LEDs for Solid State Lightening Challenges and Performance Parameters

S.S.Manaktala [#1], K.M.Singh [*2]

[#] *Research Scholar ,Dept. Of ECE , JECRC University , Jaipur*
[1] ssmanaktala.ece@jecrec.ac.in

[*] *Professor, Dept. Of ECE , JECRC University , Jaipur*
[2] kmsingh2005@rediffmail.com

***Abstract*— Light Emitting Diodes (LEDs) which work on the principle of electroluminescence, have been widely used in lighting and power display applications. LEDs are basically categorized into inorganic and organic types . The optical emission wavelength can be selected by varying material composition. III-V nitride materials with the wurtzite crystal structure (GaN, AlN, InN, and their alloys) have generated considerable interest for operation at visible spectrum wavelengths. GaN-based electronics (not pure GaN) has the potential to drastically cut energy consumption in consumer applications and power transmission utilities Performance of LED is very vital aspect, which decides its application for high power application. LED performance is under stood with the help of External Quantum Efficiency, Injection Efficiency, Internal Quantum Efficiency ,Extraction Efficiency ,Wall-Plug Efficiency, Feeding Efficiency. Light Output of Luminaries. As the injection current increases in InGaN/ GaN multiple quantum well MQW LEDs, we ob-serve a unique phenomenon called "efficiency droop" that is the reduction in LED efficiency at high injection current density. The two most modern techniques that have become the workhorses for production of the most advanced devices, including LEDs, are molecular beam epitaxial (MBE) and metal organic chemical vapor deposition (MOCVD).**

***Keywords*— Electroluminescence, Nitride Materials, Metal organic chemical vapor deposition, External Quantum Efficiency ,Injection Efficiency ,internal Quantum Efficiency ,Extraction Efficiency ,Wall-Plug Efficiency ,Feeding Efficiency.**

I. INTRODUCTION

What is LED?

LED (Light Emitting Diode) is a special diode that uses a semiconductor chip to produce UltraViolet, visible or infrared light when an electric current is passed through it. The quantum of light energy released is approximately proportional to the band gap of the semiconductor. Luminescence is the process behind light emission. We can define this as a solid surface radiates when there is an application of energy be it application of electric field.

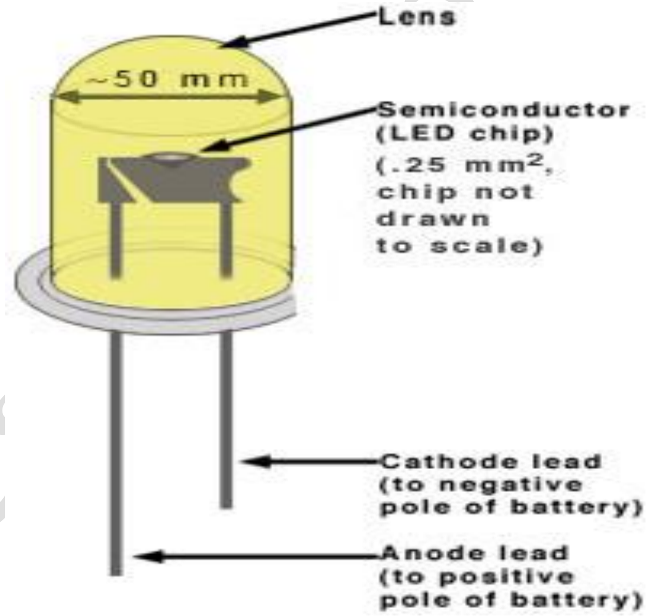

Figure 1: LED structure diagram

LEDs are made from gallium-based crystals that contain one or more additional materials such as phosphorous to produce a distinct color

Construction of Typical LED: A Light Emitting Diode (LED) produces light of a single color by combining holes and electrons in a semiconductor. A light-emitting diode (LED) is a p-n junction diode which emits light when activated. When a suitable voltage is applied to the terminals of LED, then recombination phenomenon take place and energy releases in form of photons. This effect is called as electroluminescence. Efficient light emitter is also efficient absorbers of radiation The p-n junction will be forward biased with contacts made by metallization to the upper and lower surfaces. Upper part must have some area transparent to provide path for photon escape. The silica provides passivation /device isolation and carrier confinement. All photons created must be able to leave the semiconductor to provide good efficiency.

