Study of InGaN/GaN/InGaN Multi-Layer Barrier in GaN-based Light Emitting Diode

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***Abstract*—A GaN-based light emitting diode (LED) with InGaN/GaN/InGaN multi-layer barrier(MLB) is studied. Simulation results show that GaN-based LED with MLB has better performance than conventional GaN-based LED with only one GaN barrier, which we found is due to enhancement of hole injection into quantum well and decrease of electron current leakage.**

I. INTRODUCTION

In order to improve performance of GaN-based light emitting diodes(LEDs), many structural designs have been applied. For example, a p-AlGaN layer acts as an electron blocking layer(EBL) to decrease current leakage[1]. Another design is that an n-InGaN layer acts as an electron reservoir layer(ERL) to increase carrier capture and confinement in quantum wells[2]. In addition, super-lattice(SL) can be used to increase hole injection[3]. Recently, it is reported that AlInGaN quaternary and InGaN ternary barriers can be used to match crystal lattice of quantum wells[4]. However, it is difficult to grow AlInGaN layers with high crystalline quality due to the differences between optimal incorporation conditions for Al and those for In. Also, crystalline quality of active layers might become worse as more InGaN barriers and wells are deposited repeatedly[5]. Such issue of AlInGaN or InGaN quantum barrier layers have been an obstacle to realize high-perfomance LEDs. Recently, GaN-based blue light LED with an InGaN/GaN/InGaN multi-layer barrier(MLB) structure is manufactured in experiment to achieve not only high crystalline quality but also high LED performance[6].

In this paper, the MLB LED is theoretically studied and compared to conventional LED with single GaN barrier by applying the APSYS software[7] which has been successfully applied to simulate plenty of realistic devices[8].

At first, simulation results for a conventional LED is fitted to experimental work. Then, a LED with MLB is simulated. Results are compared between the two LEDs. We find that MLB makes hole easier to be injected into quantum wells so that radiative recombination coefficient is improved and in succession output light power is boosted. We also find that MLB can remarkably prevent electron leakage due to conduction band edge of EBL is close to that of MLB. Smaller current leakage of MLB LED results in higher IQE than that of conventional LED.

II. DEVICE STRUCTURE

The structure of GaN-based LED under study is shown schematically in Fig.1. The conventional LED consists of a 3-μm-thick layer of n-type GaN standing on sapphire substrate, followed by five periods of $In_{0.15}Ga_{0.85}N$/GaN MQWs, a 200-Å-thick layer of p-type $Al_{0.15}Ga_{0.85}N$ as EBL, and a 0.3-μm-thick layer of p-type GaN. The thicknesses of quantum well and GaN quantum barrier are 2 and 15 nm, respectively. The structure for the MLB LED was similar except for that each quantum barrier is consisted of a 5-nm-thick $In_{0.1}Ga_{0.9}N$ layer, a 5-nm-thick GaN layer a 5-nm-thick $In_{0.1}Ga_{0.9}N$ layer. The device geometry was designed with a rectangular shape of 300μm x 300μm.

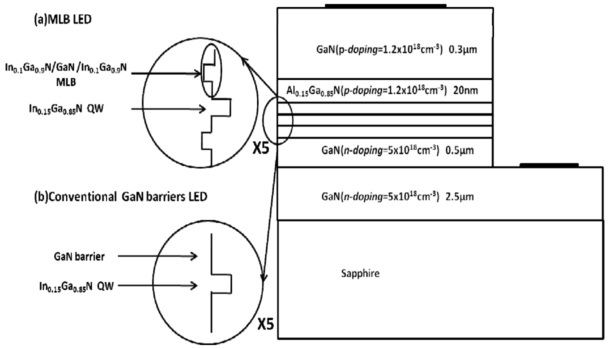

Fig. 1. The schematic structure of the GaN-based blue light LED with (a)MLB (b)GaN quantum barrier.

III. RESULTS AND DISCUSSIONS

In our simulation work, spontaneously polarized charge and piezo-charge are considered for both of the two LEDs.

Firstly, I-V and L-I curves of the conventional GaN barrier LED are simulated and fitted to experimental measurements, see Fig.2.

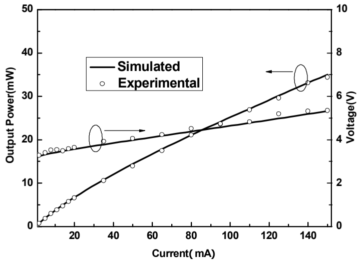

Fig. 2. Simulated and experimental I-V curves and L-I curves for conventional GaN barrier LED

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Figure 3 shows the IQE and light output power as a function of current for the two LED structures under study, it can be seen that the output power of the MLB LED is much higher than the conventional GaN barrier LED. In the same way, the IQE of the MLB LED is improved remarkably compared with that of the conventional GaN barrier LED. It is noteworthy that the efficiency droop for the MLB LED is much less than the GaN barrier LED.

