Lab Group #5

Lex Lombardi, Jack Cravener, Herbert Bieszke

LED Lighting Preliminary Report

# Photosynthesis and the Physics of Light

The photosynthetic active region (PAR) is a curve that relates the frequency to the number of photons that can be absorbed by a plant undergoing photosynthesis. Chlorophylls and other accessory pigments absorb excess energy from incident photons, radiating it away as fluoresce and heat. This leads to higher energy photons being less efficient, but easily absorbed. The two most common photosynthetic pathways are called P700 and P680, for the peak absorption spectra. P700 is a simpler, more efficient process, but P680 is adapted to dryer and hotter climates.

The PAR curve varies with plant species, tracking the absorption spectra of accessory pigments are present (including chlorophylls, carotenoids and phycobilins). Some research suggests that green light added to the spectrum allows these accessory pigments to increase absorbed power and thus, growth rate. It is speculated that this green light is not directly absorbed, but used to activate more effective pathways for other light to be absorbed. [[1]](#endnote-1)

The actual chemical process for photon capture was not well understood until recently, and is still an active area of research. Until recently photosynthesis was thought to operate entirely classically, but recently quantum behaviors have been identified in the system that transports photons to the chlorophyll. This quantum behavior, entanglement, allows the photon to explore many routes to the reactive site, and select the shortest.[[2]](#endnote-2)

# LED lighting applications

Applications of LED lighting range from the power indicator light on every computer and smartphone to road safety lighting to greenhouses. All of these applications have similar requirements: high efficiency, low cost/fixture and low maintenance. But horticulture has a few unique requirements as well. Plants can easily be burned by high bulb temperatures, and by overly intense point sources of light. Both these issues can be mitigated by proper housing design. The housing must disperse the light enough to prevent point sources and properly reject the waste heat from the LED. Just like any other lighting fixture the angle of coverage, expected throw (or distance to object being illuminated) and total power must be carefully balanced.

In greenhouses, LED lighting can increase yield per square meter by providing light to the sides of the plant, deep under the canopy. Multi-color LED units can be used to set up regulated conditions for experiments in plant growth. Industrial scale LED farms are an economic likelihood, as arable land is expected to increase yield while decreasing the number of people involved.

# LED Lighting Issues

LEDs have gained tremendous popularity as a lighting source in recent years. Their low cost, high efficiency and smaller footprint has allowed them to be used in applications ranging from simple indicators, to display backlighting, to home and area lighting sources.

## Environmental

The primary reason for the popularity of LED lighting in many applications in recent years is due to their efficiency. The theoretical upper limit for a white LED is approximately 40% of the electrical energy consumed is emitted as light[[3]](#endnote-3), compared to incandescent bulbs which come in at approximately 2-5% efficiency, while fluorescent bulbs come in around 10%. Because of this, LEDs have been heavily incentivized by power utility companies in order to encourage purchase and usage by customers. This leads to less overall energy production for the sole purpose of lighting, which “frees up” more power production for use in other areas, or leads to an overall decrease in power grid load. This in turn leads to less fuel consumption by power plants, and less pollutants emitted by coal and oil-fired plants.

While LEDs are attractive from solely an energy efficiency standpoint, the chemistry of the semiconductors that they are constructed from includes heavy metals and other elements that are poisonous to the environment.[[4]](#endnote-4) When LEDs are not disposed of in a fashion that ensures their materials will be disposed of safely, they will be disposed of with other general solid waste products. The state of California has found that “all but low-intensity yellow LEDs” leech excessive levels of copper, lead, and silver to a degree that may make them hazardous to the environment and human populations surrounding waste disposal sites.

## Societal

LEDs have made possible the miniaturization of many lighting-related products, such as electronics displays and flashlights. They have made it possible to carry miniaturized useful electronics with us on a daily basis, by increasing battery life of phones and other devices (LEDs require less power than older backlighting systems, leading to longer battery life).

## Economic

The main economic draw of LED lighting is their greatly increased efficiency compared to incandescent and fluorescent solutions, leading to lower energy consumption, with lower energy costs for consumers and power utility companies.

