Development of a Visible-NIR Photoluminescence Microspectrometer

by

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Abstract

Photoluminescence (PL) emission is an important characteristic measurement in the field of solid-state physics research. It reveals information about the electron band structure of molecules, and is particularly useful in studying thin-film materials on micron spatial scales. This work sought to design and build a simple system which can accurately measure PL in thin-film materials by applying targeted, monochromatic illumination to the sample.

By coupling a diode laser system into a metallurgical microscope, we were able to apply sufficiently energetic, monochromatic light to a small area and achieve sample excitation. Using optical filters to block reflected laser light, we collect emissions with a commercial spectrometer. The resulting PL emission spectra have low noise, and accurately identify spectral features found in literature for test materials of organic photovoltaic crystals and transition-metal dichalcogenide thin films.

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1 Introduction

Photoluminescence (PL) is the process by which materials will absorb a photon, exciting an electron to a higher-energy "excited state," the emit a photon as the electron relaxes back to a lower-energy state. Measuring PL in various different ways is a common method for characterizing semiconducting materials.

Basic PL measurements are emission and excitation, and differ only by their independent variables. Emission measurements use on wavelength to excite the material, and measure the intensity of light emitted across a spectrum. Excitation measurements use many wavelengths to excite the material, and measure the intensity of light emitted at a particular wavelength. This project is centered around PL emission measurements.

The Micro-Femto Energetics (μfE) Lab at Oregon State University has a system capable of measuring both PL emission and excitation of materials. While the system has a diverse set of uses and is scientifically valuable to have, it has certain drawbacks that make it challenging to use and limit its usefulness in taking certain measurements.

Researchers taking measurements with this system have to invest up to 90 minutes of time into starting up and shutting down the system, which makes cursory measurement of samples impractical. Because the system has a wide variety of uses, optical equipment often has to be reconfigured around it. The system uses a xenon-arc lamp and double-monochromator as its light source, leading to wide-field illumination on samples. This is significant for crystalline structures and nanomaterials, which often require illumination of a single molecular domain.

This project aimed to resolve these issues by designing a system that could measure PL emission os samples accurately, quickly, and with the potential for single-domain illumination.

2 Background

2.1 Optoelectronic Materials

2.1.1 Organic Photovoltaics: ADT

2.1.2 Quantum Dots: CdSe

2.1.3 Transition Metal Dichalcogenides: MoS_2

2.2 Photoluminescence

Photoluminescence (PL) is a mechanism by which materials absorb and emit photons. The process can be described with respect to electronic transitions within an atom or molecule.

The absorptive transition occurs first, when a photon interacts with a molecule and is absorbed. The photon's energy must be approximately equal to the bandgap of the absorbing molecule to satisfy the energy transitions allowed by quantum mechanics. When that condition is met, the photon's energy raises an electron to an excited state, where it stays for a short time.

Some number of vibronic transitions occur as the electron loses energy to radiation and vibration. **How do we measure these transitions, or their lifetimes?**

Finally, the radiative transition occurs when the electron decays back to a ground state. During the radiative transition, a photon is emitted at the bandgap energy as the electron moves from the lowest vibronic state in the conduction band to the highest vibronic state in the valence band. **This needs some work.**

2.3 PL as a Characteristic Measurement

Why is PL a useful measurement in solid state? In biological sciences? In general?

3 Experimental

3.1 Design

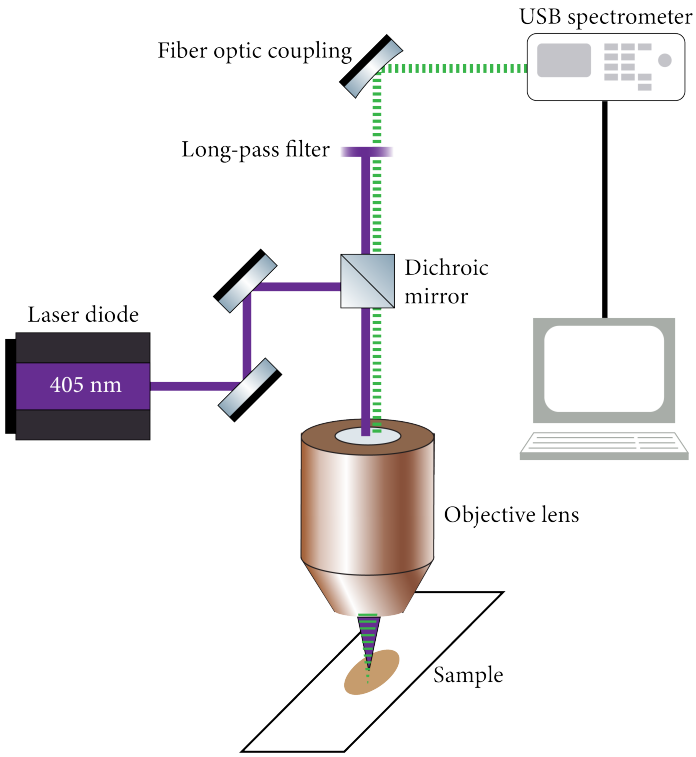

Figure 3.1: This is a caption

4 Results and Discussion

In general, results from the new system are much smoother than results from the existing system, which include quite a lot of noise. [**Future: Analyzing signal-to-noise ratio of these results.**] We suspect that this is a consequence of using wide-field illumination, as is done in the existing system, in which molecules outside the region of interest (or otherwise, with some defects) are excited and emit spectra different from that of the region of interest.[**Needs citation**]

