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Study and Performance Analysis of 550 nm $In_{0.28}Ga_{0.72}N$ LED.

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Abstract- A high and efficient green light (550 nm) LED's design and performance characteristics were studied in this work. Using Vegard's law, the calculated mole fraction was found to be $In_{0.28}Ga_{0.72}N$. The lattice parameter was investigated and amount of strain involved in the structure was also calculated alongside a lattice matched structure. For zero strain the critical thickness of the structure was also determined. Some electrical and optical properties were investigated like Internal Quantum Efficiency (IQE), External Quantum Efficiency (EQE) and Optical output Power. Each parameter were observed against the change in Current density. The effect of Shockley read Hall parameter was also investigated for achieving high Internal Quantum Efficiency, External Quantum Efficiency and output power as well.

Index Terms- Lattice matching, Strain, Internal Quantum Efficiency, External Quantum Efficiency and Shockley Read Hall Parameter.

I. INTRODUCTION

Recently in LED research, for high power application LED to increase the input current the efficiency is reduced. This phenomenon is known as efficiency droop. So for increasing the efficiency in high power there are lot of research has been going on[1]. There are some factors affecting for this phenomenon. Defect related mechanism, Auger Recombination, Electron leakage, Ineffective Electron blocking layer, poor hole injection efficiency, Electron escaping from Quantum well[2]. In this research paper, our concern is to vary the Shockley read hall parameter, which is related to Auger Recombination. One of the Shockley Read Hall Parameter is known as Auger Recombination Coefficient. Recombination through defect called Shockley Read Hall recombination does not occur in perfectly pure and without defected material. Shockley Read Hall recombination is a two step process. An electron (or hole) is trapped by an energy state in the forbidden region which is introduced through defects in the crystal lattice. These defects can either be unintentionally introduced or deliberately added to the material, for example in doping the material and if a hole (or an electron) moves up to the same energy state before the electron is thermally re-emitted into the conduction band, then it recombines. The rate at which a carrier moves into the energy level in the forbidden gap depends on the distance of the introduced energy level from either of the band edges.
Therefore, if energy is introduced close to either band edge, recombination is less likely as the electron is likely to be re-emitted to the conduction band edge rather than recombine with a hole which moves into the same energy state from the valence band. For this reason, energy levels near mid-gap are very effective for recombination [3]. To Improve the Internal Quantum Efficiency, Fixing an Optimum value of Shockley read hall parameter for High power application. By varying this Shockley read hall parameter using rate equation a high efficiency of the 550 nm LED was obtained.

II. IDENTIFICATION OF RESEARCH IDEA

To Improve the Internal Quantum Efficiency and study of the design of a LED, idea has been collected from published journals, different books, Seminars and Google also.

III. STUDIES AND FINDINGS

In this research there are two parts. One is Design study and another is application. In design study, from the wavelength, the band gap of active region was studied. Then $In_{0.28}$ $Ga_{0.72}N$ multiple quantum well (MQW) was studied. From this, Using Vegard's law composition of the material was investigated. From the composition and lattice constant Strain was founded and also founded that it was Compressive strain. The material selection lattice matched material was selected. Then from the strain, critical thickness was calculated because of reduce strain from the structure. Then using this thickness value of k was founded for finding j_{max}. Then varying the Shockley Read Hall parameter and fixed in a perfect combination that gives the highest internal quantum efficiency. Then using the internal Quantum Efficiency value the External Quantum Efficiency was calculated and also power vs current density curve was founded.

A. Vegard's Law

Vegard's law is an important law for calculation of the composition from two or more material combines with each other. In our research we can take for band gap of InN is 0.69ev, band gap of GaN is 3.4ev and bowing parameter b is 3.8ev. For 550 nm, getting band gap for direct band semiconductor is 1.8731 ev.

$$E_g \, \mathrm{In_x} Ga_{1-x}N = xE_g\,(InN) + (1-x)E_g\,(GaN) - \mathrm{bx}(1-\mathrm{x});$$

From this equation Putting the value and Composition of this material was calculated. It was 0.28.

