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Light Output Enhancement of Ultraviolet Light Emitting Diodes with Pattern HfO_2/SiO_2 Distributed Bragg Reflector

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I. Introduction

The GaN-based light emitting diode (LED) has attracted great interest due to its broad applications such as full-color displays, traffic signals, cell phone backlight, exterior automotive lighting, and printers, etc [1,2]. It has many advantages, such as energy-saving, long lifetime, environment friendly and stable. So it has a high potential to become a next generation light source. However, the external quantum efficiency (EQE) of GaN-based LEDs still requires improvement.

As for the enhancement of IQE, the IQE could be increased by improving the crystal quality of GaN. For GaN quality improvement, the epitaxial lateral overgrowth (ELOG) technique is one of the most effective approaches to decrease the density of threading dislocations (TDs) in GaN films grown on sapphire by metalorganic chemical vapor deposition (MOCVD) [3-4]. In this ELOG technique, a dielectric layer was pattern by photo-lithography as the mask and it was designed to stripes or circular or shaped holes. The layer grows vertically in the openings but also laterally over the mask, which results in a much lower dislocation density than in the openings.

In this work, we deposited a HfO_2/SiO_2 distributed Bragg reflector (DBR) on the u-GaN layer by using an e-gun evaporation system with optical in-situ monitor and then pattern the DBR structure for subsequent epitaxy regrowth. We utilize the patterned DBR structure as the epitaxial lateral overgrowth (ELOG) masks and the photon reflector to enhance the light output power. The detail of device fabrication and characteristics will be discussed later. The ray-tracing simulation was discussed to investigate the fundamental of light output enhancement.

II. Experiment

The ultraviolet LED (UVLED) samples were grown on c-plane sapphire substrates by a low pressure MOCVD system. The fabrication flowchart of UVLEDs with pattern DBR was shown in Fig. 1. First, a 30-nm-thick low-temperature GaN nucleation layer was grown on sapphire substrate, followed by a 1-μm-thick un-doped GaN layer. Then, the 9.5 pairs HfO_2/SiO_2 multiple dielectric layers were deposited on the u-GaN. The thickness of the HfO_2 layer and the SiO_2 layer was 53 nm and 69 nm, and the refractive index at 390 nm wavelength was 1.98 and 1.46, respectively. The multiple dielectric layers were patterned by a conventional lithography and lift-off technique to form circle-shape masks with the diameter of 5μm. After that, a 3-μm-thick Si-doped n-GaN layer was regrown, followed by the deposition of a InGaN/GaN MQW active region, On top of the active region is a 50-nm-thick Mg-doped p-AlGaN electron blocking layer and a 0.2-μm-thick Mg-doped p-GaN cladding layer. Subsequently, 350×350 μm2 diode mesas are defined by chlorine-based reactive ion etching. An ITO film (250 nm) was deposited on p-GaN layer as the transparent conductive layer. The Cr/Pt/Au (50 nm/50 nm/ 2500 nm) metals were deposited for the p- and n-contact pads. The UVLED without pattern DBR was fabricated for comparison.

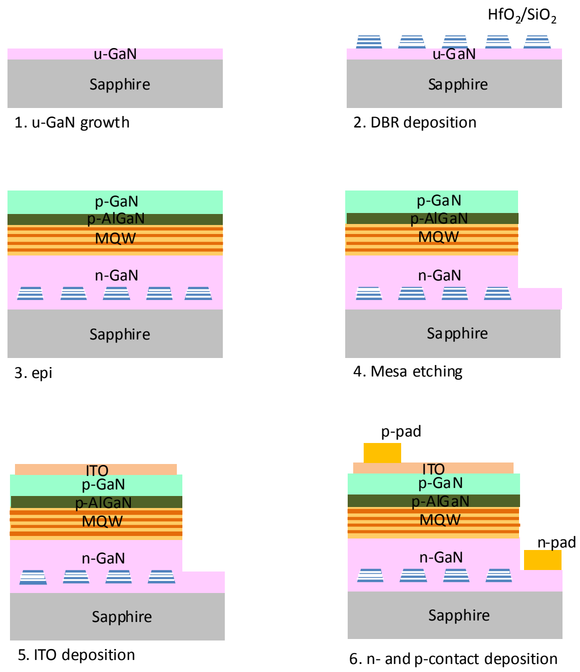

Fig. 1. Fabrication flowchart of UVLEDs with pattern DBR.

Fig. 2(a) shows the reflectivity spectrum of the 9.5-pair HfO_2/SiO_2 DBR, indicating that the maximum reflectivity was 98.4% at the wavelength of 390 nm. The reflectivity spectrum of the DBR after MOCVD 1000 ℃ backing was shown in Fig. 2(b). It reveals the maximum reflectivity was decreased to 95.4% and the center wavelength was shifted to 356 nm. The reflectivity was 88.9% at the emission wavelength 395 nm. Fig. 3(a) shows a scanning electron microscope (SEM) micrograph of the 9.5-pair HfO_2/SiO_2 DBR. Fig. 3(b) shows an enlarge view of Fig. 3(a).

