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The Improvement of Light Intensity for Nitride-Based MQW LEDs by Gradient-Stage Emitter Layer

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1. Introduction

Group III nitrides represent an important family of semiconductors for the application of optoelectronics since the band gap of their ternary and quaternary can cover the whole visible light spectrum [1]. During much effort of researchers in recent decades [2-4], the blue and green LEDs have been commercialized nowadays. However, the improvement of energy conversion efficiency for nitride-based LEDs is still an important issue for researchers in this field. It is known that for III-V compound LEDs and LDs, the QW structure is generally used in the active region because of its optimal carrier confinement and maximal optical matrix element. However, its electron capture rate is small due to the much lighter effective mass and higher corresponding thermal velocity for electrons than those for holes [5]. This results in the large leakage of electrons to the p-GaN and harms the radiative recombination efficiency. So, researchers used a charge asymmetric resonance tunneling (CART) structure as an electron emitting layer (EL) to enhance the electron capture rate of the active region. The EL offers large amount of states for electrons to accumulate before they inject into the active region and also the electrons get another path by tunneling into the active region [6-7]. Nevertheless, a thick InGaN CART layer will degrade the crystal quality of overlaying layers, including the active region. Later, the dual-stage LED, in which one set of MQW is used to replace the thick CART layer, is investigated to reduce such kind of damage [8]. Besides, the emitter layer in the dual-stage LED can be regarded as the buffer layer for the large lattice difference in the QWs and hence also improve the crystal quality of the QWs in the active region. In this paper, we modify the MQW of the EL in dual-stage LED by gradient depth, in which the wells nearer the n-type GaN have shallower depths. This modification will further improve the crystal quality of the active region because of the gradual change of lattice constant in the emitter layer and simultaneously remain the function of carrier capture.

2. Experiment procedure

All samples used in this study were grown on c-face 2-inch sapphire substrates by metalorganic vapor phase epitaxy (MOVPE) system. The structures of all samples are described as follows: 1- μ m-thick undoped GaN layer and 1- μ m-thick n-type GaN layer were first deposited. We subsequently grew a set of InGaN/GaN MQW EL with

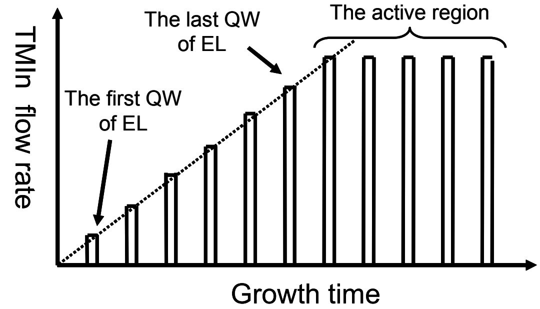

Figure 1. The illustration of flow rate for controlling the In composition of QWs in the gradient EL. The structure of EL with 6 QWs is taken as an example.

constant and gradient In composition in the cases of dual-stage and gradient-stage LEDs, respectively. But for the conventional LED, there is no EL embedded. The EL of dual-stage LED consisted of 6 pairs of undoped 3-nm-thick $In_{0.1}Ga_{0.9}N$ well layer and 12-nm-thick Si-doped GaN barrier layers. On the other hand, the In composition x of gradient-stage EL increases linearly by controlling the flow rate of In source, as shown in Fig. 1. Then five pairs of $In_{0.21}Ga_{0.79}N$/GaN MQW structure as the active region were deposited with nitrogen. Finally, a 0.2- μ m-thick p-type GaN layer was grown. After finishing the LED structures, standard process was employed. The conventional, dual-stage ad gradient-stage LEDs are labeled as sample A, B, and C, respectively.

3. Result and discussion

Fig. 2 shows the HRXRD spectra of sample A, B, and C. As shown, the crystal quality of the conventional LED is worse than the other two. This is because the inserted electron EL can be regarded as a buffer that reduces the strain effect between the InGaN QW in the active region and the underlaying bulk GaN. There are similar situation between sample B and C. It is observed that the satellite peaks in sample C is clearer than sample B. This is because the ability of strain relaxation is better for gradient-stage EL, so the crystal quality of the overlaying layers is better.

