# Effects of Luminescence Efficiency in InGaN-GaN LEDs by Inserting a LT-GaN Underlying Layer to Separate Nonradiative Recombination Centers

Ray-Ming Lin, Chung-Hao Chiang, Mu-Jen Lai , Yi-Lun Chou ,Yuan-Chieh Lu,Shou-Yi Kuo,
Bor-Ren Fang, and Meng-Chyi Wu
Department of Electronic Engineering, Chang-Gung University,
Taoyuan 333, Taiwan, R.O.C

## ABSTRACT

We have investigated the effects of nonradiative recombination centers (NRCs) on the device performances of InGaN/GaN multi-quantum-well (MQW) light-emitting diodes (LEDs) incorporating low-temperature n-GaN (LT-GaN) underlying layers. Inserting an LT-GaN underlying layer prior to growing the MQWs is a successful means of separating the induced NRCs as a result of the presence of a growth interrupt interface between the n-GaN template and the InGaN QW. We found that inserting an LT-GaN underlying layer prior to growing the MQWs could improve the external quantum efficiency of as-grown conventional LEDs. In our best case, the external quantum efficiency of a blue LED incorporating a 70-nm-thick LT-GaN was 16% higher (at 20 mA) than that of the corresponding as-grown blue LED. Finally, it would also use in optical-fiber short-wavelength communication systems at particular condition.

Keywords: InGaN/GaN MQW, nonradiative recombination center, Light-emitting diodes.

## 1. INTRODUCTION

In recent years, GaN and its alloys with InN and AlN have attracted much attention because of their suitability for use as green-, blue-, and ultraviolet-light emitters as well as for their applications in high-power electronic devices[1, 2]. The most popular application of the nitride semiconductors is in InGaN/GaN multi-quantum-well (MQW) light-emitting diodes (LEDs) that provide blue light emissions and realized full-color displays.

Akasaki et al.[3] found that introducing InGaN layers below the MQW, with SiC as the substrate, improved the photoluminescence (PL). They attributed the PL improvement to the reduction in the concentration of the nonradiative recombination centers (NRCs) near the MQW.

Nanhui et al. found that introducing an InGaN strain reduction layer between an n-GaN template and an MQW grown on sapphire, which can shift the lattice constants to the average value of the MQW region, reduced the strain in the InGaN well layer and enhanced the luminescence of the InGaN/GaN MQWs. Their GaN template layers were grown at temperatures of ca. 1100 °C, whereas the InGaN QWs were grown at ca. 800 °C[4, 5]. In such systems, a growth interrupt (GI) interface exists between the n-GaN template and the InGaN/GaN MQW; therefore, it is very possible that a large number of nonradiative recombination centers (NRCs) are generated at the GI interface (e.g., through desorption of nitrogen atoms or absorption of impurity atoms). In this study, we investigated the effects of treating the GI interface of the n-GaN template layer by inserting an LT-GaN underlying layer prior to growing the MQWs through atmosphere metal organic chemical vapor deposition (APMOCVD).We found that the electroluminescence (EL) efficiencies of InGaN MQW LEDs were affected dramatically after inserting LT-GaN underlying layers having thicknesses of 30, 50, 70, and 90 nm. We also investigated the effects of the NRCs and the strain on the optical and interfacial properties of these InGaN/GaN MQW LEDs.

## 2. EXPERIMENTS

The blue InGaN/GaN MQW LEDs were grown on a c-plane sapphire substrate using Taiyo Nippon Sanso SR2000 AMOCVD. Trimethylgallium (TMG), trimethylindium (TMI), biscyclopentadienylmagnesium ($CP_2Mg$), ammonia ($NH_3$), and silane ($SiH_4$) were used as dopants and sources. The sample structure is displayed schematically in Fig. 1. four different thicknesses of the LT-GaN underlying layer (30, 50, 70, and 90 nm) were grown at 845 ˚C using a hydrogen carrier gas.

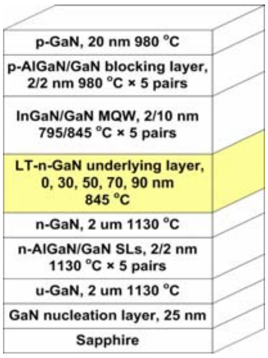


Figure 1. InGaN/GaN MQW LED structure with inserting a LT-GaN underlying layer.

