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Light Extraction Improvement of 400 nm Wavelength GaN-Based Light-Emitting Diode by Textured Structures

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거친 표면구조를 이용한 400 nm 파장 GaN계 발광다이오드의 광 추출효율 개선

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Abstract We fabricated the GaNLED emitting 400 nm wavelength and improved the optical extraction efficiency by making surface patterns on n-GaN layer and ITO layer above p-GaN. In addition, the light reflection metal under the n and p pad is made and the light reflection metal is installed on the backside of the chip. The light extraction efficiency is increased by 20 % with texturing n-GaN layer and 18% with texturing ITO layer at 20 mA. Compared to planar-surface LED, the light extraction efficiency for surface texturing both n-GaN and ITO is increased by 32% at 20mA.

요 약 400nm 파장을 방출하는 GaN LED를 제조하여, n-GaN층과 p-GaN층의 위에 있는 ITO층 표면에 패턴을 만들어 광 추출 효율을 향상시켰다. 추가적으로, n과 p패드 아래와 칩의 바닥면에 각각 광반사 금속을 설치하였다. 광 추출 효율은 20mA에서 n-GaN의 텍스쳐링에 의해 20% 증가되었고 ITO의 텍스쳐링에 의해 18% 증가되었다. 표면 처리가 않된 LED와 비교해서 n-GaN와 ITO를 함께 표면 텍스쳐링 했을때의 광 추출 효율은 20mA에서 32% 증가되었다.

Key Words : Lighting emitting diode, Texturing, GaN, Near ultra violet, and Indium tin oxide

1. INTRODUCTION

It is well-known that white light from LED is achieved by three different ways: by combining blue GaN LEDs, green GaN LEDs, and red AlGaInP LEDs, by combining YAG (Yttrium Aluminium Garnet) phosphors with blue LEDs or green and red phosphors with blue LEDs, and by combining red, green, and blue phosphors with near UV LEDs. red, green, and blue phosphors. Using blue LED and near UV LED has high energy efficiency because phosphors are used. Recently, National Institute of Material Science (NIMS) in Japan developed nitride red phosphor which has wide range of color and strong light emission intensity. GaN LED having around 400 nm emissionshas strong light emission intensity [1,2], so it waspossible to make white light with the GaN LED by combining nitride red phosphor [3].

The external quantum efficiency of LED is expressed by the product of internal quantum efficiency and the lightextraction efficiency. To extract the light generated

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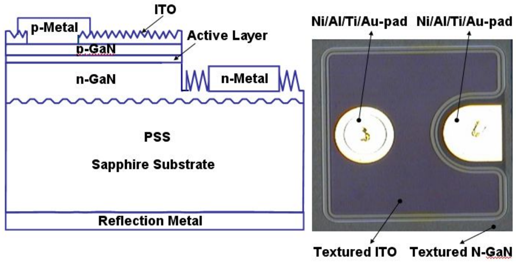
from inside of the chip requires the incident angle of light should be below critical angle, otherwise, the incident light goes back to the chip, and then eventually it can be either absorbed or scattered. The texturing on the surface was developed to increase the critical angle [4,5]. The surface patterns for sapphire layer [6, 7, 8], and ITO (Indium Thin Oxide) layer [9, 10] was developed to improve the light extraction efficiency as well.

We have been developing a red (BaRe)$Al_{11}Si_8N_{16}$ phosphor which absorbs most strong intensity around 400 nm [11]. Therefore, we need to develop around 400 nm LED and improve light extraction efficiency. In this paper, we developed the surface patterns for sapphire layer, n and p electrode reflector, n-GaNlayer, and ITO layer to improve the light extraction efficiency with around 400 nm LED. The light extraction efficiency is improved by 32% compared to conventional near ultraviolet LED.

2. EXPERIMENT

Surface pattern is made on sapphire layer to reduce the dislocations and defects of GaN buffer. With ICP RIE (Inductively Coupled Plasma Reactive Ion Etching) the surface structure is made and its size is 1.3 μm ×2.6 μm. After the buffer layer of sapphire is made, a 5 μm thick n-GaN layer, a 0.1 μm thick InGaN/GaN (MQW) layer, a 0.4 μm thick p-GaN layer, and then ITO layer are evaporated where the carrier density of p-GaN and n-GaN layer is $5\times10^{17}/cm^3$ and $3\times10^{18}/cm^3$, respectively.

To know the effect of ITO and n-GaN texturing, the 2 inch size wafer is divided to 4 parts, and the fabrication process of LED is follows; 1) normal process, 2) ITO texturing, 3) n-GaN texturing, 4) ITO and n-GaN texturing. We scribe and break to fabricate 350 μm × 350 μm GaN chip. For the process 2), 3), and 4), the light reflection metal under the n and p pad is installed on the backside of the chip. Fig. 1 shows a schematic diagram of surface-textured LED.



[Fig. 1] A schematic diagram of surface-textured LED.

