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High-Quality InGaN Light Emitting Diode Grown on GaN/AlGaN Distributed Bragg Reflector

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1. Introduction

GaN, AlN and their alloys have direct transition type band gap structure and have attracted much attention for optical devices in the blue-ultraviolet region. GaN-based edge emitting lasers have been extensively studies and have achieved room temperature continuous wave operation [1]. Recently, GaN-based vertical cavity surface emitting lasers (VCSELs) with a distributed Bragg reflector (DBR) have attracted much interest for various optical applications due to the fabrication of a smooth mirror without a cleavage technique [2]. The DBR is also effective in improving the output power of LED. Thus, the DBR plays an important rule to fabricate high performance optical devices such as LED and VCSEL. In this study, the use of the $GaN/Al_{0.27}Ga_{0.73}N$ DBR as a bottom mirror has improved the characteristics of InGaN MQW LED on sapphire. Moreover, the reflectivity as high as 98 % has been obtained by the use of the strained layer superlattice (SLS) beneath the DBR structure.

2. Experimental

A conventional horizontal atmospheric pressure MOCVD technique was employed for sample fabrication. TMG, TMA and TMI were used as a group III source materials and NH_3 as a group V. SiH_4 diluted in H_2 (10 ppm) and Cp_2Mg were used as the n-type and p-type dopants, respectively. Figure 1 shows the cross-sectional structure of InGaN MQW LED with 15 pairs of $GaN/Al_{0.27}Ga_{0.73}N$ DBR grown on (0001)-oriented sapphire substrate with two inch diameter. A thermal cleaning process was carried out at 1100 °C for 10 minutes in a stream of hydrogen ambient before growth. The InGaN MQW LED with DBR consisted of a 100-nm-thick GaN nucleation layer, a 1-μm-thick undoped GaN layer, 15 pairs of quarter-wave $GaN/Al_{0.27}Ga_{0.73}N$, a 0.5-μm-thick undoped GaN layer, a 4-μm-thick n-type GaN layer with Si-doped to $\sim 1\times10^{19}$ cm^{-3}, 3 periods of 5-nm-thick $In_{0.01}Ga_{0.99}N$ and 3-nm-thick $In_{0.13}Ga_{0.87}N$, a 20-nm-thick p-type $Al_{0.15}Ga_{0.85}N$ layer and a 0.2-μm-thick p-type GaN layer with Mg-doped to $\sim 1\times10^{18}$ cm^{-3}. The surface of p-type GaN layer was partly etched until n-type GaN layer by reactive ion etching in a BCl_3 plasma by using photoresist as the etch mask. The n-side and p-side ohmic contacts were obtained with Ti/Al annealed at 900 °C for 30 sec, Ni/Au at 600 °C for 3 min in N_2 ambient, respectively. The p-electrode was semitransparent.

The reflectivity of the DBR was measured by ultraviolet-visible spectrometer as a function of wavelength. Photoluminescence (PL) spectra were measured using a He-Cd laser as an excitation source, which was focused onto the surface of the samples at room temperature. The characteristics of LEDs were measured under DC biasing condition at room temperature.

3. Results and Discussion

The DBR structure was designed to have the peak reflectivity at the wavelength of 440 nm, which coincides with the electroluminescence (EL) peak of the InGaN MQW LED. Figure 2 shows the reflectivity of 15 pairs of $GaN/Al_{0.27}Ga_{0.73}N$ DBR measured at room temperature. A peak reflectivity of 75% was obtained at 435 nm. Figure 3 shows the PL spectra of the MQW structures with and without DBR. As shown in Fig. 3, the PL spectra were modulated strongly for the MQW structure with the 15 pairs of $GaN/Al_{0.27}GaN_{0.73}N$ DBR. The mode space, for example 6.6 nm between 436.9 nm and 443.5 nm, was caused by the vertical cavity formed between the surface and the DBR. The mode spacing was in good agreement with the calculation. The forward voltage was 4.5 V at 20 mA and the series resistance was 60 Ω for the LED with the DBR, which were comparable to those of the LED without DBR. Figure 4 shows the EL spectra of the LEDs with and without DBR at the forward current of 20 mA. The peak wavelengths of LEDs with and without DBR were 430 nm and 434 nm, respectively, and the FWHM of the peak emission was 22 nm for the both LEDs. The peak wavelength of EL spectra agreed well with the peak wavelength in the DBR.

The I-L characteristics of the LEDs are shown in Fig. 5. The optical detector was set above the surface of samples to detect surface emitting. The output powers of the LEDs with and without DBR were 120 μW and 79 μW at 20 mA, respectively. The output power of LED grown on the DBR is about 1.5 times larger than that of the LED without DBR. The external quantum efficiency at 10 mA has been improved from 0.16 % to 0.23 % by use of the DBR. The DBR structure has contributed to the enhancement of the optical output from LED.

The DBR with the reflectivity above 99 % is required for the fabrication of VCSEL. By inserting a 100 periods of $GaN/Al_{0.27}Ga_{0.73}N$ (25 Å/25 Å) SLS beneath the DBR structure, the reflectivity as high as 98 % has been achieved.

These results indicate that the DBR combined with the SLS is useful for the VCSEL on sapphire.

4. Conclusion

The InGaN MQW LED grown on the 15 pairs of DBR with a reflectivity of 75 % was fabricated for the first time to the best of our knowledge. The output power of 120 μW at 435 nm was about 1.5 times as large as that of the conventional LED. The DBR is very promising for the fabrication of high performance GaN-based LED and VCSEL.