## 3. RESULTS AND DISCUSSION

To examine the origin of the band gap shifting effect of LEDs after inserting the LT-GaN underlying layers [d: 0 (sample A), 30 nm (sample B), 50 nm (sample C), 70 nm (sample D), and 90 nm (sample E)], we recorded the corresponding EL spectra at room temperature (RT) with various forward injection currents (Fig. 2). Upon increasing the injection current from 1 to 10 mA, the EL blue-shifts of samples A–E were 7.4, 7.5, 7.4, 4.9, and 4.9 nm, respectively. the injection carrier density in our EL measurements was low and, therefore, we suspect that the carrier screen effect was the main factor responsible, As a result, the quantum confinement Stark effect (QCSE) becomes smaller and the transition energy becomes larger, leading to a blue-shift of the peak wavelength. Moreover, the magnitude of the QCSE can be scaled by the blue-shifts, depending on injection current. In Fig. 2, we observe that the values of the EL blue-shifts of samples A–E were all quite similar, suggesting that their QCSEs were also similar. To observe the effect on the light emission after inserting the LT-GaN underlying layers, we recorded EL relative intensity-injection current characteristics of samples A–E (Fig. 3). We observed an increase in the relative EL intensity for sample E (d = 70 nm) at 20 mA; it was 20.6% higher than that of the as-grown bare-chip LEDs of sample A (averaged at 5 mW of sample E ; derived by integrate sphere).

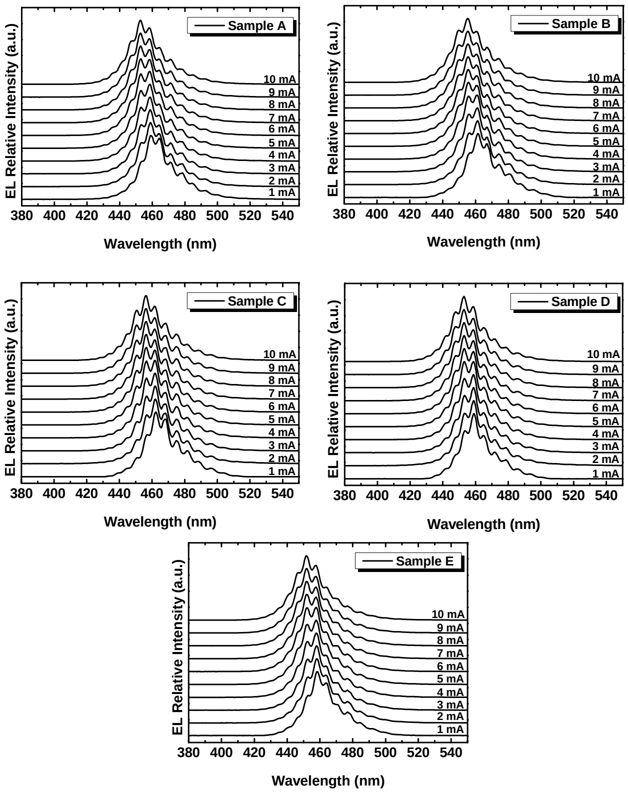


Figure 2. The EL spectra of LEDs at different injection current from 1 mA to 10 mA.

Fig. 4 displays the slope efficiencies (dL/dI) plotted as a function of d for samples A–E operated at 100 mA. At an injection current of 20 mA, the external quantum efficiencies (EQEs) of the InGaN/GaN MQW LEDs increased by 4.1, 8.6, 16.0, and -2.8%, respectively, relative to that of the as-grown sample A.

Two possible reasons for the improved EL luminescence efficiency of the blue LEDs after inserting a comparatively thick LT-GaN underlying layer prior to growing the MQW are (i) the successful separation of the MQWs and the GI interface and (ii) the reduced effect of the NRCs in the InGaN MQWs.

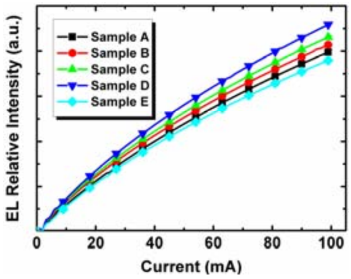


Figure 3. EL relative intensities of the InGaN/GaN MQW blue LEDs with 0, 30nm, 50nm, 70nm and 90nm LT-GaN, respectively.

