A Techincal Description of LED Light Bulbs

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Table of Contents

A Brief History of The Light Bulb and LEDs

Incandescent Light Bulbs:

In 1802, Sir Humphrey Davy, an English chemist also credited with discovering the element Potassium, was one of the first people to discover artificial lighting. He noticed that when a piece of carbon was connected to battery terminals it glowed, and his invention was called the electric arc lamp (“History”, n.d). Although it was not practical nor it did glow for long periods of time, it kickstarted a century that would bring about immense advances in electricity and artificial lighting. Over the next several decades, other scientists made strides to make conventional light bulbs such as the ones we are accustomed to today. Efforts included English Physicist Joseph Wilson Swan’s carbonized paper filaments vacuum bulb in 1850 (Matulka & Wood, 2013). It was not until 1879 when American businessman/inventor, Thomas Edison patented the revolutionary incandescent light bulb that light bulbs become a viable artificial lighting source with practical and commercial applications. It worked by passing a current through vacuum enclosed filament, and heating it up to a certain temperature until it glowed thus producing light. His company settled on a final version of his bulb in 1880 with a model that had a bamboo carbonized filament that lasted up to 1200 hours. All other successful iterations of the incandescent light bulb were based on this version (Matulka & Wood, 2013).

CFL light bulbs:

Although the incandescent light bulb was game-changing, it was notorious for being extremely inefficient as 90% of the energy it used was dissipated via heat and not its intended purpose of lighting (“History”, n.d). A newer more efficient light bulb was needed and it came in the form of the **compact fluorescent** light bulb. Constructed with a bulb that has an inner phosphor coating, the fluorescent light bulb works by passing a current through two electrodes that producing ultraviolet light which is then converted to visible light when it hits the inner coating of the bulb. It’s early renditions came in the 19th century when German glassblower Heinrich Geissler and physician Julius Plücker discovered a method of producing light by passing a current through a long tube with no air. Their invention became known as the Geissler tube Which became the foundation upon which fluorescent light bulbs were invented (Matulka & Wood, 2013). Spurred by European research on phosphors (materials that convert invisible ultraviolet light into useful white light), the US invested heavily in fluorescent lamp research programs in the 1930s. After years of research, the first practical fluorescent lights were widely adopted by the US navy and energy powerplants in the 1940s. These lights lasted longer and were about three times more efficient than incandescent bulbs (Matulka & Wood, 2013). It was not until the mid-1980s that early CFLs hit the consumer market and they sold for $25-$30, varying from region to region and the utility company serving each region. These early CFLs were clunky, big, and did not fit well with fixtures. They also had low light output and often had performance issues. Since the 1990s, tremendous improvements have been made in fluorescent lighting as they are now more efficient and cheaper. They are 75% more efficient than incandescent lighting, and an average ENERGY STAR CFL costs as little as $1.74

when purchased in a four-pack (Matulka & Wood, 2013). They also still remain the most widely used light bulb

LED light bulbs:

Unlike CFL and incandescent light bulbs which produce a significant amount of heat when in use, the Light-emitting Emitting Diode is a type of solid-state lighting that conducts very little heat when producing light. It relies on a semiconductor diode to convert electricity into light through electroluminescence, a phenomenon where the emission of photons is caused by the excitation of a material (Britannica, 2021). Electroluminescence was reported in 1907 by English engineer HJ Round and the first light-emitting diode was reported in 1927 by Russian scientist O.V. Losev but LED technology did not make significant advances until the 1960s, a few years after the birth of semiconductor physics in the 1940s and 1950s (Andrews, 2015, p1). The first visible-spectrum LED light was invented in 1962 by Nick Holonyank Jr. of General Electric in the form of a red diode (Matulka & Wood, 2013), and in 1994, Shuji Nakamura of Nichia Corporation demonstrated the first high brightness blue LED. His work would be seminal in the invention of the white LED which relied on phosphor coating to convert the blue diode emitted light to white light (Andrews, 2015, p1). Commercially, the first LED lamp was introduced in 1968 by Hewlett-Packard and Monsanto Company in the form of indicator lamps (Andrews, 2015, p2). They had poor performance as they could only produce deep red light which was unsuitable for commercial lighting but had applications in technologies such as infrared sensors and signals used in TV remote controls. It was not until 2007 that commercial LED light bulbs started to be commercially viable for consumers due to the passing of legislation such as the Energy and Independence Security Act (EISA) of 2007 which incentivized and spurred innovation in the replacement of 60W incandescent bulbs with more energy-efficient ones. Through programs such as the Tomorrow Lighting Prize competition, innovation for creating a practical consumer-friendly LED light bulb bolstered. For example, In 2009, Phillips was awarded $10 million as the winner of the program along with partner promotions and incentives for developing a 60 W high efficiency LED (U.S. Department of Energy, 2011). As of today, LED light bulbs are the most efficient light bulbs currently available as they have the highest luminous efficacy - a measure of light bulb efficiency with units of lumens (a measure of emitted light) per watts (amount of power drawn by the light bulbs). More specifically, LED light bulbs have a luminous efficacy of 85 lm/W compared to incandescent and CFL which have 15 lm/W and 75 lm/W respectively (Matulka & Wood, 2013).

