

行政院國家科學委員會專題研究計畫 成果報告

子計畫五：用晶圓接合與溼式蝕刻方式來剝離側向覆蓋生長
之氮化鎵磊晶層(3/3)

計畫類別：整合型計畫

計畫編號：NSC93-2216-E-009-010-

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執行單位：國立交通大學材料科學與工程學系(所)

計畫主持人：吳耀銓

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【光資訊關鍵性材料製程與性質研究-子計畫五：

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一、摘要

1. 中文摘要

關鍵詞：氮化鎵，晶圓接合，異質磊晶，藍寶石。

本計畫主要的目的在於解決氮化鎵(GaN)薄膜異質磊晶(heteroepitaxial)於藍寶石(sapphire)基材所衍生的許多問題。期望藉由晶圓接合(wafer bonding)，轉移氮化鎵磊晶層於它種基板上。

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2. 英文摘要

Keywords : gallium nitride, sapphire, wafer bonding,.

Vertical InGaN-GaN light emitting diodes (LEDs) epitaxial films were successfully fabricated on a 50mm Si substrate using wafer bonding and laser lift-off technology. A high-temperature stable organic film, rather than a solder metal, was used as the bonding agent. It was found that the intensity of the light from the vertical InGaN LED chip was 2.8 times that of the conventional sapphire-substrate LEDs at an injection current of 20 mA. The vertical InGaN LEDs were operated at a much higher injection forward current (280mA) than were sapphire substrate LEDs (170mA). The light-output pattern of the vertical InGaN LEDs is more symmetrical than that of the sapphire-based LEDs. The vertical InGaN LEDs remain highly reliable after 1000 h of testing.

二、前言及研究目的

The epitaxial growth approaches have considerably increased the brightness of light-emitting diodes (LEDs), and results in rapid advancements in efficiency, the available emission spectrum, the higher power and the application methods. These improvements, coupled with the inherent properties of solid-state devices - low voltage operation, high reliability and low cost - have enabled LEDs to be applied extensively in solid-state lighting and displays. In these applications, LEDs are increasingly replacing conventional technologies.

High-brightness GaN-based light-emitting diodes (LEDs) have attracted considerable attention for their versatile applications in mobile phones, full-color displays and lighting.¹⁻² Although the development of these GaN-based LEDs is very successful, the poor conductivity of p-GaN limits the performance of LEDs because of current crowding.³⁻⁴ This problem can be solved using a thin Ni/Au layer or a highly transparent (> 80%) indium tin oxide (ITO) layer as a current spreading layer.⁵⁻⁶ However, the poor electrical characteristics (electrical resistivity= 10^{11} – 10^{16} ohm-cm) of the nonconducting sapphire substrate are such that the electrodes of the p- and n-metal are both on the top surfaces of the devices. Some of the active layer in the n-contact region is sacrificed. Besides, the heat dissipation of the sapphire substrate is also poor, so the GaN-based LEDs are generally operated at low injection current. These problems can be solved by

transferring GaN LEDs on Si⁷⁻⁸ and Cu substrates⁹ to improve the performance and heat dissipation of the devices. Much of this investigation is focused on intermetallic bonding and shows no damage on a small size transfer LED devices. In this work, an n-side-up InGaN LEDs with vertical electrodes was developed by organic bonding. A high-temperature stable organic film, rather than a solder metal, is utilized as the bonding agent to prevent any possible reaction with the metal reflector. The performance and the reliability of the vertical InGaN LEDs were investigated.

三、研究方法

A 50mm sapphire and Si substrates were used. The InGaN-GaN films were grown on a sapphire substrate by low-pressure metalorganic chemical vapor deposition (MOCVD). The LED structures comprise a 0.3 μm -thick Mg-doped GaN, an InGaN-GaN multiple quantum well (MQW) with seven period, a 2 μm -thick Si-doped GaN, a 2 μm -thick undoped GaN layer film and a GaN buffer layer on sapphire substrate. The system of omnidirectional mirrors¹⁰ was then deposited on the InGaN-GaN LEDs to form a p-side contact layer and a reflection layer. This LED wafer was bonded to a silicon substrate covered with a high-temperature stable conductive organic film and a compressive load of 10 kg/cm^2 . It was then annealed at 200°C for 60 min.