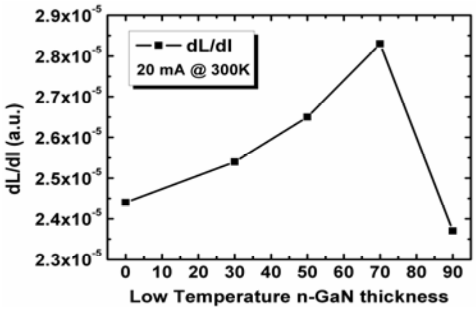
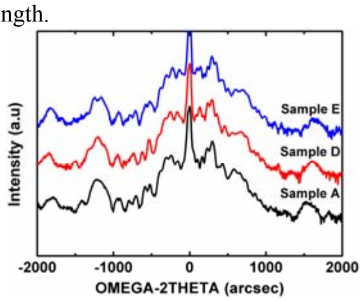


Figure 4. Slope efficiencies of the InGaN/GaN MQW LEDs with 0, 30nm, 50nm, 70nm and 90nm LT-GaN, respectively.

Next, we examined the interfacial properties of the samples. Fig. 5 displays the $\omega$-2$\theta$ scans for the (0002) reflection of the InGaN/GaN MQW LEDs of samples A, D, and E. The higher-order satellite peaks of samples A and D are both clearer and sharper than that of sample E, indicating the abruptness of the interface and the good crystallinity of the InGaN/GaN MQW LEDs after inserting LT-GaN underlying layers at thicknesses of up to 70 nm. The presence of a 90-nm-thick LT-GaN clearly deteriorated the structure of the LED’s interface and its crystallinity, through such features as point defects and interface roughness, due to a shorter migration length.



F.igure 5. HRXRD $\omega$/2$\theta$ scans for the (0 0 0 2) reflection of the sample A, D and E

## 4. CONCLUSION

We have developed a method for modulating the thickness of the LT-GaN underlying layer between the n-GaN templateand the InGaN MQWs to improve the luminescence efficiency of blue LEDs. In the presence of the LT-GaN underlying layer, the EQEs of the InGaN/GaN MQW LEDs having values of d of 30, 50, 70, and 90 nm increased by 4.1, 8.6, 16.0, and -2.8%, respectively, relative to that of the as-grown sample A. Two possible reasons for the improved EL luminescence efficiency of the blue LEDs after inserting a comparatively thick LT-GaN underlying layer prior to growing the MQWs are (i) the successful separation of the MQW and the GI interface and (ii) a decrease in the effect of the NRCs in the InGaN MQWs. As a result, we conclude that inserting an LT-GaN underlying layer prior to growing the MQWs can be performed to improve the EQEs of as-grown conventional blue LEDs. Finally, it would also use in optical-fiber short-wavelength communication systems at particular condition.

## 5. REFERENCES

[1] T. Mukai and S. Nakamura,“Ultraviolet InGaN and GaN Single- Quantum- Well-Structure Light-Emitting Diodes Grown on Epitaxially Laterally Overgrown GaN Substrates”Jpn. J. Appl. Phys, vol. 38, Part 1, pp. 5735-5739, 1999.

[2] X. Guo and E. F. Schubert,“Current crowding in GaN/InGaN light emitting diodes on insulating substrates”J. Appl. Phys, vol. 90, no. 8, pp. 4191, 2001.

[3] T. Akasaka, H. Gotoh, T. Saito, and T. Makimoto,“High luminescent efficiency of InGaN multiple quantum wells grown on InGaN underlying layers”Appl. Phys. Lett, vol. 85, no. 15, pp. 3089, 2004.

[4] T. Takeuchi, S. Sota, M. Katsuragawa, M. Komori, H. Takeuchi, H. Amano, and I. Akasaki,“Quantum-Confined Stark Effect due to Piezoelectric Fields in GaInN Strained Quantum Wells”Jpn. J. Appl. Phys, vol. 36, pp. L382-L385, Part 2, 1997.

[5] N. Nanhui, W. Huaibing, L. Jianping, L. Naixin, X. Yanhui, Han Jun, D. Jun, and S. Guangdi,“Improved quality of InGaN/GaN multiple quantum wells by a strain relief layer”Journal of Crystal Growth, vol. 286, no. 2, pp. 209–212, 2006.