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# Performance Evaluation of Advance LED Structures and Applications

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**Abstract**

Nowadays, LEDs are most commonly used lighting source in indoor as well outdoor applications. This paper is a comparative analysis for the evolution of LED to nowadays commercially used high Brightness (HB) LED, white LED and organic LED replacing the older lighting sources which were expensive and consumes a lot of power. Different LED structures have been compared on the basis of their optical, electrical, thermal and mechanical properties.. The techniques to improve the intensity and brightness of LED's are also described. The increase in the luminous flux is dependent on the electrical parameters of the diode. Different LED structures are discussed including new LED materials based on their applications.

**Keywords**

Light Emitting Diode, High brightness LED, White LED, Organic LED etc.

## 1. Introduction

With the discovery of PN junction diodes more things were being discovered and added to their features as well and one of them is LED i.e. PN junction with some specific type of materials like (GaAsP) when is forward biased gives the light energy which may be visible or invisible[1]. Nowadays LED's have become the most important part of optoelectronic devices as it is replacing all light resources because it consumes less power is inexpensive. There are many other reasons for their development, and they are its brightness, flexibility, suitable driving voltage, efficiency, lifetime and its rugged construction[1]. Earlier GaAsP which emits yellow to red and GaP which emits green to red light were used as LED but now as the technology has evolved we have seen great development in LED too from conventional LED to more like high brightness (HB) LED and organic LED (OLED)[2-3].High brightness LED simply depends on the different types of material that are diffused in conventional LED's to increase its brightness while its power consumption should not

ISSN: 0971-1260
Vol-22-Issue-16-August-2019

increase[2-3].While earlier organic LED was not as successful due to some drawbacks, but it has shown some dramatic improvements in its efficiency and reliability and hence is also popular nowadays. Two main types of OLED's are used which is either based on conjugated polymers or based on small molecular weight materials. OLED requires different techniques such as thermal evaporation or spin coating. The properties of organic LED's are completely different than inorganic one. Now lastly, we are going to discuss white LED's which is the most important in all of them as it is widely used. The first white LED was introduced in 1990 but it was not as efficient, it was only in year 2000 that its use accelerated dramatically [4-5]. The intensity of white LED's depends upon luminous flux and luminous flux depends on the electrical and thermal interrelations as shown in the below Figure1.

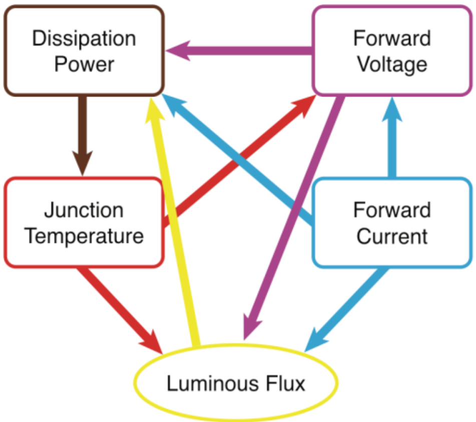


*Figure 1: Electrical and thermal interrelations [4]*

Luminous flux can be determined by weighting two functions: one that relates the emitted flux percentage with the temperature of junction and the other one which relates the emitted flux percentage with the forward current. This review paper shows the improvement in the method of calculating luminous flux which is already been proposed[4-5]. LED is simply forward-biased PN junction diode which gives light energy either in visible range or invisible range with the change in its material properties.Hall, Fenner, Kingsley, Soltys and Carlson (HFKSC) in 1962 reported experimentally that coherent infrared radiation (invisible) is been generated from the forward biased GaAs PN junction and this was the first step of the LED's invention which gave them idea that with the suitable doping in the PN junction diode they can make the diode such that it will release visible radiation and that's what they did with forward-biased Ga($As_{1-x}P_x$) if the crystal is direct semiconductor[5].The first glowing LED was developed by Holonyak in sixties which emitted red light of very low efficiency. The evolution of LED is called Craford's law which tells us about the 10

ISSN: 0971-1260
Vol-22-Issue-16-August-2019

times increase in output light performance per decade. In 1970 first LED was discovered with green, orange and yellow light[5]. Organic LED was discovered by Tang and Van Slyke in 1987 in Eastman Kodak's research laboratories which were thin-film layer OLED. The first polymer-based OLED was invented in 1990[6]. The major chalanges in the designing of LED structures are light extraction based mismatch in refractive index, thermal degration for high junction temperature, photodegradation induced by UV radiation and mismatch between LED die with encapsulant.

