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Analysis of Quantum Well LED based on InGaN and GaN semiconductor materials

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***Abstract*— The characteristics of blue InGaN multiple quantum well (MQW) Light Emitting Diodes (LEDs) and GaN based Multiple Quantum Well are compared. The current-voltage (I-V) curve, internal quantum efficiency (IQE), spontaneous rate are investigated and compared. The simulation results show that the newly GaN /InGaN LED (Device 2) has reduced the forward voltage due to reduced energy barriers for electron and hole transport as compare to InGaN/InGaN based LED (Device 1). InGaN/InGaN attribute to the enhancement of carriers confinement induced by the improved potential barrier height for electrons and holes, and the refinement of electron–hole spatial overlap caused by the reduced polarization effect between the well and barrier. The Internal Quantum Efficiency (~98.5 %), Output Power (~1467.1 W/m) and spontaneous rate (~ 615.2 ×1026) achieved is more in case of GaN 3QW LED as compared to InGaN based LED.**

***Index Terms*— Analysis, MFCC, Dynamic Time Warping, Parkinson's disease, Matching, Voice.**

I. INTRODUCTION

LED is the most emerging display device which having long life as well as high quality and efficiency. In the LED blue color is most favorable among the researchers because of high efficiency. There different materials are chosen to improve the IQE and power rating of LED. In this paper two different structure of blue LED i.e. GaN/InGaN and InGaN/InGaN based LED are simulated and optimized and different parameter of these structure are compared.

Recently, researchers improved the optical performance of the LEDs by replacing the conventional GaN barriers with InGaN barriers, which suggests that the efficiency droop can be improved by the suppressing polarization effect between the barrier and well, and the decreased potential barrier height for the carriers to transport in the active region. The electron leakage still cannot be suppressed effectively due to the reduced potential height for electron caused by the severe polarization effect at the interface of the last InGaN barrier and GaN Electron Blocking Layer (EBL). Here we present device with active and barrier layer of QW of InGaN material and studied the device by varying In-ratio in well and achieving a device suitable for solid state lighting. We optimized the IQE , Spontaneous rate, turn on voltage and Power for different value of current.

II. DEVICE STRUCTURE

The structure consists of a 200 nm thick Si-doped InGaN layer (n doping = 2 × 1018 cm− 3). The active region consisted of four 2.5-nm-thick InGaN Quantum Wells (QWs), sandwiched by five 9-nm-thick InGaN barriers. On the top of the last quantum barrier, there were a 3 nm thick GaAlInN layer, 20-nm-thick P GaAlInN Electron Blocking Layer (EBL) (p-doping = 3 × 1019cm− 3) and a 150-nm-thick p-GaAlInN cap layer (p-doping = 1 × 1019cm− 3) .Two LEDs with different active layer, one with InGaN and other with InGaN, has been studied. The properties of the LEDs were studied numerically with the advanced physical model of semiconductor devices simulation software (APSYS)[13].

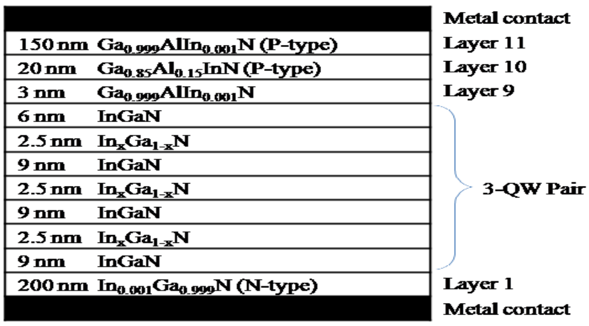

Fig. 1.(a) Device 1-InGaN/InGaN based MQW LED

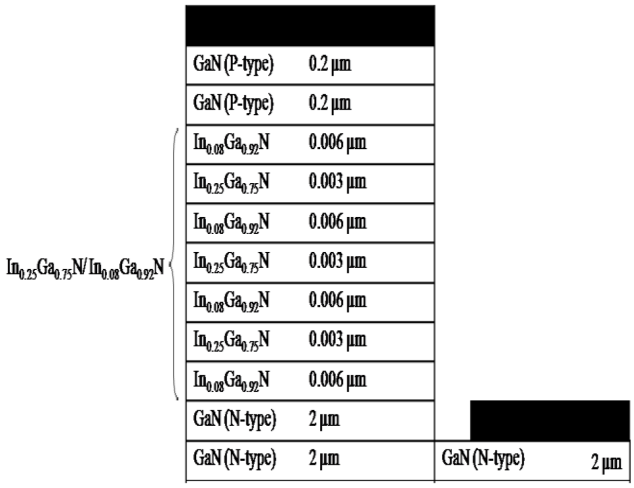

Fig. 2.(b) Device 2- GaN/InGaN based MQW LED.