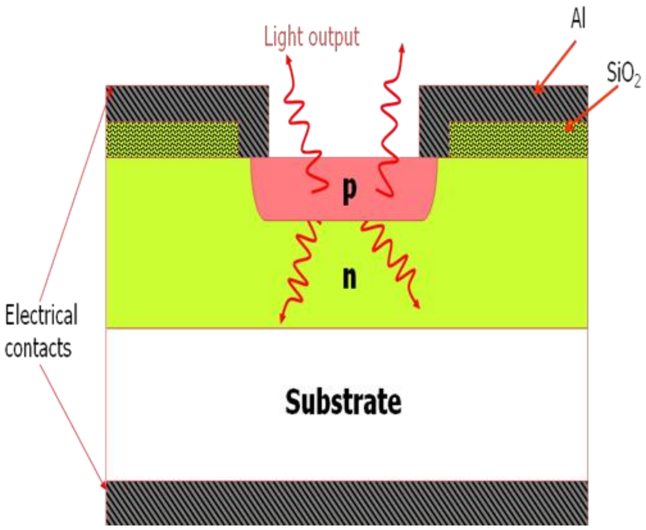

Figure 2: Electroluminescence, in LED

Recombination of charge carriers which results in radiative transmission to produce the required color of LED. As explained above, color of light emitted is dependent on band gap Eg. So correct material is chosen with the Eg required for particular color. The color of light depends upon the energy band gap of the semiconductor.

$$\varepsilon_g = h\nu$$
$$\nu = \frac{c}{\lambda}$$

Where is bandgap energy, is Plank constant, is frequency of light emitted, c is light velocity and is the wavelength of the light emitted.

Direct band gap semiconductors allow efficient recombination. There must be little or no reabsorption of photons to get good efficiency. For Ultraviolet LED with wavelength λ ~0.5-400nm will require Eg > 3.25eV. Visible LED with λ ~450-650nm will require Eg = 3.1eV to 1.6eV. Infrared LED with λ ~750nm- 1nm will require Eg = 1.65eV. Materials must be chosen with refractive index which allow light to 'get out' of the LED (Ferral,R.M,2012).

Emission wavelength of LED: When sufficient voltage is applied to the chip across the leads of the LED, electrons can move easily in only one direction across the junction between the p and n regions. Electrons of n region gaining sufficient energy to cross the junction and Recombination of charges in P region on the application of voltage increases the flow of current also with each recombination of electron with positive charge a quantum of electromagnetic energy is released.. The carrier injected into the semiconductor material is proportional to the irradiative recombination which also decides the flow of current in the junction, Emission wavelength is given by

$$\lambda g = hc/(EC\text{-}EV)$$

EC-EV = Eg where Eg is energy gap between conduction band and valance band ,so emission wavelength λg = hc/Eg

II. LED AS A LIGHT SOURCE

The light emitting diode has been discovered in 1904 demonstrated very low emission efficiency s is made of semiconductor diode made of silicon carbide (SiC). Development of wider band gap III-V compounds have helped the growth of visible light emitting diode.

GaN LIGHT EMITTING DIODE

The first GaN/InGaN/GaN double heterostructure LEDs, reported in early 1993,13 showed improved output power to 125µW at an emission wavelength of 440 nm, corresponding to the energy bandgap of the InGaN active region. Later reports described devices with output power of more than 1,000µW and reduced operating voltage of approximately 3.6 V.

Advantages of GaN LED:

1- GaN can be doped with silicon (Si) or with oxygen to n-type and with magnesium (Mg) to p-type; however, the Si and Mg atoms change the way the GaN crystals grow, introducing tensile stresses and making them brittle. Gallium nitride compounds also tend to have a high dislocation density, on the order of a hundred million to ten billion defects per square centimeter.

2- GaN with a high crystalline quality can be obtained by depositing a buffer layer at low temperatures. Such high-quality GaN led to the discovery of p-type GaN, p-n junction blue/UV-LEDs and room-temperature stimulated emission (essential for laser action).

