AlGaInP LEDs with surface anti-reflecting structure*

Chen Yixin(陈依新)†, Shen Guangdi(沈光地), Li Jianjun(李建军), Han Jinru(韩金茹), and Xu Chen(徐晨)

(Beijing Optoelectronic Technology Laboratory, Beijing University of Technology, Beijing 100124, China)

Abstract: A kind of AlGaInP light emitting diode (LED) with surface anti-reflecting structure has been introduced to solve the problems of low light efficiency and restricted luminous intensity. The new structure can be demonstrated theoretically and experimentally, and LEDs with the new structure have higher on-axis luminous intensity and larger saturation current than conventional LEDs and LEDs with ITO film only, which is caused by higher external quantum efficiency and also higher internal quantum efficiency. The new LEDs are especially suitable for working at large injected currents.

Key words: quantum efficiency; AlGaInP LEDs; anti-reflecting structure
DOI: 10.1088/1674-4926/30/8/084009 **PACC:** 7280E; 7360F; 7865K

1. Introduction

High brightness AlGaInP light emitting diodes (LEDs) are used in many optical devices, such as outdoor displays, traffic signals, automobile indicators, and display backlights[1,2]. The main aim of LED study is to obtain high brightness at the same injected current; namely, to improve the LEDs' internal and external efficiency. LEDs with AlGaInP active region material have an internal efficiency as high as 95%[3], but the external quantum efficiency is very low, generally only 5% of conventional LEDs[4]. The reasons for this are as follows: (1) Light with a wavelength of 620–630 nm emitted to the GaAs substrate is absorbed strongly. One solution for this is to grow a DBR (distributed Bragg reflector) layer between the active region and substrate; however, DBRs only have high reflectivity to near vertical light[5]. Another solution is to use the flip-chip structure, in which the GaAs substrate is substituted by a mirror or transparent substrate, but the process is very complex[6]. (2) The refractive index of semiconductors is very different from that of air; light emitted from the semiconductor to air would be restricted by the complete reflecting effect–as for GaP, only light with an incidence angle smaller than 17° would escape; other light is reflected or absorbed. To solve this problem, a film with a refractive index between air and a semiconductor has previously been provided on the LED surface, to enlarge the critical reflecting angle and ensure that much more light is emitted[7]. In this paper, we provide a new surface anti-reflecting structure to solve the second problem effectively.

2. Experiments

2.1. Design of surface anti-reflecting structure

First, a surface figure was fabricated on an epitaxial wafer, and an etched surface could be obtained by photolithography technology. The figure is a trapezium 9 μm on the top and 3 μm below, and the height is 3 μm, so the angle is 45 °. In Fig. 1(a) of an LED with a planar surface, light at the critical angle can be emitted, but light not at the critical angle could be completely reflected at the semiconductor–air interface, according to the Snell law, and could be absorbed by the active region or substrate and finally changed into heat. In Fig. 1(b) of an LED with an etched surface, the light emitting route has been changed, i.e. light not at the critical angle may also be emitted.

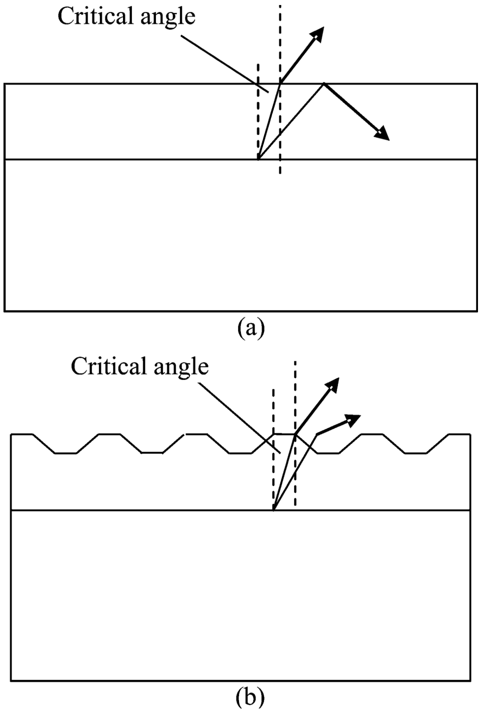

Fig. 1. Light transport route of (a) LEDs with planar surfaces and (b) LEDs with etched surfaces.

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* Project supported by the National High Technology Research and Development Program of China (No. 2006AA03A121), the State Key Development Program for Basic Research of China (No. 2006CB604900), and the Fund of Beijing University of Technology (No. ykj-2007-1073).