Fig. 1 (a) shows the schematic diagram of the InGaN/InGaN QW LED device which is taken under study by varying numb er of QW for two devices, one for InGaN/InGaN QW LED a nd other for GaN/InGaN QW LED. The shape of well is trian gular because of the polarization-induced electric field in bot h the devices. Device B is GaN based Quantum Well LED ar e designed with two P type layer with different doping profil e. As standard structure with these two P type layer having th ickness 0.2µm. Doping P layer $1x10^{21}$ cm^{-3} and $5x10^{22}$ cm^{-3} i

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n the second last and last P layer respectively. Well are forme d from InGaN and base material is GaN. P type layers are als o formed by GaN material. Thickness of well are formed wit h the thickness 0.003µm and 0.006µm as active and barrier r espectively.

III. RESULTS AND DISCUSSION

The APSYS simulation software is a device simulator based on finite-element which solves Current continuity equations, Poisson-Schrödinger equations, , heat transfer equations and hydrodynamic equations, including K.P model for MQW band structure, quantum tunnelling model for hetero junction, heat flow model for self-heating.

With the help of APSYS the simulation of InGaN/InGaN LED (Device 1) and GaN/InGaN LED (Device 2) by varying number of quantum well has been done and different parameters are studied. The current-voltage (I-V) curves, Internal Quantum Efficiency (IQE), Light output power and spontaneous rate of Device 1 and Device 2 is shown in the following figures.

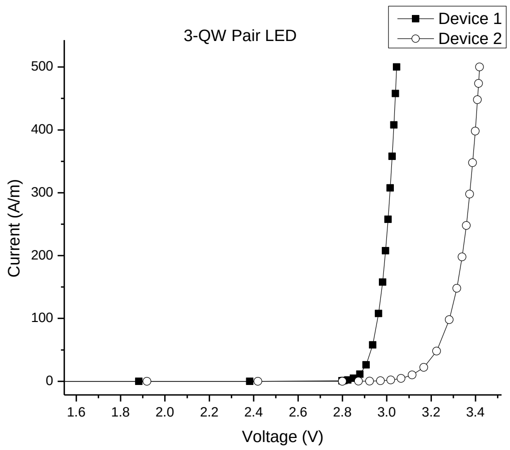

Fig. 2(a). IV characteristics of device 1 and device 2 for 3 Quantum well

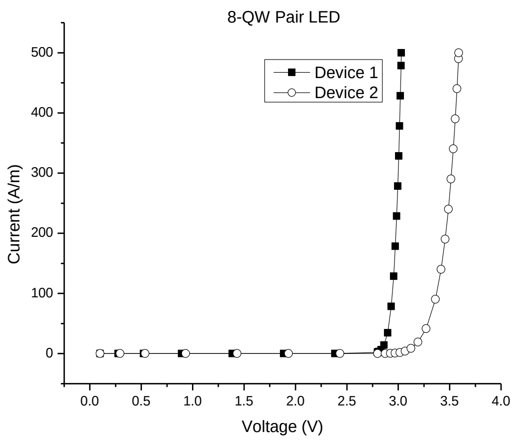

Fig. 2.(b) IV characteristics of device 1 and device 2 for 8 Quantum well.

Fig. 2(a) is comparison of device 1 and device 2 with 3-QW pair while fig. 2(b) shows for 8-QW pair device 1 and device 2. From figures it can be seen that the turn on voltage in case of device 1 is less as compare to device 2 in both the cases. With the increase in number of well the turn on voltage of device 1 decreases while that of device 2 does not show symmetrical variation. The decrease in turn on voltage is due the leakage current and it also shows that transport of carrier is improved in the device. In case of device 1 the turn on voltage is about 2.8 V while for device 2 it is around 3.1 V. Depending on the application the two devices can be used.