**Working principle of LED**

The Light Emitting Diode (LED) is simply a forward-biased PN junction acting as source photons. The output emitted photons are proportional to the magnitude of forward current thus higher the value of forward current higher is the LED's output [7]. The schematic symbol of LED diode is as shown in the below figure.

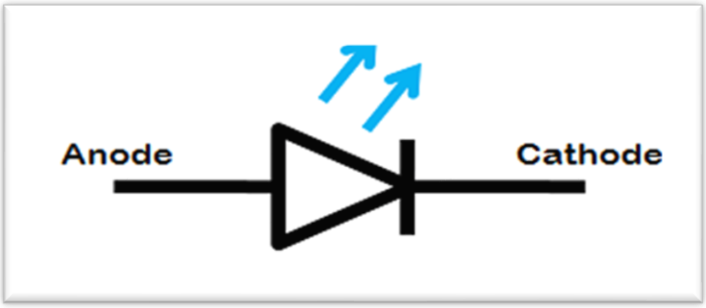


*Figure 2: LED Symbol [7]*

The emitted photon radiations are shown in Figure 3. A proper biasing is required to establish photon emission that can be further utilised as source of light. The LED structure is also very important to receive photons efficiently.

ISSN: 0971-1260
Vol-22-Issue-16-August-2019

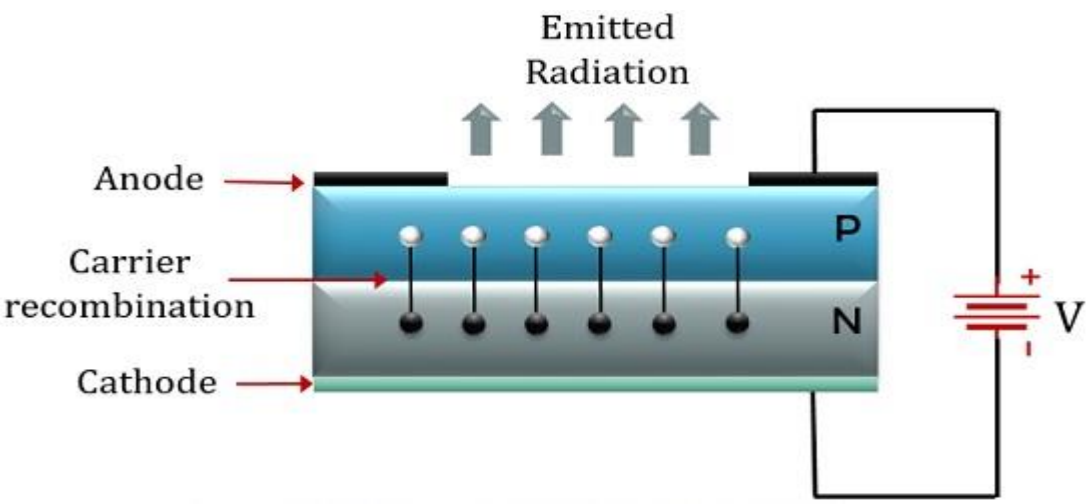


*Figure 3: LED Structure [7]*

Here an N-type layer is grown on a P-type substrate by the process of diffusion then a thin P-type layer is grown on N-type layer. The metal contacts are also grown on PN junction to make anode and cathode terminals. The recombination of electrons and holes in forward bised PN junction is responsible for the release of light energy.When LED is forward biased, the electron and holes in the diode move towards the junction and recombination of holes and electrons takes place [7]. After recombination the electrons present in N-region conduction band recombine with holes present in the P-region valance band. The wavelength($\boldsymbol{\lambda}$) of emitted photon is dependent on the band-gap($E_g$) of LED materials.

$$\text{From Planck relation, } h\upsilon = E_g$$

$$\text{and } E_g(eV) = \frac{1.24}{\lambda(\mu m)}$$

In normal diodes this energy is dissipated in the form of heat to the crystal. Depending on differet LED materials and their bandgap, the LED can radiate light in different colours such as red, green, yellow, blue, orange etc. Some of the LED's emit infrared light [7].