A 50mm InGaN LED wafer was successfully bonded to a Si substrate. The sapphire substrate was then removed by laser lift-off with a frequency-tripled Nd YAG laser at 355 nm¹¹. No peeling or crack was observed on the bonded sample, revealing that the bonding strength was sufficiently high to exceed the sapphire substrate removing process. The n-GaN roughening surface was obtained by treatment with boiling KOH solution on undoped GaN and using inductively coupled plasma (ICP) to remove undoped GaN until Si-doped GaN was exposed. The Ti/Al/Pt/Au dots with a diameter of 100 μm and Ti/Au were deposited onto the n-side (n^+ -GaN contact layer) and the underside of the Si substrate. Figure 1 presents the structure and the roughened surface. Finally, as shown in Fig. 2, the vertical InGaN LED wafer was successfully cut into isolated devices, each with an area of 300 \times 300 μm^2 . Evidently, the mechanical strength of the bonding interface was sufficiently high to endure the processes associated with vertical InGaN LEDs.

三、結果與討論

The vertical InGaN LED devices are easier to process and have advantages over conventional sapphire-based LEDs. The dicing process for vertical InGaN LED devices can replace the complicated process of – dry etching to mesa, laser scribing and breaking of the sapphire-based LEDs. The light emitting area is increased by 15 % because only a single electrode is present on the topside of vertical InGaN LED devices as shown in Figure 3(a). For comparison, standard sapphire-substrate LEDs with an ITO current spreading layer was prepared from the same InGaN-GaN LED epitaxial material. The samples described herein were only cut into chips without encapsulation, before electrical and optical measurements were made.

Figure 3(b) plots the current against voltage (I - V) of LEDs with an area of 300 \times 300 μm^2 . The vertical InGaN LEDs exhibited normal p - n diode behavior with a forward voltage of 3.2 V at 20 mA. In this regard, they were similar the conventional LEDs, indicating that neither wafer bonding nor the device process

degrades the performance of vertical InGaN LEDs.

Figure 3(c) depicts the effects of injection the current on the luminous intensity of the vertical and conventional InGaN LEDs. The light intensity of the vertical InGaN LED chip is 2.8 times that of the conventional LEDs at an injection current of 20 mA. As presented in Fig. 1, this difference is caused by the improvement of the emission of light from the vertical InGaN LEDs by using only one electrode, the reflection of the downward-traveling light by an omnidirectional mirror, and the roughening of the n-GaN surface. (When the surface of the n-GaN was smooth, the light intensity of the vertical InGaN LEDs chip was double that of the conventional InGaN LED.) Notably, the current can spread uniformly without a thin metal layer (Ni/Au) or a transparent layer (ITO), because the vertical LEDs structure was p-side-down and n-side-up, with an n-metal electrode. Accordingly, the vertical InGaN LEDs do not exhibit the current crowding problem on the top emission area. Therefore, the emission of light is better than that of the conventional sapphire-based LEDs.

Figure 3(c) also reveals that vertical InGaN LEDs can be operated with an injection forward current of 280 mA, which is 170 mA greater than that used in sapphire-substrate LEDs, because the thermal conductivity of Si ($168 \text{ Wm}^{-1}\text{K}^{-1}$) is 4.8 times higher than that of sapphire ($35 \text{ Wm}^{-1}\text{K}^{-1}$). However, this improvement in heat dissipation is not as large as was expected because the thermal conductivity of the organic film was poor. The effects of heat dissipation on the performance of LEDs could be plotted as a peak shift as a function of DC drive current. As shown in Fig. 3(d), when the DC drive current increased from 100 mA to 300 mA, the emission peak wavelengths of the sapphire-based LEDs shifted toward longer wavelengths - from 462.3nm to 474 nm, whereas that of vertical InGaN LEDs on the Si substrate shifted from 462.6nm to 466 nm. These peak shifts were caused by Joule heating.¹² Evidently, this Si wafer bonding technique reduced the Joule-heating problem of conventional sapphire-based LEDs.

Figure 4 displays the light-output pattern of the conventional LED and vertical InGaN LED chips. It shows that the light-output pattern of the vertical InGaN LED chip is more symmetrical than that of sapphired-based LEDs, and the power angle of the vertical InGaN LED chip is smaller than that of sapphire-based LEDs, since the vertical InGaN LEDs were designed to have greater extraction efficiency using only one electrode, reflecting downward light, and having a rougher n-GaN surface. Accordingly, most light is easily reflected upward. Additionally, the vertical InGaN LEDs were fabricated by replacing the transparent sapphire substrate with a Si substrate. Thus, only a few photons can be emitted from the side.

The lifetime of vertical InGaN LEDs was tested at a forward current of 50 mA at 55°C. The voltage variation was under 3% and the output luminescent intensity was not degraded during 1000 h of life testing, as presented in Fig. 5.

