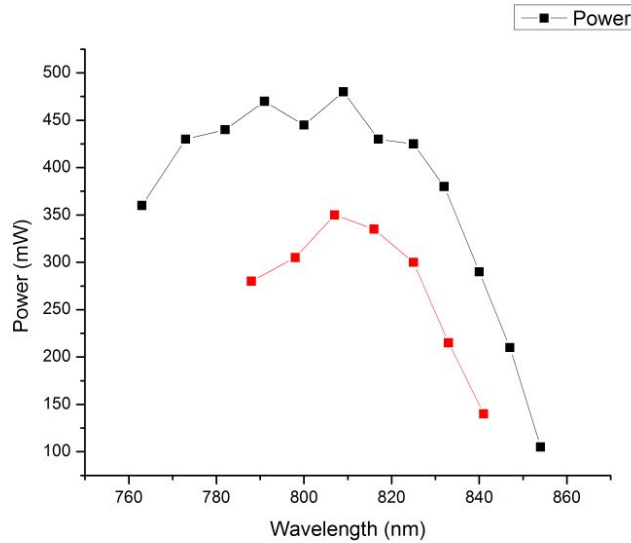
Figure 3: The curve in red represents the initial optimal tunable range of the Ti:Sapph laser. The black curve represents the optimal tunable region seen after moving the laser to its experimental location and re-optimizing its output.

The Experiment

At this point, I began setting up the experiment. Before any optics could be put down, however, there were some issues I needed to resolve. First, the power of the beam incident upon the sample had to be reduced from 480 mW, the output of the laser, to 1 mW. Second, in order to successfully read the PL signal, as much of the luminescence must be captured because it is emitted in all directions from the sample. Third, all of the beam light and gathered PL had to be focused onto the detector. Finally, I had a small amount of space in which to set up the experiment.

To decrease the power of the filter, I placed a Neutral Density filter in the path of the output of the laser. This filter allowed for adjustments, resulting in a high range of possible output power (116 – 8150 µW). In order to gather as much PL as possible, I placed a large collimating lens just after the sample. The light was then passed through a focusing lens and down onto

the detector. Due to the lack of table space available for the experiment, I had to set the sample at 45º with respect to the beam direction instead of having the beam go through the sample; this makes the PL signal weaker and harder to find. A diagram of the experimental setup can be seen in Figure 4.
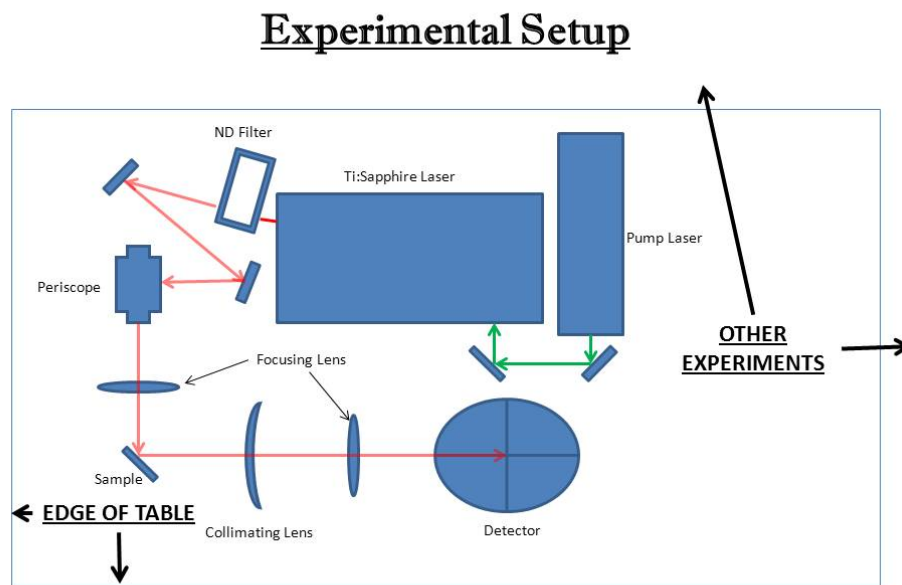
Experimental Setup

Figure 4: The photoluminescence experimental setup.

Once the experiment had been set up, I began running it and looking for the photoluminescence signal. I started by using a quantum well sample that was composed of ten 10 nm thick GaAs wells, surrounded by AlGaAs barriers. The sensor I used was an OceanOptics® USB2000; at first I tried an optical spectrum analyzer paired with a fiber coupler, but that sensor did not have high enough sensitivity. Galan Moody, a graduate student also working in my lab, had run a very similar experiment to mine; his sample was the same type of quantum well and he was pumping it at around the same wavelength, only his sample was in a cryostat. Based on his experimental finding of a PL peak at ~820 nm, and taking into account that because my sample was not in a cryostat or being cooled in any way that it would

luminesce at approximately 20 nm above, I was expecting to see a PL signal at approximately 840 – 850 nm.

