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Light Emitting Diodes: Enlightened the Past, Brightening the Future

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Abstract ***"Incandescent light bulbs lit the 20th century; the 21stcentury will be lit by LED lamps". Since the energy crises of the 1970s, researchers have introduced many more efficient light sources, but now all are being replaced with LEDs. Light emitting diode or LED bulbs are emerging as the most energy-efficient source of lighting, with a LED bulb using only 1/10th as much energy as a normal incandescent bulb and half as much energy as a compact fluorescent lamp (CFL) to produce the same amount of light. Moreover, the pace at which LEDs have come to dominate the market has been astonishingly high. This paper is intended to provide a brief review about how LEDs emerged from its embryonic face to successful advancements, creating wider avenues to expansion.***

Keywords: LED, LUMEN, DIODE, SEMICONDUCTOR, XP-G2

1. Introduction

From the most complex electronic systems to basic systems, LEDs forms the base for lighting scheme. Some of the types of lighting schemes are Direct, Semi-direct, Indirect and semi-indirect lighting schemes. Even most complex lightning schemes require simple, cheap, robust and durable light sources. LEDs check all the above criteria. The idea of LED got its spark from Henry Round in 1907, acquired its meaning and life from Losev and became visible with Holonyak's efforts.

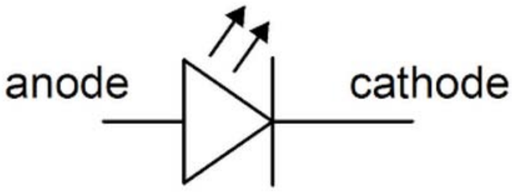

Figure 1: Symbol of LED [1].

1.1 History

The first practical visible-spectrum (red) LED was developed in 1962 by Nick Holonyak Jr., while working at General Electric Company. Holonyak is seen as the "father of the light emitting diode". M. George Craford, a former graduate student of Holonyak, invented the first yellow LED and improved the brightness of red and red orange LEDs by a factor of ten in 1972. In 1976, T.P. Pearsall created the first high brightness, high efficiency LEDs for optical fiber telecommunications by inventing new semiconductor materials specifically adapted to optical fiber transmission wavelengths.

Up to 1968 visible and infrared LEDs were extremely costly, so had little practical application. The Monsanto Company was the first organization to mass-produce visible LEDs, using gallium arsenide phosphide in 1968 to produce red LEDs suitable for indicators. Hewlett Packard (HP) introduced LEDs in 1968, initially using GaAsP supplied by Monsanto. The technology proved to have major applications for alphanumeric displays and was integrated into HP's early handheld calculators.

In the 1970s commercially successful LED devices at under five cents each were produced by Fairchild Optoelectronics. These devices employed compound semiconductor chips fabricated with the planar process invented by Dr. Jean Hoerni at Fairchild Semiconductor. The combination of planar processing for chip fabrication and innovative packaging techniques enabled the team at Fairchild led by optoelectronics pioneer Thomas Brandt to achieve the necessary cost reductions. These techniques continue to be used by LED producers [2].

With the galvanizing advancements around LED related technologies, large businesses established their interest through significant investments as shown in figure 2.

ASSIGNEE NAME	TOTAL
KONINKLIJKE PHILIPS ELECTRONICS N V	135
SAMSUNG ELECTRO MECHANICS CO	128
PHILIPS SOLID-STATE LIGHTING SOLUTIONS INC.	80
KOITO MANUFACTURING CO. LTD.	55
FU ZHUN PRECISION INDUSTRY (SHEN ZHEN) CO. LTD.	47
DONGGUAN KINGSUN OPTOELECTRONICS CO	37
TOYODA GOSEI CO. LTD.	36
SONY CORPORATION	34
MATSUSHITA ELECTRIC WORKS LTD	30
SHARP KABUSHIKI KAISHA	28

Figure 2: Companies in order of number of patents filed in LED lighting [3]

1.2 Working and Characteristics of LED

LED works on the principle of electroluminescence. Like a normal diode, the LED consists of a chip of semiconducting material doped with impurities to create a p-n junction.