**2. LED Materials and their applications**

LEDs based on solid state technology(SSL) is growing its importance and market shares in coming years. Few polymeric material such silicone, Bisphenol-A Polycarbonate, Polymethyl methacrylate, Epoxy and Phosphors, are most commonly used LED materials[8]. These materials are characterised

ISSN: 0971-1260
Vol-22-Issue-16-August-2019

on the basis of their thermal, electrical, optical and mechanical properties to be utilised for optmum LED performance. The optical material used as part of LED structures as shown in Figure 4.

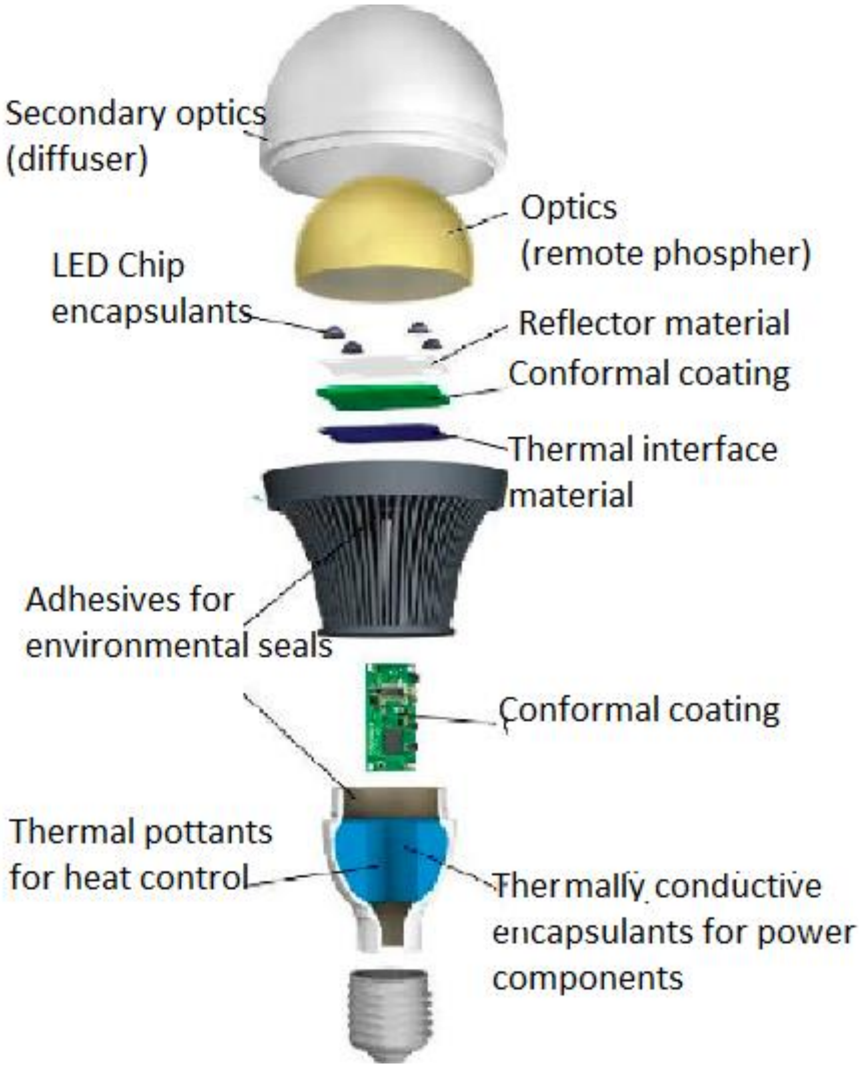


Figure 4 Different Part of LED structure[8]

Silicone is semiorganic material where organic materials like methyle or vinyle are combined with inorganic Si-O substrate. Silicone shows superior optical and thermal properties alon with excellent UV light resistant and structural stability in long run[9-10]. Bisphenol-A Polycarbonate(BAP-PC) shows relatively high elastic modulus, high thermal stability and good fracture resistance. BAP-PC are prefered in CDs, DVDs, sunglasses, riot shields and automotive interior[11-12]. A Thermo plastic PMMA(Polymethyl methacrylate) [13] is the cheapest LED material in the market mainly used in biomedical applications with excellent UV tranmittance properties. Epoxy[14] is mainly ued in PCB because of its low cost, good mechanical stability and easier manufacturing process.

