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Improving Light Extraction Efficiency of $(Al_xGa_{1-x})_{0.5}In_{0.5}P$-Based Flip-Chip Light-Emitting Diode with a Geometric Sapphire Shaping Structure

Yea-Chen Lee, Chia-En Lee, Hao-Chung Kuo, Tien-Chang Lu, and Shing-Chung Wang

National Chiao Tung University, Department of Photonics and Institute of Electro-Optical Engineering,
1001 Ta Hsueh RD., Hsinchu, Taiwan 300, R.O.C.
Phone: +886-3-5712121 ext. 56327 E-mail: alenlee.eo94g@nctu.edu.tw

1. Introduction

Recently, high brightness and high efficiency light-emitting diodes (LEDs) have been more extensively applied to many different applications that these purposes are environmental-protections and energy-savings. These widely applications such as automobile components, traffic indicators, full-color displays, interior and exterior signalling applications and solid-state lighting systems, etc. will be achieved in future life [1]. The epitaxy technique on the AlGaInP materials was improved excellently in recently years, and the internal quantum efficiency of the AlGaInP-based LEDs structure that was approached 100% [2], but the light extraction efficiency is less than the GaN-based LEDs. The cause of the result is that large difference value of the refractive index between the GaP window layer (n=3.2) and air (n=1) or epoxy (n=1.3). According to the Snall's equation, the narrower critical angle (θ_c) is merely 18.2˚ so that most of the emission light will suffer from the total internal reflection (TIR) effect. This innate drawback influences the light extraction efficiency especially on the AlGaInP-based materials. Several methods have been implemented to enhance the light extraction efficiency on the AlGaInP-based LEDs structure [3]-[5]. In this study, a novel AlGAInP flip-chip LEDs (FCLEDs) structure was demonstrated, having a geometric sapphire substrate (GSS-FCLEDs) via a glue bonding process. The GSS-FCLEDs which has an oblique shaping sidewall on its sapphire substrate, and the epilayer surface which has a nano-scale rough texture. The benefits of these processing purposes are in order that the photons generated within the LED structure can escape cone after multiple TIR between the air and semiconductor interface; moreover, the light extraction efficiency can effective to improve especially on AlGaInP-based LEDs.

2. Experiments

In this study, the AlGaInP-based LEDs with the dominant wavelength at 590 nm were grown on 2-inch GaAs substrates by a low pressure metal–organic chemical vapor deposition (MOCVD) system. In chip processes, a c-plane sapphire substrate was lapped and polished from 450 µm to 250 µm thickness. After that, a 2.5 µm-thick SiO_2 film as a function of the wet-etching hard mask deposited onto the backside of sapphire substrate via plasma enhanced chemical vapor deposition (PECVD) and defined chip size pattern (1000 µm × 1000 µm) via a standard photolithography and following wet etching process. This sapphire substrate which backside has patterning was immersed into a high temperature (350ºC) mixture solution (H_2SO_4/H_3PO_4) for 65 min. The etching rate of the sapphire substrate is closely achieved 1.5 µm/ min in this investigation. The epi-wafer having a nano-scale rough texture was produced on epi-wafer surface of GaP window layer. Nono-scale rough texture surface were formed by a Ni metal ultra-thin film (10nm). After the epi-wafer was treated in the rapid thermal annealing (RTA) under 750ºC ambiance for 1 min, the Ni film was clustered a Ni nano-mask on GaP surface. The rough texture surface was finished after the epi-wafer was suffered an inductively coupled plasma (ICP) etcher process. A 280 nm-thick ITO was deposited on the surface as functions of current spreading, transparent conductive layer and lower reflective index window layer. The epi-wafer was flipped and bonded by glue to the sapphire substrate which has pattern on the backside. The wafer pair was loaded into a furnace under 300°C for 40 min in nitrogen ambiance. After wafer bonding process, the absorbing GaAs substrate and the etching stop layer were removed by chemical etching solution. The mesa was formed via ICP etcher, terminated until the ITO film was exposed. The Au/AuGe (100 nm/20 nm) metals, which functions as an ohmic contact layer and a higher reflector were deposited on the ITO film and n-AlGaInP pads. Finally, the geometric sapphire shaping wafer was subjected to laser scribed and broken into 1000 µm×1000 µm chips size in this study. The AlGaInP-based GSS-FCLEDs, which has an oblique sapphire shaping sidewall, were flip-chip bonded on silicon sub-mount using Panasonic ultra sonic flip chip bonder for electrical and optical properties measurements by CAS140CT-152 array spectra-meter system.

