White Paper

LEDs: Everything You Wanted to Know

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Introduction

The rapid pace of modern technology is making many types of products smaller and more powerful. Moore's law predicts that the number of transistors in a dense integrated circuit doubles approximately every two years. However, this doesn't apply only to integrated circuits; Moore's law is also reflected in Light Emitting Diode (LED) technology. An LED is made up of many small dies. The same advancements that allow packing more transistors into an integrated circuit also allow LEDs to become brighter and more compact.

LEDs are fast becoming the future of lighting. Their high light output and low power consumption make them ideal solutions for meeting the new requirements being enacted due to recent legislation. However, it isn't possible to compare an LED light to traditional lighting sources using previous terminology, such as describing an LED's light output in terms of wattage. LEDs also have different constraints on operating conditions, manufacturing, and the type of light produced. In short, LEDs are a new technology that is very different than older light sources. This document is meant to be a resource for understanding LED technology, offering a reference for designers, engineers, managers, and anyone else working with them for using and designing for them properly.

Intro to LEDs (Light Emitting Diodes)

As the name suggests, an LED is a type of diode that emits light. The principles on which LEDs operate were discovered by Russian scientist Oleg Losev in 1927, but he was unable to develop practical applications for them. In the 1960s, LEDs were developed to the point where they could be used in practical applications. At first, LEDs were used for small indicator lights and displays. As the technology advanced, it was applied to general lighting tasks. Although they can often replace older lighting technologies, LEDs differ from them enough that commonly understood older metrics and terminology can't be used to describe an LED's performance. This section offers background on LED operating fundamentals that will be helpful in understanding the information in later sections.

A diode is a type of semiconductor device. A semiconductor is a material capable of being both an insulator (a material that resists the flow of electricity, that is, electrons), and a conductor (a material that allows the flow of electricity). The way a semiconductor conducts electricity depends on how the material is prepared by a process called doping, which involves adding impurities. Depending on the type of material added, the semiconductor will have an excess of free electrons (N-type) or a lack of free electrons (P-type). A diode is created when an N-type semiconductor is paired with a P-type semiconductor. By themselves, both types of semiconductors will inhibit the flow of electricity. The excess electrons of an N-type semiconductor act as barriers, blocking any electrons from flowing through the material. The missing electrons of a P-type semiconductor act as holes; any electrons that flow through the material will fall into the holes and stop, which also inhibits electron flow. However, N-type and P-type semiconductors can be used in combination to create a device that will only allow electrons to flow one way.

When a current is applied to a diode with the source attached to the N-type and the ground attached to the P-type semiconductor, the electrons from the current will cause the extra electrons in the N-type semiconductor to move into the holes in the P-type semiconductor (**Figure 1**), removing the obstacles that were preventing the electrons from flowing through the semiconductor material. This makes it so that the diode will only conduct electricity in one direction (**Figure 2**).

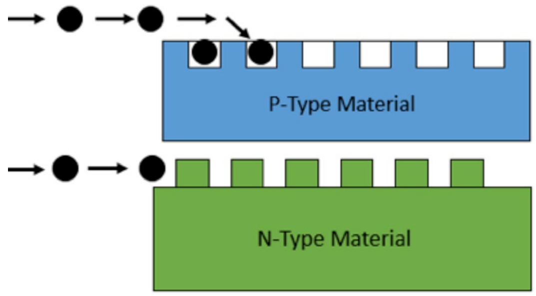

Figure 1: Flow of electrons being impeded by both P-type and N-type semiconducting material

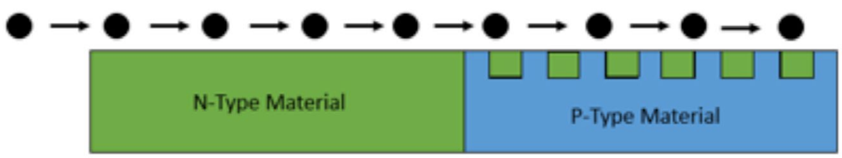

Figure 2: The flow of electrons is no longer being impeded by the semiconducting material due to the movement of excess electrons in N-type material filling the holes in P-type material.

Moving the electrons from the N-type semiconductor over to the P-type semiconductor dissipates energy. In normal diodes, this energy is dissipated as heat, but an LED emits electromagnetic radiation (light) as well as heat (**Figure 3**).

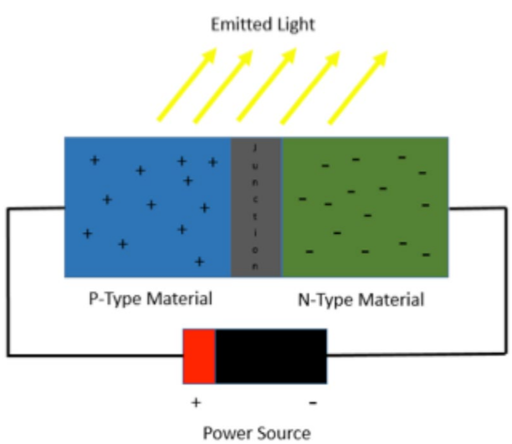

Figure 3: A schematic of an LED producing light by having electricity flow through the P-type and N-type material.