References

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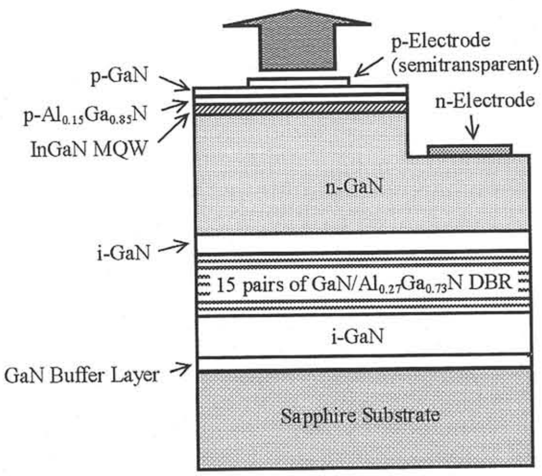

Fig. 1. Schematic structure of InGaN MQW LED grown on 15 pairs of GaN/$Al_{0.27}Ga_{0.73}N$ DBR.

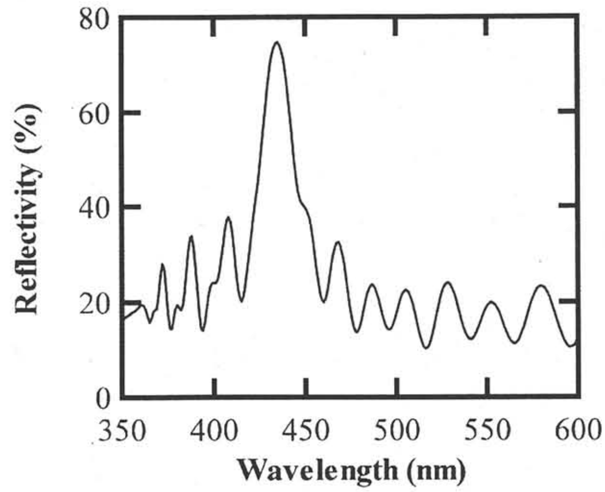

Fig. 2. Reflectance spectra of 15 pairs of GaN/$Al_{0.27}Ga_{0.73}N$ DBR.

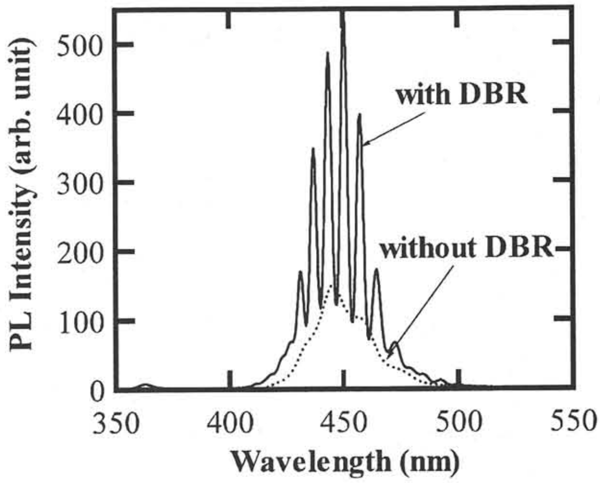

Fig. 3. Photoluminescence spectra of MQW structures with and without 15 pairs of GaN/$Al_{0.27}Ga_{0.73}N$ DBR.

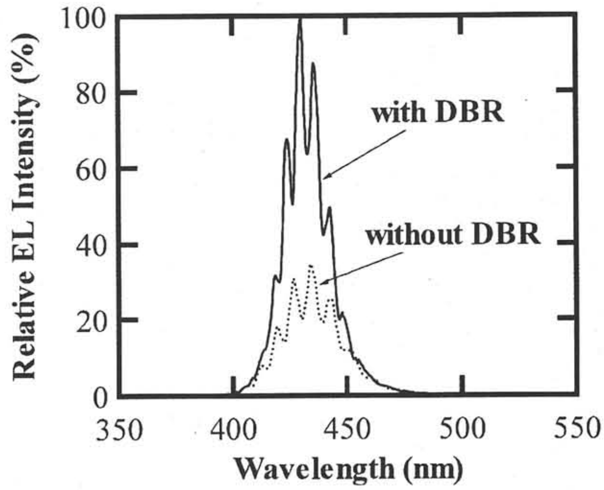

Fig. 4. Electroluminescence spectra of MQW LEDs with and without 15 pairs of GaN/$Al_{0.27}Ga_{0.73}N$ DBR.

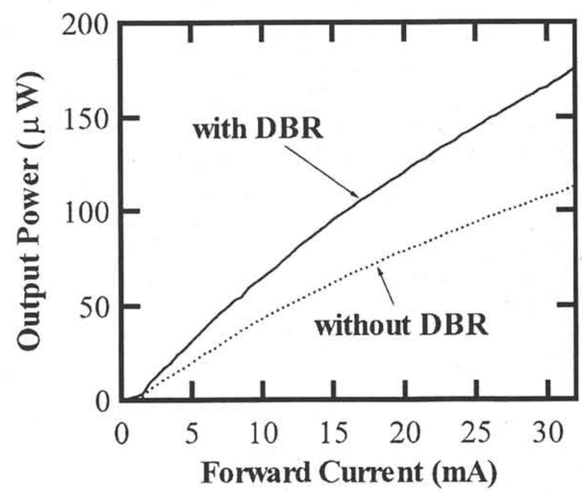

Fig. 5. I-L characteristics of the MQW LEDs with and without 15 pairs of GaN/$Al_{0.27}Ga_{0.73}N$ DBR.