A novel approach to measuring from non-blackbody emissions of LEDs under varying lattice temperatures near zero bias.

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Submitted to the Department of Physics, Oregon State University

In partial fulfilment of the requirements for the degree BSc in Physics

Submitted on May 8, 2020

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Abstract

As responsible energy usage is becoming more and more a part of the public conscience, a key practice of this idea emerges. Specifically, using the energy we do have with maximum efficiency. While the laws of thermodynamics remain a limiting factor, research has been done to show that properties of LEDs can allow them to tread the line of what is physically possible and supposedly use less energy than what would otherwise be expected.

An example of such research has been done here, at OSU. The emissions of LEDs with various metallic compositions and activation wavelengths were measured using an apparatus and graphed alongside each other. Multiple trials were done at varying temperatures to evaluate the role the lattice temperature had on the LED emissions.

The resulting data showed a pattern of LED's reaching a maximum emission voltage before the current passing through them reached their activation wavelengths. In addition, increasing temperatures made this maximum emission occur sooner, though not as strongly as we expected.

Chapter 1: Introduction

1.1: Objective

In our world, there is no shortage of problems that need solutions. The issues of acquiring reliable energy and heat for not just a few, but for entire populations being one of them. Many scientists and people have made tremendous efforts to achieve this goal. And as of now, it would appear that right here at Oregon State University, a team of students, faculty, and industry leaders, have joined their ranks.

Over the past year, Michelle Jeliazkova YiPeng (Luke) Teo, assisted by Prof. Matt Graham, and energy industry leaders Peter and Frank Orem, have been measuring the emissions of InGaAs LEDs under various conditions, specifically under varying temperatures, and electronic voltage, to test a unique property. That being, their ability to emit more emissions, whether in the form of heat or intensity, than should be possible under the laws of energy conservation. For such a momentous discovery, it is paramount to ensure that the measurements behind it are not affected by a mistake on a technical, digital, or human level.

1.2: Experimental Background

As mentioned prior, this thesis is focused on analyzing the methods of measuring the emissions from LED's under varying conditions, in the hope that they might prove that it is possible to convert wasted heat energy into electric potential. While at first glance, this claim might appear whimsical, there is actually much experimental evidence of this claim in practice.

A unique property of semiconductors like our LEDs, is their ability to transfer energy between electrons while operational. Mostly owed to them consisting of various metals. In our case, Indium, Gallium, and Arsenic, or InGaAs, for short. Ideally, this energy isn't supposed to exceed the energy produced by electrons interacting through the "lattice" of positive metal atoms, satisfying conservation of energy. But in practice, it has been found that certain metals exhibit electron energy greater than what their energy in the lattice is expected to be [2]. A leading hypothesis behind this phenomena is the energy passing through the metal components excites these electrons, forming them into carrier pairs, which result in an excess of emitting photons compared to its expected band-gap energy.

This output from our LEDs is expected to be consistent with ideal Diode Current equation:

$$I_D = I_S(e^{V_D/n*V_T} - 1) \quad \text{Eq. 1.1}$$

Where I_D is the diode current, I_S is the saturation current, which diffuses minority carriers, V_D is the diode voltage, V_T is the thermal voltage, which is simplified to $k_b * T/q$ and n is the ideality factor, which varies depending on how closely our diode is following this equation. [1]

