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High light output intensity of titanium dioxide textured light-emitting diodes

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ABSTRACT

Higher light output intensity and wider polar radiation pattern of InGaN/GaN multiple quantum well (MQW) light-emitting diodes (LEDs) with a different nanoscale titanium dioxide (TiO_2) textured densities film have been observed. The light output power values and external quantum efficiency of the conventional LEDs at an injection current of 20 mA are 6.34 mW and 11.7%, respectively. The light output power values and external quantum efficiency of the nanoscaled TiO_2 textured LEDs at an injection current of 20 mA are 7.55 mW and 14%, respectively. The light output intensity and power values of the nanoscaled TiO_2 textured LEDs is approximately 65% and 20% higher than that of the conventional LEDs, respectively.

1. Introduction

Applications for the wide band gap nitrides includes emitters in the light-emitting diodes (LEDs), laser diodes (LDs), photoconductive detectors and photovoltaic detectors in the blue-ultraviolet (UV) range of the light spectrum. Currently, GaN-based blue and green LEDs could be used in full color displays and traffic light lamps. The high brightness LEDs are necessary in these applications. One important issue of LED is how to increase external quantum efficiency. Textured surface has been demonstrated that it is an effective technique to enhance external quantum efficiency and to reduce total internal reflection between the semiconductor and air [1]. Light escaped from the active layer of LEDs into air much more easily with a textured surface will be anticipated. Thus, the light output power values and external quantum efficiency of such LEDs with a textured surface is higher than that of conventional LEDs. It was studied that a high light output power values in LEDs was achieved by patterned sapphire substrate (PSS) technique [2–7] and roughness surface [8,9]. On the other hand, surface roughness was defined by processes such as indium tin oxide (ITO) with a textured surface [10,11], etching thin film [12,13] and sidewall roughness [14]. However, such methods can also induce the output power values and external quantum efficiency although surface leakage current may be generated also by those processes.

In this study, we have obtained higher light output intensity and external quantum efficiency of InGaN/GaN multiple quantum well (MQW) LEDs using a different titanium dioxide (TiO_2) textured films on the top of *p*-GaN surface. The atomic force microscope (AFM) images, output power and current–voltage (*I–V*) characteristics and of InGaN/GaN MQW LEDs with a different TiO_2 textured densities film will be discussed.

2. Experimental procedure

The InGaN/GaN MQW LEDs were grown by metal organic chemical vapor deposition (MOCVD). The LEDs structure consists of a low-temperature-GaN nucleation layer, a 2-μm-thick undoped GaN bulk layer, a 2-μm-thick Si-doped n^+-GaN layer, five periods of InGaN–GaN multiple quantum wells, and 0.2-μm-thick Mg-doped p^+-GaN layer. Device patterns and mesa layer were defined by standard photolithography and inductively coupled plasma reactive ion etching (ICP-RIE) techniques. The device chip size was 1.5×10^{-3} cm^2. Mixed TiO_2 solution (0.5 M) containing of TiO_2 powder (1 g) and isopropanol (25 ml) was prepared. The nanoscaled TiO_2 film with different densities was controlled by an amount of mixed TiO_2 solution and coated times. The nanoscaled TiO_2 textured densities which were 1.7×10^8 cm^{-2} (as "Sample A"), 2.6×10^8 cm^{-2} (as "Sample B"), 3.8×10^8 cm^{-2} (as "Sample C") and 4.4×10^8 cm^{-2} (as "Sample D") were spun and coated on a topp-GaN surface, and without a TiO_2 textured film (as "conventional LED"). The ITO film was evaporated on the *p*-GaN surface

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and was subsequently alloyed at 600 °C in N_2 ambient. In this process, the nanoscaled TiO_2 textured film is embedded between GaN and ITO film. Cr–Pt–Au contacts were evaporated on the *p*- and *n*-GaN layer as bonding pad and *n*-type ohmic contacts. The InGaN/GaN MQW LEDs were characterized by *I–V* measurements performed with a Hewlett-Packard 4155 semiconductor analyzer. The light output power characteristics of bare chip LEDs were analyzed with an integrated sphere detector.

3. Results and discussion

The schematic drawings of the conventional and nanoscaled TiO_2 textured InGaN/GaN MQW LEDs structures are shown in Fig. 1a and b, respectively. AFM images of the nanoscaled TiO_2 film with different densities film are shown in Fig. 2a–d. The nanoscaled TiO_2 textured size is about 500 nm. The reverse leakage current at an applied bias of −1 V and operation bias voltage at an injection current of 20 mA are subject to nanoscaled TiO_2 textured densities as shown in Fig. 3. A reduction of reverse leakage current and an increase of operation bias voltage with different nanoscaled TiO_2 textured densities are observed owing to a change in injection area, i.e. the leakage current density remains constant.