Science Behind the LED: SemiConductors and Diodes

Semi-Conductors:

The main component of LED light bulbs are the light emitting diodes, which usually come as LED chips inside the bulb. As mentioned earlier, LEDs produce light via electroluminescence, the emission of photons (packets of light energy) caused by the electronic excitation of a material. Materials that display this property are called semiconductors and are made out of elements such as silicon and germanium. A **semiconductor** is a material whose heat and electrical conductivity lies between that of conductive materials such as iron or copper and insulators such as glass or rubber (Holton et al, 2016). There are two types of semiconductors, namely intrinsic and doped semiconductors. **Intrinsic semiconductors** consist purely of a semiconductive element such as silicon but are not often used alone in diode fabrication due to their instability and dependence on temperature for electrical conductivity (Sedra & Smith, 2015, p139). When mixed with impurity elements such as Boron and Phosphorus which provide extra electrons or holes (pockets of positive space electrons are attracted and thus move around in), a material becomes more electrically conductive and it is called a **doped semiconductor** (Sedra & Smith, 2015, p139).

There are two types of doped semiconductor materials namely **N-type** materials and **P-type** materials. N type materials have higher concentrations of electrons and are thus more negatively charged while P type semiconductors have higher concentrations of holes and are more positively charged. Consequently, holes and electrons are called **charge carriers**(Sedra & Smith, 2015, p139).

Light and Diodes:

A diode consists of N-type material bonded to a piece of P-type material and with electrodes (electrically conductive wires) attached on each end. An interesting phenomenon occurs when a voltage source such as a battery is connected to the diode. When the positive terminal of the battery is attached to the P- side electrode and the negative terminal of the battery is attached to the N-side terminal, a current begins to flow through the diode and it is said to be **forward-biased** (Sedra & Smith, 2015, p157). When the negative terminal of the battery is attached to the P-side electrode and the positive terminal of the battery is attached to the N-side terminal, current does not flow through the diode and it is said to be **reverse-biased** (Sedra & Smith, 2015, p157). As current flows in the forward bias configuration, electrons move from the N side to the P side and holes go from the P side to the N side. Because the movement of charge carriers is from their areas of high concentration to areas of low concentrations, the carriers go from higher potential to lower potential thus releasing energy in the form of photons (Harris et al, 2002). Depending on the material, light of a certain wavelength is produced through these photons which is conceived as visible light of differing colors. For example, silicon diodes only release light that is not in the visible spectrum whereas aluminum-gallium-arsenide (AlGaAs) diodes, a doped semiconductor most LEDs are fabricated from, release visible spectrum light (Harris et al, 2002). It is through this seemingly complicated yet simple process of electrons on the move that LEDs produce light.

Parts of an LED Light Bulb

Althought the Light Emitting Diodes are the most important and interesting part of an LED light bulb, the light bulbs themselves actually come with several other parts that serve their own critical functions namely the diffuser, LED chips, heat sink, circuit driver, housing, and base.

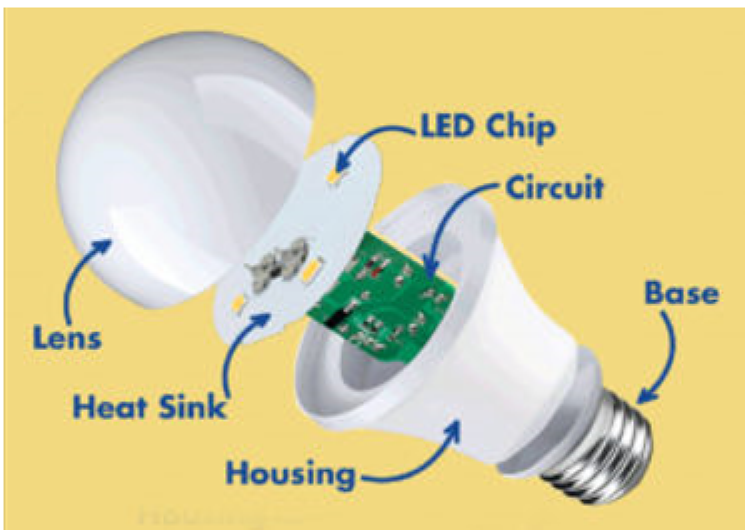

Figure 1: Anatomical view of the parts of an LED

Source: *The Anatomy of a LED Light Bulb*. (n.d.). TCPI.com. Retrieved December 13, 2021, from https://www.tcpi.com/breaking-led-anatomy/