The amount of light the LED produces is controlled by the electrical power that flows through it. Two factors contribute to electrical power: voltage and current. The voltage in an LED is mostly constant due to the way the electrons shift between the P-type and N-type semiconductor material. Therefore, current is the major factor that determines the amount of light an LED produces. The downside is that high currents produce excess heat, so the current in the LED must be controlled or the LED will overheat and self-destruct.

Types of LEDs

Each of the many different types of LEDs has its own advantages and disadvantages. This section explains the different types of LEDs and their typical uses and operating conditions.

AC

Alternating current (AC) LEDs can run on AC electricity. Most LEDs can run only on direct current (DC) electricity, but internal circuitry in AC LEDs allows powering and controlling them by AC without an AC-to-DC converter.

Bi-color

Bi-color LEDs have two different color die (small internal diodes that produce the light for an LED) that allow the LED to change from one color to another. These die are placed antiparallel to each other (that is, connected in parallel but with their polarities reversed) so that reversing the electrical current will cause the light emitted by the LED to change.

Flashing

Flashing LEDs contain circuitry that causes them to flash. For most of these LEDs, the period of the flash is fixed. These LEDs are typically used as indicators; some advanced units can flash multiple colors alternately.

High-brightness

High-brightness LEDs are designed to output hundreds or thousands of lumens of light. They can handle up to 1A of current, but thermal management is critical for these types of LEDs because they will burn out within seconds if not properly cooled. A single high-brightness LED is powerful enough to replace a flashlight bulb; a high-brightness LED array can produce even higher lumen outputs.

Midrange

Midrange LEDs are well-cooled, single-die packages. A midrange LED is suitable for applications that require approximately 10 to 100 lumens; due to midrange LEDs' increased light output, they can handle currents up to 100mA. Typical applications include light panels, emergency lighting, and taillights.

Miniature

Miniature LEDs are composed of a single die and come in small packages designed to mount on circuit boards or electronics. These low power devices consume only 1–20mA. They can't be used in applications that produce lots of heat because their small size limits their ability to dissipate it.

OLEDs

Organic LEDs (OLEDs) are not based on semiconductor material but of organic material that is designed to act like a semiconductor. OLEDs are a newer type of LED and have several advantages over traditional LED technology; OLEDs are lighter, more efficient, and brighter. They have a faster response time and can be attached to flexible materials. However, this new technology has a shorter lifespan, less durability, and is more expensive to produce than other LEDs. Although they are not currently commercially viable, OLEDs are predicted to be the next major advancement in lighting and display technology.

Tri-color

Tri-color LEDs have three different color die that allow them to switch between three colors. Three separate control leads control the colors. The RGB (Red, Green, and Blue) LED is a variant of the tri-color LED, primarily used in LED displays.

White Light

White light is made up of a spectrum of multiple different wavelengths of light and is not easily reproducible by an LED die, which produces light in single wavelengths. However, placing layers of phosphor over the die of an LED can broaden the spectrum of wavelengths of light it emits, allowing it to produce white light. Another technique is to use an LED that can emit multiple wavelengths. Tri-color LEDs can produce different wavelengths of light; light of multiple wavelengths can be blended to simulate white light. The most common white LEDs manufactured today are dies that produce blue light and have either phosphor coating integrated on the die or an exo-phosphor shell.

LED Material

Several semiconductor materials have been used to manufacture LEDs over the years. Early LED technology used gallium phosphide (GaP) and aluminum gallium arsenide (AlGaAs). GaP could generate light that was in the red to yellow-green part of the spectrum; AlGaAs could emit light in the green to infrared portion of the spectrum. However, both materials were inefficient, unable to withstand high temperatures, and had short lifespans. GaP has been phased out of use in production LEDs due to its shortcomings. AlGaAs is still used because of its ability to produce red and infrared light.

Aluminum indium gallium phosphide (AlInGaP), indium gallium nitride (InGaN), and gallium nitride (GaN) are replacing GaP and AlGaAs as the semiconducting materials of choice for most commercial LEDs. These materials have long lifespans and can withstand high temperatures and currents, which makes them ideal for LED use. With the development of AlInGaP, InGaN, AlGaAs, and Gan LEDs, commercial LEDs can produce all colors in the visible light spectrum, except for pure yellow and white; ultraviolet and infrared light can also be produced. However, by using phosphor technology or multiple wavelengths of light, any color of visible light, including white and yellow, can be produced.

LED Terminology

This section briefly introduces terms and properties related to LEDs and lighting. However, this discussion should not be considered complete; many of these topics have entire fields of study dedicated to them.