三、未來的方向

- (1) 將此技術用在 Cu 基板。
- (2) Cu 基板之切割。

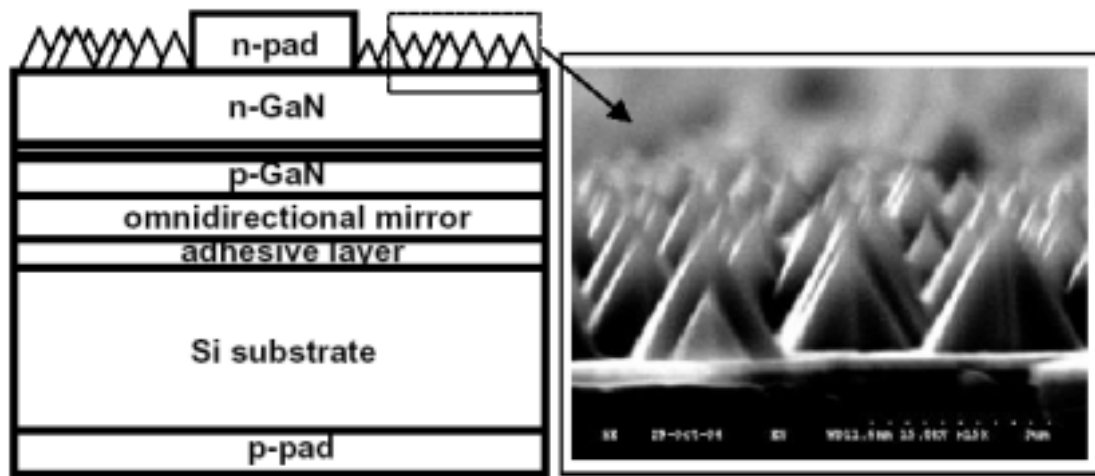


Fig. 1. (a) Schematic illustration of the vertical InGaN LED structure. (b) the SEM image of roughened surface.

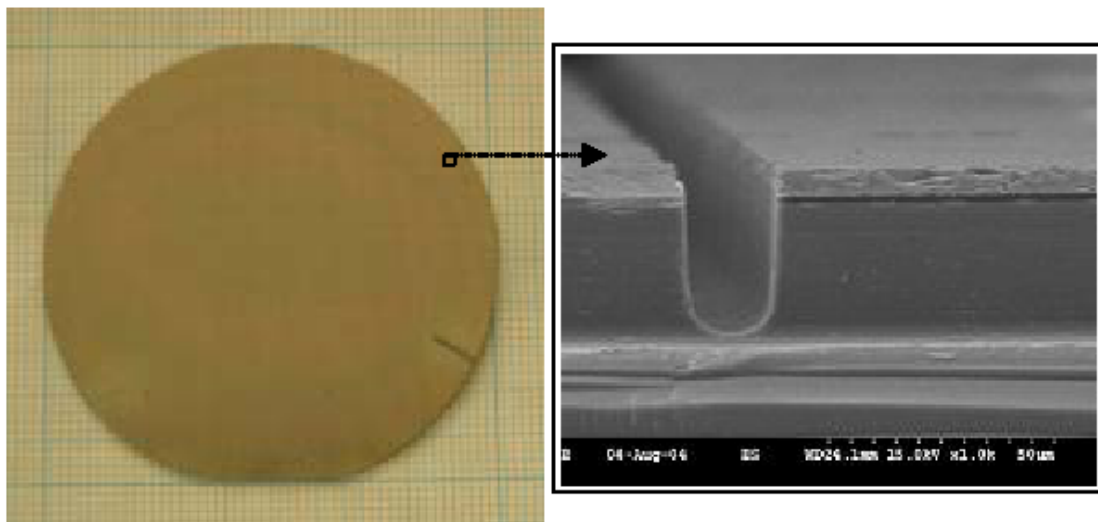


Fig. 2. (a) The OM image of an InGaN LED wafer bonded on a 50mm diameter Si substrate. Wafer was successfully cut into isolated devices with an area of $300 \times 300 \mu\text{m}^2$. (b) the SEM image of the cross section of the LED structure after dicing process.