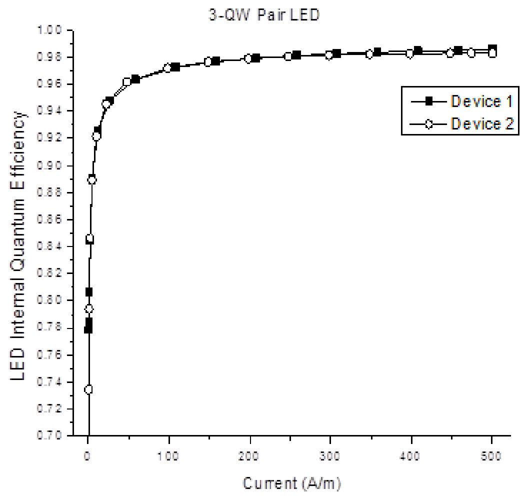

Fig. 3(a). IQE characteristics comparison of device 1 and device 2 for 3 Quantum Well.

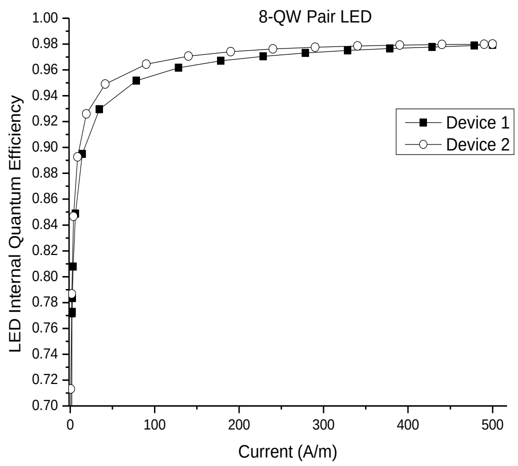

Fig. 3.(b) IQE characteristics comparison of device 1 and device 2 for 8 Quantum Well.

Fig. 3 shows the comparison of LED Internal Quantum Efficiency (IQE) with respect to current for Device 1 and Device 2. The figures show that peak efficiency in case of device 1 lies between 90 to 95 % while for device 2 it lies between 94 to 97%. It shows that for low current device 2 is achieving more efficiency as compare to device 1 and for high current both devices are achieving ~98% efficiency. This increase in efficiency is due to trapping of more carriers (hole) between the last barrier (of width 6 nm) from the above p-type layer. In case of device 1 the maximum achieved efficiency (98.58 %) is for 3 QW pair LED while in case of device 2 maximum efficiency (98.569 %) is achieved for 1 QW LED at high current.

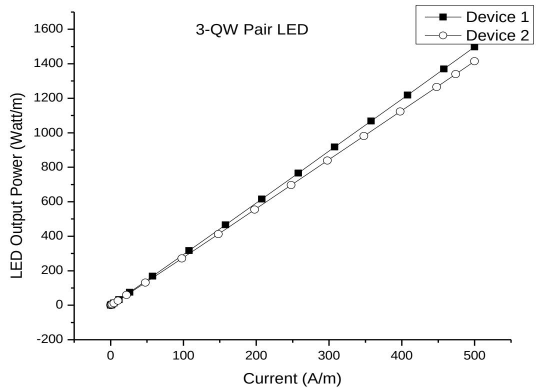

Fig. 4(a). Power-Current characteristic comparison of Device 1 and Device 2 for 3 Quantum Well LED.

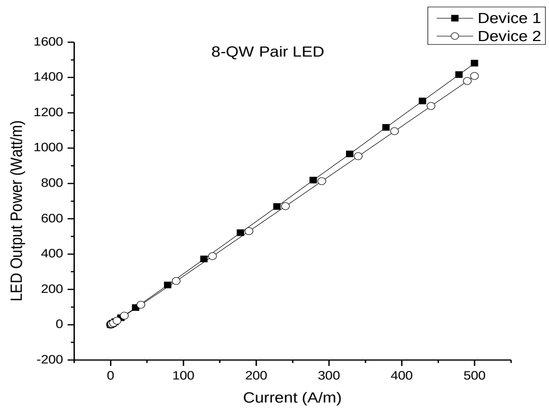

Fig. 4(a). Power-Current characteristic comparison of Device 1 and Device 2 for 8 Quantum Well LED.

