覆晶技術及磊晶膜轉移技術應用於氮化鎵發光二極體發光效率提升之研究

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摘要

由於氮化鎵基材發光元件可廣泛的應用於如指示燈、各種照明、光儲存等領域，因此自1960 年代以來氮化鎵相關材料成為世界上各研發團體的重要研究課題之一，且在此數十年間氮化鎵材料與元件特性上有屢有重大的發現與進展。本論文主要研究目的係提供提升氮化鎵發光二極體元件特性之方法。其中，主要藉由覆晶技術及磊晶膜轉移技術製作高功率與高亮度發光二極體並研究分析此二類元件之主要特性。發光波長介於紫外光至綠光之間的LED，一般都是在藍寶石基板上，以氮化鎵(GaN)製作而成，然而由於此型基板的低熱傳導性質及絕緣特性，使得該類LED 只能做低功率元件的應用。為克服此一缺點，透過覆晶技術及磊晶膜轉移技術，可有效的提升元件之光電特性。

於覆晶型發光二極體方面，主要開發於藍寶石基板製作微米柱陣列及幾何形狀化結構的製程技術，另外，再藉由磊晶技術於微米柱陣列藍寶石基板成長氮化鎵磊晶層及表面粗化結構，並針對不同的製程技術於覆晶型發光二極體的影響進行探討。在第一部分，我們成功的利用乾蝕刻製程技術在藍寶石背面製作出微米柱陣列，使得光萃取效率得以提升。在量測結果部分，發光波長在460奈米下，有製作微米柱陣列的覆晶發光二極體的光輸出增加了10%~68%相較於傳統的覆晶發光二極體。在第二部分中為了提升光功率輸出，我們成功的利用化學濕蝕刻製程技術在藍寶石背面製作出幾何形狀化結構，經過濕蝕刻製程技術，我們在藍寶石背面蝕刻出(1-106)、(11-25)和(1-102)的晶格面，相較於(0001) c軸而言角度分別是30˚、50˚和60˚，深度有100微米左右，這些晶格傾斜

面和相當厚的藍寶石視窗層對光萃取效率的提升有很大的幫助。在量測的結果部分，在電流350毫安培下，有製作幾何形狀化的覆晶發光二極體的光功率輸出增加了55%。在第三部份，我們更結合了磊晶技術於微米柱陣列藍寶石基板成長氮化鎵磊晶層及表面粗化結構成功製作三重光散色層覆晶型發光二極體，同時解決光由氮化鎵至空氣、氮化鎵至藍寶石基板、及藍寶石基板至空氣之高折射係數差所造成之全反射效應，在電流350毫安培下，具三重光散色層覆晶型發光二極體之光功率輸出增加了60%。

於薄膜型發光二極體方面，係利用晶片接合及雷射剝離技術製作薄膜型發光二極體，藉由將成長於sapphire 基板上之氮化鎵磊晶層轉移至具高導熱性及導電性基板，此薄膜型發光二極體可於高電流操作下保持其光輸出功率呈之線性增加。本研究主要探討表面結構對薄膜型發光二極體取光效率的影響，藉由網狀型表面粗化結構及光子晶體表面結構的開發，增加薄膜型發光二極體表面取光效率。在第一部分，我們成功的將成長於微米柱陣列藍寶石基板成長氮化鎵磊晶層轉移至具高導熱及導電特性之矽基板，再利用濕蝕刻粗化技術來達到網狀型表面粗化結構效果，同時並探討不同表面結構對元件特性的影響，在電流350毫安培注入下，具網狀型表面粗化結構之薄膜型發光二極體光功率輸出增加了20%。在第二部分中，我們成功的開發具光子晶體表面結構之薄膜型發光二極體，在本論文中，我們於薄膜型發光二極體表面製作八櫳準光子晶體結構，除了能有效增加元件之取光效率外，此元件亦能實現一般Lambertian遠場對稱光型。

Study of Light Extraction Enhancement for GaN-based Light Emitting Diodes by Flip-Chip and Epilayer-Transfer Technology

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Abstract

In the thesis, we report the flip-chip and epilayer-transferred types GaN-based LEDs for improving the light extraction efficiency of devices.

In the part of flip-chip type LEDs, the light-emitting diodes (FC-LEDs) with micro-pillar-array structure, the FC-LEDs with geometric oblique sapphire structure, and FC-LEDs with triple light scattering layers were investigated. In the first part, the micro pillar arrays structure is formed on the bottom side of sapphire substrate by dry etching process to increase the light-extraction efficiency. The light output power of the FC-LED is increased by 68% for a 3.2 μm textured micro pillar on the bottom side of the sapphire substrate. Our work offers promising potential for enhancing output powers of commercial light-emitting devices. In the second part, the sapphire shaping structure is formed on the bottom side of sapphire substrate by chemical wet etching technique for light extraction purpose. The crystallography-etched facets are (1-106), (11-25) and (1-102) plane against the (0001) c-axis with the angles range between ~30°- ~60°. These large slope oblique sidewalls and greatly thick sapphire windows layer are useful for enhancing light extraction efficiency. The light output power of sapphire shaping FC-LEDs (SSFC-LEDs) was increased 55 % (@ 350 mA current injection) compared to that of conventional FC-LEDs (CFC-LEDs). In the third part, the FC-LEDs with triple light scattering layers were demonstrated by conjunction with the

epi-growth on micro-pillar array sapphire substrate and naturally textured p-GaN surface. The totally internal reflection effect could be effectively reduced between the GaN-air, GaN-sapphire, and sapphire-air interfaces. The light output of the FC-LEDs with triple light scattering layer structure was increased about 60% (@350 mA current injection).

The epilayer-transferred type LEDs were fabricated by the combination of wafer bonding and laser lift-off techniques to transfer the GaN epilayer to a better thermal dissipation and conductive substrate. In this part, the epilayer-transferred type LEDs with modified surface structures were demonstrated including roughened mesh surface and photonic crystal surface structures. In the first part, the epilayer-transferred type LEDs with the roughened mesh surface were proposed by transferring the GaN epilayer which was grown on a pattern sapphire substrate to a high thermal conductivity and electrical conductive silicon substrate and roughening the mesh surface by chemical wet etching process. Under 350 mA current injection, the epilayer-transferred type LEDs with the roughened mesh surface presents a further enhancement of 20% in output power comparing with that of regular epilayer-transferred type LEDs. In the second part, the epilayer-transferred types LEDs with the 8-folds photonic crystal surface structure were demonstrated. By adopting a photonic crystal surface structure, the light extraction efficiency was effectively improved. In addition, a Lambertian far-field pattern was also realized.

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