ANSI

The American National Standards Institute (ANSI) is a non-profit organization that helps set the standards for products, services, systems, and personnel in the United States. ANSI also promotes standards internationally so American products, services, systems, etc. can be used around the world.

Ambient Light

Ambient light comes from the surrounding environment. It must be considered when designing or choosing an LED device. Common ambient light sources include the sun, moon, and nearby lighting devices.

Ambient Temperature

Ambient temperature is the temperature of the surrounding environment. It is commonly represented by the symbol Ta in thermal systems. The larger the difference between the temperature of a thermal system and the ambient temperature is, the more heat that will be dissipated.

Array

An array is a grid of dies; each die is an individual diode that makes up the entire LED device. The dies can all be the same color or different colors. They might be connected in one or more "channels," which may be individually controllable to adjust intensity or overall color. For example, one channel may contain all the red dies, which are arranged more or less evenly around the package. The same is true for the green dies, the blue die, and (if present) the white dies (**Figure 4**).

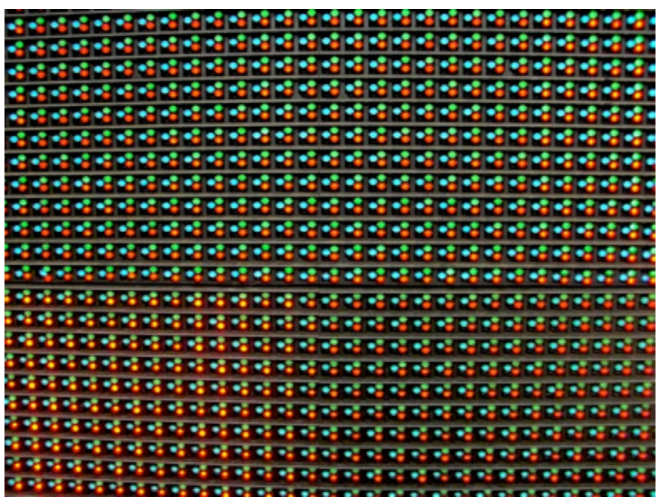

Figure 4: An array of RGB LEDs. The LEDs are placed in groups of three, which act as a single unit. Different combinations of red, green, and blue LEDs are activated to generate different colors. Image courtesy of Ryan Devenish.

Binning

As LEDs are manufactured, variations in the process produce LEDs of varying quality, which are sorted into bins based on their parameters. In theory, all the individual LEDs that go into a device have identical characteristics. However, in practice, this is impossible and there will be some variation in the LEDs. Different manufacturers have different standards on how tight the variation between the LEDs in a device must be. When binning an LED, the parameters used are the color output, the amount of light emitted, and the forward voltage. Variations in the light output and the color of light will lead to worse performance. This is due to interference patterns created by individual LEDs outputting light at differing frequencies and light levels. Variations in the forward voltages can lead the LED to burn out due to a large current draw.

Black Body / Black Body Radiator

A black body or black body radiator is a theoretical object that absorbs all electro- magnetic radiation, so it reflects no light and appears completely black. When a black body is heated, the color of light it emits depends on the temperature (see **Figure 5**). This is the basis for the color temperature curve used to describe the color of light.

Figure 5: A horseshoe being forged. The heated portions of the black horseshoe emit light of different colors proportional to the temperature of the metal. Image courtesy of Anthony.

Chromaticity

Chromaticity is the objective measurement of the color of light. It is based on the light's hue and saturation. A chromaticity diagram (**Figure 6**) allows determining the color of light by using the hue as the angular polar coordinate and the saturation as the radial polar coordinate.

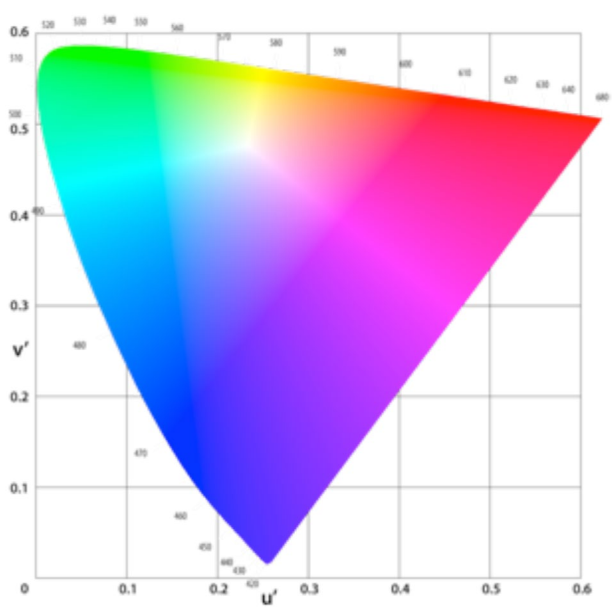

Figure 6: Chromaticity diagram. Using polar coordinates, hue as angular coordinate and saturation as radial polar coordinate, the color of light can be determined quantitatively.