## Technical

LED lighting requires more “support” in the form of an electronic circuit than incandescent lighting (which requires none, as it itself is the load). At its simplest, an LED lighting circuit requires only a voltage source with a resistor in series with the LED in question. The voltage source must supply enough voltage so that the LED (which has a constant voltage drop) has its constant required voltage supplied, but not so much that the LED is damaged by too much current. A resistor is used to “slow” the current through the circuit in order to not damage the LED. This setup, while useful for indication and small-scale purposes, is inefficient for large lighting arrays due to the energy lost in the resistor (IR^2) in series with the LED. In larger applications designed for large-scale lighting, the support circuit would consist of a constant-current power supply which would drive multiple LEDs in series. The constant-current supply is used in order to control the current (which was done by the resistor in the simple example) without overwhelming and damaging the LEDs. This allows the voltage to “float” to whatever the LED string requires, and allows the designer great control over the current through the LEDS. The current through an LED drives how much light is emitted from it.

# LED Characteristics

LED lighting is an important advancement in the lighting industry. It has provided several improvements over the incandescent lighting option. These improvements include:

* Lower energy consumption
* Longer lifetime
* Smaller size
* Faster switching

It was noticed that LEDs will lose efficiency as you push higher current levels through them. This phenomenon has been observed to be up to a 20% drop in efficiency. After observing this phenomenon, it was also noted that the drop in efficiency is less severe at higher temperatures.[[5]](#endnote-5) In addition to the behavior at higher temperatures, it was observed that LED light output increases at extreme low temperatures.

On the note of one of the above bullets, LEDs have a significantly longer lifetime than other lighting options. High power LEDs can last up to 50,000 hours[[6]](#endnote-6) while lower power LEDs can last up to 100,000 hours. This is significantly higher than incandescent lighting which can range between 750 and 2,000 hours.

# LED Lighting System Electronic Components

LED lighting systems require more components than typical incandescent lighting systems because the power going into an LED must be conditioned. Lighting components that are typically used in LED lighting systems are:

* Driver
* Reflector
* Heat sink
* Ballast resistor

The LED driver is meant to regulate the power that goes to the LED. Since some LED properties change with heat, the driver also makes sure that the power going to the LED will produce a constant amount of light. Without the proper driver, an LED can overheat, have poor performance, or not work at all.[[7]](#endnote-7)

Most of the power that goes into a high power LED is changed into heat (70% heat to 30% light)[[8]](#endnote-8). Because of this, there is a great need for heat dissipation in most LED applications. LED applications will normally have a heat sink in it for this reason. The heat sink is made of a thermal conductive metal that will move the heat away from the LED. There are normally fins on the heat sink itself to increase the surface area that is exposed to the air. These fins will help dissipate the heat more quickly in order to prevent the LED from overheating.

LEDs are mainly only diodes that also happen to produce light. Diodes have minimal resistance because they are only meant to block current going one way and allow it to go the other way. Because of this, if an LED were to be connected directly to a power supply it would have an enormous amount of current traveling through it. This will most likely force the LED to “let out its magic smoke”. The best way to prevent this from happening is to place a resistor in series with the LED. This will resist the current enough (if the resistor is big enough, but also not too big) to prevent the LED from overheating. This resistance must be finely tuned because if the resistance is too high then there will not be enough current traveling through the LED to produce a usable amount of light. At the same time, the resistance has to be big enough to prevent too much current from traveling through the LED.

1. Kim, H.-H., Goins, G. D., Wheeler, R. M., & Sager, J. C. (2004). Green light supplementation for enhanced lettuce growth under red and blue light emitting diodes. Horticultural Science, 1617-1622. [↑](#endnote-ref-1)
2. Panitchayangkoon, G. a. (2011). Direct evidence of quantum transport in photosynthetic light-harvesting complexes. Proceedings of the National Academy of Sciences, 20908-20912. [↑](#endnote-ref-2)
3. <http://phys.org/news202453100.html>, “White LEDs with super-high luminous efficacy could satisfy all general lighting needs” [↑](#endnote-ref-3)
4. <http://pubs.acs.org/doi/pdf/10.1021/es101052q>, Potential Environmental Impacts of

   Light-Emitting Diodes (LEDs): Metallic Resources, Toxicity, and Hazardous Waste Classification” [↑](#endnote-ref-4)
5. <http://www.digikey.com/en/articles/techzone/2011/oct/identifying-the-causes-of-led-efficiency-droop> “Identifying the Causes of LED Efficiency Droop" [↑](#endnote-ref-5)
6. <https://web.archive.org/web/20090410171009/http://www1.eere.energy.gov/buildings/ssl/life_measuring.html> “Measuring Light Source Life” [↑](#endnote-ref-6)
7. <http://www.luxdrive.com/products/what-is-a-driver/> “What is a LED Driver?” [↑](#endnote-ref-7)
8. <http://en.wikipedia.org/wiki/Thermal_management_of_high-power_LEDs> “Thermal management of high-power LEDs” [↑](#endnote-ref-8)