B. Lattice Matching

Lattice matching is a very important parameter for the light emitting device. This epitaxial growth one layer is top of another layer. That's why lattice matching is an important parameter. If these layers are not matched properly then the performance will degrade. Matching of lattice structures between two different semiconductor materials allows a region of band gap change to be formed in a material without introducing a change in crystal structures. In this research InN lattice constant was 3.5446 Å and GaN lattice constant was 3.186 Å. Lattice constant of $In_{0.28}Ga_{0.72}N$ was obtained the value of 3.28 Å.

$$a(In_{0.28}Ga_{0.72}N) = 0.28 \times a(InN) + 0.72 \times a(GaN)$$

C. Strain Effect

Strain is a parameter that amplifies the two layers one is top of another in adequately matched with each other is called no strain. In here when $a_{In_{0.28}Ga_{0.72}N} > a_0$ means here substrate lattice matching parameter is greater than layer lattice matching parameter then it is called Compressive strain. Then when $a_{In_{0.28}Ga_{0.72}N} < a_0$ means here substrate lattice matching parameter is smaller than layer lattice matching parameter then it is called Tensile strain.

$$\epsilon = \frac{a_{In_{0.28}Ga_{0.72}N} - a_0}{a_0}$$

From this equation we can get the value of strain is 3.14%. That is Compressive Strain.

D. Critical Thickness

Critical thickness is a thickness that measures the optimum thickness of a layer is finely stay up in bottom layer. If Thickness s more than the critical thickness then structure will break down. If the thickness is considering more less than structure will not perform accurately. So the thickness should consider a little less than the critical thickness [4].

$$t_c = \frac{a_{GaN}}{2\times\epsilon} [4]$$

Here the value of GaN lattice constant is 3.186 Å. So the critical thickness $In_{0.28}Ga_{0.72}N$ well is 5.07 nm. In here 5 Quantum well layer and everyone is 5.07nm. So total active layer thickness is 25.35 nm.

E. Shockley Read Hall Parameter:

Shockley Read Hall parameter is a parameter, for which Internal Quantum Efficiency is depended. A is named as monomolecular recombination Coefficient. C is called as a Auger recombination rate. The range of Auger recombination rate $C=1.4 \times 10^{-31}$ Cm^6/s up to $C=9.0 \times 10^{-30}$ Cm^6/s. Range of mono molecular recombination coefficient is $A=1 \times 10^6$ s^{-1} up to $A=3.0 \times 10^8$ s^{-1}. Taking $B= 10^{-10}$ Cm^3/s. In this value, we can fixed the value as $A=1 \times 10^8$ s^{-1}, $B= 10^{-10}$ Cm^3/s, $C=3 \times 10^{-31}$ Cm^6/s. then we can get the value of $\eta_{max} = 0.90$. And $J_{max} = 16.57$ A/Cm^2.

$$\eta_{max} = \frac{B}{B+2\sqrt{AC}} \text{ ....(1)[5]}$$

And

$$J_{max} = \frac{KA}{C}\left(B + 2\sqrt{AC}\right) \text{ ....(2) [5]}$$

$$K = \frac{qd}{\eta_j}; \text{ [5]}$$

And the rate equation of Internal Quantum Efficiency,(η)

$$\eta = 1 - \frac{(1-\eta_{max})}{2J}\left(1 + \frac{\eta J}{\eta_{max} J_{max}}\right)\sqrt{\frac{\eta J J_{max}}{\eta_{max}}} \text{ ......(3) [5]}$$

Using this equation in MatLab software we can get the IQE vs Current Density curve. After that using equation4 in MatLab we can get External Quantum Efficiency vs current density curve.

$$\eta_{int} \times \eta_e = \eta_{ext} \text{ ....(4)[6]}$$

Here $\eta_e$is the extraction efficiency. Extraction efficiency is how much recombine electrons photons are coming away from inside. And External Quantum Efficiency is the multiplication of Internal Quantum Efficiency and Extraction Efficiency.

$$P_{LED} = \eta_{int} \times \eta_{Axt} \times J \times \frac{hf}{q}; \text{ ....(5)[7]}$$

From this equation we can get the curve of Output Power vs Current Density curve.