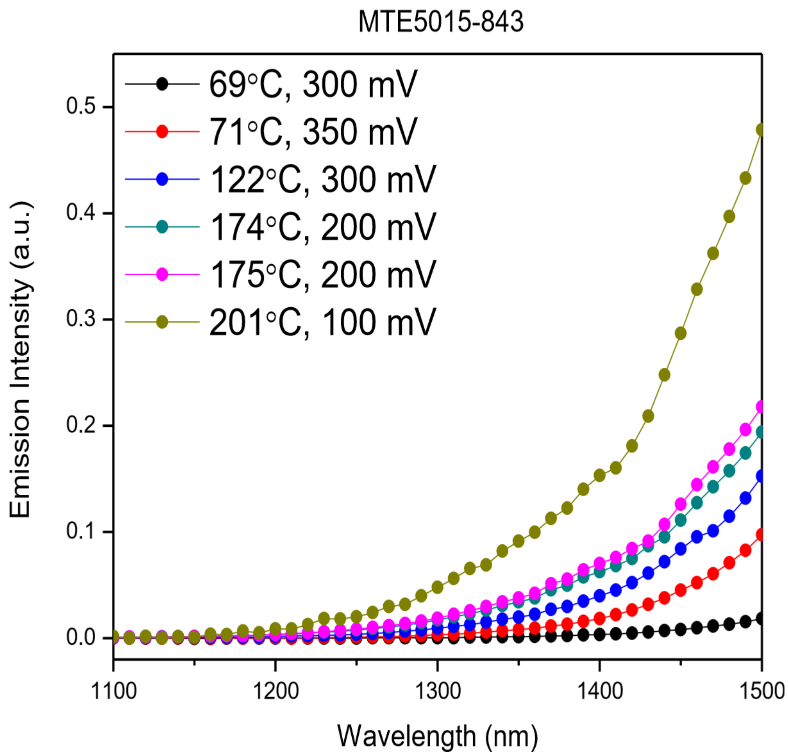

Figure 1.1: A graph adapted from the work of past student experimenters Michelle Jeliazkova YiPeng (Luke) Teo, Prof. Matt Graham, and energy industry leaders Peter and Frank Orem. Showcasing multiple tests performed in the previous experimentation on a 1550 nm LED at varying temperatures, with data taken at varying frequencies between 1100 and 1500 nm. [3]

To combat this phenomena, the excess energy produced by the LED is released as heat and light intensity. This results in a situation where, at first glance, an electrical device appears to operate using less power than expected, and being a potential source of extra heat.

While much research has gone into evaluating this claim, there lies untapped potential for the commercial and energy applications of this phenomena. Producing more heat than what would be normally expected would mean meaningful applications towards appliances and technology people rely on every day.

1.3: Evaluation of Testing Methods

To ensure this sensational new information is in line with established scientific principles and experimental practices, the methods must be tested vigorously. Not just to ensure proper consistency, but because the experimental apparatus has so many components being used for this experiment.

The process being evaluated contains many complicated physical and digital components that, if not oriented properly and carefully monitored, could significantly impact results. This includes various electronic components which range from a function generator, to a lock-in amplifier to filter out noise from our emissions.

This is to say nothing of potential digital complications that could arise from this procedure. The computer used to import this data and the machines themselves have their own unique glitches that must also be accounted for in evaluating this data. Specifically, if detecting emissions from the LED under a certain intensity from the lock-in amplifier, origin would multiply the absolute value of these emissions by ~60 thousand, so it needs to be taken into account and adjusted when plotted.

A primary reason for this repetition of this experiment is to compare not only consistency when compared to similar experiments, but to itself. Multiple repetitions of the experiment are needed to confirm the results of our data stay consistent.

Chapter 2: Methods

While the experimental apparatus and the testing of these LEDs are similar to what has been done previously by my research partners and Mentors, there are some key differences to be noted, specifically the variables of these Diodes that will be tested, alongside keeping a close eye on the workings of the device itself.

2.1: Experimental Apparatus

The apparatus being used to measure the radiation from the LED's is a fairly complex one that involves many components both physical and digital. Each of which impacts the accuracy of our measurements and needs to be monitored carefully.

