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# GaN-based resonant cavity light emitting diodes using dielectric distributed Bragg reflector and aluminum mirror

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## 1. Introduction

Recently, GaN-based resonant-cavity light-emitting diodes (RCLEDs) have attracted many interests and applications as light sources in plastic optical fiber (POF) and communication systems [1-2]. Compared with conventional LEDs, the RCLEDs reveal inherent advantages including narrower spectrum linewidth, larger bandwidth, superior directionality of the emitted light, better fiber-coupling efficiency and high light extraction efficiency. In general, the RCLEDs consist of an active region containing multiple quantum wells (MQWs) sandwiched in a Fabry-Perot (FP) resonator of two reflectors [3-4]. In most of the reported RCLEDs structure, the bottom mirror usually employs GaN/AlGaN Bragg mirror. However, to avoid crack formation in the distributed Bragg Reflector (DBR), the performance of such structure is ultimately limited by the low-Al-content of the used AlGaN layer. Furthermore, even a very high reflectivity (>90%) required for RCLEDs structures can be obtained using a large numbers of mirror periods with low-Al-content in DBR structures, the optical properties of the resulted DBR structure suffer from light scattering caused by the roughness at the mirror interfaces. In this work, we propose a simple method for fabricating RCLEDs and to enhance the light output intensity by incorporating/depositing an aluminum (Al) mirror and a dielectric distributed Bragg reflector (DDBR) on the polished backside of sapphire substrates and the top of the LEDs, respectively.

## 2. Experimental

In this study, Al is chosen as the bottom reflector, which reveals a very high reflectivity of 90% at visible light wavelength. Figure 1 (a) shows the reflection of various Al thickness as a function of wavelength. We used precision lapping and polishing machine to polish the backside of sapphire substrates. The roughness of the polished sapphire reduces from the original 126nm to 0.92nm for making as a mirror like surface. A 40-nm-thick Al film was then deposited on the polished sapphire backside as the bottom reflector. The DDBR consisting of $TiO_2$ (n=2.32) and $SiO_2$ (n=1.46) dielectric pairs was deposited on the top of the LEDs using electron-beam deposition system with optical monitoring system to obtain high reflection precisely at blue light wavelength. Figure 1 (b) shows the reflection of DDBR increases with the evaporated $TiO_2/SiO_2$ pairs. The epitaxial layers of the LEDs were grown on c-plane sapphire substrates using a MOCVD system. The structure is composed of a 50-nm-thick GaN buffer layer, a 3-μm-thick Si-doped GaN layer ($3\times10^{17}$ cm$^{-3}$), an undoped InGaN/GaN multiple quantum well (MQW) active layer, a 50-nm-thick Mg-doped $Al_{0.2}Ga_{0.8}N$ layer ($1\times10^{17}$ cm$^{-3}$), and a 300-nm-thick Mg-doped GaN layer ($3\times10^{17}$ cm$^{-3}$). The InGaN/GaN MQW active layer consists of ten periods of 3-nm-thick $In_{0.23}Ga_{0.77}N$ well and 7-nm-thick GaN barrier. The grown samples were then annealed at 750°C for 30 min in $N_2$ ambient for the activation of generating holes. First, conventional LEDs were fabricated from the epitaxial layers by standard fabrication process reported previously [5] as shown in Fig. 2(a). Then, 40-nm-thick Al mirror and DDBR layer with three $TiO_2/SiO_2$ dielectric pairs were deposited on the polished sapphire backside and the top of the LEDs, respectively.