ISSN: 0971-1260
Vol-22-Issue-16-August-2019

Phosphor are used in array of white-light LEDs. The blue photons produced in phosphor LEDs are converted into white light by the photoluminescence (PL) process[15].

## 3. Classification of LED structures

### High Brightness LED

Along with the development in not only in $A^{II}B^{V}$ compound semiconductors but also in their ternary and quaternary alloys that are incorporated in LED structures has also been developed a lot in these recent years. The recent trends in the fabrication of LED's which uses double heterojunction or multi-quantum wells active layers have increased the efficiency of LED several times. Development of high brightness LED's is mainly divided into two main orientations: first using $(Al_xGa_x)_{0.5}In_{0.5}P$ active layer lattice matched to GaAs (which give colour radiations from amber to red) and secondly $GaN/In_xGa_{1-x}N$ nitride-based technology (which gives colour from green to blue)[16]. LED's that uses AlGaInP quaternary alloy was developed in mid-1990's using GaAs as substrate whose efficiency has reached a value of approximately 12lm/W. A disadvantage of that kind of substrate is its non-transparency for visible light, which results in photon absorption by substrate. To remove this problem wafer bonding technique after selecting an etching of AlGaInP epilayers highly transparent GaP is placed in contact [16]. Slight pressure is applied to the wafer layers and bonded area spreads laterally across the whole wafer. GaP has the transmission which is above 60% for all the wavelengths ranging over 560nm. By changing the substrate from absorbing to transparent doubles the output flux can be increased up to 30% at 632nm [17]. Hewlett- Packard has modified the existing LED structure and called it truncated inverted pyramid (TIP) [4]. The TIP LED's performance increases to 100lm/W for amber light, which is the eight times of the value of the first GaAs LED and hence quantum efficiency is also increased to 50% because of the development in nitride structures for blue to green colour and due to increase in performance made them widely used and cheaper also [18]. Layers of GaN, AlGaN and InGaN are grown by the process of MO VPE on sapphire or SiC substrate as shown in the below figure:

ISSN: 0971-1260
Vol-22-Issue-16-August-2019

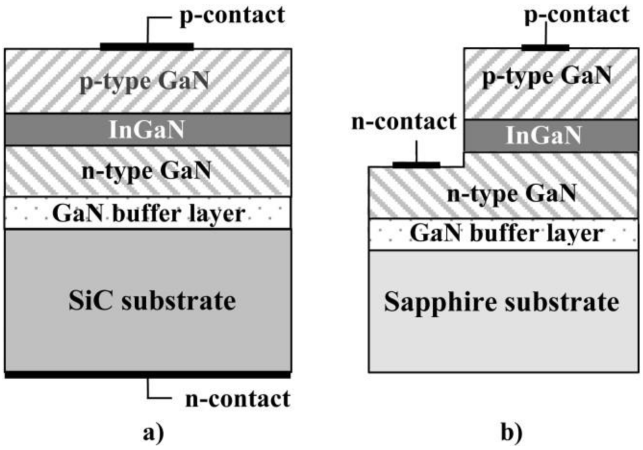


*Figure 4: nitride-based LED structure grown on (a) SiC; (b) Sapphire substrate [10].*

The active $In_xGa_{1-x}N$ layer covers the energy of the bandgap ranging from 1.95-3.4eV. All kinds of LED structure consist of buffer layers contain many dislocations. Sapphire is cheaper and transparent whereas SiC gives the advantage from device processing point of view. Nowadays the concentration is on the increasing the intensity of nitride-based LED's have been increased from 15lm/W to 50lm/W, and the goal of nitride-based LED's is to increase the intensity up to 100lm/W and to use blue HB LED's as the main source of light [19]. A through-hole LEDs are preferred in traffic light because of good tolerance for non-uniform radiations[20].