† Corresponding author. Email: chenyixin_410@emails.bjut.edu.cn

Received 27 September 2008, revised manuscript received 15 March 2009

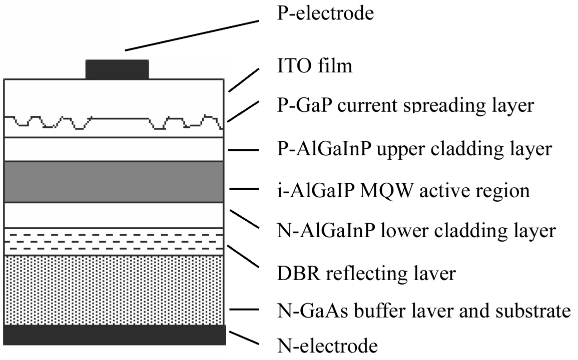

Fig. 2. Cross section view of an AlGaInP red LED.

In LEDs, the refractive index of the semiconductor is very different from air, and according to law, a large portion of the light generated in the active region emitted from the semiconductor to air would be restricted[8, 9].

In order to solve this problem, a conductive and anti-reflecting ITO film is introduced; its refractive index is between that of semiconductor and air, so the critical angle is larger. The carrier concentration of ITO is 10^{21}–10^{22} cm^{-3}, and the transmission index is larger than 90%; the film is useful to improve the external quantum efficiency of AlGaInP LEDs.

2.2. Fabrication of devices

Figure 2 shows a cross section view of an AlGaInP red LED, which was grown by MOCVD. The epitaxial structure is as follows: the substrate is GaAs with a deflection of (100) to (110) 15°, above this is the GaAs buffer layer to reduce mismatch during the growth; the active region is a multi-quantum well (MQW) of $(\text{Al}_x\text{Ga}_{1-x})_{0.5}\text{In}_{0.5}\text{P}$ without intentional doping. The upper and lower cladding layers are $(\text{Al}_{0.7}\text{Ga}_{0.3})\text{In}_{0.5}\text{P}$ with Mg and Si doping respectively; between the lower cladding layer and the buffer layer there is a DBR layer, in order to reflect the light emitted to the substrate vertically and escape absorption by the GaAs substrate. Above the upper cladding layer a GaP current spreading layer with a thickness of 8 μm and a carrier concentration of about 10^{-19} cm^{-3} is grown.

The processing of the new LEDs with surface anti-reflecting structure is as follows: first, make the epitaxial wafer clean and dry. Second, use photo-lithography technology to form the surface figure; for wet etching this has isotropic characteristics. The size of the photo-lithography mask plate is as shown in Fig. 3; the period is 7 μm, and the space is 3 μm. Third, for wet etching, the surface figure is formed by photo-lithographic glue, and the etching solution is made up of phosphate, muriatic acid and de-ionized water, with a volume proportion of 10 ml : 40 ml : 10 ml. The whole etching process lasts for 9 min. The figure after etching is shown in Figs. 4 and 5. We measured the size of the figure; the period is 3 μm and the depth is 3 μm, which are in accordance with the design.

ITO film is then grown on the etched surface by evaporation. The thickness of 3000 Å is decided by the rule $3\lambda/4n$, where λ = 625 nm is the LED wavelength, and n = 1.7008 is the refractive index of ITO. The square resistance is about 8 $\Omega/\square$ tested using the four-probe method, and the permeation index is 92%, tested by a spectrophotometer. The remaining processing is to form the p-type and n-type electrodes of AuZnAu and AuGeNi respectively; the LED chip size is 300 μm by 300 μm.

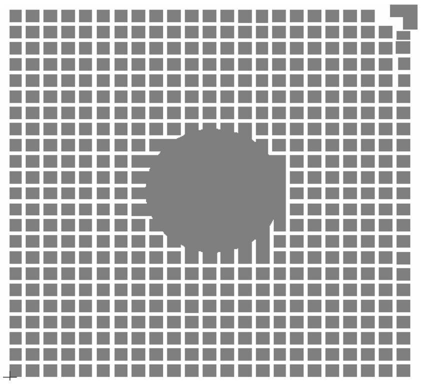

Fig. 3. Schematic of figures in the photo-lithograph plate.

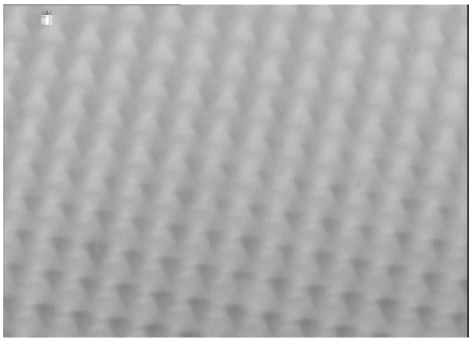

Fig. 4. Top view of surface after etching.