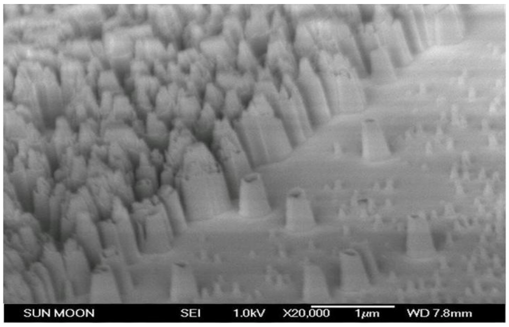
The surface of the epilayer is cleaned with HCl : DI water = 1 : 1, H_2O, and then H_2SO_4: H_2O_2 = 3 : 1. The ITO layer is prepared with E-Beam evaporator. The temperature of the ITO growing is 250℃, and itsthickness is measured with 2,150 Å. The annealing is done at 500 ℃ for 2 minutes with RTP (Rapid Thermal Process) while nitrogen gas flows.

ITO texturing is done for 1 minute with wet etching solution at room temperature. Some part of ITO layer is removed completely with wet etching to make p type electrode.

With ICP RIE the texturing of n-GaN layer is made by dry etching and its height is about 1um. After that, the n, and p pad of electrode are evaporated by Ni/Al/Ti/Au with 20Å/4,000Å/50Å/10,000Å. With PECVD (Plasma Enhanced Chemical Vapor Deposition) the SiO_2 is grown with thickness of 650Å for passivation purpose, and then Ti/Al metal layer is formed on the backside of Sapphire. The chips is made for SMD (Surface Mounted Device) type, packaged, and luminous fluxes are measured by CDS 5000 of Lab sphere whose the diameter of the light integration sphere is 10 inches.

3. DISCUSSION

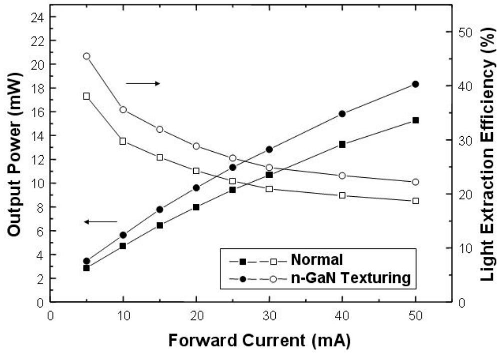
The incident light goes back to the chip when the incident angle of the light is above critical angle. The texturing on the surface increased the critical angle and improved the light extraction efficiency of the chip [4,5].



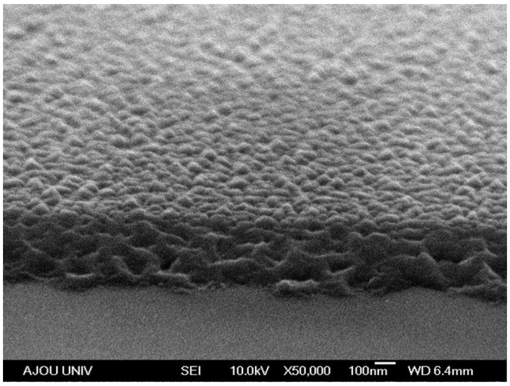
[Fig. 2] SEM photographs of surface-textured n-GaN.

Fig. 2 shows SEM photographs of surface-textured n-GaN. The average diameter and height of the pattern is 0.25 μm and 0.5 μm, respectively, where the pattern is uniform. Normal LED has reflection pattern in sapphire and has reflector layer on the bottom of the LED. Fig. 3 shows the output power and extraction efficiency of textured n-GaN layer LED as a function of forward current. The output power of normal chip is 8 mW at 20 mA while that of surface-textured n-GaN LED is 9.6 mW at 20 mA. Compared to the normal chip, the output power of surface-textured n-GaN LED is increased by 20%. The light extraction efficiency of the LED is 29% at 20 mA where internal quantum efficiency is assumed to 50% [12]. We expect that the light extraction efficiency is influenced by the reflection between n-GaN and Sapphire layer, as well as by the reflection layer located below the Sapphire layer. Surface pattern is made above the sapphire layer and metal reflection layer is located below the sapphire layer. It is expected that the light extraction efficiency from the texturing of n-GaN layer is related to the surface area ratio of n-GaN layer to n type electrode, in which the ratio is 30 % in the LED.

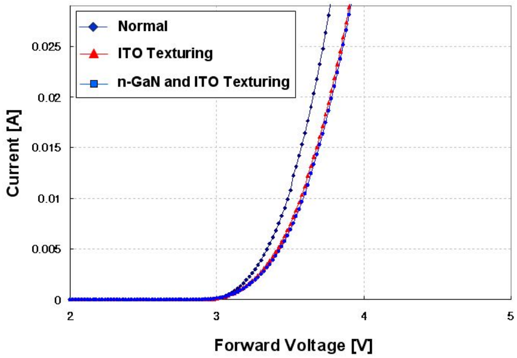
Fig. 4 shows SEM image of surface- textured ITO. As shown in Fig. 4, the surface-textured pattern of ITO layer is uniform in size whose diameter and height is 40 Åand 100 Å, respectively, where the thickness of ITO layer is 2,150 Å. Fig. 5 shows current-voltage characteristics of surface-textured ITO LED. From Fig.5, the forward I-V curve characteristic of both cases is almost same, that is, the electrical resistance is not changed much by the texturing effect.



