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The Formation of Air Void on Patterned Sapphire Substrate by Selective Photoresist Carbonization

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ABSTRACT

In this study, to improve the light extraction efficiency of light emitting diodes, we investigated new methods that form an air void on patterned sapphire substrate (PSS) without wet etching process. It was confirmed GaN was grown on specific planes such as n-like plane, c-plane in PSS by behavior of GaN growth on PSS as time changes. Air void can be built up by suppressing c-plane and growing on n-like plane in PSS lens, using selective photoresist mask. To analyze the cause of selective growth on PSS, the contact angle measurement was implemented and the cause of growth suppression can be found by the surface energy from contact angle.

Keywords: gallium nitride, patterned sapphire substrate, metal-organic chemical vapor deposition

1. Introduction

Gallium nitride (GaN)-based light emitting diodes (LEDs) have attracted much attention in solid-state lighting such as full color or white LED displays and backlights for liquid crystal displays. Although GaN-based LEDs are commercially available, there is room for improvement of external quantum efficiency (EQE). The EQE of LEDs is primarily linked with internal quantum efficiency (IQE) and light extraction efficiency (LEE). The low IQE is attributed to the low crystal quality of GaN epitaxial layer [1] which affected by the threading dislocation density (TD) by the large lattice mismatch of lattice constant and thermal expansion coefficient between the GaN epitaxial layer and sapphire substrate [2-4]. Another major issue for low EQE is low LEE, which primarily results from total internal reflection of light caused by the difference in refractive indexes of GaN and the sapphire substrate. Because of total internal reflection, most of the photons generated from multi-quantum well (MQW) cannot escape from GaN. Therefore, improvement of IQE and LEE is a major issue for high performance LED.

Many useful growth techniques have been proposed to enhance the EQE of GaN-based LED. To improve crystal quality for IQE, various concepts such as epitaxial lateral overgrowth(ELOG) [5-7], pendeo-epitaxy(PE)[8], AlN buffer layer[9], facet-controlled epitaxial lateral overgrowth [10,11] and multi-step method [12] have been implemented. Several methods including use of patterned sapphire substrate (PSS) [13-16], embedded air void [17,18], patterning of transparent conductive oxide layer [19], and sidewall etching of GaN [20,21] have been also developed to improve the LEE of LED. Among these technologies for EQE, the PSSs method is recently being used in manufacturing industries because of the enhancement of IQE and LEE by decreasing TD and improving photon scattering. However, air void structure in LEDs has been also studied as means to increase IQE and LEE for high efficiency optoelectronic devices [22-24]. Although most of LEDs with air void have been made using an additional crystallographic wet etching process [22-24], excessive wet etching process can result in epitaxial growth problem including surface pits and a rough surface [25].

To overcome issues by wet etching process, a new method to build up air void by the growth of GaN on lens ridge of PSS was proposed without a wet etching process. But it is not easy to control the behavior of GaN growth on various planes existed on PSS.

In this study, we investigate the behavior of GaN growth on PSS and introduce a method to fabricate air void by the control of the surface energy on PSS lens, using selective photoresist carbonization.

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