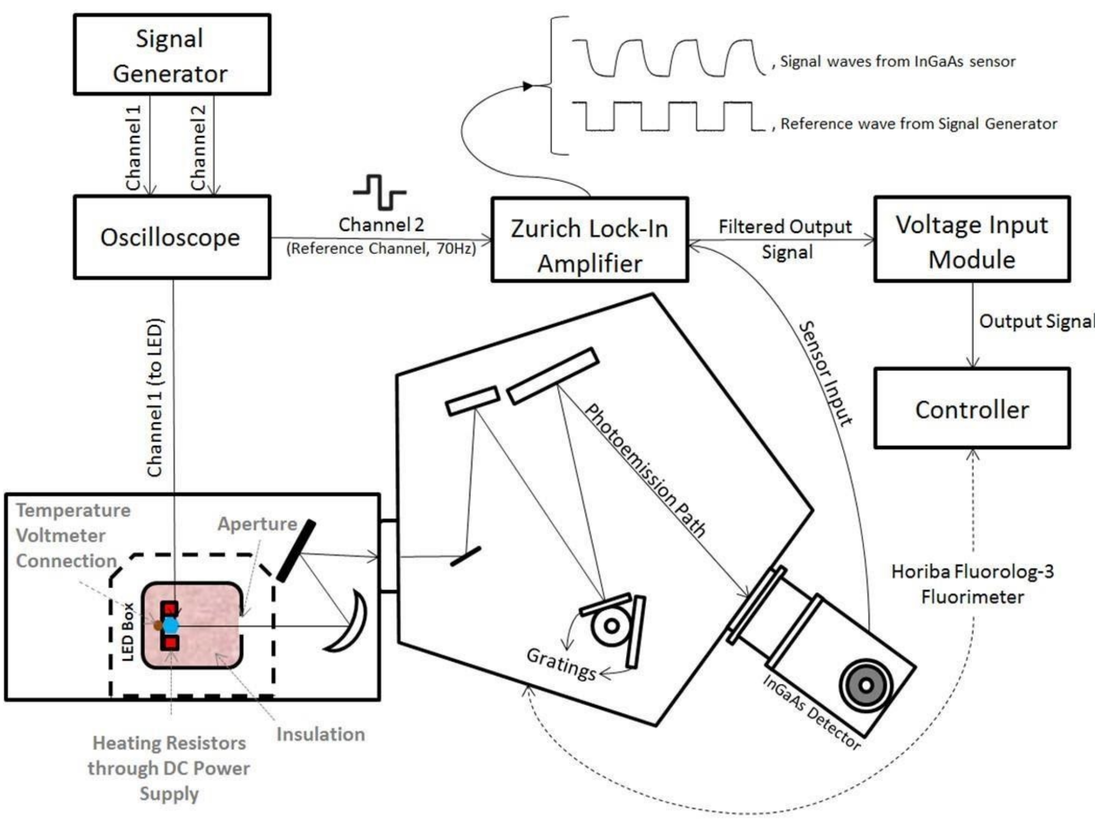

Figure 2.1: A model of the Experimental Apparatus, designed by Matthew Graham, Frank Orem, and Peter Orem, with help from YiPeng (Luke) Teo and Michelle Jeliazkova. [3]

The Figure above shows a simplified model of the physical apparatus through which we will be measuring properties of the LED emissions. The LED box as shown above in figure 2.1 consists of a simple cork-based box, containing insulation to minimize the effects of outer temperature on the LED, represented by the blue dot. Said diode is anchored to a small metallic structure in the box and powered via a function generator and an oscilloscope, through both of which, we are able to vary the current traveling through and the potential difference dissipating across the diode. A specialized voltmeter is wired behind the LED (whose connection is represented by the brown dot) and will measure the temperature of the LED throughout the experiment.

As the emissions leave the main chamber, they travel through the path above, bouncing off gratings until they arrive in the specialized InGaAs detector, (that is cooled by liquid nitrogen) in order to have the angle of the entry measured and recorded, and to be input as signal waves. However, before being input, any noise that might exist in the emission, and thus their signal wave counterparts, is filtered through a lock-in amplifier, which is connected to the original oscilloscope above as a reference point. The filtered signals from these waves are then sent to a voltage input module, where their voltage is measured, and then saved into the computer, alongside the angle of entry measured earlier.

The data recording was automated with the program Origin-Lab, which is responsible for allowing us to count the very weak near-IR forces emitted from these sources. It also serves as a sort of control panel of sorts for monitoring the various electronic devices that are a part of this setup. Its functions include physical ones, such as widening or condensing the slit at the entrance to the InGaAs detector to allow less noise from the emission beam. However, its primary purpose is with graphing these emissions in terms of their voltage, wavelength, frequency, temperature, and intensity over the course of a period of time.

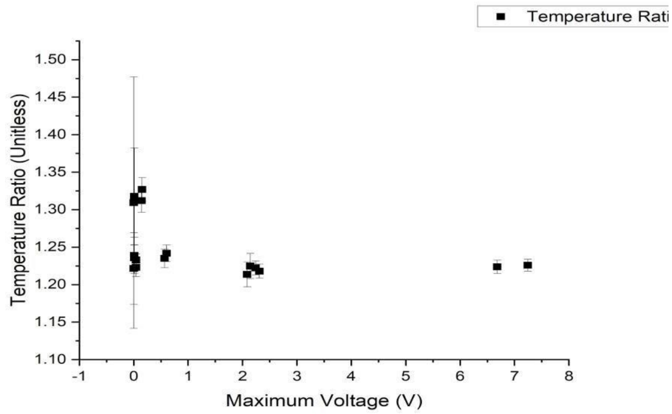

Figure 2.2: An example graph of the Maximum voltage of a set of LED emissions graphed against a ratio of the initial LED temperatures and final InGaAs detector emissions temperatures.