4.1 ADT TES-F

For a drop-cast sample of ADT TES-F on glass, we selected a region of interest which appeared to be a single crystal, with few visually distinguishable defects. The crystal was also selected such that its surface area was larger than the area illuminated by the new system's laser beam. The emission spectra of the region of interest are shown in Figure 4.1.

[**Future: Convert wavelength from nm to eV. This seems to be a more common unit in solid state.**]

Both spectra in Figure 4.1 show a clear peak around 630nm, which has been reported in other research. [**Needs citation. Perhaps Ostroverkohva? 10.1117/12.875375**] The spectra measured by the new system also shows a secondary peak near 600nm, which is not evident in the spectra taken by the existing system.

4.2 CdSe Quantum Dots

[**Coming soon.**]

4.3 MoS_2

[**Coming soon.**]

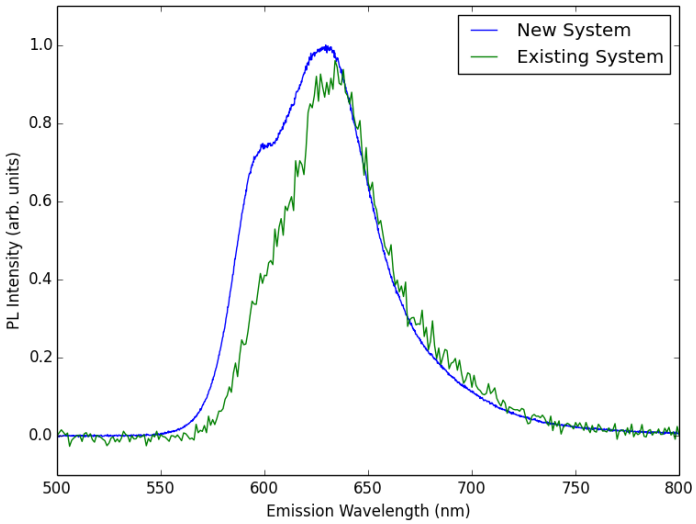

Figure 4.1: PL emission spectrum of ADT TES-F, excited at 405 nm. Wide-field illumination used by the existing system to excite the sample yields a noisy spectrum, and does not excite the secondary peak that is shown clearly in the results from the new system. A single crystal, larger than the laser spot, was selected among smaller neighboring crystals for this measurement.

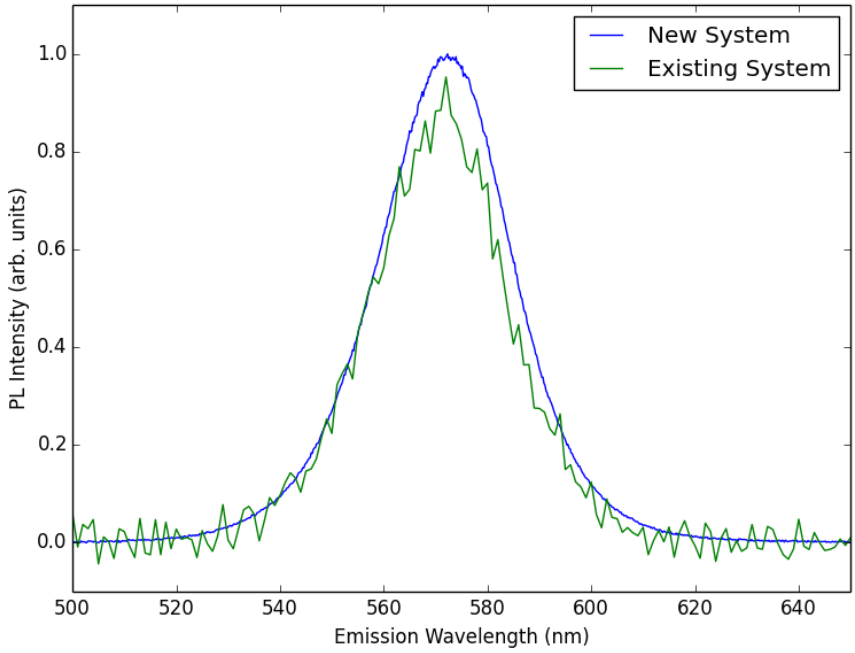

Figure 4.2: PL emission spectrum of a cluster of CdSe quantum dots on ?? substrate, excited at 405 nm. Unlike measurements on ADT, these measurements were taken in a region of interest which is sparsely populated with quantum dots, with one target grouping illuminated by the laser.

5 Conclusion

Acknowledgements

References

A Code