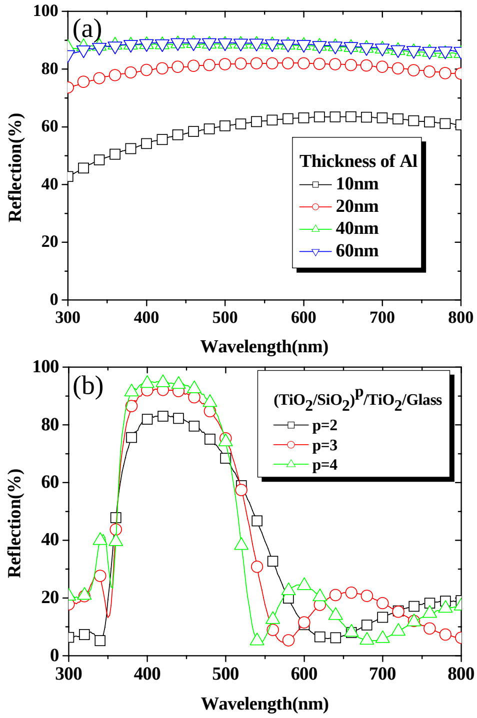
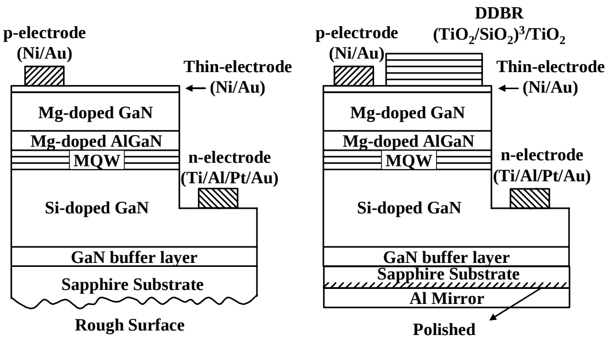



Fig. 1. Reflection of (a) Al mirror with different thickness (b) DDBR with different p pairs.




(a) (b)

Fig. 2. Structure of (a) conventional LEDs and (b) LEDs with the top DDBR and bottom Al mirror.

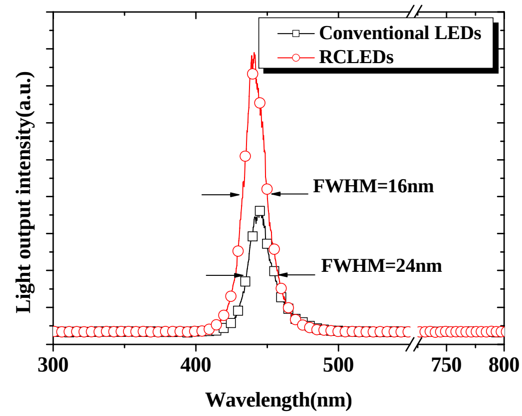



Fig. 3. Electroluminescence of conventional LEDs and RCLEDs.

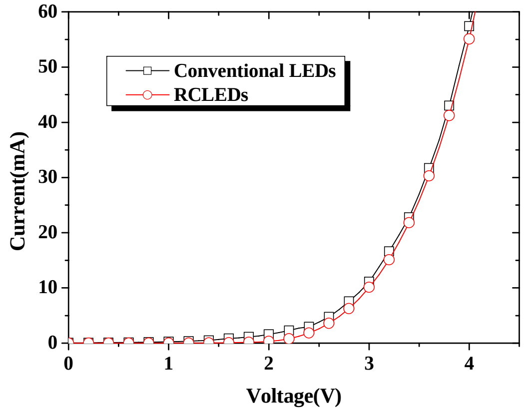



Fig. 4. Current-voltage characteristics of conventional LEDs and RCLEDs.

## 3. Results and Discussion

To investigate the output light wavelength and intensity, the electroluminescence (EL) emission of the conventional LEDs and RCLEDs were measured and shown in Fig. 3. It can be seen that a 216% increase in output light intensity at an emitting wavelength of 440nm of RCLEDs compared with conventional LEDs. The light output intensity increase of RCLEDs is deduced from the resonator of the top DDBR and bottom Al mirror. The full width at half maxima (FWHM) of intensity of RCLEDs also becomes narrower than that of conventional LEDs by ~8nm from 24nm to 16nm. The narrower FWHM of RCLEDs is attributed to the resonance effect caused by the DDBR and Al mirror. Figure 4 shows the current-voltage characteristics of the conventional LEDs and RCLEDs measured by an HP-4145 semiconductor parameter analyzer. It is worth to noting that the conventional LEDs and RCLEDs reveal similar I-V characteristics. The forward voltage of both the LEDs operated at 20 mA is about 3.3 V.

## 4. Conclusions

In summary, a superior bottom reflector of Al mirror was deposited on specially polished sapphire backside. In our deposition technique, DDBR can be controlled to get high reflection at blue light wavelength with optical monitoring system coupled with electron-beam evaporator. Comparing with the conventional LEDs, the output light intensity increase by 216% and FWHM of intensity reduce by 8nm. These improvements are attributed to the resonance effect caused by the DDBR and Al mirror reflectors. According to the experimental results, the simple fabrication of RCLEDs can be expected as a promising method for increasing the extraction efficiency and narrower wavelength of GaN-based LEDs.

## Acknowledgements

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