3. Results and Discussions

A schematic diagram of the AlGaInP-based GSS-FCLEDs structure (Fig. 1(a)) were demonstrated via glue bonding process, having an oblique sapphire shaping sidewall and a nano-scale rough texture on the p-GaP window layer. In this investigation, the oblique sidewall angle was depended on the sapphire crystallography such as the crystalline facets were R-plane (1102), M-plane (1010), and A-plane (1120) against the c-axis (0001) and their angles against the c-axis (0001) are about 60°, 50°, and 29° respectively. In Fig. 1(b) described that the different output light path of the novel GSS-FCLED structure and the oblique-free FCLEDs. It is significantly that both critical angles are the same; however, the GSS-FCLEDs, having excess smaller the incident angle than FCLEDs. In other words, the novel GSS-FCLEDs structure, which has more opportunities of output light escaped from the oblique sidewall to air (or epoxy). Fig. 2 (a) shows the scanning electron micrograph (SEM) of geometrics sapphire shaping profile that every square is 1mm^2. Fig. 2(b) is a GSS-FCLEDs chip cross section view, which is undergone laser scribbling and breaking. As this figure, the oblique sidewall angle is closely 61.8°, according to the R-plane (1102) against the C-plane (0001). Fig. 2(c) is Ni nano-mask clustered after 750 °C thermal treatment by RTA, and its height is approximately 300 nm. Fig. 2(d) shows that the GaP surface, which has rough texture surface after ICP dry-etching process. In Fig. 3(a)-(e) shows that the corresponding luminous intensity-current-voltage (L-I-V) characteristics of the GB-LEDs, the oblique-free FCLEDs and the noel GSS-FCLEDs. The GB-LEDs (Fig. 3(f)) is that the epi-wafer was bonded on sapphire substrate, but the structure is n-side-up form. As these results, the power saturation of FCLED (or GSS-FCLEDs) is less than the GB-LEDs since the flip-chip has better thermal dispersion advantage. Furthermore, it is clearly observed that the luminous intensity of the GSS-FCLEDs is larger than the FCLEDs. Cause of the result is that the oblique sidewall can reduce the TIR effect and improves the light extraction efficiency. Fig. 3(g) shows that the novel GSS-FCLEDs photomicrographs view under 70 mA current injections.

4. Conclusions

In sumary, the AlGaInP-based GSS-FCLEDs structure, having an oblique geometric sapphire substrate were fabricated via glue bonding. The luminous intensity of this evolutional structure can enhance approximately 35% than FCLEDs structure. As this result, it was demonstrated that the GSS-FCLEDs structure can not only reduce the TIR effect but enhance more opportunities of output light escaping from the transparent substrate.

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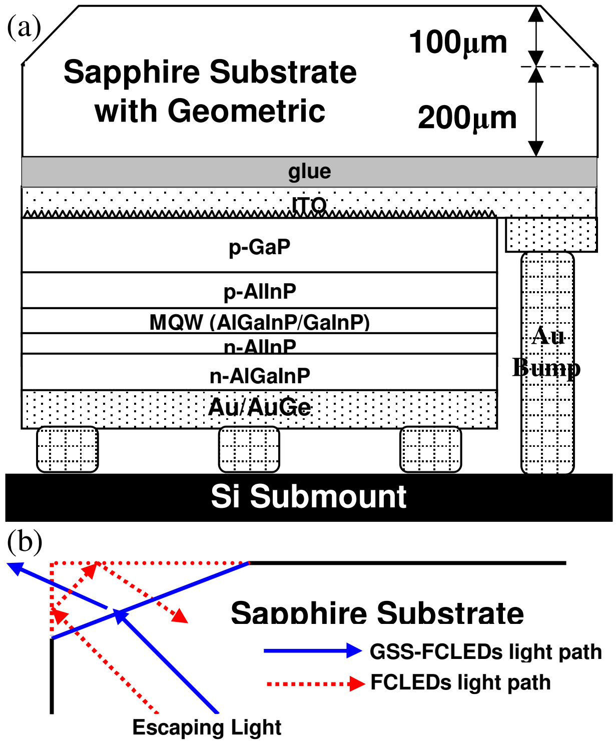

Fig. 1 (a) Schematic diagram of the AlGaInP-based GSS-FCLEDs structure with an oblique sapphire shaping sidewall were demonstrated by glue bonding. (b)Described with the different output light path of the novel GSS-FCLEDs and the oblique-freel FCLEDs.

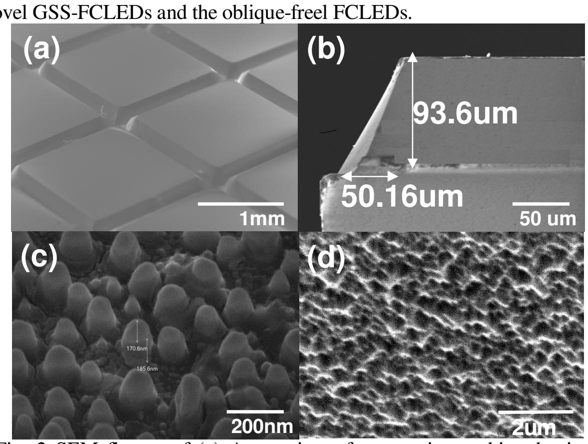

Fig. 2 SEM figures of (a) A top view of geometric sapphire shaping structure. (b) The cross section view of GSS-FCLEDs chip with an oblique sidewall. (c) Ni nano-mask clustered after RTA treated. (d) Nano-scale rough texture surface after ICP dry-etching process.

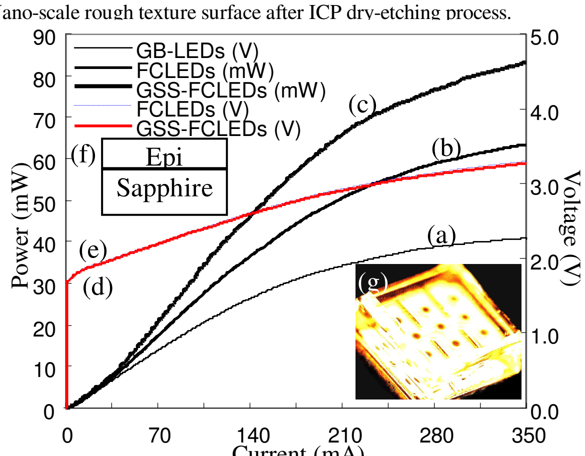

Fig. 3 (a)-(e) The corresponding L-I-V characteristics of the GB-LEDs, FCLEDs, and GSS-FCLEDs. (f) The schematic structure of GB-LEDs. (g) The photomicrographs view of GSS-FCLEDs.