

# The Design and Implementation of a Photoluminescence Experiment

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## Introduction

First I should give a little background information on exactly what photoluminescence is. Photoluminescence is a process where we can get the number of defects that are in a type of electronic material. That is the substance that is used as the conductor in electronic gadgetry. The less defects a substance has, the better efficiency it has when used in electronics and thus the more predictable it will behave during usage. This is extremely important because many times we could have a large charge that we want to flow only one way in a circuit and with these defects we could get charge going to opposite way leading to anything from a short circuit to a potentially fatal shock.

The majority of defects in an electronic material centers in a “forbidden region” known as the bandgap. The bandgap is the area between the conduction and valence bands in an electronic material. It is mainly a term used in reference to semi-conductors because it has the most relevance to them. They have a range of roughly near zero for metals, 1 to 7 eV for semi-conductors, and above 10 or 11 eV for insulators. The larger the bandgap, the more insulate the substance is. However, the defects depend on electrons that exist in the bandgap. Theoretically a substance that was 100% efficient would have no electrons in this “forbidden region”, but that doesn’t happen in everyday life. The substances have electrons throughout their bandgap, mostly in discrete levels, which determine their efficiency. The more electron levels in a substance’s bandgap, the less efficient the material is. Sometimes, the defects act as “traps”, which impede the flow of electrons. In that case the electrons combine with holes at the defect sites called “recombination centers”. These decrease the charge carrier concentration and reduce

efficiency. This is where photoluminescence comes in. It is with photoluminescence that we learn how many of these discrete electron levels exist in a substance.

So how does Photoluminescence work? It basically requires 4 main components- a light source, a sample, a light filtering system, and a light detector. The physics behind it is pretty simple. The light from our source hits the sample causing production of electron-hole pairs as well as electron interactions. Some of these interactions cause an emission of light, which is then filtered to its different energies and then recorded by the detector. All of this must occur in the dark. Since we're actually measuring light, data can easily be corrupted. The amount of energy required for an electron to travel over the bandgap is known and therefore light emitted from energies smaller than that must come from the defects. That leads to the only problem with photoluminescence. The number of defects can be found but the exact location of the discrete levels can not. However, we can determine the location of the defects by other means (cathodoluminescence, surface photo-voltage).

### Experimental Design

To start with we had all the major components needed for the experiment. We had a Liconix model 4210NB HeCd laser. The laser is capable of producing both a UV and visible light at 325 and 442 nm respectively. Originally the laser had the 442 nm mirrors installed in it. However the laser is over 12 years old and originally only had an expected tube lifetime of 6000 hours. Therefore we figured maybe we ought to check the output of the laser to see just how much power it had left. We measured it to be putting

out 4.1 mW at the 442 nm setting. That's decreased a pretty good amount from the minimum of 10 mW it was putting out in Jan. 1987. Add into the equation the fact that it produces half-power in the UV and you've potentially got a problem. However we proceeded on in the hope that the laser would produce enough light.

As for our light-filtering system, we were blessed to have the use of a brand-new Oriel MS257 monochromator. Through the use of four filters and three gratings, the Oriel gave us great flexibility in the data we took. It could handle wavelength from 170 nm (well into the UV) up to 24  $\mu\text{m}$  (deep into the Infrared). The Oriel could also handle system control from an external PC, which led to easier programming.

As for our light-detector, we chose the S-20. Out of the three that we currently have in the Brillson Lab (S-1, S-20, Germanium), the S-20 seemed best suited for our application. It can handle a range of energy from 1.4 up to 3.5 eV. If we go IR with our laser, the Germanium detector would serve the purpose better (0.5-2.0 eV range), but that situation will be explained later.

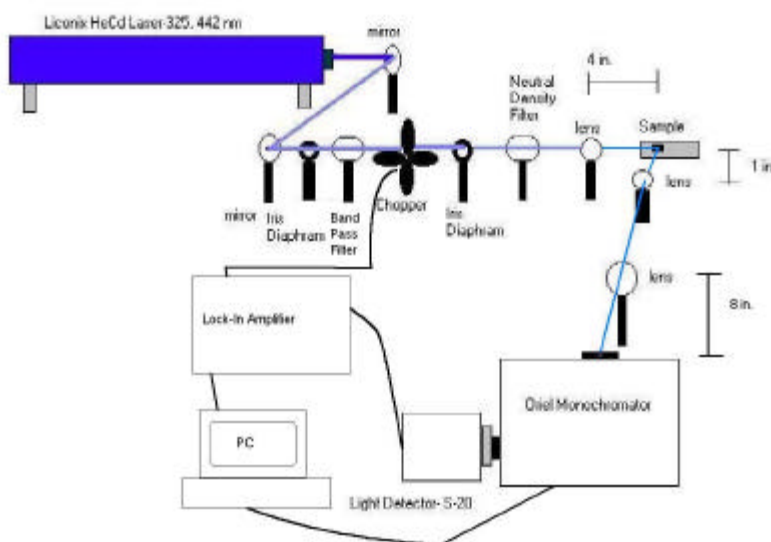
As for the samples, we already had some ZnSe left over from a surface photovoltage experiment. We used it for all our test runs and first data. We have a wide range of different types of samples to work with. However as our set-up gets more advanced we hope to move on to GaN. Our experiment was originally designed to study GaN as well as the other Nitrides. But for the time being ZnSe is serving its purpose.