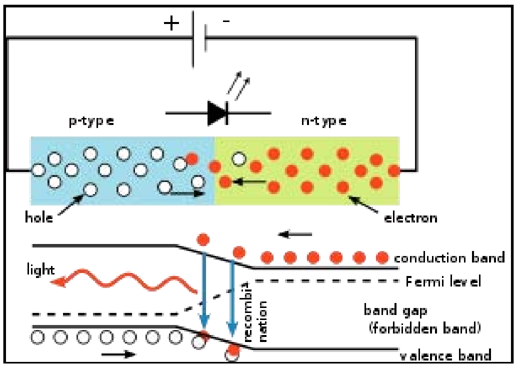

Figure 3: The inner working of an LED, showing circuit (top) and band diagram (bottom) [4].

As in other diodes, current flows easily from the p side, or anode, to the n side, or cathode, but not in the reverse direction. Charge carriers—electrons and holes—flow into the junction from electrodes with different voltages. When an electron meets a hole, it falls into a lower energy level, and releases energy in the form of a photon. The wavelength of the light emitted, and therefore its color, depends on the band gap energy of the materials forming the p-n junction. In silicon or germanium diodes, the electrons and holes recombine by a non radiative transition which produces no optical emission, because these are indirect band gap materials. The materials used for the LED have a direct band gap with energies corresponding to near infrared, visible or near ultraviolet light. [3] The following table shows the different semiconductors used in LEDs along with the corresponding colors of light emitted

Typical LED Characteristics		
Semiconductor Material	Wavelength	Colour
GaAs	850-940nm	Infra-Red
GaAsP	630-660nm	Red
GaAsP	605-620nm	Amber
GaAsP:N	585-595nm	Yellow
AlGaP	550-570nm	Green
SiC	430-505nm	Blue
GaInN	450nm	White

Figure 4: Table showing different semiconductors along with corresponding wavelength and color of light emitted [5]

Out of the above mentioned semiconductors, Aluminium Indium Gallium Phosphide and Indium Gallium Nitride are used in the latest technologies. [6]

1.3 Factors Affecting Brightness and Performance

Why a Green LED appears brighter than a Red LED even though both use same current? The answer being that a human eye has maximum sensitivity to light near 550 nm region of yellow – green part of the visible spectrum. There are some important parameters of LED responsible for its performance and brightness, which are as follows:

- **Luminous Flux (different materials)**
  It indicates the light energy radiating from LED. It is measured in terms of Lumen (lm) or Milli lumen (mlm)
- Luminous Intensity
  Luminous intensity is an expression of the amount of light power emanating from a point source per unit solid angle. It is measured as Candela (cd) or milli candela (mcd) Brightness of LED is directly related to its luminous intensity.
- **Luminous Efficacy**
  It is the emitted light energy relative to the input power. It is measured in terms of lumen per watt (lm w).
- **Forward current**
  Forward current (I_f) is the current flowing through the LED when it is forward biased and it should be restricted to 10 to 30 Milli Amperes otherwise LED will be destroyed.
- **Viewing Angle**
  Viewing angle is the off – axis angle at which the luminous intensity fall to half its axial value. This is why LED shows more brightness in full on condition. This justifies high bright LED having narrow viewing angle so as to focus the light into a beam.
- **Forward Voltage**
  Forward voltage (V_f) is the voltage drop across the LED when it conducts. In ordinary LEDs the forward voltage drop range from 1.8 V to 2.6 Volt. However in Blue and White ones, it goes up to 5 volts. The table shown below, the forward voltage drop of common LEDs.

Table 1: Voltage drop across LEDs

COLOR	VOLTAGE DROP
Red	1.8V
Orange	2V
Yellow	2.1V
Blue	3.6V
Green	2.2V
White	3.6V

- **Speed of Response**
  Speed of response represents how fast an LED is switched on and off. This is an important factor for LEDs in its switching applications like communication systems.