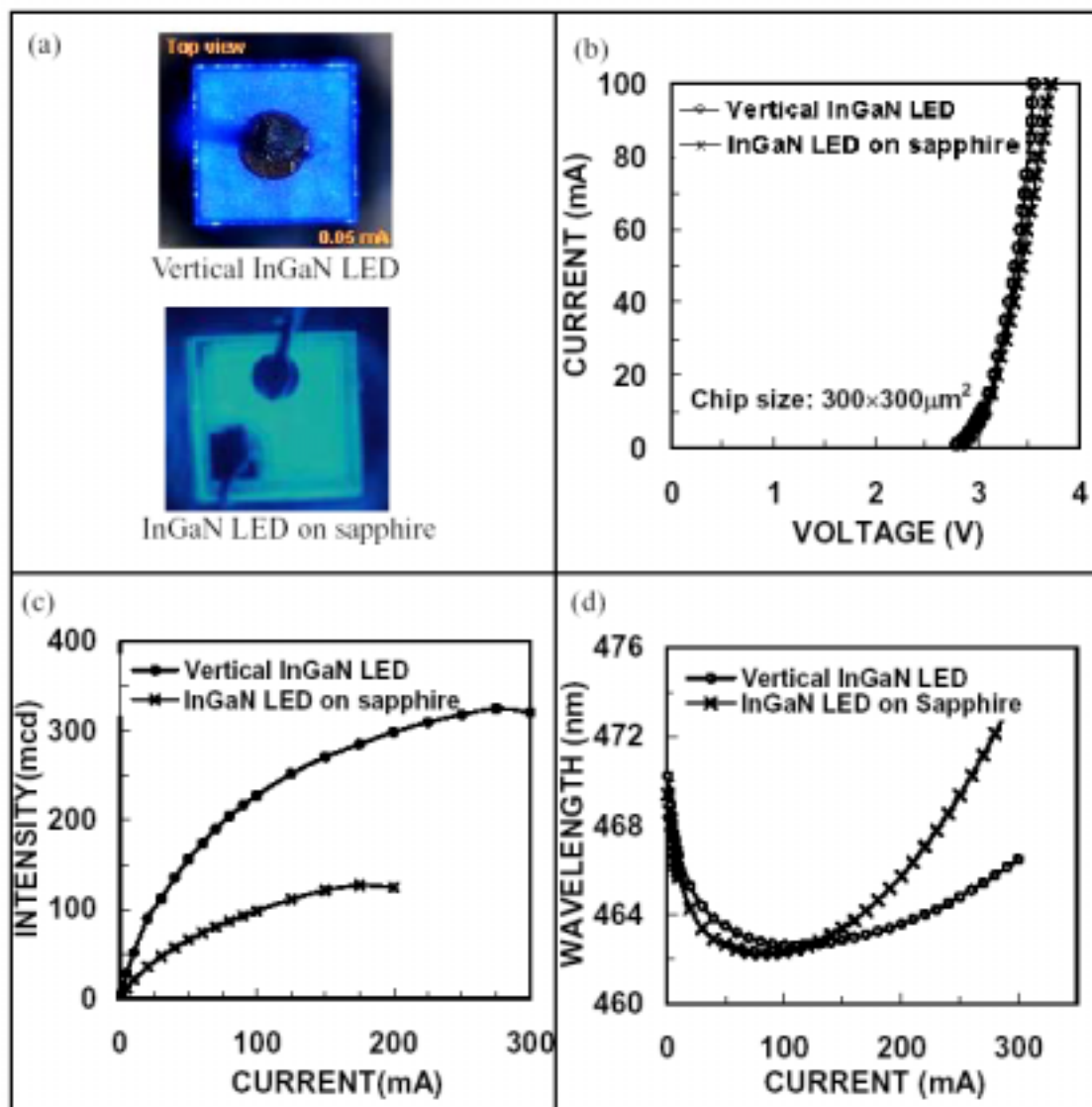


Fig. 3. The performances of vertical and conventional InGaN LEDs. (a) Top view photograph of the LEDs. (b) Current-voltage (I - V) characteristics of the LEDs. (c) The effects of injection the current on the luminous intensity of LEDs. (d). The peak spectral wavelength as a function of DC drives current of the LEDs