This example graph in figure 2.2 highlights the graphs able to be made in Origin, which displays that even with extensive noise-canceling components of our experiment in place, the data we are able to collect is nevertheless imperfect. This emphasizes why the testing of this process using various different parameters is so important. The hope being that, with enough tests, this noise can be explained in a way that satisfies our understanding of thermal physics, optics, and electrodynamics.

2.2: Testing Procedure

In order to gain a complete picture of how accurate our digital and physical components are, many aspects of the LED must be tested, including the potential difference of the voltage capable of traveling through the LED and that which is emitted from it while active, the range of temperatures at which data can be taken, and the physical makeup of the LED components.

Using the external DC power supply attached to the LED box, the temperature will vary between set values of Kelvin which will be measured by multiple thermocouples.

Using our signal generator, the voltage of the signal flowing through the LED will be varied between 0.5 and 4.9 V, with the maximum being a hard limit that should not be exceeded under any circumstances, due to fear of damaging the LED.

Chapter 3: Results/Data

3.1: Experienced Physical complications

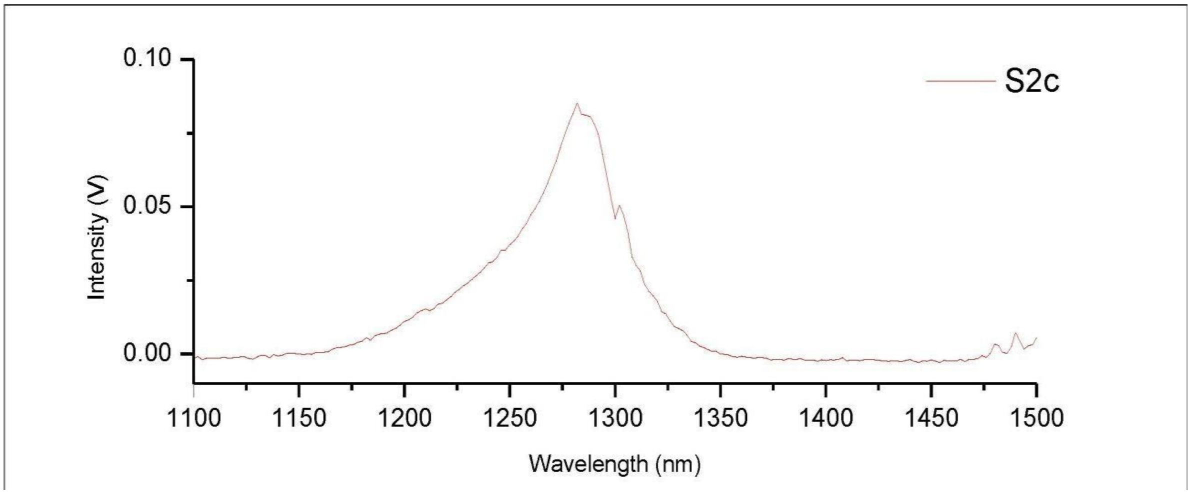

Figure 3.1: Testing an InGaAs LED with a bandgap frequency of 1300 nm, using a signal with varying frequencies ranging from about 1100 to 1500 nm. It was performed in 700 nm ambient light