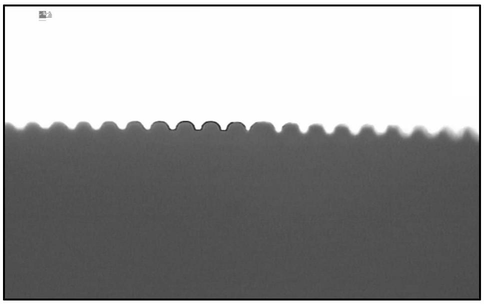

Fig. 5. Side view of surface after etching.

We fabricated conventional LEDs with the same epitaxial wafer but without surface anti-reflecting structure as a reference. The processing for these is: make the epitaxial wafer clean and dry, and then form the p-type and n-type electrodes of AuZnAu and AuGeNi respectively. The chip size of the LED is 300 μm by 300 μm. We also fabricated another LED with ITO thin film as its only difference from conventional LEDs, as a reference.

3. Results and discussion

The test results of the LEDs are shown in Fig. 6 and the on-axis luminous intensities of conventional LEDs, LEDs with ITO film and the new LEDs are 103.5, 122.4 and 145.2 mcd at 20 mA respectively. The new LEDs have the highest brightness. The saturation current of the three LEDs is 105, 115 and 125 mA; the on-axis luminous intensity is 370, 450 and

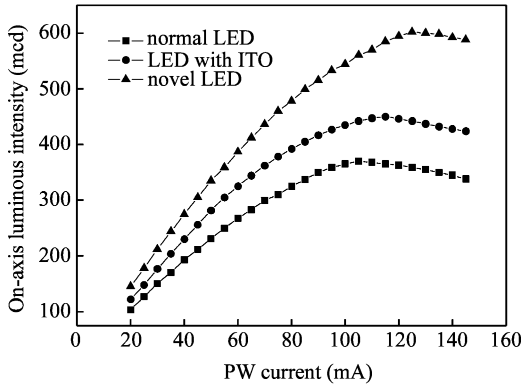

Fig. 6. Relationship between pulse current and on-axis luminous intensity of the three different LEDs.

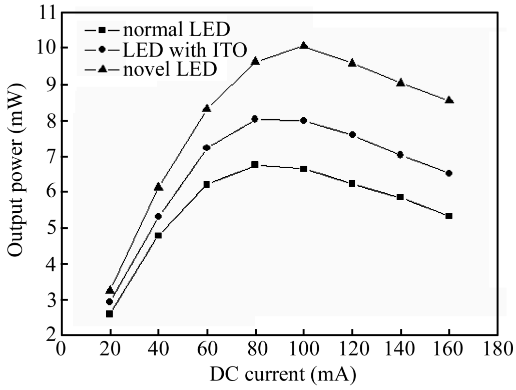

Fig. 7. Relationship between DC current and output power of the three different LEDs.

602 mcd accordingly.

The reason for this is as follows: the three kinds of LEDs can generate a great deal of light at large injected currents, but for conventional LEDs, a large portion of this light is absorbed and changed into heat because of the low external quantum efficiency; the heat is larger, and the internal quantum efficiency and luminous intensity are reduced more rapidly; the all light efficiency is low which makes the saturation current and on-axis luminous intensity very low. For the new LEDs or LEDs with ITO film which have a high external quantum efficiency (in particular, the new LEDs have the highest external quantum efficiency of the three kinds), the absorption and heat are reduced, so much more light generated at large currents could be emitted compared with conventional LEDs, and the saturation current and on-axis luminous intensity are higher. Therefore. the new LEDs are suitable for working at large currents and could show high luminous intensity.

Figure 7 shows the LED's output power changed by DC current. The reason for this is the same as the explanation above. The saturation current of conventional LEDs and the new LEDs is 80 and 100 mA respectively. The difference is 20 mA which is the same as the LEDs working at pulse current, as Figure 6 shows. The difference is induced by the surface texture and ITO film in the new structure; the light efficiency is high and the heat would be reduced in the new LEDs.

4. Conclusion

A kind of AlGaInP LEDs with surface anti-reflecting structure has been introduced to solve the problems of low light efficiency and restricted luminous intensity. The new LEDs have higher on-axis luminous intensity and larger saturation current than conventional LEDs and LEDs with ITO; this is caused by higher external quantum efficiency and also higher internal quantum efficiency. The on-axis luminous intensity and saturation current of the new LEDs is 602 mcd and 125 mA, which are suitable for working at large injected currents.

Acknowledgement

The authors thank Zou Deshu, Liu Ying, Zhang Xiaojia, Ou Yangliu, and Liu Baolin for device fabrication, and Xu Chen, Zhao Yongdong and Deng Jun for technical support.

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