Fig. 4 shows the LED output power with respect to current for Device 1 and Device 2. Both devices show linear characteristics and this linearity is important for modulation in analog transmission. From the figures it can be seen that the device 1 is giving more output power as compare to device 2. So for high output power application device 1 can be preferred. Both devices shows a slightly downward shift of the curve i.e. decrease in output power as number of well is increasing. The difference in the output power can be due to the light scattering from the surfaces.

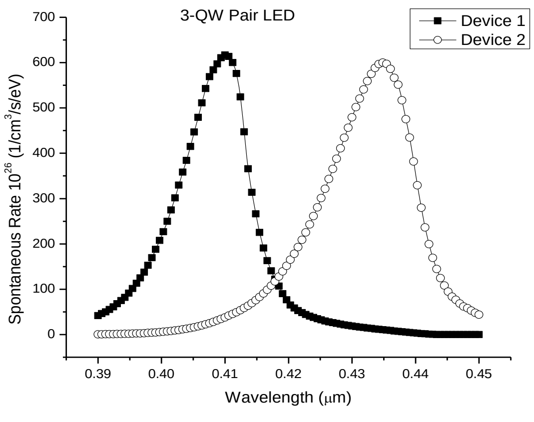

Fig. 5(a). Spontaneous Rate v/s Wavelength of Device 1 and Device 2 for 3 Quantum Well LED.

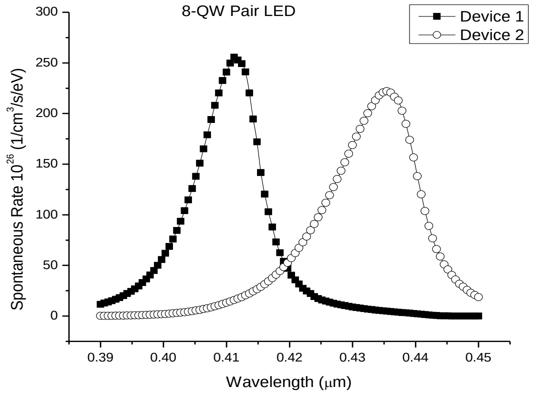

Fig. 5(b). Spontaneous Rate v/s Wavelength of Device 1 and Device 2 for 3 Quan-tum Well LED.

Fig. 5 shows the spontaneous rate at different wavelength for Device 1 and Device 2. These figures depicts that as number of well is increased the spontaneous rate decreases. In case of device 1 the peak wavelength achieved is 0.410 μm while in case of device 2 it is ~0.435 μm. From the results it is depicted that device with higher In-concentration produce higher wavelength and thus are highly suited for solid state lighting.

Table 1. Comparison Of Different Parameters Of Device 1 And Device 2

	Turn on Voltage (V)		Efficiency at current 500A/m (%)		Output Power at current 500A/m (Watt/m)	
	3-QW	8-QW	3-QW	8-QW	3-QW	8-QW
Device 1 (InGaN/ InGaN LED)	2.878	2.862	98.58	97.93	1497.8	1481.4
Device 2 (GaN/ InGaN LED)	3.114	3.124	98.32	98	1414.5	1408.1

From Table 1 it can be seen that the device 1 has achieved more efficiency at high current (98.58%) for 3-QW pair and in case of 8-QW pair both devices achieved ~97.9% so device 1 with 3-QW pair can be used in the applications where efficiency is the first priority. Device 1 is also giving more output power both in 3-QW pair (~1497 w/m) and 8-QW pair (~1481 w/m).

IV. CONCLUSION

From the study it can be concluded that both the devices are giving output in same frequency range, the peak wavelength of device 1 (~410 nm) and of device 2 (~430 nm) lie in the same range. The device 2 shows more shift towards blue range. The device 1 achieves its maximum efficiency (~98.58%) with 3-QW pair while device 2 achieves its maximum efficiency (~98.56%) with 1-QW at high current. From the results it is studied that device 2 has more charge confinement as compared to device 1 within the voltage range 0.75 V to 5 V. It is also observed that device 1 has more spontaneous rate as compared to device 2 but it does not have perfect blue color.

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