GaN light emitting diodes with wing-type imbedded contacts

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Abstract: A wing-type imbedded electrodes was introduced into the lateral light emitting diode configuration (WTIE-LEDs) to reduce the effect of light shading of electrode in conventional sapphire-based LEDs (CSB-LEDs). The WTIE-LEDs with double-side roughened surface structures not only can eliminate the light shading of electrode and bonding wire, but also increase the light extraction and light output power. Contrast to CSB-LEDs, a 79% enhancement of output intensity in the WTIE-LED was obtained at 100 mA injection current. Similarly, the output power of packaged WTIE-LEDs was enhanced 59% higher compared with the packaged CSB-LEDs at the same injection condition. Therefore, using the imbedded contact to reduce light shading would be a promising prospective for LEDs to achieve high output power.

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References and links

1. Introduction

High luminescence gallium nitride (GaN) light-emitting diodes (LEDs) have attracted great attention due to their promising potential to replace conventional mercury-containing lamps for some lighting applications, including traffic signals, backlights for liquid crystal display, and solid state lighting. However, in order to obtain more LED output power, the LEDs are usually operated at high injection current. The high injection current operation generates the current-crowding effect and LED efficiency droop issues. The current-crowding is attributed that the unequal carrier mobility between holes and electrons in LED structure, which confines the path of carrier flow near the electrode, resulting in a nonuniform light emitting form active region. On the other hand, the efficiency droop easily occurs at operating high injection current due to the low thermal dissipation of sapphire substrate. Vertical-type LED configuration was adopted to improve the two issues above [1–5]. The vertical-type LEDs are fabricated using a combination technique of wafer bonding and sapphire substrate separation. While thin film LEDs and substrate transferring improve the poor thermal dissipation of substrate, more work is required to achieve high output power for vertical LEDs, especially for the light shading caused from the electrode on the top surface of LED and the reflectivity reduction in p-type metal contact as mirror layer after high-temperature annealing treatments [6–8]. Generally, the light shading issue can be solved through using flip-chip configuration [9]. However, it is required for precisely contact alignment when metal contact pads of flip-chip LED were connected on the circuit substrate. Meanwhile, the configuration cannot provide good thermal dissipation due to only the less of connection area between the LED and the Si substrate. Therefore, in this study, we introduced an imbedded electrode design into the lateral LEDs to solve the electrode shading issue [10]. An improved chip process was designed for the fabrication of n-side up with imbedded electrodes to avoid the previously enumerated processing issues. The use of LEDs with imbedded electrodes exhibits not only the precise alignment process is unnecessary but also the LED output power is increased due to the electrode shading elimination.

2. Experimental

The standard LED structures are grown on c-plane (0001) sapphire substrates by metal-organic chemical vapor deposition. The sandwich p-i-n structure consists of a 2-μm un-doped GaN, a 2-μm Si-doped n-type GaN layer, a about 1-μm InGaN multi-quantum wells structures, and Mg-doped p-type GaN layer with roughening surface. To avoid run-by-run epilayer quality influence, all LEDs were fabricated using the same 2-inch epilayers. Two kinds of LED configurations are presented in this study; one is fabricated on sapphire substrate (denoted as CSB-LEDs) and the other one is fabricated into a thin film n-side up configuration (denoted as WTIE-LEDs). Each chip size and dominant wavelength of both LEDs is 20 × 38 mil2 and 450 nm. The schematic of the fabricated flowchart of CSB-LEDs is shown in Fig. 1(a)-1(c). Contrast, the fabrication flowchart of the WTIE-LEDs was displayed in Fig. 1(e)-1(k). One can see that the LED structure was bonded to a Si substrate using low-temperature glue bonding technique. In order to obtain more LED light reflection, a SiO2 oxide layer and a multiple metal layer as mirror were pre-coated on the Si substrate (i.e. oxide/Al/Ti/Si substrate). The use of low-temperature bonding process can avoid the degradation of mirror layer instead of using high-temperature metal bonding method. Subsequently, laser lift-off (LLO) technique was employed to remove the sapphire substrate. Particularly, it is not necessary for the WTIE-LEDs to precisely align their n- and p-electrodes to a circuit substrate because of a specific wing-type electrode design. The wing-type electrodes were designed to directly connect from p-GaN surface to n-GaN surface and using a SiO2 layer as insulator between electrodes and epilayers prevent leakage current generation. After wafer bonding and sapphire separation, the roughened surface of n-GaN was created through using a NaOH solution. In Fig. 1(k), another
Ti/Ai/Ti/Cr/Au metal contact was deposited on the exposed wing-type electrode area; it is unlike CSB-LEDs, whose n-electrode was fabricated upon the active layer. Therefore, the WTIE-LED output power will be expected to increase by eliminating the electrode shading. Moreover, Figs. 1(d) and 1(l) show the plane-view SEM images of CSB- and WTIE-LEDs, respectively.

