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Fabrication of AlGaN-based vertical light-emitting diodes

Seon Min Bae[a], Hunsoo Jeon[a], Gang Seok Lee[a], Se-Gyo Jung[a], Kyoung Hwa Kim[a], Sam Nyung Yi[a], Min Yang[a], Hyung Soo Ahn[a,]*, Young Moon Yu[b], Suck-Whan Kim[c], Seong Hak Cheon[d], Hong-Ju Ha[d] and Nobuhiko Sawaki[e]

[a]*Department of Applied Sciences, Korea Maritime University, Busan 606-791, Korea*
[b]*LED-Marin Convergence Technology R&BD Center at Pukyong National University, Busan 608-737, Korea*
[c]*Department of Physics, Andong National University, Andong, Gyeongbuk 760-749, Korea*
[d]*CSsol.Co., Ltd, Busan 606-791, Korea*
[e]*Department of Electrical and Electronics Engineering, Aichi Institute of Technology, Toyota, Aichi 470-0392, Japan*

The AlGaN-based vertical light-emitting diodes (LEDs) on thick GaN epilayer were fabricated by a hydride vapor phase epitaxy with multi sliding boat system. The optical and electrical characteristics of AlGaN-based vertical LEDs were evaluated using a scanning electron microscopy, electroluminescence and I-V measurements. The AlGaN-based vertical LEDs structure has hexagonal symmetry, 500 μm in diameter and above 67 μm in growth thickness. At the room-temperature, the broaded strong peak and relatively high intensity peak were gradually measured at 405 nm with increasing injection current. And a forward operator voltage was measured to be about 7.5 V.

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Key words: HVPE, AlGaN, Double heterostructure, Vertical light-emitting diodes.

Introduction

The GaN-based wide-band-gap semiconductors are widely used in various applications such as light-emitting diodes (LEDs), laser diode (LDs) and high-power/high-frequency RF devices [1-4]. Especially, LEDs are one of the most important applications of wide-band-gap GaN material due to the control with different doping concentration of active layer, the light wavelength from 390 nm to 780 nm which can be widely used in full-color displays, high efficient and reliable green traffic lights, and flat-panel room lighting to replace present incandescent and fluorescent fixtures [6-8].

Sapphire substrates, which most commonly the (0001) orientation but also on the a- and r- planes, are used for the fabrication of III-nitride-based LEDs due to its wide availability, hexagonal symmetry, low cost and its ease handling and pre-growth cleaning [5-7]. The sapphire is also suitable at high temperatures (~1000 °C) required for high surface quality GaN epitaxial growth together with thermal stability [6]. The sapphire substrates, however, have several problems, such as the nonconductivity, high series resistance and low thermal conductivity [1, 2, 7-10]. Therefore, GaN-based LEDs on sapphire substrate requires two electrodes on the same side (lateral-electrode), resulting in a large chip, complicated contact and packaging schemes and difficulty of design for electrode pattern [1, 2].

In order to solve such disadvantages, a method which fabricated two electrodes on the other side (top-down) has been adopt by using GaN substrate, lift-off the grown epilayer from the insulated substrate (vertical-electrode). This vertical LEDs on the conductive substrate have the advantages of a large emission area on the chip as a result of the use of transparent electrodes, low series resistance as a result of having the shortest current path, high thermal conductivity as a result of the direct bonding to a heat sink, and lower operation voltages than those of the lateral LEDs [8].

In this work, the vertical AlGaN-based LEDs on thick GaN epilayer were fabricated by hydride vapor phase epitaxy (HVPE) and their optical and electrical characteristics were evaluated.

Experiments

The HVPE method is commonly used for fabricating the template substrate because its growth rate is relatively faster than other growth techniques. On the other hand, this method is rarely used for fabricating the double hetero (DH) structure due to the same reason. However, the use of the HVPE method with multi-sliding boat system has some advantages on fabricating the DH structure, such as easy growth of multi-layer like LEDs, relatively simple facilities especially and a thick AlGaN layer.