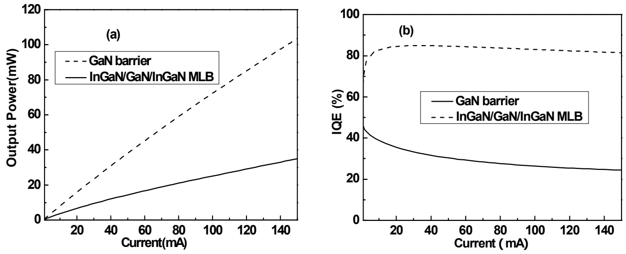

Fig. 3. (a) light output power and(b)IQE versus current for the two LED structures under study

Figure 4 shows the radiative recombination (RR) coefficient in the active region at 150mA. It indicates that RR comes mainly from the last QW near p-side and RR of the MLB structure is much larger than that of GaN barrier structure, which directly causes that light output power of the MLB structure is much higher than that of GaN barrier structure(shown in Fig.3. (a)).

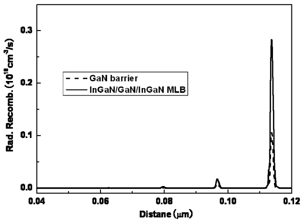

Fig.4. Radiative recombination coefficient for the two LED structure at 150mA

The RR coefficient is calculated by $B(np - n_i^{\ 2})$[7],where B is recombination coefficient rate, n is electron concentration, p is hole concentration and n_i is intrinsic carrier concentration. Fig.5 shows that electron concentrations in the last QW are nearly same in the two LED structures, but hole concentration in the last QW of the MLB structure is much higher than that of the GaN barrier structure, which indicates that hole concentration is the key reason which makes big discrepancy of the RR coefficient between the two LEDs..

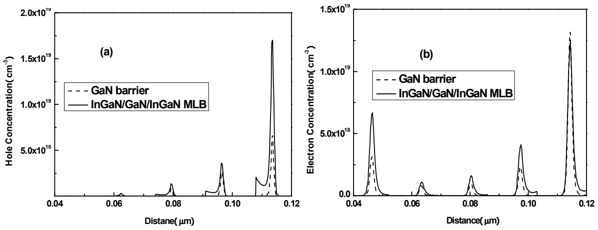

Fig.5. (a) hole concentrations and(b)electron concentrations for the two LED structure at 150mA

Besides, Fig 6 shows the electron current density distribution of the two structure. It's delighting to see that electron current leakage rate(J_n(p-region)/ J_n(n-region)) decrease from 0.63 to 0.14 when applying MLB structure. Such decrease explains the phenomena that IQE of MLB structure LED drops much slower than that of GaN barrier LED(shown in Fig3.b).

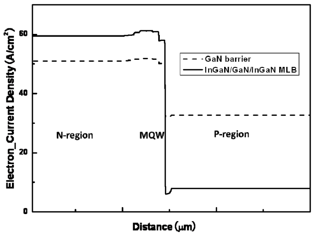

Fig.6. Electron current distribution for the two LED structure at 150mA

Energy band diagram of the two LEDs at 150 mA are plotted in Fig.7. We can see that conduction band edge of EBL in the MLB LED is very close to conduction band edge of MLB, which indicates that electron can be effectively blocked and thereby current leakage can be remarkably prevented. Oppositely, such situation is much worse for GaN barrier LED. Electron carrier can get through EBL much easier.

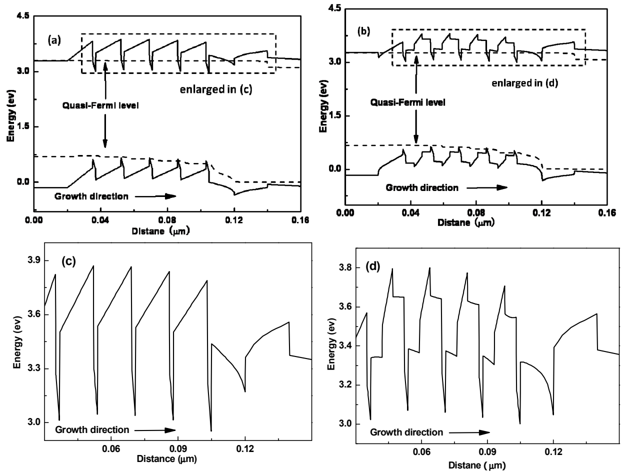

Fig. 7. (a) Energy band diagram of conventional GaN barrier LED (b) Energy band diagram of MLB LED (c) Enlarged drawing of the conduction barrier of conventional GaN barrier LED(d) Enlarged drawing of the conduction barrier of MLB LED

IV. CONCLUSIONS

In this paper, simulation work is made to compare a InGaN/GaN/InGaN multi-layer barrier LED with conventional GaN barrier LED. Simulation results show that the multi-layer barrier not only improves hole injection into quantum wells, but also reduces electron current leakage. Its significant advantage may help design LEDs with better performance.

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