# 表面微結構化技術增進三五族半導體發光二極體發光效率之研究

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## 摘　　要

近年來，因三五族發光半導體能將注入之電能直接轉換成光輸出此一獨特之材料特性能，發光二極體元件已被預測為下一世代之照明光源。然而，在高亮度應用的需求上，現階段可見光波段的發光二極體元件與傳統照明光源相比較，其發光效率還是不足。除此之外，在現今能源節約與環保意識抬頭的時代，更需要精密設計發光二極體元件的結構，使其能更進一步提升發光效率，以達上述之需求。

針對此點，本論文提出了一個新穎的結構能夠同時且有效地提升氮化銦鎵發光二極體元件之內部量子效率與光淬取效率。

對於氮化銦鎵發光二極體元件來說，除了全內反射限制住光子被淬取的數目之外，其發光效率主要的限制是來自於缺少適合成長此材料磊晶片的基板。也因此，相當高密度的差排缺陷 (Dislocation defects) 會在發光二極體元件的活性層中出現並減少電子電洞複合產生光子的機率，使得元件的發光效率降低。為了改善這個問題，我們利用化學濕式蝕刻的方式來製作具有特定晶格斜面 (Facet) 圖樣的藍寶石基板。我們發現將氮化銦鎵發光二極體元件成長在此特殊基板上將會有效地提升元件之內部量子效率與光淬取效率。本論文將詳細地討論其主要的物理機制—為何此結構能同時且有效地提升上述兩項重要的元件發光效率。

為了有效地解決螢光粉轉換效率與專利侵權這兩個普遍存在在現階段產業界所製作的白光發光二極體元件上的問題，我們在本論文也提出利用並結合藍寶石

基板剥離(Sapphire laser lift-off)與晶片接合技術( Wafer bonding) 來製作互補色雙波長(470-nm/550-nm)且無螢光粉參雜( Phosphor free)的白光發光二極體元件。在電流的注入之下，此元件有著相當平坦與寬廣的電激發光譜結合著藍綠光的發射。此白光發光二極體元件的出光效率最高可達約一百二十流明每瓦。此白光發光二極體元件有著相當高的潛力來促進固態照明時代的到來。

# Research on Light Emission Enhancement of III-V Light-Emitting Diodes by Surface Modified Techniques

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## Abstract

Light-emitting diodes (LEDs) are revolutionizing the world. Due to the unique characteristics of III-V compound semiconductor that provides the direct transfer of electrical energy into light, LEDs have been forecasted as lighting sources of next generation. However, efficiency of present state-of-the-art visible-spectrum LEDs are still low, as compared to that of conventional lighting sources specifically applied for high-flux utilization. In addition, since concerns of energy-conservation and environment-protection become emergent over the world, the desire for more sophisticated and high-efficiency LEDs structure's designs is even intense than ever.

In the first section of this thesis, we design a novel structure to simultaneously enhance both internal quantum efficiency and light extraction efficiency of InGaN-based LEDs.

For InGaN-based LEDs, in addition to the total internal reflection restricting photons extraction, the major difficulty is the lack of low-cost, single-crystal GaN to use as a growth substrate. Thus bunches of dislocation defects are normally observed inside active regions and served as nonradiative recombination centers. To alleviate these issues, we propose a novel structure of InGaN-based LEDs grown on chemical wet etching-patterned sapphire substrate (CWE-PSS) for simultaneously enhancing both internal quantum and light extraction efficiencies. The detail of physical mechanisms responsible for the dual enhancement in internal quantum efficiency and light extraction efficiency are also investigated in this thesis.

In the very end of this thesis, to alleviate the phosphor-convention issue commonly observed in conventional white light LEDs, phosphor-free InGaN-based dichromatic-color blue/green (470-nm/550-nm) LEDs are well designed and successfully fabricated by using sapphire laser lift-off (LLO) and wafer-bonding schemes. Flat and broad EL spectra with combination of blue and green colors are emitted, accompanying with the maximum luminous efficiency of 120lm/W. This integrated dichromatic lighting structure has a great potential to facilitate the early coming of solid-state lighting.

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