Fig. 4 shows the light output intensity of the conventional LEDs and the nanoscaled TiO_2 textured LEDs with different densities. The light output intensity of the conventional LEDs, Sample A, Sample B, Sample C and Sample D by driven at an injection current of 20 mA are approximately 11.9, 14.6, 16, 19.6 and 20 mcd,

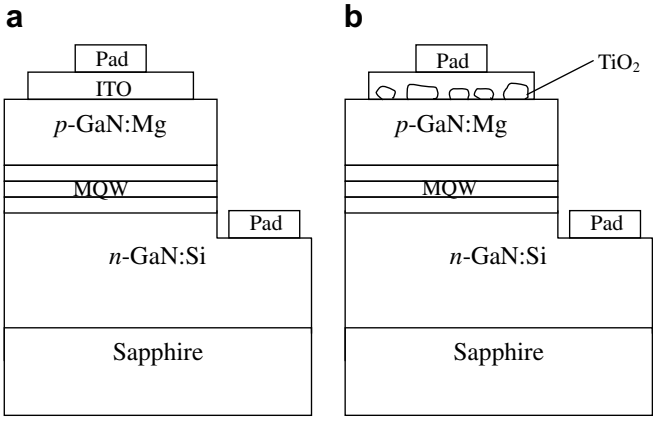

Fig. 1. Structure of (a) the conventional and (b) nanoscaled TiO_2 textured InGaN/GaN MQW LEDs.

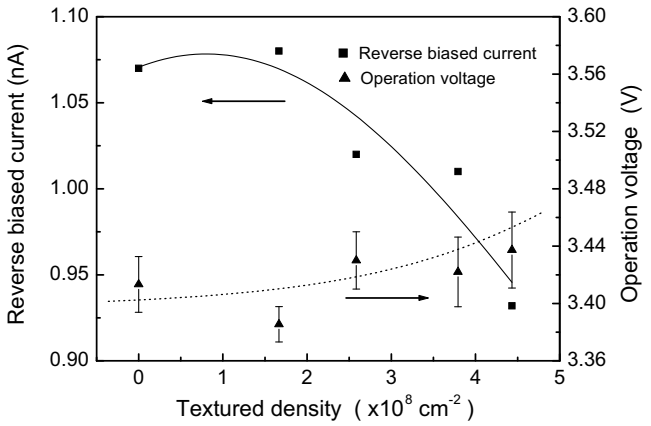

Fig. 3. The reverse biased current (at voltage 1 V) and operation voltage (at injection current 20 mA) with different nanoscaled TiO_2 textured densities.

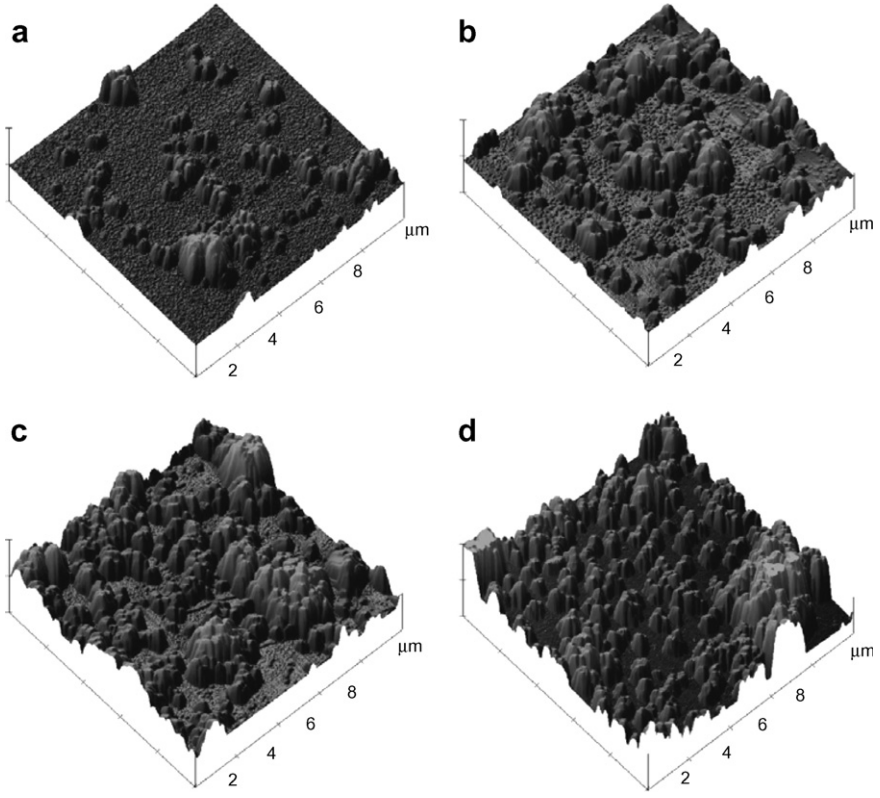

Fig. 2. AFM images of nanoscaled TiO_2 textured InGaN/GaN MQW LEDs with different densities: (a) sample A, (b) sample B, (c) sample C, and (d) sample D.