3. Results and discussion

X-ray diffraction (XRD) measurement is used to evaluate the change of epilayer strain before and after substrate transformation. The peaks of GaN and ITO were clearly shown in the XRD pattern (see Fig. 2) and no obvious difference in peak shape and peak position was found even after the LEDs epilayer was transferred from sapphire substrate onto Si substrate. Compared with the CSB-LED results, the higher XRD intensity of GaN peak in WTIE-LEDs may be ascribed that the sapphire separation and different x-ray incident side [11,12]. Meanwhile, the XRD pattern of WTIE-LEDs also indicated that there is no significant stress was induced after wafer bonding. It evidenced that low-temperature glue bonding process can reduce the stress effect compared to high-temperature metal bonding.
Figure 3 shows the current as a function of the forward voltage (I-V) for WTIE-LEDs and CSB-LEDs. One can see that the forward I-V curves were almost the same for the two LEDs. It indicates the WTIE-LED performance is unaffected by the extra fabrication processes, such as wafer bonding, LLO, and surface texturing. The forward voltage for WTIE-LED and CSB-LEDs is both 2.8 V at 20 mA injection. Moreover, the reverse leakage current of LEDs at operating reverse voltage of 5V was measured to be $-0.381$ and $-0.131$ $\mu$A for CSB- and WTIE-LEDs, respectively, as listed in the inset table of Fig. 3. Figure 4 presents the luminance intensity of LEDs without epoxy as a function of injection current. It was found that the intensity of WTIE-LEDs was higher than that of the CSB-LEDs. The intensity of WTIE-LEDs was 79.3% higher than that of CSB-LEDs at an injection current of 100 mA. Due to the p-electrode of WTIE-LEDs (marked by red circle) was embedded underneath the active region, the light from active region can directly emit toward the LED top surface. Contrast, in CSB-LED cases, the light will be shaded by p-electrode and decrease the LED output power, as shown in the inset of the Fig. 4. Additionally, the roughened n-GaN surface and high reflectivity of mirror layer also contribute in the increase of light extraction for the WTIE-LEDs. Figure 5 shows the output power of both LEDs with epoxy package as a function of injection current. Similar optical results of LED performance were observed in both
packaged LEDs. At 100 mA injection current, the output power of WTIE-LEDs was enhanced 59% as compared to CSB-LEDs and the output power value of WTIE- and CSB-LEDs is 86.33 and 54.19 mW, respectively.

Fig. 4. Luminance intensity as a function of injection current for WTIE-LEDs and CSB-LEDs

Fig. 5. Output power as a function of injection current for WTIE-LEDs and CSB-LEDs.

4. Conclusion

In this study, we successfully fabricated wing-type imbedded contacts LEDs structure. The InGaN LEDs epilayers were transferred from sapphire substrate onto silicon substrate. The XRD patterns proved that the crystalline quality of the thin LEDs epilayers was not deteriorated...
after substrate removal. Moreover, a 59% higher enhancement in LED output power was demonstrated by the WTIE-LEDs. The results exhibit not only the LED output power was increased due to eliminating a 9% electrode area compared to the CSB-LEDs, but also the double-side roughened surface and mirror layer in WTIE-LED contribute to the increment of light extraction.

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