Color Model

A color model is a mathematical way of describing color using color components. Two common color models are Red, Green, and Blue (RGB) and Cyan, Yellow, Magenta, and Kontrast (CYMK), where any color is theoretically represented by a combination of these colors (**Figure 7**).

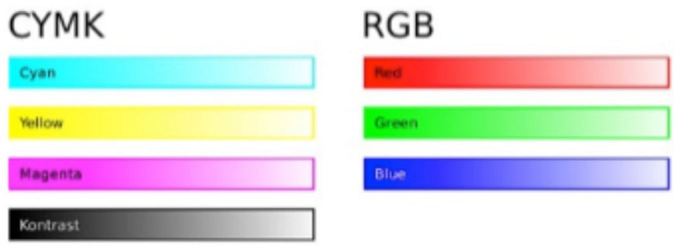

Figure 7: Examples of the CYMK and RGB color models. Image courtesy of Lukas Kästner.

Color Spectrum / Visible Spectrum

The visible spectrum is the wavelengths of light visible to the human eye. This ranges from around 390 nanometers (violet light) to 750 nanometers (red light). Most natural light includes many different wavelengths of light, which combine to create white natural light or a different color of light (**Figure 8**).

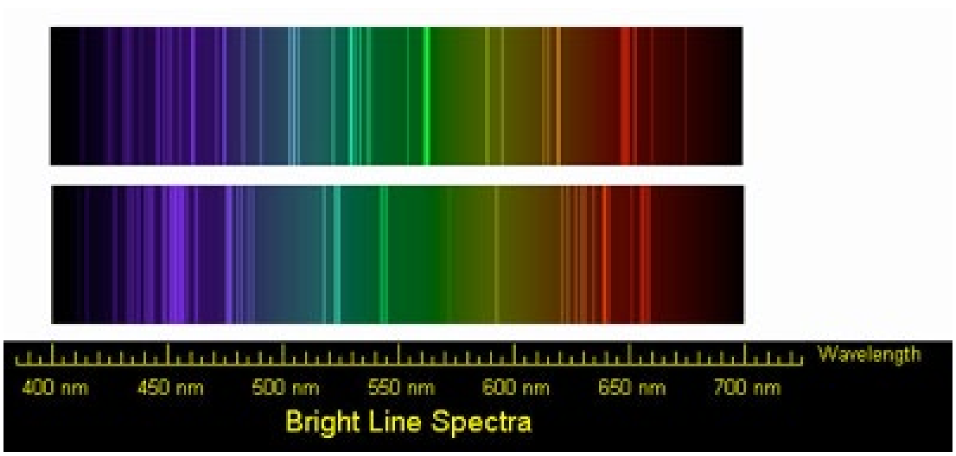

Figure 8: An example of the different wavelengths contained within a sample of light. Image courtesy of NASAGlobalAstro.

Color Temperature

Color temperature (**Figure 9**) is the temperature at which an ideal black body, a theoretical object that absorbs all electromagnetic radiation, will emit a certain color. Color temperature is used to describe the color of light emitted by a light source. The specifications for many light bulbs and LEDs use color temperature to describe the color of light emitted. The unit for color temperature is degrees Kelvin, which allows for the color of emitted light to be quantified using a simple unit. Color temperature ranges from red for lower temperatures to blue for higher temperatures; it does not include green or purple light.

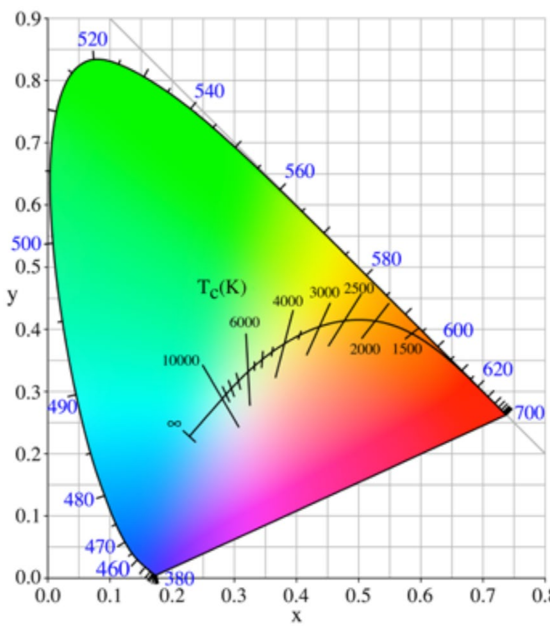

Figure 9: The color temperature of light is included on a chromaticity diagram. Red light is included on the low temperature spectrum; blue light is on the high temperature spectrum. Purple and green light are not included in color temperature.