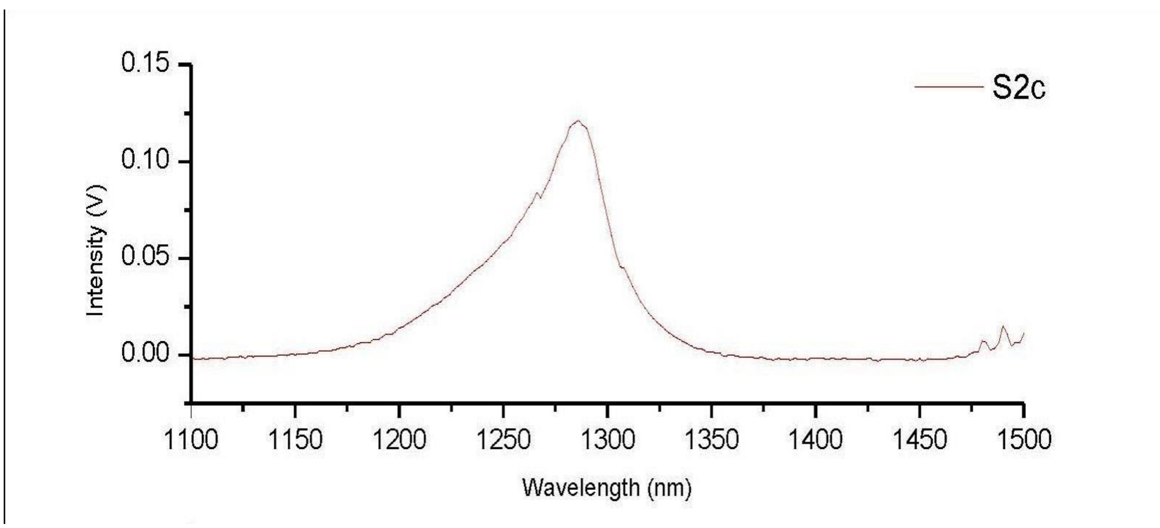

Figure 3.2: A similar experiment, also testing an InGaAs LED with a bandgap frequency of 1300 nm, using a signal with varying frequencies ranging from a \bout 1100 to 1500 nm. This time, it was done allowing for 800 nm ambient light.

Much like previous tests, there is a clear and present uptick in intensity of the LED far before the expected band-gap frequency. These results also stayed consistent at varying temperatures, indicating that outside heat sources did not affect the internal energy of these LEDs while they were operating. Trials done by previous students involved with this project portrayed similar, if not identical situations for the LED. No matter what temperature the surroundings, presence of ambient light, or even expected bandgap wavelength of the LED tested, the experimental wavelength always appeared to be lower.

3.2: Experienced Physical and Digital Complications

Thankfully, no physical complications were experienced, and the digital conversion of the LED emissions went reasonably smoothly. The closest thing to an issue would be due to a glitch in Origin, where, since we were dealing with emissions, it had the tendency to multiply emissions too low for the detector to pick up by 80,000. That being said, it was easily corrected, and even when taken into account, does not explain the lower apparent bandgap wavelength of the energy required by our LED’s.

Chapter 4: Conclusion

It is no secret to scientists that the work done in pursuit of a better understanding of how our universe behaves rarely remains static. It must be tested thoroughly, and repeatedly, to ensure its validity and to help branch into other fields. This research was undertaken by the group I am lucky to be a part of, in the hope that we could be a part of this grand tradition. By testing these LEDs under varying conditions, including temperatures, ambient light, and wavelength of energy flow, we have refuted this unique phenomena others have documented witnessing in similar diodes. We collectively find that these light emitting diodes do not require the full amount of electrical energy expected by the blackbody emissions curves to activate and produce light at zero-bias, suggesting that they must produce at least some of this required energy themselves, by functioning as a nanoscale thermocouple.

While I did test LEDs of varying semiconductor band gap compositions, this discovery warrants further testing of different compositions, to see if some metallic combinations are more likely to produce this phenomena than others. In these times of radically shifting energy sources, and the implications of devices that could use less energy than they already do, the opportunities this discovery opens up should not go unexplored. With this new insight into how nature works, we can pave the way for a brighter future, one LED at a time.

Acknowledgements:

References Cited

[1]: Orem, Peter, et al. “Measuring Thermally-Driven LED Emissions via Voltage Modulation near Zero Bias.” Electronics, v ol. 7, no. 12, 2018, p. 360., doi:10.3390/electronics7120360.

[2]: Yang, Kyounghoon, et al. “Numerical Modeling of Abrupt Heterojunctions Using a Thermionic-Field Emission Boundary Condition.” Solid-State Electronics, vol. 36, no. 3, 1993, pp. 321–330., doi:10.1016/0038-1101(93)90083-3.

[3]: Teo, YiPeng (Luke), Jeliazkova, Michelle, et al. “Harvesting non-blackbody radiation from low-bandgap LEDs at zero bias” Pub 2019. Accessed March 6, 2020