The PL spectra shown in Fig. 3 also identify the observation in Fig. 2. The increment of the intensity of the main peak from the sample A to B is much larger than that from B to C. On the other hand, the identity of the peak positions indicates the similar structure parameters of the active regions for the three samples. The I-V characteristics

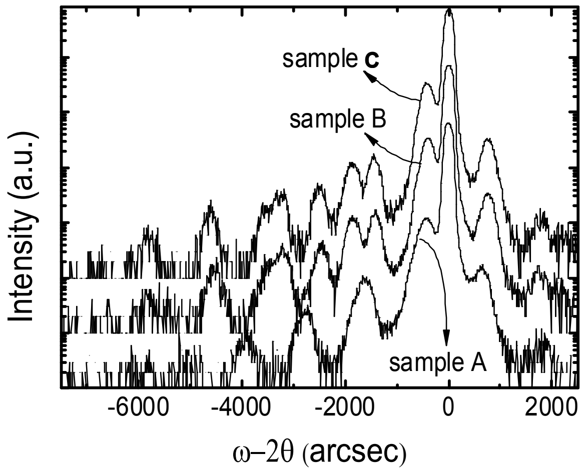

Figure 2 The HRXRD spectra measured from sample A, B, and C.

are measured but not shown here. The curves for the sample B and C are identical and both have lower forward voltages than that of sample A. Similar situation is observed between the dual-stage and conventional LEDs in the previous work [8]. The reason was believed to be that the inserted EL can also act as a good current spreading layer and hence reduce the forward voltage.

Fig. 4 is the comparison of the L-I measurement for sample A, B, and C. It is clearly shown that at low injected current, the light intensities of the three samples are similar, for example, at current region lower than 10 mA. This is because at low current injection, the leakage of electrons is not obvious. So the effect of EL does not outstand. When the current increases, the increment of light intensity for dual- and gradient-stage LEDs becomes larger than that of the conventional one. The gradient-stage one exhibits the best performance. At 20 mA injected current, the gradient-stage LED can enhance the light intensity at about 63% and 20% compared to the conventional and dual-stage LED, respectively.

3. Conclusions

The EL with gradient depth of QWs is used to improve the electron capture rate of nitride-based LED. Careful

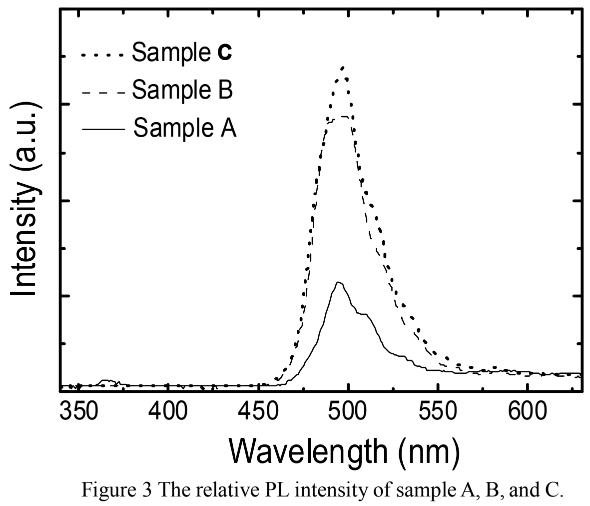

Figure 3 The relative PL intensity of sample A, B, and C.

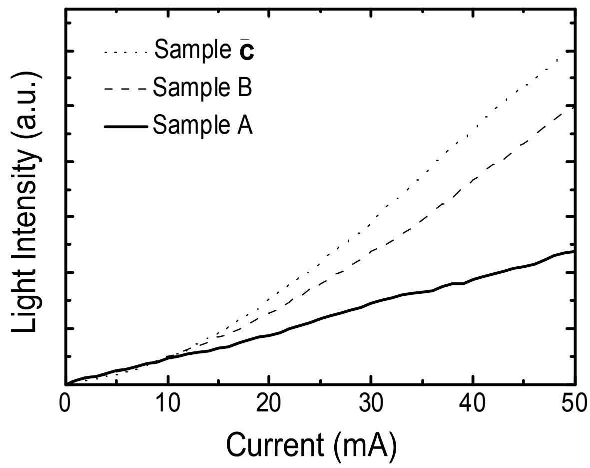

Figure 4 The comparison of L-I characteristics for sample A, B, and C.

comparison with the dual-stage EL was made. The results show that the gradient-stage EL can further improve the light intensity of the LED, about 20% increment compared to dual-stage LED at 20 mA since the crystal quality is better.

Acknowledgements

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Abstract

We demonstrate the improvement of the light intensity for nitride-based light emitting diodes (LED) using an emitter layer (EL) with gradient depth of quantum wells (QWs). The dual-stage multi-quantum well (MQW) LED is also fabricated for comparison. The results shows that the gradient-stage EL can further improve the light intensity of the LED, about 20% increment compared to dual-stage LED at 20 mA due to the improvement of the crystal quality and the better electron capture rate of graient-stage than dual-stage.