Color Rendering Index

The Color Rendering Index (CRI) is the quantitative measure of how closely a light source reproduces the color of an object when the object's color is compared to the color observed under natural light.

Cool Light

Cool light comes in at 5500 Kelvin (K) or higher on the color temperature scale. Cool light is typically bluish in color, and is considered harsh and artificial.

Current

Current is the flow of electricity. The International System of Units (SI) unit for current is an Ampere, which is defined as one coulomb per second. A common analogy used to describe current is to relate it to the flow of water in a hose. A large current is similar to a large amount of water flowing from a fire hose, while a small amount of current is like water trickling from a garden hose. This is why current is the property of electricity that will harm people. The more electricity that flows through a system, the more harm that it will cause.

CYMK Color Model

The CYMK color model uses Cyan, Yellow, Magenta, and Kontrast to replicate a wide range of colors. Cyan, Yellow, and Magenta are removed from light in different proportions to get a desired color. Black is used as an additional additive to add efficiency to the color model.

Diffuser

Diffusers are devices that scatter light. They are commonly made out of translucent materials such as ground glass, Teflon, or opal. They are used with LEDs to spread out the light emitted. Without a diffuser, the light from an LED will appear harsh because it comes from a single identifiable point (**Figure 10**).

Figure 10: A diffuser made for an LED light. The LED light is scattered by the diffuser so there is no identifiable single source of light. Image courtesy of Russell Harrison Photography and flickr.com.

Diode

A diode is constructed by coupling P-type and N-type material in a PN junction. P-type material has a lot of holes with positive charge and a N-type material has a lot of electrons with negative charge. When these two materials are combined in close proximity, electrons from the N-type material fill the holes in the P-type material. Thus, in the region close to the junction, the carriers (electrons and holes) are depleted, where only positive and negative ions can exist. This region is referred to as "depletion region" (**Figure 11**). The P-type side is called the anode and the n-type side called the cathode. An anode has positive potential so it collects electrons; the cathode has negative potential so it emits electrons to the anode.

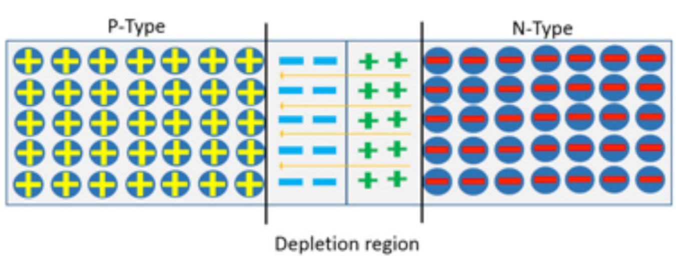

Figure 11: The P-type material, N-type material, and the depletion region that make up a diode.

A diode has a nonlinear behavior, meaning that its output is not proportional to the voltage. It works in three situations: forward biasing, reverse biasing, and breakdown (**Figure 12**). In forward biasing, the anode is more positive than the cathode and current flows from anode to cathode. In the low voltage region, the current is small. After the voltage reaches a specific threshold, a small increase in voltage will cause large growth in current. The relationship between voltage and current is exponential in this region.

$$I = Is\left(e^{Vd/\eta VT} - 1\right)$$

In reverse biasing, the cathode is more positive than the anode. The tiny current that flows from cathode to the anode is called reverse saturated current. In this region, the depletion region is extended and the current is very small for all reverse voltages lower than the breakdown voltage.

Breakdown occurs when voltage in reverse biasing reaches a level that causes a large current to pass through the diode. Breakdown voltage is a parameter of a diode that defines the largest reverse voltage that can be applied without causing an exponential increase in the current in the diode.

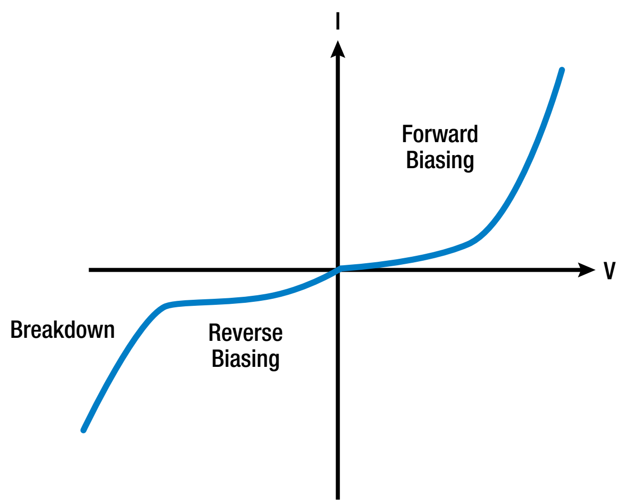

Figure 12: The electrical behavior of a diode. As a voltage is applied, the diode will go from not conducting electricity to conducting electricity freely once a certain voltage is reached.