III PERFORMANCE PARAMETERS

LED performance can be majored using following parameters-

1- External Quantum Efficiency
2- Injection Efficiency
3- Internal Quantum Efficiency
4- Extraction Efficiency
5- Wall-Plug Efficiency
6- Feeding Efficiency

1- External Quantum Efficiency (EQE)
The ratio of the number of photons emitted from the LED to the number of electrons passing through the device - in other words, how efficiently the device coverts electrons to photons and allows them to escape.

EQE = [Injection efficiency] x [Internal quantum efficiency] x [Extraction efficiency]

2- Injection Efficiency
In order that they can undergo electron-hole recombination to produce photons, the electrons passing through the device have to be injected into the active region. Injection efficiency is the proportion of electrons passing through the device that are injected into the active region

3- Internal Quantum Efficiency (IQE - also termed Radiative Efficiency)
Not all electron-hole recombinations are radiative. IQE is the proportion of all electron-hole recombinations in the active region that are radiative, producing photons.

4- Extraction Efficiency (also termed Optical Efficiency)
Once the photons are produced within the semiconductor device, they have to escape from the crystal in order to produce a light-emitting effect. Extraction efficiency is the proportion of photons generated in the active region that escape from the device.

5- Wall-Plug Efficiency (also termed Radiant Efficiency)
Wall-plug efficiency is the ratio of the radiant flux (i.e the total radiometric optical output power of the device, measured in watts) and the electrical input power i.e the efficiency of converting electrical to optical power.

Wall-Plug Efficiency = [EQE] x [Feeding efficiency]

6- Feeding Efficiency
Each electron-hole pair acquires a certain amount of energy from the power source when the LED is operating. Feeding efficiency is the ratio of the mean energy of the photons emitted and the total energy that an electron-hole pair acquires from the power source (Zhao H.P.2011).

IV CHALLENGES IN LED LIGHTENING

Efficiency Droop

It is the phenomena that specify that there is reduction in LED Efficiency at high injection current density.
Non radiative augur recombination plays a major role in LED Droop in Multiple Quantum Wall LED. Polarization in active well and lattice mismatch causes inadequate confinement of electrons in active region thus overflow of electrons in P-region which is the cause of drop of efficiency.
As the efficiency of LEDs improves, LEDs find more applications such as back light unit, automotive headlights, and general illumination. However, as injection current increases in InGaN/GaN multiple quantum well MQW LEDs, we ob-serve a unique phenomenon called “efficiency droop” that is the reduction in LED efficiency at high injection current density.
To improve the efficiency of MQW LEDs, the electron blocking layer EBL has played an important role in effectively confining electrons in the MQW region of most MQW LEDs

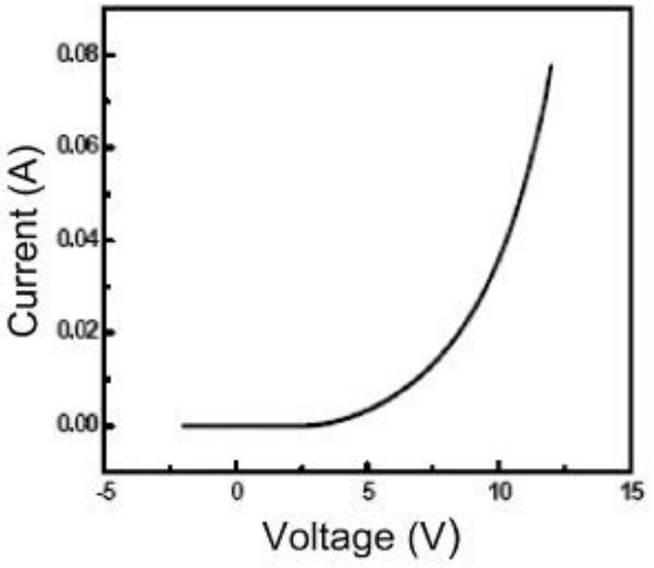

Figure 3: Voltage-Current for LED

Figures 4a and 4b show that the output power of the three LEDs increases sub linearly as the current density increases. At low current density

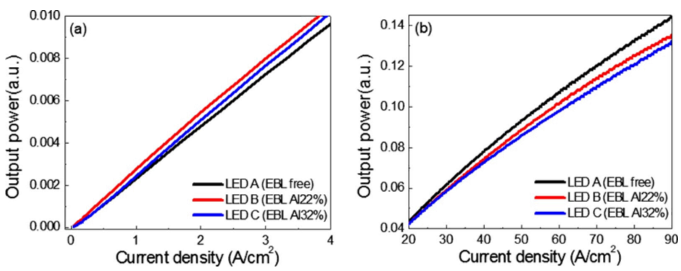

Figure 4a and Figure 4b

Fig.4a, the output power of LEDs B and C is higher than LED A. However, as Current density further increases.
Fig. 4b,the output power of LEDA surpasses other LEDs, and the difference of output power becomes larger as the current density increases.