IV. STRUCTURES

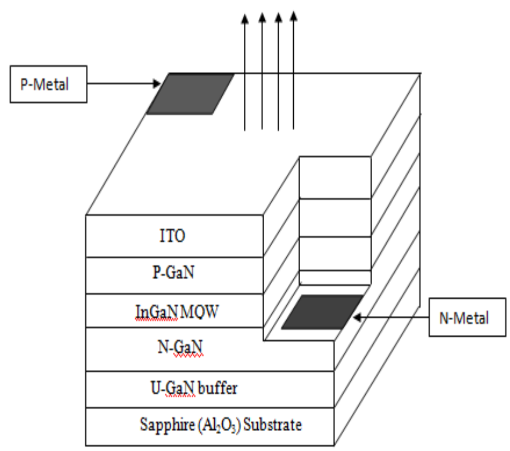

Figure 1: Basic Structure of 550 nm LED.

Here in this structure 3 μm thick U-GaN Buffer layer, 2 μm N-GaN layers, 5.07 nm of each, five layers consist of 25.35 nm thickness of multiple quantum well. Top of the active layer is P-GaN layer. This is Mg doped 200 nm thick layer [8]. Here Indium Titanium oxide layer is used to improve the extraction efficiency.

IV. RESULTS

We were using the MATLAB software to investigate different result.

In result section from the variation of Shockley Read Hall parameter at first we can consider $A=10^8 s^{-1}$, $B=10^{-10}$ Cm^3s^{-1}, $C=3\times10^{-31}Cm^6s^{-1}$.

Now From equation 1 & 2we can get, $\eta_{max}= 0.90$ and $j_{max}= 16.57$ qs^{-1}. And using equation 3 putting the value of η_{max} and j_{max} we can get the curve of variation of Internal Quantum Efficiency vs

Current Density curve red line indicate the value of η_{max}= 0.90 and j_{max}= 16.57 qs^{-1}.

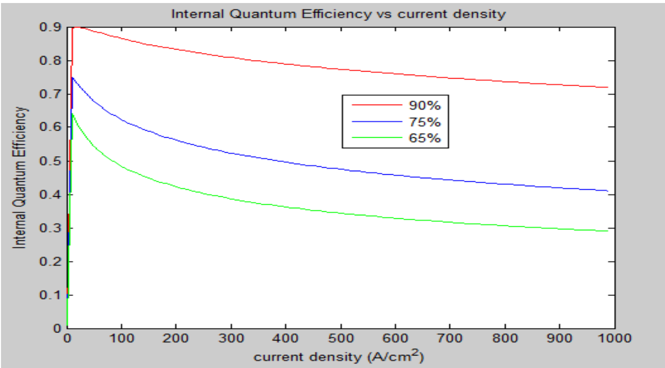

Figure 2: Internal Quantum Efficiency vs Current Density curve.

After that Blue line indicates the Shockley Read Hall parameters are $A=8\times10^7 s^{-1}$, $B=10^{-10}\ Cm^3s^{-1}$, $C=3.5\times10^{-30}\ Cm^6s^{-1}$. From the value of Shockley Read Hall Parameter we can get the value of η_{max}= 0.75 and j_{max}= 12.20 qs^{-1}. After that the green line indicates the Shockley Read Hall Parameters are $A=8\times10^7 s^{-1}$, $B=10^{-10}\ Cm^3s^{-1}$, $C=9\times10^{-30}\ Cm^6s^{-1}$. From this value we can get the η_{max}= 0.65 and j_{max}= 5.46 qs^{-1}.

After that we were investigate the output power vs Current density curve and to get it using equation 5.