Lens:

The lens is also known as the optics bulb or the diffuser. LED lights are usually brighter than incandescent and fluorescent light bulbs thus they need an optical casing that helps diffuse some of the light's intensity and also help the LED have the look and feel of a normal light bulb.

Furthermore, the lens also helps in evenly distributing light that is produced by the LED chips. Depending on the shape of the bulb, it can also determine which direction the light rays emitted illuminate. The optics bulb is usually made of plastic rather than glass to avoid shattering upon impact (“The Anatomy of a LED Light Bulb”, 2021)

Figure 2: Sample LED lenses

Source: *Bicom led lenses*. (2014, November 19). LED professional. Retrieved December 13, 2021, from https://www.led-professional.com/products/led-optics/bicom-led-lenses

LED Chips:

LED chips are the central part of the light bulb, and they contain the actual diode soldered atop a conductive semiconductive board. When current passes through the chip circuitry, the light bulb emits light that is proportional to the amount of current passing through the chip. This means the amount of light being emitted can also be adjusted according to the amount of current passing through the chip, another benefit of using LED lights. The chips can come as an array of chips on printed circuit board or one big singular chip on a printed circuit board that emits uniform light

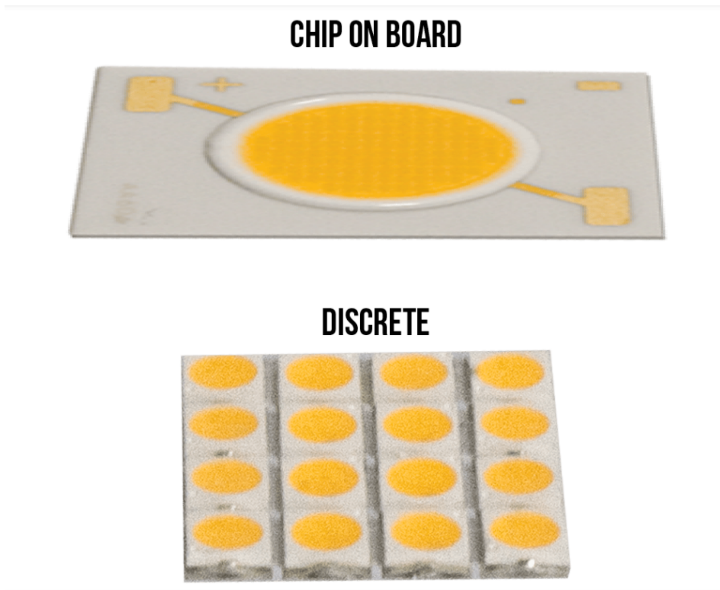

Figure 3: LED chip in a singular chip on board and discrete assortment

Source: ***The Anatomy of a LED Light Bulb*****. (n.d.). TCPI.com. Retrieved December 13, 2021, from**

https://www.tcpi.com/breaking-led-anatomy/

Circuit/ Driver:

The circuit, also known as the LED driver, is essential to controlling the amount of current flowing through the LED chips thus controlling the intensity of the light being emitted. It also plays a very important role in stabilizing current and voltage fluctuations to ensure the LED chips maintain a steady current and voltage level. This helps the light bulb avoid burning out and also maintain constant lighting. Furthermore, as the light intensity is proportional to the amount of current passing through the LED chips, the driver also helps provide dimming functionality for the light bulbs, another benefit of using LEDs over their counterparts.