Efficacy

Efficacy is the ratio of light emitted by an LED in lumens to the amount of electrical power put into the LED in watts. Efficacy is generally read as lumens per watt (Lm/W). When this document was written, the highest efficacy commercially available LED is 200 Lm/W.

Efficiency

Efficiency is the ratio of how much power is put into a system to how much useful power is output from a system. The efficiency of an LED is the ratio of electrical power put into the LED to the power of the light emitted by the LED. In general, LEDs are extremely efficient and become more efficient. Efficiency is generally presented as a percentage. Example: LEDs today are almost 20–25% efficient. This means LEDs convert 20–25% of the power put into them into light and the balance is turned into heat.

Full Spectrum

Full spectrum light contains the wavelengths of the entire visible spectrum. By definition, white light is full spectrum light because it contains every wavelength of visible light.

Heat Sink

A heat sink is a device used to remove heat from a thermal system. Heat sinks are designed with a large surface area so that air flowing across the surface will remove the heat from the system (**Figure 13**). Heat sinks are commonly used with LEDs to ensure they do not overheat. A thermal compound is commonly used to make sure that the LED transfers its heat to the heat sink.

Figure 13: A heat sink attached to an LED device. The fins on the heat sink increase its surface area, improving heat dissipation.

Illuminating Engineering Society of North America (IES)

The Illuminating Engineering Society of North America (IES) is the technical authority on lighting in North America. IES is dedicated to promoting the art and science of quality lighting.

Integrating Sphere

An integrating sphere is used to measure the total light emitted by a light source. By fully enclosing the light source, an integrating sphere allows the system to measure optical power directly.

LED Driver

Because an LED is a current-driven device, a "driver" is necessary to provide the desired current. A driver may range in complexity from a simple resistor to a driver providing dimming for red, green, blue (RGB), and white channels, while compensating for changes in the LED's temperature.

LED Light Engine

An LED light engine is a device that contains an LED or LED array, an LED driver, and all other components necessary for its operation. It is a fully assembled device capable of producing light (**Figure 14**). 6,000 LED die can be cut from a single wafer. The resulting LED die are then assembled into a final package.

Figure 14: An example of an LED light engine. An LED light bulb has all the components necessary to produce light. Image courtesy of Team EarthLED.

LED Manufacturing

LEDs are made from a base semiconductor material that is selected based on the specific color of light desired. Semiconductor material (**Figure 15**) is produced in a high-pressure environment in which the individual components are mixed together into a solution.

Figure 15: Raw semiconductor material used in the creation of LEDs. Image courtesy of Stahlkocher.

The semiconductor solution is drawn into a crystalline semiconductor rod by a seed rod. The semiconductor rod is cut into thin wafers (**Figure 16**) that are used as the base for the LED. Additional semiconductor material is grown on this wafer and impurities are added to these layers to create the N-type and P-type semiconductors used to create diodes. Metal is added to the top of the wafer to create leads for the LED. Next, the wafer is cut into pieces to produce the individual LED die; more than 6,000 LED die can be cut from a single wafer. The resulting LED die are then assembled into a final package.

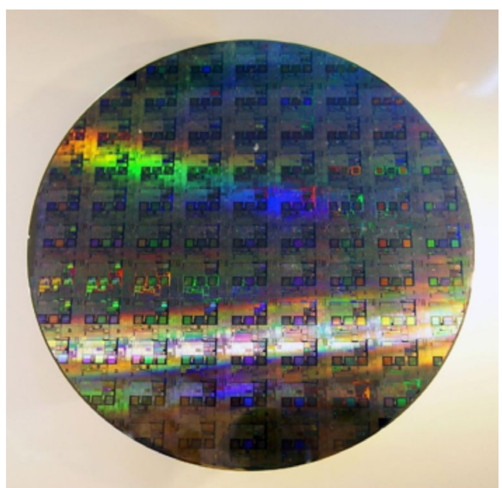

Figure 16: Wafers made out of semiconducting material. Image courtesy of Peellden.

Although more than 6,000 LED die can be cut from a single wafer and several thousand wafers a few microns thick can be produced from a single rod, very few of the LEDs produced are suitable for use in a commercial product. The remaining LEDs are of varying properties and must be sorted into bins based on their properties. One of the major sources of errors in semiconductor material is malformation of the crystal of which they are composed. The semiconductor must be a single crystal for the LED to work properly; any improper mixing of the base materials will cause multiple crystals to form, which degrades the LED's performance. Another major source of manufacturing error occurs when cutting the individual die from the wafer. It is difficult to cut out the LEDs from the wafer accurately; many are cut out improperly, rendering the die unusable. Both of these sources of error are not easily controlled; even when a usable LED is produced, it can have vastly different properties from another LED from the same batch.

Luminous Efficiency

Luminous efficiency is the ratio of the total lumens emitted by a light source to the expected lumens emitted by a light source. When multiple light sources are combined, such as in an array of LEDs, the number of lumens produced don't add up as one might expect. Some of the light is canceled out by competing wavelengths of light or is blocked by the geometry of the device.