In this work, the AlGaN-based vertical LEDs were performed with an atmospheric pressure using the

*Corresponding author:
Tel : +82-51-410-4781
Fax: +82-51-404-3986
E-mail: ahnhs@hhu.ac.kr

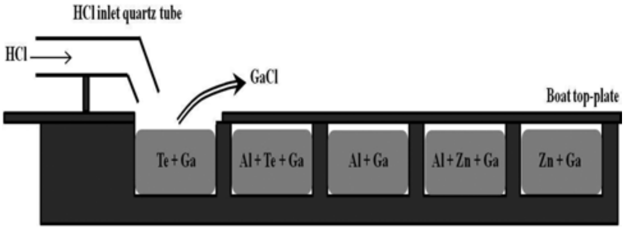

Fig. 1. The multi-sliding boat system in the mixed-source HVPE method.

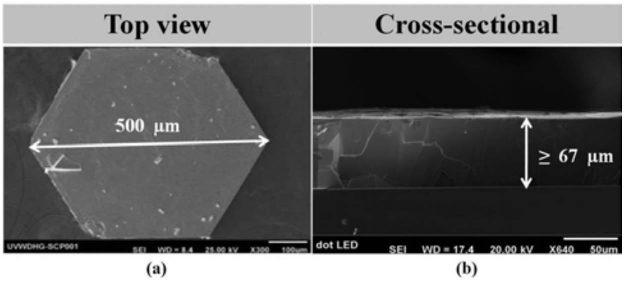

Fig. 2. Top view and Cross-sectional SEM images of the AlGaN-based vertical LEDs.

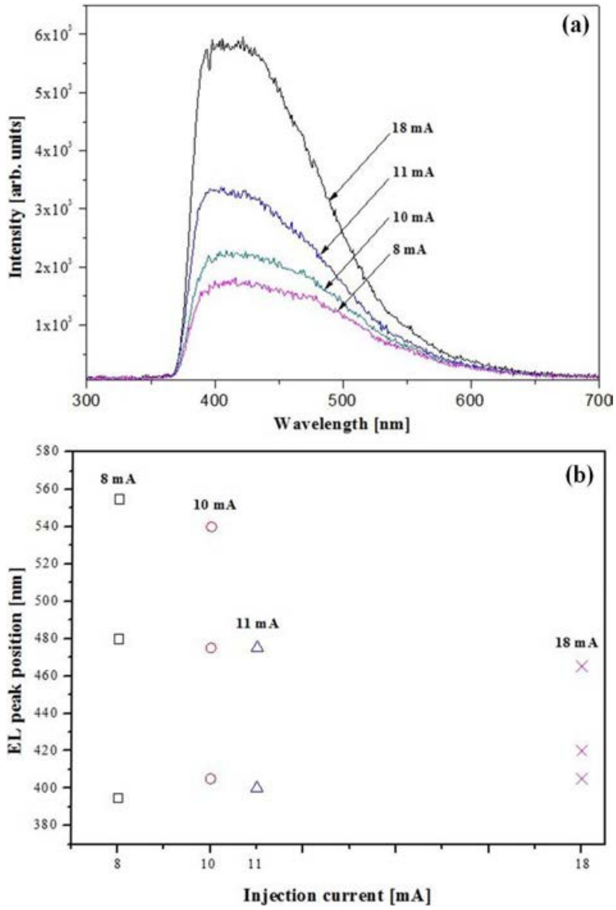

Fig. 3. (a) Room-temperature electroluminescence (EL) spectra and (b) EL main peak position of the AlGaN-based vertical LEDs at different injection current.

mixed-source HVPE method. It is alternative growth method against conventional HVPE growth. Fig. 1 shows the multi-sliding boat system in the mixed-source HVPE method. Multi-sliding boat is separated by five wells which was put in (Te + Ga) for n-type buffer layer, (Al + Te + Ga) for n-type cladding layer, (Al + Ga) for active layer, (Al + Zn + Ga) for p-type cladding layer and (Zn + Ga) for p-type cap layer, respectively. When the LED structure was grown, the top plate on boat was pushed by HCl tube and then moved to position over the melt. Therefore, only one well was able to be exposed and the chemical reaction between NH_3 and an aluminum-gallium chloride were formed by HCl that was flowed over metallic Ga mixed with dopant. The growth was proceeded at atmospheric pressure in the source zone temperature and growth zone temperature at 900 and 1100 °C, respectively. The gas flow rate of HCl and NH_3 was kept at 10 sccm and 800 sccm, respectively. The transparent metal electrode of Ni/Au (35/35 Å) and p-type electrode of Cr/Ni/Au (150/150/500 Å) was deposited gradually using an E-beam evaporator. Finally, n-type electrode of Ti/Al (500/500 Å) was deposited. A scanning electron microscope (SEM), electroluminescence (EL) and I-V properties were used for the characterization at room temperature.