Figure5 is the measured external quantum efficiency EQE for All three LEDs .All the LEDs show a maximum EQE at every low current density below 5 A per cm2,then the EQE drops rapidly with current density. At low current density below 15 A per cm2,the EQE of LEDs B and C is higher than

LED A. However, at a current density of about 15 A per cm2, the EQE of LEDA surpasses the EQE of LEDs B and C, and the EQE of LED A is higher by 5.6% and 8.6% than those of LEDs B and C, respectively, at 90 A per cm2 .

This result is of important interest because most LED have EQE at high current density if EBL is used, but this study shows that the EQE of LEDs , without an EBL is higher than that of LEDs with an EBL at high current density. Therefore, efficiency droop is improved in LEDs without an EBL

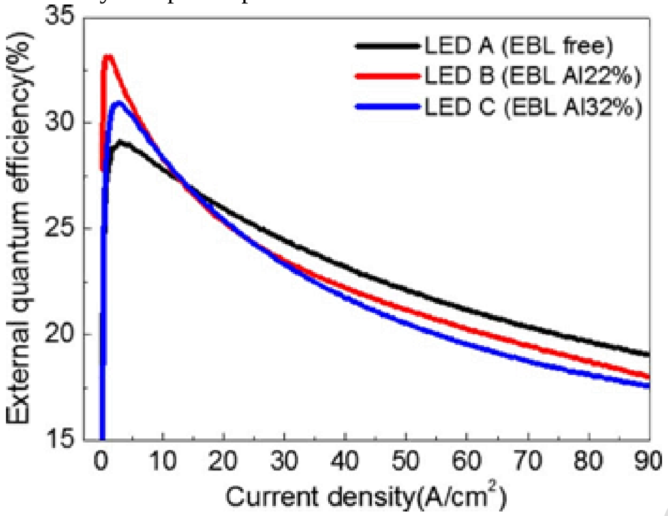

Figure 5: EQE and current/voltage

We explain the difference of EQE behavior of LEDs with and without an EBL at low and high current densities as following. At low current density, EBL can effectively block the electron flow by a high barrier height between Ga N barrier and EBL in conduction band and the confined electrons can participate in radiative recombination.
Meanwhile, the accumulated holes at the notch formed between EBL and p-GaN can easily tunnel into MQW region via EBL with the assistance of intermediate states in EBL, even though EBL appears to block holes in the valence band as a result LED with EBL show high EQE at low current density. However less EQE of EBL LED at high current density is due to the decreased potential barrier height between GaN barrier and EBL in conduction band, and electrons tend to overflow.
This indicates that the electron concentrations in three LEDs at high current density are not significantly different and the hole injection process to the MQW region becomes a limiting factor in determining EQE. Further more ,the hole transport to the MQW is dominated by a diffusion process since the tunneling process is negligible compared to the diffusion process at high current density.
Consequently, the potential barrier due to EBL suppresses the diffusion of holes from the
p-GaN layer to the MQW region at high current density, resulting in a lower EQE of LEDs with an EBL compared to LEDs without an EBL. The suppression of efficiency droop in LED without and EBL at high current density attributes to an increased hole injection efficiency (Titkove,2012).