Since we had all the major components of the experiment, all that was left to acquire was the small stuff. However, our lab didn't have any optical equipment before our experiment so we had to order everything new. We had to order various bases,

stands, filters, and mirrors that were required for the set-up. I'll get into the details of these later when I discuss the actual layout of everything on the table.

In addition to this sample holders and a stand for the laser had to be constructed. I constructed 10 sample mounts so that we could have many samples mounted and ready to go at one time. They were constructed of aluminum with a tungsten wire as the holding device. The laser stand was also made of aluminum. It consisted of four 1 inch diameter rods that set  $2\frac{3}{4}$  inches tall making the laser light an exact 5 inches off the table height. This went with our height our experiment was to occur at. Everything on the table was to be 5 inches high.

### Experimental Layout



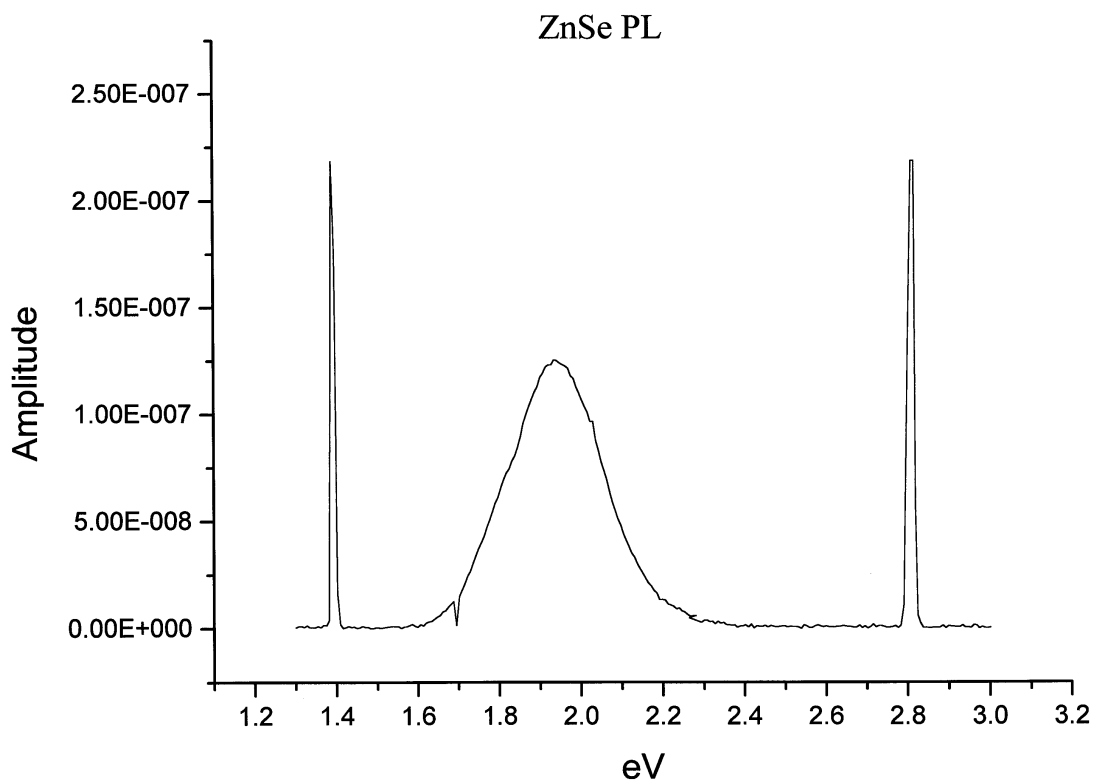
The easiest way to describe the optics of the experiment is to follow the light beam. As it leaves the laser, it next bounces off two mirrors. These are used for alignment of the beam. Both are adjustable giving great flexibility to the direction of the