Results and discussions

Figure 2 shows top view and cross-sectional SEM images of the AlGaN-based vertical LEDs with thick GaN with HVPE method with multi-sliding boat system. It is seen that the morphology is hexagonal symmetry, because the LEDs chip is consisted of AlGaN, and diameter of the LEDs chip was approximately 500 μm. From the cross-sectional image which is observed before the separation from the sapphire substrate, the total growth thicknesse of the center and edge is measured to be above 67 μm with flat surface. The AlGaN-based DH structure was consisted of (1-101) facets of six directions and the top is (0001). The balance between adsorption and desorption of the precursors on (0001) leaded to the flat surface as shown in Fig. 2(b).

The room-temperature EL spectra of the AlGaN-based vertical LEDs operated at a function of injection currents is shown in Fig. 3(a). The EL measurement was carried out on a bare LED wafer using different DC injection current. A broad peak of superiority at 405 nm was observed at the injection current of 8 and 10 mA. When the injection current increased, the intensity of near the 405 nm peaks rapidly increased. Also, the widths of the peak markedly decreased and the peaks slight shift to a longer wavelength especially at injection currents of larger than 11 mA. Fig. 3(b) shows the EL peak positions of the different injection current AlGaN-based vertical LEDs. When the injection current increased, the widths of peak decreased and magnified peak of near 405 nm. This phenomenon which is the decreased widths of the peak represent that the band-edge emission from the AlGaN

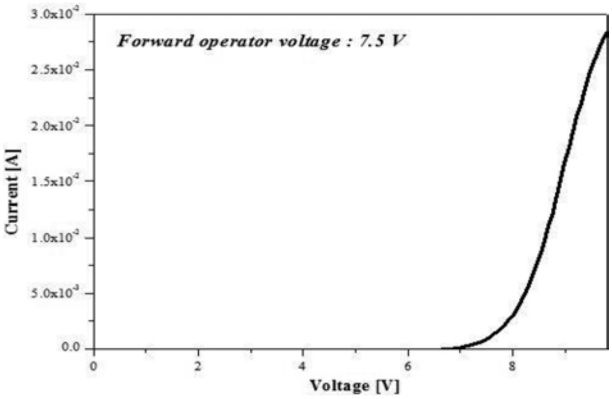

Fig. 4. Current-Voltage (I-V) characteristic of the AlGaN-based LEDs.

active layer becomes dominative at function of increasing injection currents [11, 12]. This result indicates that these slight shifted peaks were due to the thermal shift caused by the joule heating of the higher resistivity of the p-/ n- electrodes, and the AlGaN layers with Al composition [11]. It can be demonstrated from these results that the growth of AlGaN epi-layer and nearly blue-LED are successfully grown by the mixed source HVPE method with multi sliding boat system.

Figure 4 shows the current-voltage characteristic of AlGaN-based vertical LEDs. The curve of I-V exhibited the typical asymmetric, non-linear behavior. Forward operator voltage (V_F) was estimated to be approximately 7.5 V. The value of the differential resistance is estimated to be about 76 Ω, indicating a high resistance of p- and n-type AlGaN layers with Al composition [13]. Considering the fact that the sample used for the measurements was not vacuum-metallized with Ohmic contact, this result reprects fairly good electrical characteristics comparing to conventional AlGaN-LEDs (lateral-electrodes). The vertical LEDs have better current spreading effect than lateral-electrodes LEDs [8, 14]. Thus, if the quality Ohmic contact is achieved, the excellent electrical characteristics could be expected.

Conclusions

The AlGaN-based vertical LEDs on thick GaN epilayer were fabricated using HVPE method. The morphology of these LEDs were hexagonal symmetry. The diameter and growth thickness were 500 μm, above 67 μm, respectively. A broaden strong peak and the high intensity peaks at 405 nm in higher forward current were observed in the different injection currents. These results respected the thermal shift and band-edge emission of active layer with increasing injection current. The forward operating voltage of AlGaN-based vertical LEDs was about 7.5 V and differential resistance was 76 Ω. Such a high resistance might be affected Al composition AlGaN structure such as p- and n- type AlGaN layers. Even though the HVPE vertical LEDs needs to be more improved in optical and electrical properties, the vertical LEDs with thick GaN epilayer can be used for fabricating the high brightness LEDs with less complication in design of device structure.

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