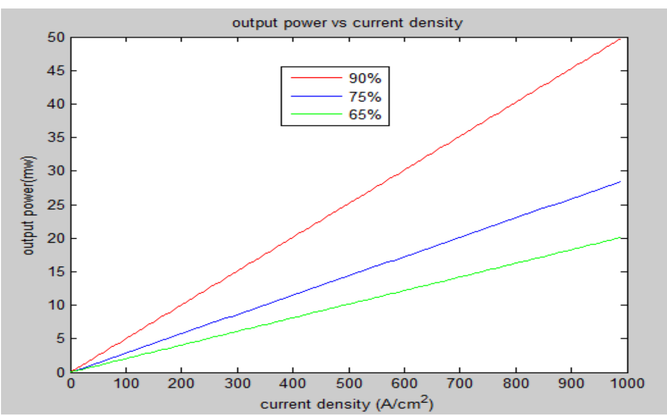

Figure 3: Output power vs Current density curve of Green LED.

In red line 90% Internal Quantum Efficiency we are getting high output power compare to 75% and 65% Internal Quantum Efficiency line.

External Quantum Efficiency is the multiplication of Extraction Efficiency with Internal Quantum Efficiency. Extraction Efficiency is how much extract the photon from the Recombination of electron hole pair. More or less extraction efficiency is around 50%. So in this research we can use the Extraction Efficiency 45%.

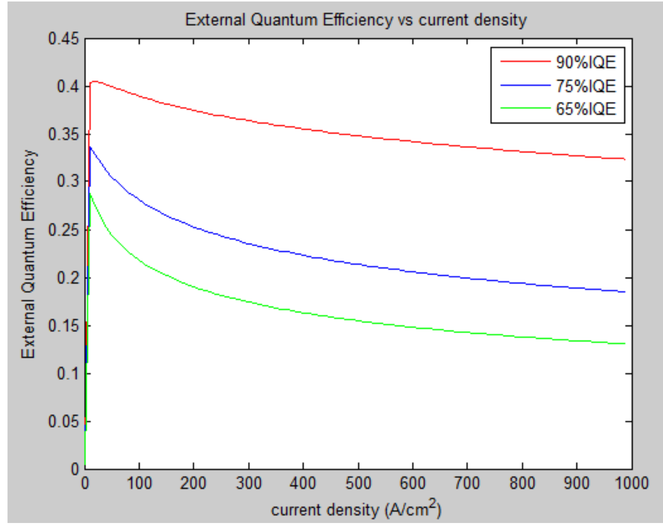

Figure 4: External Quantum Efficiency vs Current Density curve.

In this curve obtains from equation 4 and here we can see that 90% internal quantum efficiency we can get 41% External Quantum Efficiency. For 75% Internal Quantum Efficiency we can get 33% External Quantum Efficiency. For 65% Internal Quantum Efficiency we can get 29% External Quantum Efficiency.

Table 1: Result comparison for variation of Shockley Read Hall Parameter.

Serial no.	A s^{-1}	B $Cm^3 s^{-1}$	C $Cm^6 s^{-1}$	J_{max} qs^{-1}	η_{max}	IQE	EQE	Output Power Mw
1	8×10^7	10^{-10}	9×10^{-30}	5.46	0.65	0.65 - 0.29	0.29 - 0.13	0-20
2	8×10^7	10^{-10}	3.5×10^{-30}	12.20	0.75	0.75 - 0.41	0.33 - 0.18	0-28
3	10^8	10^{-10}	3×10^{-31}	16.57	0.90	0.90 - 0.72	0.40 - 0.32	0-50

From the table we can see that the third combination of Shockley read hall parameter gives the better result for Internal Quantum Efficiency, External Quantum Efficiency and optical Output Power.

V. FUTURE WORK

In this Research we were investigate how to improve internal quantum Efficiency but considering a value of external quantum efficiency as 45%. But in future we will try to Improve the External Quantum Efficiency. For External

Quantum Efficiency output is lower. We will try to improve the External Quantum Efficiency 45% to higher then it will give the highest performance.

VI. CONCLUSION

In Group III – V semiconductor, especially nitride based semiconductor in high power application Efficiency Droop is a normal phenomenon. So high power application efficiency decreased. But in this research in rate equation the improvement in Internal Quantum Efficiency has been observed by varying Shockley Read Hall parameter. For a specific combination of parameters of the designed structure the Efficiency droop can be reduced and improved Internal Quantum Efficiency for this specific Green LED can be obtained. In practical applications we can use this LED structure to obtain high power output and other LED structures can also be investigated for this purpose.

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