It took many adjustments before the beam was well coupled into the sensor, but eventually I began to see a very prominent peak (which was coming from the laser beam), as well as surrounding noise and peaks. After adjusting the alignment of the experiment so that the noise was reduced and zooming in on the region I was looking for PL in, I started to see a peak that appeared to stand out from the peaks surrounding it; it was a broader peak, and it also appeared to have higher intensity. Initially, I thought that this peak was photoluminescence, but I had to test it.

I replaced the sample with a mirror at the same position and orientation so that the beam was reflecting into the sensor. In this way, I could compare the spectrum coming off of the mirror with the spectrum I saw from the sample, and thus see if the peak truly was photoluminescence. The results can be seen in the following figure:
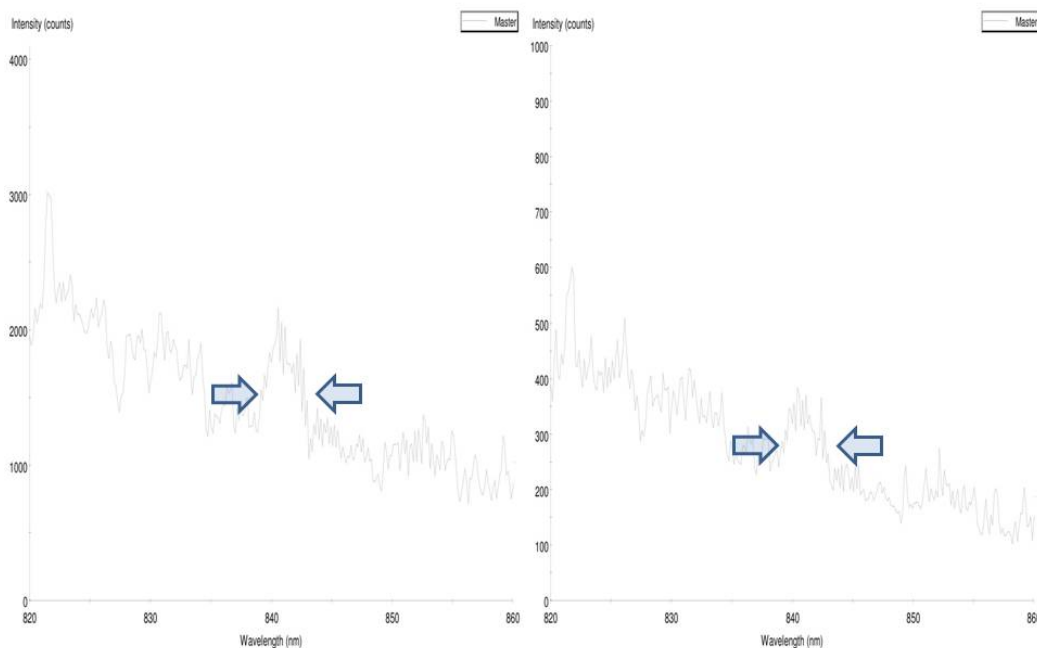
Figure 5: The spectrum from the sample can be seen at left. The arrows indicate the location of the peak that was thought to be photoluminescence. The graph on the right represents the spectrum from the mirror, where the same peak can be observed.

From comparing the two graphs, it becomes clear that the peak I expected to be photoluminescence is in reality just noise, most likely coming from the laser itself. This result, then, exemplifies the need for some revisions in the setup of the experiment.

Future Work

As for the work that still needs to be done on this project, there are a number of things that can be done to improve the probability of success of the setup.

First of all, a more stable and adjustable mount needs to be created for the birefringent filter. The mount it is currently on has several issues; for one, it is quite front-heavy and thus is much harder to place without moving when fastening it down. Also, the mount is crude and does not have a way for the angle with respect to the beam to be adjusted, which would make placing the filter at precisely the Brewster's angle much easier.

Secondly, the control of the BRF tuning needs to be automated and controlled by a computer. Having achieved this, the BRF would be able to be tuned by making adjustments on the computer rather than by hand, which is much more accurate. This can be achieved through the use of a picomotor; the picomotor would sit at the top of the mount, driving its peg vertically up and down, which would replace the action of the micrometer that is currently in the filter.

Lastly, the cover for the Ti:Sapphire laser needs to be cut so that it can function with the cover on. This will increase the stability of the laser because accidental adjustments (such as bumping optics inside the laser cavity) cannot be made. The cover will also prevent dust from getting into the cavity and will keep it much cleaner for much longer, reducing the need for cleaning the optics. Last, the cover needs to be altered to allow for the pump beam to enter the cavity (it currently hits the side of the cover when it is on the laser), and the hole in the top of the cover for the BRF micrometer/driver needs to be re-cut to accommodate its new position (the BRF's position in the laser cavity changed from its original manufacturer location due to the cavity being setup in a simple manner rather than as a ring).

Acknowledgements

References

[1] - Paschotta, Rudiger. "Ring Lasers." *Encyclopedia of Laser Physics and Technology*. RP Photonics Consulting, GmbH, 2011. Web. <http://www.rp-hotonics.com/ring_lasers.html>.