**Organic LED (OLED)**

In basic structure of OLED, an active organic layer is inserted between the two electrodes in which one of them is transparent and is kept on a glass or plastic substrate. A material that is used as transparent anode is indium tin oxide (ITO), which has combination of conductivity, transparency and high work function. A small difference is must in between the work function of electrode and appropriate energy level of organic materials for the effective injection of charge carriers in OLED. The metals which have low work function like Ca, Al, or alloy of Mg, Ag are used as cathode. In the first-ever polymer OLED PPV Poly (p-phenylenevinylene) has been used as polymer [21]. The other types of polymers that are typically used in OLED are PPP poly (phenylene) PT (polythiophene) etc. The single layer OLED devices have smaller quantum efficiency which causes the location recombination zone near the organic-electrode interface and also gives rise to quenching. This drawback can be overcome in the double or multilayer configuration of OLED, where materials having specific transport and emission properties are being used.In the double layer OLED's

ISSN: 0971-1260
Vol-22-Issue-16-August-2019

configuration consists of the hole injection contact layer, electron transport layer and electron injection contact. The widely used small molecular weight hole transport materials are NPB (4,4'-bis[N-(1-naphthyle-1-)-N-phenyl-amino]-biphenyl) and TPD (N,N'-diphenyl-N,N'-bis(3-methyl-phenyl)-[1,1'-biphenyl]-4,4'-diamine) but the best known among all the molecular weight is $Alq_3$(tris–(8-hydroxy-quinoline)aluminium) [22]. The OLED's with proper dopant dyes molecules shows the higher output efficiency. These dopants are mostly fluorescent dyes with red shifted emission relative to host. This phenomenon leads to the efficient energy transfer from host to the dopant and also leads to reduction of self- quenching mechanism. Further improvement in it involves more complicated multilayer device configuration as shown in figure below:

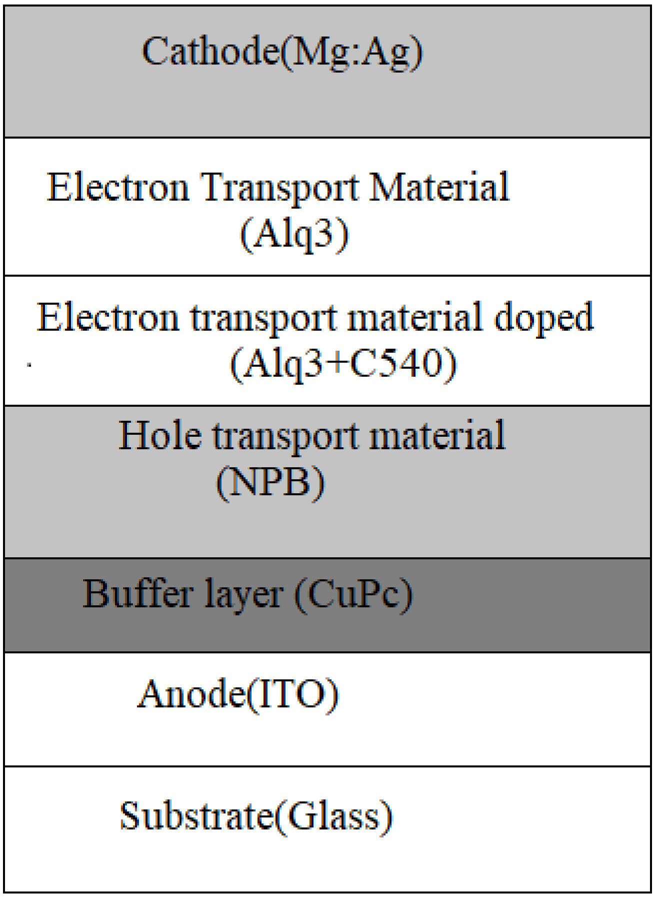


*Figure 5: Schematic structure of OLED [12]*

Although the inorganic LED's are lesser complex in OLED the main driver is cost as the polymer-based OLED's can be fabricated by the cheap spin coating technology and with the small molecular devices which are mainly fabricated with the thermal evaporation, hence the cost is a promising factor when the production is large. The other technologies are also there such as inkjet deposition or