Luminous Flux

Luminous flux is the power of light, weighted for wavelengths to which the human eye is sensitive. Defined as one lumen over one steradian, it is also expressed in units of watts. Luminous flux is used to describe the power of light that is visible to the human eye

Lumen

Lumen is an SI unit for luminous flux, the total amount of light emitted. This unit is based on the old standard of the amount of light emitted by a candle. Lumens are used to indicate the brightness of a light source. Although the lumen output of a device does indicate the amount of light it emits (**Figure 17**), it does not fully indicate the perceived brightness of the light source. Brightness of light is also affected by the concentration of the light or lux.

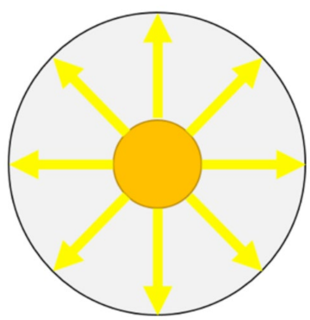

Figure 17: Lumens are a measure of the total light output of a light source.

Lumen Maintenance

Lumen maintenance is the lifetime performance of an LED. As LEDs age, they produce less light than a brand new LED. The lumen maintenance is expressed in percentages of the light output of a new LED.

Lux

A lux is one lumen per square meter. It describes the concentration of light in a certain area (**Figure 18**). The more concentrated the lumens in a certain area, the brighter the light is. Lenses or other reflecting objects can concentrate the light to certain areas, increasing lux and perceived brightness.

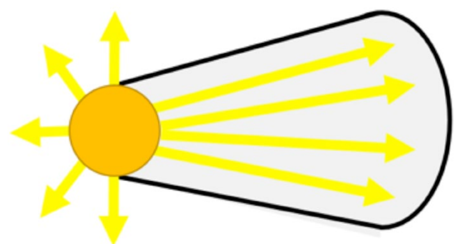

Figure 18: Lux is the measure of all the concentration of light.

MacAdam Ellipse

The MacAdam Ellipse refers to the regions in the chromaticity diagram where colors are indistinguishable by a person (**Figure 19**).

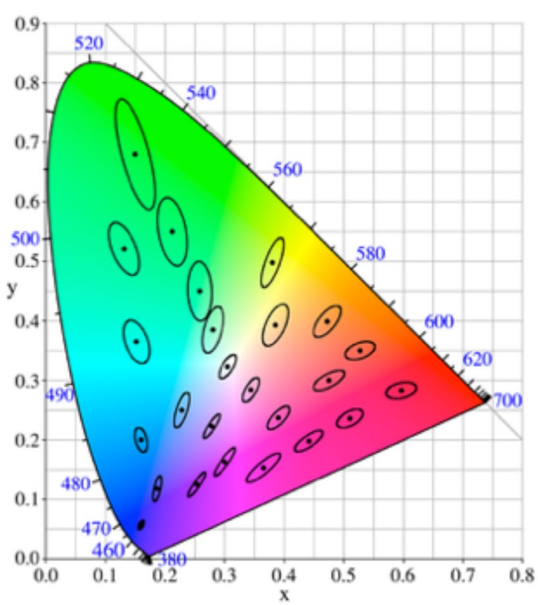

Figure 19: MacAdam Ellipses in the chromaticity diagram. The ellipses indicate regions where light is indistinguishable by a person.

N-type Material

N-type material is material in a semiconductor that has an excess of electrons, making it negatively charged. The excess electrons block the flow of electrons. N-type material will only conduct electricity when paired with P-type material and the proper voltage is applied to the material.

P-type Material

P-type material is material in a semiconductor that has a lack of electrons making it positively charged. The missing electrons create holes, which block the flow of electrons. P-type material will only conduct electricity when paired with N-type material and the proper voltage is applied to the material.

Planckian Black Body Locus

The Planckian black body locus is the line drawn on the chromaticity diagram that shows the color of light that is described using color temperature.

Pulse Width Modulation (PWM)

Pulse Width Modulation (PWM) is used in LED drivers to control LEDs. A PWM is a signal that turns the LED on and off at high frequencies (**Figure 20**). PWM can be adjusted to vary the amount of time that the LED is on and off, allowing the LED to be dimmed. The switch from on to off happens so quickly that people can't notice it.