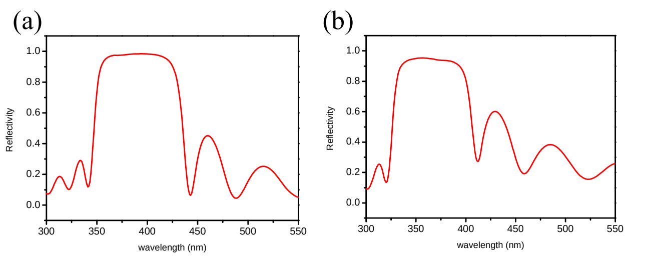

Fig. 2. Reflectivity spectrum of (a) HfO2 and SiO2 9.5 pairs DBR before MOCVD baking and (b) the DBR after MOCVD 1000 ℃ backing.

(a) (b)

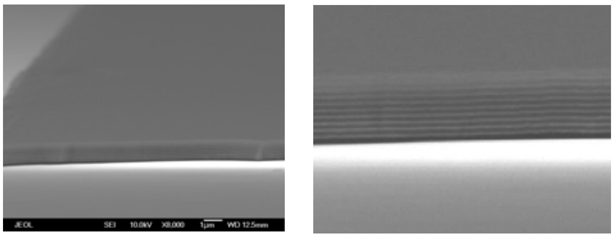

Fig. 3 (a) Scanning electron microscope (SEM) micrograph of the 9.5-pair HfO_2/SiO_2 DBR. (b) an enlarge view of (a).

III. Results and discussions

Fig. 4(a) and 4(b) show the SEM images of the conventional UVLED surface and UVLEDs surface with pattern DBR after epitaxial growth by MOCVD. The surface pits densities of the conventional UVLEDs and UVLEDs with pattern DBR were 2.5×10^6 and 1.6×10^6 cm^{-2}, respectively. Surface pits are believed to be originated from the threading dislocation terminations with the surface. Therefore, the less surface pits show the possibility of dislocation reduction. It is found that the surface pits density of UVLEDs with pattern DBR could be effectively reduced from 2.5×10^6 to 1.6×10^6 cm^{-2}; in the other words, 36% surface pits density reduction of UVLEDs with pattern DBR was demonstrated as compared with the conventional UVLEDs.

(a) (b)

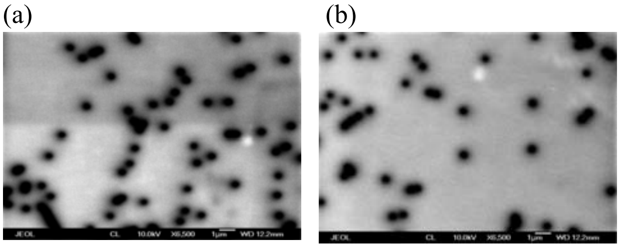

Fig. 4. SEM images of (a) the conventional UVLEDs surface and (b) UVLEDs with pattern surface after epitaxial growth by MOCVD.

Fig. 5 exhibits the light output power and operation Voltage as a function of forward current (L-I-V curve) for both the conventional UVLEDs and UVLEDs with pattern DBR before package. At a driving current of 20 mA, the output powers for the conventional UVLEDs and the UVLEDs with pattern DBR were 5.06 and 8.86 mW, respectively. Compared with the conventional LED, the illuminant intensity of UVLED with pattern DBR was increased by a factor of 1.75 at the emission wavelength 395 nm. In other words, we can achieve 75% increase of output power for UVLEDs with pattern DBR by using the DBR deposition and regrowth technique. At a driving current of 20 mA, the working voltages for the conventional UVLEDs, and UVLEDs with pattern DBR were 3.52 V, and 3.45 V, respectively. The lower voltage of UVLEDs with pattern DBR could be attributed to the quality improvement of p-type GaN as a result of the reduction of TD density.

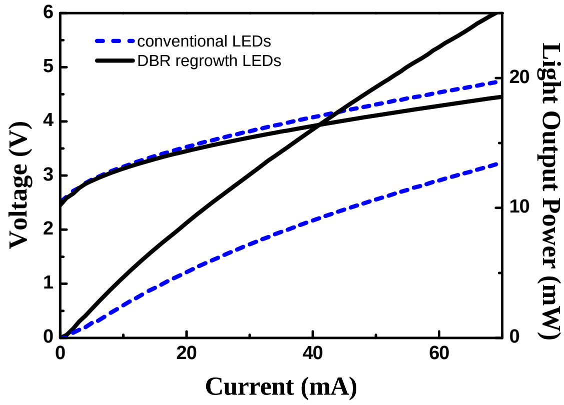

Fig. 5. Measured L-I-V characteristics of the fabricated UVLEDs

The simulation results of rays tracing indicate that the enhancement of light extraction efficiency of UVLEDs with pattern DBR was 61% as compared with the conventional UVLEDs.

VI. Conclusion

In summary, the UVLEDs with pattern DBR structure were fabricated via an e-gun evaporation system with optical in-situ monitor and ELOG technique. The luminous intensity of this novel structure can be enhanced approximately 75% than the conventional UVLED structure. The improved light extraction efficiency can be further supported by the simulation results and the increase of light output power of UVLEDs with pattern DBR can be verified by ray-tracing situations. As a result, the UVLEDs with pattern DBR can not only reduce the TD density in GaN but also increase the amount of photons escaping from the GaN to the air.

Acknowledgment

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