Improvement of the blue LED using patterned sapphire substrates with low threading dislocation densities

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1. Introduction

III-V nitride compound semiconductors have been widely used in optoelectronic and high temperature electronic devices, because of their wide band gap, chemical stability and high temperature stability [1, 2]. At present GaN-based device technologies include light emitting diodes (LEDs), laser diodes (LDs), and UV detectors on the photonic side and microwave power and ultrahigh power switches on the electronic side [3]. Even though blue/green light-emitting diodes (LEDs) are commercially available, it is still difficult to fabricate the high efficiency GaN LEDs. The main reason for this difficulty is due to the great number of threading dislocation densities occur when group III nitride alloys are grown on lattice mismatched c-plane sapphire substrate [4, 5]. The previous studies on InGaN/GaN LED devices clearly show that it is most desirable to grow InGaN/GaN heterostructures that have low dislocation densities and large surface areas in order to increase the emission efficiency. Patterning the sapphire substrate could play an important role in overcoming the existing dislocations and difficulties encountered in light extraction. In this paper, we demonstrated the high output power InGaN/GaN LED structure prepared through MOCVD growth on c-plane sapphire substrate patterned with lens shape. The structural analysis of these materials is observed using scanning electron microscopy (SEM) and double crystal X-ray diffraction DCXRD. The characteristics optical were measured using а photoluminescence system. The electroluminescence spectra and luminance intensity of the fabricated LED are also calculated.

2. Experimental

GaN epilayers were deposited on a patterned sapphire $(0 \ 0 \ 0 \ 1)$ substrate using MOCVD with a horizontal quartz reactor. Before growing GaN epilayers, the sapphire substrate was patterned by dry etching method to form lens-shaped pattern array as shown in Fig.1. We observed that the lens-shaped pattern is uniformly arranged in equal size. The sapphire substrate was etched by means of inductively coupled

plasma (ICP). The gas flow of Cl_2 and Ar in the ICP etching was 30 and 10 sccm, respectively.

The LED structures were grown on sapphire substrates using MOCVD. In the growth process trimethylgallium (TMGa), trimethylindium (TMIn), and ammonia (NH₃) were used as gallium, indium, and nitrogen precursors. Biscyclopentadienyl magnesium (Cp₂Mg) and disilane (Si₂H₆) were used as p- and n-type dopant sources, respectively. The blue LED structure comprised of 25 nm thick low temperature GaN nucleation layer, 2 μ m thick undoped GaN layer, a 4.5 μ m thick Si-doped n-GaN layer, an InGaN-GaN multiple quantum wells (MQWs) active region of 450 nm emitting wavelength. Following the InGaN MQWs growth, a 130 nm thick Mg-doped p-GaN was grown at a temperature of 1020°C. A 5 nm/5 nm thick Cr/Au metal layer is used to form the p- and n-type metal contact.

The LEDs were fabricated on the PSS through the same above said process. The surface morphology of the PSS was observed with a field emission scanning electron microscope (FESEM) and atomic force microscopy (AFM). The structural properties of GaN epilayers were investigated by DCXRD. The current-voltage (I-V) and PL measurements of the LEDs were also carried out.

3. Results and Discussion

Figure 1(a) and 1 (b) shows the plane and cross sectional view of scanning electron microscope (SEM) images of dryetched PSS. It shows that the PSS array had a smooth surface with uniformly arranged lens patterns with equal in size.

Figure 2(a) and 2 (b) shows SEM images of the GaN surface layer as a function of key growth steps on PSS for the growth time of 40 min and 80 min, respectively. It can be observed clearly that the lateral growth of the GaN layer initially grown on the $(0\ 0\ 0\ 1)$ c-plane on the patterned region was increased by increasing the growth time. This results in smooth surface over the patterned region.

Figure 3 shows the results of PL spectra of the LED fabricated on PSS measured at 10K and 300K, respectively. It is noticed from the figure that the emission peak positions are 355 nm and 362 nm for the Si-doped GaN on PSS at 10K and 300K. The PL measurements performed at 10K and 300K was

used to calculate the internal quantum efficiency (IQE) of the samples. The IQE of LED samples can be estimated from the integrated PL intensity ratio between 10K and 300K. At room temperature, the IQE values were approximately 49.08 % and 30.4% for LEDs on UPSS and PSS, respectively. These higher IQE value can be attributed to the reduction of non-radiative recombination centers by the improved material quality using PSS.

Figure 4 shows the room temperature EL peak intensity variation of the PSS-LED for various injected current. The comparison of room- temperature EL spectra at a forward current of 20 mA, from an LED on patterned sapphire substrate and that on an unpatterened sapphire substrate shows a minor wavelength blue shift of \sim 3nm. The EL intensity of the PSS-LED is indicated from a comparison with a conventional LED as higher by about 52 %. It is well known that the multi-quantum well emission efficiency is related to the leakage current through dislocations. Hence, such a significant enhancement in EL intensity is attributed to the reduction of threading dislocations that induce nonradiative recombination centers using a PSS.

4. Conclusions

In conclusion, this paper presented the fabrication of blue LED with lens-shaped pattern prepared by ICP dry etching method. The patterned sapphire substrate LED structure could improve the output power due to the enhancement of the extraction efficiency and internal quantum efficiency by decreasing the threading dislocation density. It was also found that the EL intensity of PSS/LED was 52% larger than that of UPSS/LED (Results not shown here).

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Fig. 1 The surface structure of blue LED chip fabricated on PSS and UPSS (a)&(c) plane view of PSS and UPSS, (b)&(d) cross sectional view of PSS & UPSS.



Fig. 2 (a) and (b) represent the scanning electron microscope images of GaN surface on patterned sapphire substrate at a growth time of 40min and 80 min



Fig. 3 The photoluminescence spectra of LED on PSS at 10 K and 300 K $\,$



Fig. 4 The room temperature EL peak intensity variation of the PSS-LED for various current

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