V FUTURE OF LED LIGHTENING

In recent years, with the advent of MBE, MOCVD and other experimental techniques, the influence of quantization of band states on the different physical properties of nanostructured materials such as quantum wells, quantum well wires, quantum dots, inversion layers, magnetic quantization, and different field added dimensionally reduced systems. The influence of band structures on the physical properties of quantized structures is becoming increasingly important.
In recent years, development of the field of III-nitride (III-N) semiconductor technology has been spectacular. There are two fundamental reasons to choose the III-nitride for blue light sources. The foremost reason is that AlN, GaN and InN have direct band gap energies of 6.2, 3.4 and 0.7 eV, respectively, at room temperature, so they cover the spectra from ultraviolet (UV) to the entire visible spectrum.
The other main advantage of III-N over other wide-band semiconductors is the stronger chemical bond, which makes the nitride very stable and resistant to degradation under strong electric current and high temperature. Numerous GaN-based devices, including light emitting diodes (LEDs), laser diodes (LDs), photo detectors and high power microwave power switches have been developed and brought to market during the last several years. LEDs are used in various lighting applications, including flash lights, automotive lighting, traffic signals, TVs and very large displays, and they are now widely commercially available. Other applications for blue LEDs include medical diagnostic equipment and photolithography. The future, especially for general lighting applications, is promising since white light can be produced by exciting wide band phosphors by blue or UV-LEDs. In general, the structure of an LED is a compound semiconductor epitaxial film grown on a suitable substrate. The two most modern techniques that have become the workhorses for production of the most advanced devices, including LEDs, are molecular beam epitaxy (MBE) and metal organic chemical vapor deposition (MOCVD) (Kidyank Y.Y,2011).

MOCVD is a non-equilibrium growth technique, which relies on vapor transport of the precursors and subsequent reactions of group-III alkyls and group-V hydrides in a heated zone. A feature of MOCVD technology is that it can create a thin uniform film in nanometer units. This is a dominant feature for growing the GaN layers on a sapphire substrate.

VI. REFERENCES

1. Zhao H. P, Liu G. Y., J. Zhang (2011) Approaches for high internal quantum efficiency green InGaN light-emitting diodes with large overlap quantum wells, Opt. Exp., vol. 19, no. S4, pp. A991– A1007

2. Dahal R, Pantha B, . Lin J. Y, and . Jiang H. X, (2009), InGaN/GaN multiple quantum well solar cells with long operating wavelengths, Appl. Phys. Lett., vol. 94, no. 6, pp. 063505-1–063505-3.
3. Feng I., K., Lin J. Y, and . Jiang H. X (2011) ,Erbium-doped alInGaN alloys as high-temperature thermoelectric materials,Appl. Phys. Exp., vol. 4, no. 5, pp. 051001-1–051001-3
4. Zhang J., Kutlu S., Liu G. Y. (2011),High-temperature characteristics of seebeck coefficients for AlInN alloys grown by metalorganic vapor phase epitaxy, J. Appl. Phys., vol. 110, no. 4, pp. 043710-1–043710-6.
5. Farrell R. M., Young E. C., Wu F.,. DenBaars S. P (2012), Materials and growth issues for high-performance nonpolar and semipolar light-emitting devices, Semicond. Sci. Technol., vol. 27, no. 2, p. 024001
6. Zhao H. P., Liu G. Y., Arif R. A(2010), and Current injection efficiency quenching leading to efficiency droop in InGaN quantum well light-emitting diodes,Solid State Electron., vol. 54, no. 10, pp. 1119–1124.
7. Zhao H. P., Liu G. Y., Arif R. A (2013) ,Analysis of internal quantum efficiency and current injection efficiency in III-nitride light-emitting diodes, J. Display Technol., vol. 9, no. 4, pp. 212–225
8. . Lin G.-B, D., J Meyaard, (2012),Analytic model for the efficiency droop in semiconductors with asymmetric carrier-transport properties based on drift-induced reduction of injection efficiency,Appl. Phys. Lett., vol. 100, no. 16, pp. 161106-1–161106-4
9. Wang, J. Hao Z., Y(2012), An improved carrier rate model to evaluate internal quantum efficiency and analyze efficiency droop origin of InGaN based light-emitting diodes, J. Appl. Phys., vol. 112, no. 2, pp. 023107-1–023107-6.
10. Titkov E., Y.-M. Park, (2012),Blue light emitting diode internal and injection efficiency, AIP Adv., vol. 2, no. 3, pp. 032117-1–032117-4
11. Kioupakis E., Rinke P.(2011),, Indirect auger recombination as a cause of efficiency droop in nitride light-emitting diodes,[Appl. Phys. Lett., vol. 98, no. 16, pp. 161107-1–161107-3