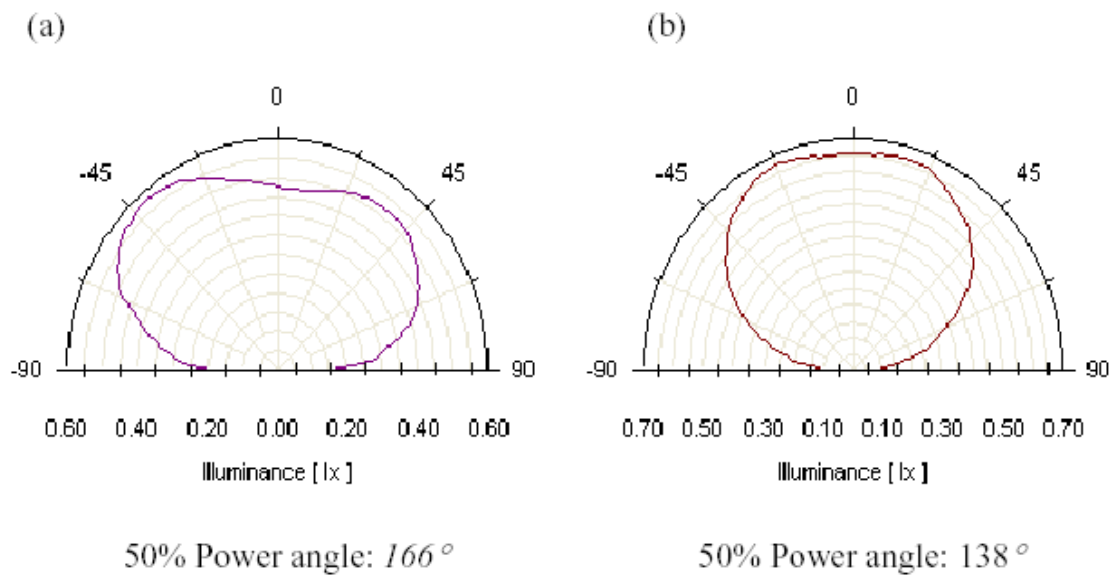


Fig. 4. The light-output patterns of (a) sapphire-based LEDs and (b) vertical InGaN LEDs

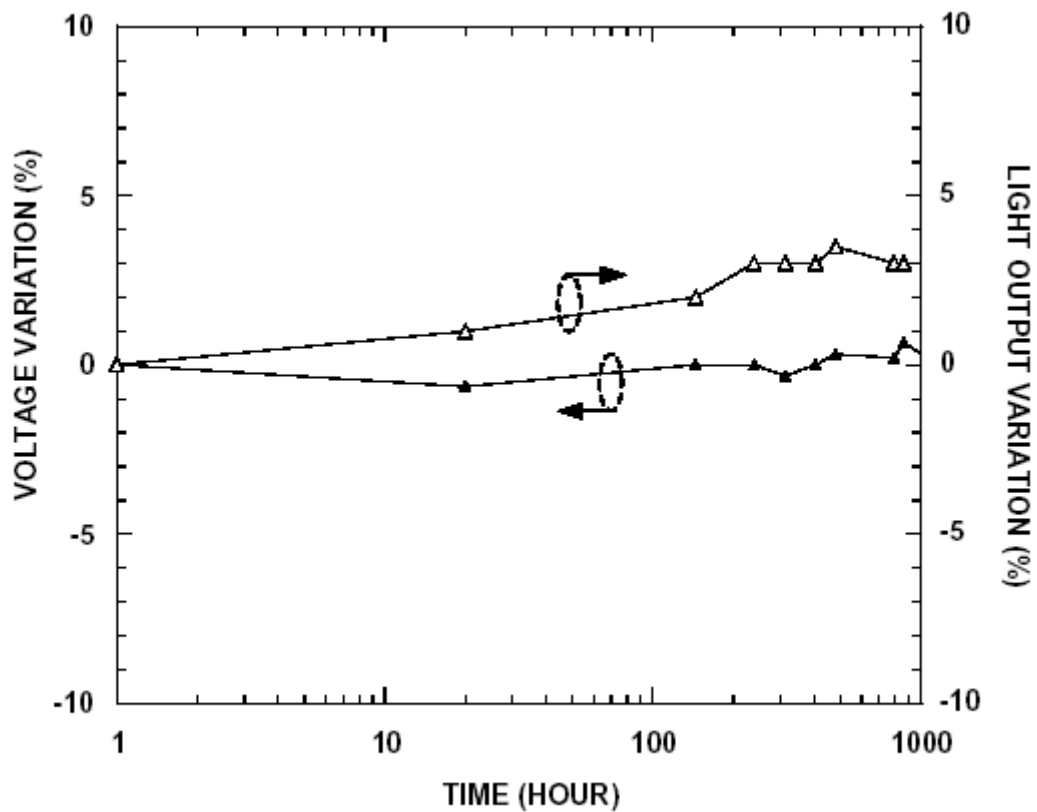


Fig. 5. Reliability test of vertical InGaN LEDs under stress-condition of 55°C and 50mA .

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