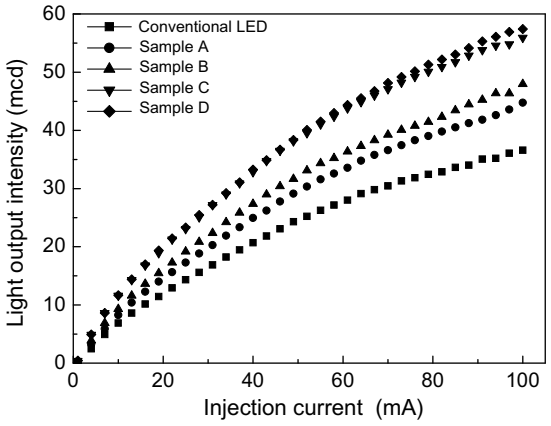

Fig. 4. Light output intensity of the conventional and different nanoscaled TiO_2 textured densities LEDs.

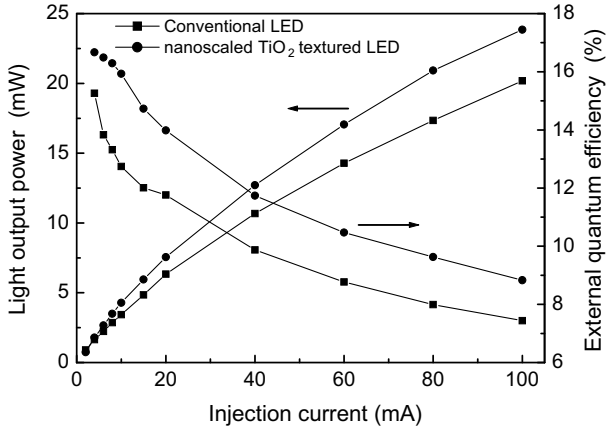

Fig. 5. Light output power values and external quantum efficiency of the conventional and different nanoscaled TiO_2 textured densities LEDs.

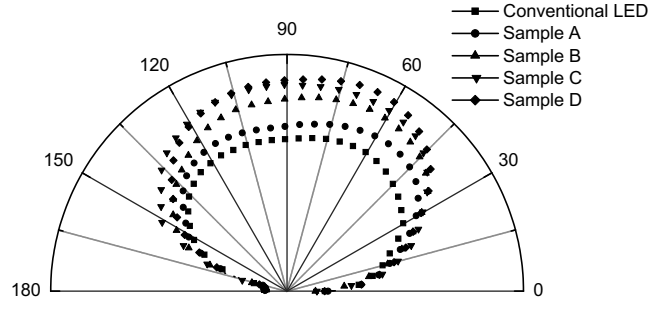

Fig. 6. Polar radiation pattern of the conventional and different nanoscaled TiO_2 textured densities LEDs.

respectively. The light output intensity of the nanoscaled TiO_2 textured LEDs (Sample D) is about 65% higher than that of the conventional LEDs. This result indicates the higher light output intensity is attributed to a reduction of the total internal reflection effect and an increase in the level of surface light scattering induced by forming an appropriate TiO_2 textured densities at a top *p*-GaN surface. The light output power characteristics of bare chip LEDs were measured by an integrated sphere detector and are shown in Fig. 5. The light output power values and external quantum efficiency of the conventional LEDs at an injection current of 20 mA are approximately 6.34 mW and 11.7%, respectively. The light output power values and external quantum efficiency of the nanoscaled TiO_2 textured LEDs (Sample D) at an injection current of 20 mA are approximately 7.55 mW and 14%, respectively. The external quantum efficiency of the nanoscaled TiO_2 textured LEDs (Sample D) is approximately 20% higher than that of the conventional LEDs.

Polar radiation pattern of the conventional LEDs and nanoscaled TiO_2 textured LEDs with different densities are shown in Fig. 6. The polar radiation pattern of the nanoscaled TiO_2 textured LEDs is wider than that of the conventional LEDs. In general, the light output power values and external quantum efficiency of LEDs are limited by the total internal reflection between the semiconductor and air interface for a flat surface. Wider polar radiation pattern in LEDs may implicate a reduction of the total internal reflection and thus increase the surface light extraction efficiency by the forming of a appropriate TiO_2 textured film at a top *p*-GaN surface. The light extraction from the LED surface into air is much more easily with this textured surface and thus, higher light output power behavior can be characterized.

4. Conclusion

Higher light output intensity and wider polar radiation pattern of InGaN/GaN MQW LEDs with different nanoscaled TiO_2 textured density films have been fabricated. The light output power values of the conventional and nanoscaled TiO_2 textured LEDs at an injection current of 20 mA are 6.34 and 7.55 mW, respectively. The external quantum efficiency of the conventional and nanoscaled TiO_2 textured LEDs at an injection current of 20 mA are 11.7 mW and 14%, respectively. The light output intensity and power values of nanoscaled TiO_2 textured LEDs are approximately 65% and 20% higher than that of the conventional LEDs, respectively.

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