1.4 Efficacy

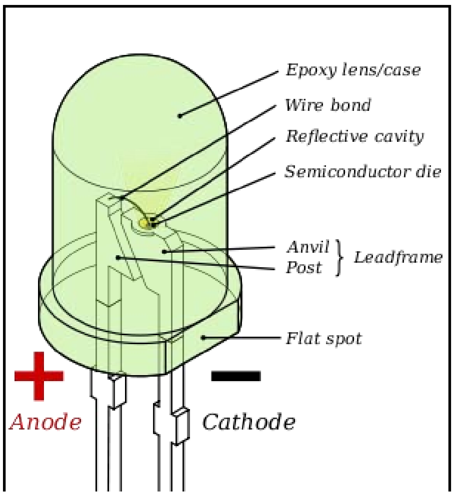

Figure 1.4: Casing of an LED, there are two terminal posts connected by a small chip made of Gallium compound. [7]

When the visible LEDs were invented in the 1960s a key part of maximizing luminous efficacy, has been recognized as maximizing the refractive index of the LED encapsulant used for packaging, The total internal reflection (TIR) can be reduced at the interface between the LED chip and the encapsulation material by Higher index encapsulants.

Initially, high-index epoxies were used for longer-wavelength LEDs, but lower-index silicones were quickly adopted for GaN-based LEDs (including white) because typical LED packaging epoxies tended to yellow with prolonged exposure at wavelengths below about 500 nm, resulting in reduced operating lifetime.

Ideally, nearly perfect light extraction can be obtained when the encapsulant index closely matches the refractive index of the LED chip. But a combination of high indices for LED semiconductor compounds, ~2.3 for GaN-based LEDs and ~3.3 for AlInGaP LEDs, and low indices for optically clear organic encapsulants makes this ideal optical arrangement impossible to achieve. [8]

The semiconductor's minimal decrease in luminous flux over the operation period causes the LED to be able to remain in maintenance-free use, in many areas of application, longer than other light sources.

1.5 Factors Responsible for Life of LED

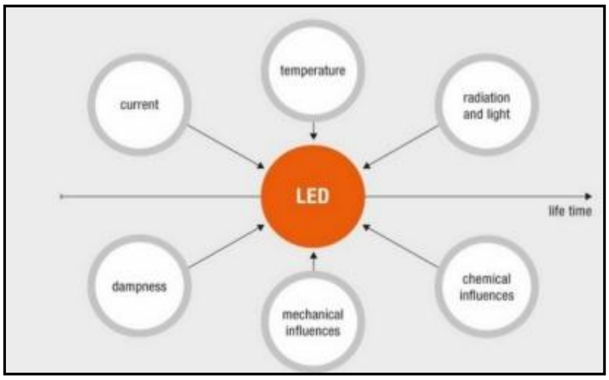

Figure 1.5: Factors affecting life of LED [9]

a) Temperature

When light is emitted, heat is produced, which has an effect both on the life cycle and on the LED's luminous flux. This applies to both the individual LED and to an entire LED module. To divert the heat, either we can choose the best possible installation method or we can use suitable heat sinks as the underlying principle being: The cooler it is, the longer the LED's life cycle and the more efficient and brighter it is.

b) Mechanical effect

If a LED is exposed to mechanical forces, this can have a negative effect on its operating life, or can even destroy it. The occurrence of mechanical forces can be during LED manufacture, assembly or handling and during the use of certain materials which develop mechanical forces during large temperature fluctuations.

c) Power consumption

Power consumption is commensurate to the amount of current in the operating range specific to any LED or LED module. Every LED, and also every LED module, can be operated within a specific current range. The lower the current is within this range, the less energy is released and the lower the heat production is, which has a direct effect on the operating life.

d) Light radiated

The particular LED's housing design plays an important role in the aging process of the particular component, influenced by the light emitted by the chip. With many housing designs, the built-in reflector ages a lot in the first few hundred operating hours as a result of the high intensity and luminance of the light emitted by the chip.