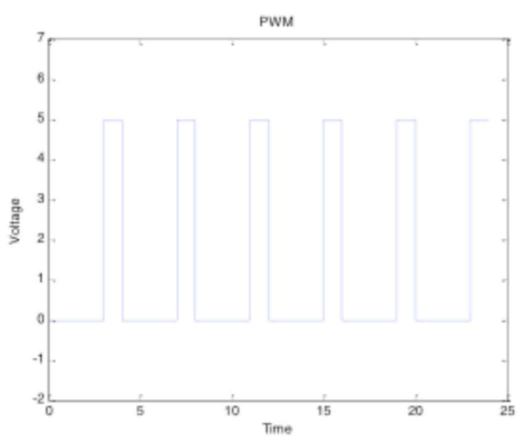

Figure 20: A Pulse Width Modulated signal turns on and off rapidly. The frequency of this switching between on and off happens so fast that it simulates a lower power level.

Radiant Flux

Radiant flux is the power of light over the entire electromagnetic spectrum. Radiant flux is defined as one lumen over one steradian.

Resistance

Resistance is the opposition to the flow of electricity. The SI unit of resistance is the ohm, which is defined as the ratio of the voltage to current flowing through an object. A common analogy used to describe electrical resistance is to compare it to a valve on a hose. High resistance means that very little or no electricity will flow, just like a valve that is barely opened. A low resistance means that electricity will flow easily, just like a valve that is opened fully.

RGB Color Model

The RGB color model uses red, green, and blue to replicate a wide range of colors. The red, green, and blue lights are combined together in different proportions to get the desired color.

Standard Deviation of Color Matching (SDCM)

The Standard Deviation of Color Matching (SDCM) is the metric used to describe the difference between various colors. The unit for SDCMs is the MacAdam Ellipse. One to three SDCMs or MacAdam Ellipses are considered to be minimal color difference and not noticeable to humans. Larger SDCMs will result in noticeable color differences.

Steradian

Steradian is the SI unit for a solid angle. It is defined as the ratio of the subtended area to the square of the radius from the vertex. It is effectively the 3-dimensional equivalent of the radian. A sphere has a 4D steradian.

Sunlight

Sunlight includes ultraviolet, visible, and infrared light. The intensity of the light typically produced by the sun (**Figure 21**) varies by the wavelength of the light. People use the different types of light produced by the sun in a variety of ways.

Ultraviolet light is defined as light with a wavelength of 100 to 400 nanometers and is best known for causing sunburns. Visible light, which humans use to see by, is light with a wavelength of 380 to 780 nanometers. Infrared light, which has a wavelength of 700 to 1,000,000 nanometers, allows seeing with night vision goggles.

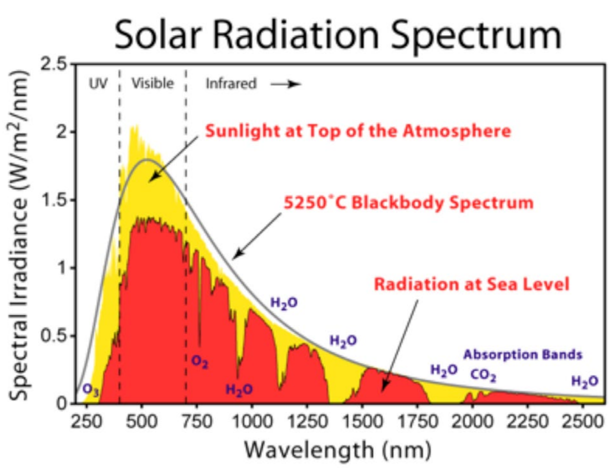

Figure 21: The different wavelengths of light and their power density.

Thermal Management

Thermal management is the dissipation of heat from a thermal system. In electronics or any other heat-sensitive system, too much heat can damage the system. Techniques like heat sinks, fans, and liquid cooling are used to draw the heat out of the system to keep it cool.

Thermal management is important in LEDs because they naturally generate lots of heat; if the heat is not properly dissipated, it can cause the LED to damage itself.

Thermal Resistance

Thermal resistance is the measure of how much a material or a thermal system resists the flow of heat. The lower the thermal resistance, the faster heat is dissipated and the lower the temperature of the material or system will be. The unit for thermal resistance is degrees Celsius per watt.

Voltage

Voltage is the difference in electric potentials between two objects. The proper definition for voltage is that it is the work done by per unit charge against an electric field to move between two points. A common analogy used to describe voltage is to relate it to water pressure. In the same way that pressure will cause water to flow from one point to another, voltage causes electricity to flow from a positive charge to a negative charge. The higher the pressure or voltage, the greater the "force" behind the flow of water or electricity. Although the words "high voltage" are commonly used to warn people about a potentially hazardous electrical system, voltage is not actually the electrical property that is dangerous to a person. For example, a static shock can have a voltage of a million volts but is not dangerous. In contrast, a wall outlet with a voltage of 120 volts can kill someone who gets shocked by it.

Warm Light

Warm light falls between 2700K and 3000K on the color temperature scale. Warm light is yellow in color and is considered softer and calming.

Watt

The watt is the SI unit for power and is defined as Joules per second. Although watts can be used to describe the power output of any type of system, for LEDs, watts are typically used to describe the power draw of the electricity and the heat generated by the LED.

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