ISSN: 0971-1260
Vol-22-Issue-16-August-2019

printing are also used and is as popular as the above mentioned technology. Apart from the criteria of efficiency we need to see the reliability of OLED also which is not as good because they react with oxygen and moisture and hence are kept in inert atmosphere. The recent OLED's luminous efficiency is observed to be greater than 60lm/W, and its lifetime is greater than 50 hours and driving voltage is below 5V [22]. The OLED is self- emitter which means that unlike LCD (liquid crystal display) they do not need any back-lighting and can be very thin with low power consumption.Organic Les have a lot of potential because it can act as area light source and can be driven at lower voltages. Also, the OLEDs does not include any harmful material as in solid state LED like mercury.

**White LED Design**

Against the backdrop of a rapidly growing of HB LED's of all colours, white LED's have attracted special interest as is highly used in cars, traffic information signs, displays etc. Although the output of green, blue and red LED can be combined to produce light of any colour including white but a second alternative for producing white light with fluorescent converters which emits a broad spectrum of longer wavelengths. The combination of InGaN high brightness LED with fluorescent converter also gives white light which has efficiency of 10lm/W [23]. The most important step in the development of LED is to fabricate devices, which utilises UV emitters as the primary source of light combined with a converter material, which absorbs 100% of this UV radiation and also reemits the whole visible wavelengths range. White light can be produced by the OLED's also by the combination of the proper dopant, but they give smaller efficiency and has some voltage drawbacks too. White LED's are facing bigger challenge in this huge market, mainly in general illuminations [23]. Figure 6 shows the LED's market prediction which gives the increasing tendency of white LED's performance.

 

ISSN: 0971-1260
Vol-22-Issue-16-August-2019

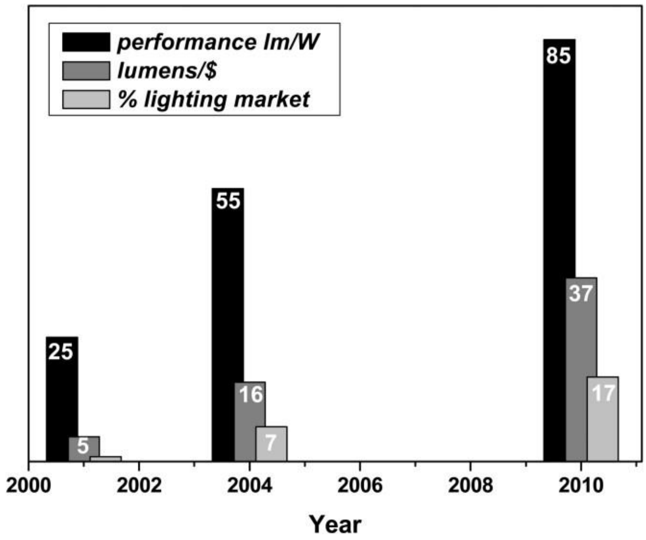


*Figure 6:White LED market prediction [15]*

**Table 1.Comparison of the efficiency of three LEDsystem**

| S.N. | Type of LED system | Luminous intensity in lm/W |
|---|---|---|
| 1. | High brightness LED | 50lm/W |
| 2. | Organic LED | 60lm/W |
| 3. | White LED | 10lm/W |

## 4. Conclusion

LED has potentially replaced several other light sources in domestic and industrial purposes. For example, the older lighting sources like tungsten bulbs and tube lights have been replaced by LED bulbs and not only that the older cathode ray tube(CRT) and even liquid crystal display (LCD) television have been replaced by LED television with even at reduced cost and longer life. Nowadays with technology evolution in LED, OLED (organic LED) is highly used because of its higher luminous intensity and eco –friendly behaviour. The bigger challenge is for white LED's to increase its performance beyond 80lm/W while it has lots of future scopes. The future of LED is clearly very bright in terms of its increased brightness, with more colours and also with even lesser energy consumption.

ISSN: 0971-1260
Vol-22-Issue-16-August-2019

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