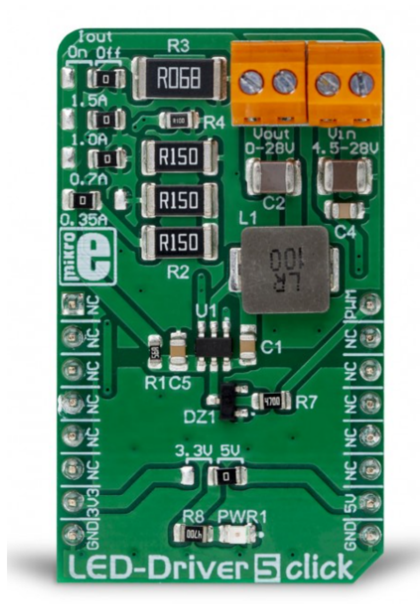

Figure 3: LED produced by MikroElektronika

Source: ***Led driver 5 click*****. MikroElektronika. (n.d.). Retrieved December 13, 2021, from**

https://www.mikroe.com/led-driver-5-click.

Heat Sink:

Although LED light bulbs produce significantly less heat than their incandescent and fluorescent counter parts, they still produce heat that if not appropriately managed could damage the LED chips and ruin the light bulb. The chips sit atop a printed circuit board which sits atop a piece of conductive metal known as a heat sink. It's main purpose is to take the heat away from the light emitting diodes and down into the base of the light bulb which is usually insulated by the plastic socket.

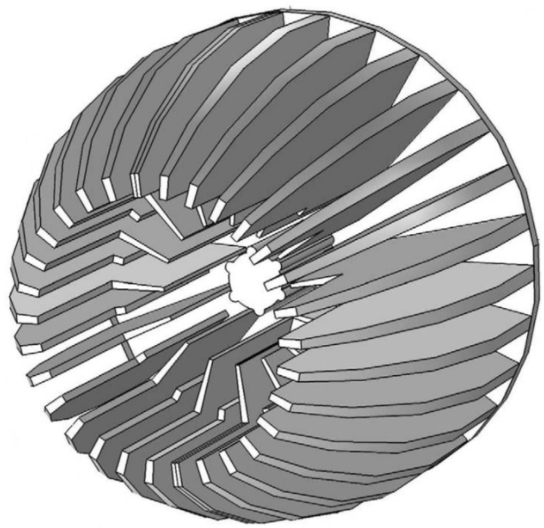

Figure 3: CAD model of LED heat sink

Energy efficiency and thermal simulations of a retrofit led light bulb by the University of Turku **(2016, July 4). Retrieved December 13, 2021, from** **https://www.led-professional.com/resources-1/articles/energy-efficiency-and-thermal-simulations-of-a-retrofit-led-light-bulb-by-the-university-of-turku-1.**

Housing:

The housing encloses the circuit driver and also helps in aiding the heat sink take some of the heat away from the chips and into the base. It is also critical in protecting the circuit driver that has electrical components as well as absorbing some of the heat produced by it. In some bulbs, the LED heat sink and the housing come as the same component

Base:

The base is responsible for connecting the light bulb to a power source, which is usually a lamp socket connected to electrical wiring. In lighting for a house, the base is designed to screw in the same way that a a normal light bulb would but light bulb bases vary in their form depending on the lighting situation being considered.

Figure 4: LED base assortment

Source: ***The Anatomy of a LED Light Bulb*****. (n.d.). TCPI.com. Retrieved December 13, 2021, from**

https://www.tcpi.com/breaking-led-anatomy/

Conclusion

The LED light bulb is an innovative piece of technology that owes its success to the many critical parts it consists of but crucially the semiconductor technology that is the light-emitting diode. In recent years, LED light bulbs have become a more and more popular lighting choice for households, offices, and factories. Although the incandescent and the fluorescent light bulb are still used, LEDs have only grown more and more popular in their adoption since their introduction in 2007. One of the biggest factors in impeding early LED adoption was their price. In recent years, LED prices have plummeted, offering their benefits at an affordable price point for consumers. For example, the price of a 60W replacement LED light bulb was $25 in 2012 whereas today the typical LED replacement light bulb can be found for as low as $2 (EPA, 2017).

Figure 4: Common Bulb Techonologies with Yearly Cost (*EPA, 2017*)

Lastly, LED light bulbs have the highest life span of all light bulbs, so much so that even if they may be more expensive than their counterparts in some instances, they end up paying for themselves in the long run due to their energy efficiency. For example, the average cost per 0.10 KWh (Killowatt hour), for LED, CFL, and incandescent light bulbs is $21.25, $35, and $150 respectively. LED light bulbs also beat out their competition in terms of lifespan with 25,000 hours for LEDs compared to 10,000 hours for CFLs and 1,200 hours for incandescent light bulbs ("LED light bulbs: Comparison charts", n.d.). LEDs are the preferred lighting choice now and in the future. As their adoption continues, they will eventually phase out CFL and incandescent light bulbs.

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