e) Dampness

The LED itself is robust, non-sensitive, vibration-proof and unbreakable. Dampness is not a problem if it is used properly as it is not the LED itself but various metal parts, connections and electronic components inside a LED module that are sensitive and may corrode and can thus cause the module to fail. Corrosion can also be prevented by a suitable choice of materials for the LED. In order to achieve the highest possible operating life of the LED modules, dampness protection is important.

f) Chemicals

Stress to the LED caused by chemical influences can vary greatly depending on the application location. For this reason, all environmental conditions must be taken into consideration when planning an LED lighting system. The following effects, among other things, have a negative effect on the operating life:

- Corrosive atmosphere (air with high sulfur dioxide content)
- Coastal climate with medium salt content
- Chemical industry
- Swimming pools with medium chloride content

2. Applications & Advantages

Industrial Applications of LED Technology include:

- Electric Light Sources
- Semiconductor Technology
- Audio Electronics
- Optics Medical Devices
- Computer Peripheral Equipment
- Traffic Control Systems
- Scanning Equipment
- Computer Data Transfer Devices
- Heat Transfer & Control Systems
- Kitchen Appliances
- Dental Equipment
- Automobile Lighting Systems
- Telecommunication systems.

LED lights have a variety of advantages over other light sources:

- High-levels of brightness and intensity
- High-efficiency
- Low-voltage and current requirements
- Low radiated heat
- High reliability (resistant to shock and vibration)
- No UV Rays

- Long source life
- Can be easily controlled and programmed

3. Popularity Quotient

Over the past decade, LED technology has advanced at light speed. In the past, lack of colors and the low intensity made LEDs useful only as indicator lights. As manufacturing methods and technology improved, the LED quickly found home in more and more applications. These days, LED is becoming a preferred light source for many more than simple indicators, for example: multicolor LEDs which glow in different colors depending upon input currents.LED light sources are also gaining popularity due to the growing energy conservation movement. According to the U.S. Department Energy, no other lighting technology offers as much potential to save energy and enhance the quality of our building environments.

4. Present Scenario

4.1 CREE XP-G2

Solid-state lighting (SSL) product developers have used the Cree XP-G in a wide variety of products ranging from street lights to flashlights. Now, we have a brighter, more-efficient XLamp from XP-G2 family available, which is 20% more lumens and lumens per watt.

Combining high light output, reliability and efficacy, XP-G2 is optimized for directional, high-lumen applications, from indoor and outdoor to portable and lamp retrofits. It is being specified both at 25°C and hot 85°C operating temperatures in terms of lumen and color output.

- In cool white at 350 mA of current, the XP-G2 delivers efficacy of 151 lm/W at 85°C and 165 lm/W at 25°C.
- At the hot temperature, the family can deliver 139 lm in cool white and 114 lm in warm white, both at 350 mA.
- Maximum drive current: 1500 mA
- Low thermal resistance: 4 °C/W
- Wide viewing angle: 115°
- Unlimited floor life at ≤ 30 ºC/85% RH
- A flashlight based on XP-G LEDs that delivered 320 lm could produce 385 lm with the same beam pattern using XP-G2 LEDs. **[10]**

4.2 Indoor Farm Illuminated by LEDs

In eastern Japan, Shigeharu Shimamura turned a former Sony Corporation semiconductor factory into the world's largest indoor farm illuminated by LEDs and these special LED fixtures were developed by GE Lighting and emit light at wavelengths optimal for plant growth. **[11]** The technology was tested in March 2012 and final design came up a year later.

5. Conclusion

According to a new report from IHS, the use of smart lighting in offices worldwide is set for an impressive growth in the next five years as LED lamps will overtake traditional lamps by 2019. Furthermore, the revenue from LED lamps is expected to grow at a compound annual growth rate (CAGR) of 21.4% and will overtake traditional lamp revenue in offices by 2019. **[12]**

Thus, as demonstrated in this review, it can be inferred that LEDs have evolved since their invention and this trend will continue. It has given a new direction to innovations in the field of electronics and continues to unravel more.

The technical potential is still not exhausted by any means and that is why LED represents the future of lighting.

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