beam. (It's a lot easier than moving around the laser!) As it bounces off the second mirror it passes through an Iris diaphragm. This is used for adjusting the power of the beam and also for creating a pinhole to improve beam uniformity. I mean you can completely shut the diaphragm so that no light gets through or you could open it to some variable degree. After that is a bandpass filter that blocks out all light except the wavelength of our laser. From there the light goes through a chopper. This is to take the continuous wave of the laser and chop it up to higher frequencies. At the higher frequencies the dominant noise is white noise making us get a stronger signal. Then it travels through another iris diaphragm before going through a neutral density filter. This filter reduces the light uniformly over a broad spectral region. Some scans will be done with the ND filter in the loop and some without to see the difference. From there the light is focused down from a 1-inch anti-reflective lens with a focal length of 4 inches onto the sample. At a focal length of 1 inch there is another 1-inch lens catching the light the sample is giving off and straightens it out. It sends the light then through a 2-inch lens at an 8-inch focal length that is used to focus the light into the monochromator. From there the light is split into the different energies and detected by the S-20 or other light detector. However there is one more step before the data is sent back. It must go through a lock-in amplifier so that the frequency of the chopper can be matched to that of the data. Then it is shipped back to the controlling PC and LabView-, which is the controlling program we use.

### Experimental Problems

The first trouble came from where we thought it would-, our laser. You see it may operate at both 442 and 325 nm, but it didn't say how hard it was to go from one to another. You have to take out the 442 mirrors within the laser and replace them with the 325 mirrors. To do so you must align a HeNe laser so that it shines completely through the HeCd one. Once you have it perfectly aligned with no reflections anywhere you can change the mirrors and then align them. Several times we accomplished this but when we fired up the HeCd with the UV mirrors in it wouldn't lase. After a week worth of effort we abandoned hope of our Liconix lasing in the UV region and replaced them with the 442 nm mirrors. This limited the materials we could draw data from. 442 nm is only energy of 2.8 eV, which is not greater than the 3.4 eV bandgap of GaN that originally was our goal of studying. However we persisted on since ZnSe's bandgap is also 2.8 eV with hopes of getting some data before the summer ended.

After 8 weeks of planning, hoping, and lastly compromising, everything was mounted and ready for a test-run. We fired everything up and amazingly beautiful data came pouring out. The sample we had in at the time was nothing spectacular, a piece of ZnSe found at the bottom of one of our vacuum chambers that had been baked at about 475°C, but the results was remarkable. Here is the graph of that first scan.



You can definitely see a peak at 1.92 eV. With the naked eye during the run you could see that the light coming off the sample had a pink tint to it which would correspond to around 1.9 eV. At 2.8 eV we have a spike in intensity that is expected because that is the energy that the laser is coming in at. Some of the light is being reflected off the surface. The spike at 1.4 is only the reflection of the 2.8 spike in the UV. Also the scan showed no band edge emission, which is a property of heavily annealed ZnSe. The fact that our data was so clear after so long was really exhilarating. I don't know if it's a lack of my own personal research experience or what, but to actually see everything come together and work so well was a real rush.

### Future Projects

I am told that the first objective is to get a new laser that operates in the UV realm. With the current set-up, we are real limited to what we can study. Once the laser has been acquired, GaN is the first substance on the agenda. It was with GaN in mind that the idea of a PL set-up in the Brillson Lab was proposed. Hopefully we can compare annealed with unannealed samples and GaN doped with various other agents in the near future. Also, GaN / InGaN / GaN quantum wells are to be studied. Too bad I won't be around....

### Conclusions

In conclusion I just want to state what a learning experience this summer has really been. Coming in I hadn't had even the basic electronics course and was thrust into the life of working in a state-of-the-art electronics engineering lab. I needed to travel a long way in a short time. I'm still not an electronics expert by any means but I'm proud in the fact that I gave it my all for 10 weeks and learned all that I could.

Also I'd like to take this opportunity to thank some folks that made my summer possible. First off I'd like to thank the National Science Foundation for funding this great program. It's a great thing for a physics undergraduate to experience and without them this would never be. Next I'd like to thank Shawn Bradley, a graduate student in the Brillson Lab at OSU. He was really patient with me this summer and was really a great role model. The PL set-up was really his baby from day one and I was just along for the ride, but what a wild ride it was. Finally I'd like to thank Dr. Linn Van Woerkom for

being a tremendous captain of the ship. He was a wonderful leader and had lots of patience even when we was on his last nerve.