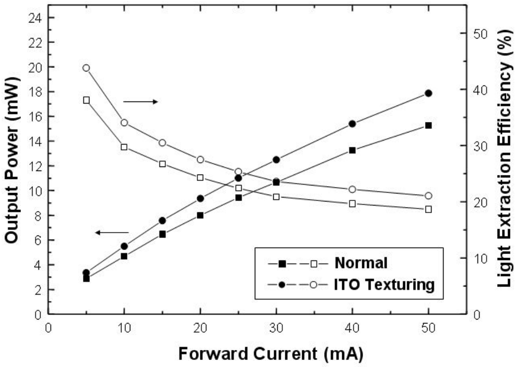
[Fig. 3] The output power and extraction efficiency of surface-textured n-GaN LED as a function of forward current.



[Fig. 4] SEM image of surface-textured ITO.

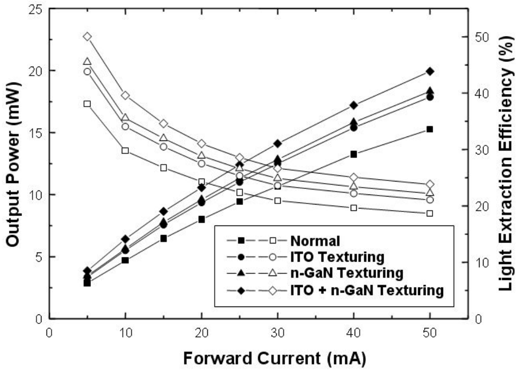


[Fig. 5] Current-voltage characteristics of surface -textured ITO LED.



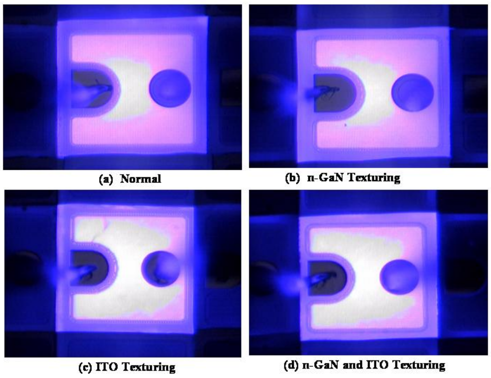
[Fig. 6] The light output power and extraction efficiency of surface-textured ITO LED as a function of forward current.

Fig. 6 represents the light output power and extraction efficiency of surface-textured ITO LED as a function of forward current.Compared to normal type, the light output power of textured ITO layer LED is increased by 18% and the light extraction efficiency is increased by 20% at 20 mA.



[Fig. 7] The light output power and light extraction efficiency vs forward current of LED with and without surface texturing of n-GaN and ITO.

Fig. 7 shows the light output power and light extraction efficiency vs forward current of LED with and without surface texturing of n-GaN and ITO. The light output power of the conventional chip is 8 mW at 20 mA. The surface texturing effect of n-GaN is increased by 20% in light extraction efficiency while that of ITO is increased by 18%. The light extraction efficiency for both n-GaN and ITO texturing is increased by 32%. It can be explained that the light extraction efficiency of two texturing is not added completely because some of light is involved to two texturing effects.



[Fig. 8] Pictures of light emission patterns of LEDs for many different types of texturing: (a) normal type, (b) n-GaN texturing, (c) ITO texturing, and (d) n-GaN and ITO texturing.

Fig. 8 shows the pictures of light emission patterns of LEDs for many different types of texturing. The operation current is 5 mA. Dark half circle in the Fig. 8 represents n type electrode in n-GaN layer and dark circle represents ITO layer in p-GaN layer. Pink colored circle enclosing ITO layer and outside part enclosing n type electrode are n type layer. Compared with conventional chip (a), the LED having surface-textured n-GaN shows thatthe outside part of ITO area becomes brighter. The area of surface-textured ITO becomes brighter, as shown in Fig. 8 (c), and most part of LED becomes uniformly bright for both surface-textured n-GaN and surface-textured ITO.

4. CONCLUSIONS

We have improved the light extraction efficiency of 400 nm wavelength LED by texturing n-GaN layer and ITO layer. The texturing of n-GaN and ITO layer is made during chip process, and the dimension of the chip is 350 μm × 350 μm. The light output power of LED driven at 20 mA is 8 mW for normal chip, 13 mW for surface-texturedn-GaN, 12.5 mW for surface-textured ITO, and 14 mW for both surface-textured n-GaN and surface-textured

ITO. The light extraction efficiency for n-GaN texturing, ITO texturing, and both n-GaN and ITO texturing is increased by 20, 18, 32%, respectively, at 20 mA.

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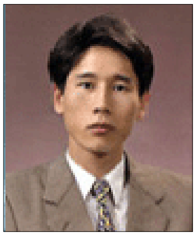

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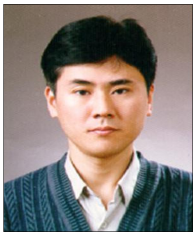

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