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Light Enhancement Al_2O_3 Passivation in InGaN/GaN based Blue Light-emitting Diode Lamps

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Abstract

In this study, sputtered Al_2O_3 thin films were evaluated as a passivation layer in the process of InGaN-based blue LEDs in order to improve the brightness of LED lamps. In terms of packaged LED lamps, lamps with Al_2O_3 passivation layer emanated higher brightness than those with SiO_2 passivation layer, and LED lamps with 90 nm Al_2O_3 passivation layer were the brightest among four kinds of lamps. Although lamps with Al_2O_3 passivation had a slight increase in operating voltage, their brightness was improved about 13.6 % compare to the lamps made of conventional LEDs without the changes of emitting wavelength.

Key Words : InGaN, GaN, Al_2O_3, LED, Sputtering system, Packaged lamp

1. INTRODUCTION

GaN-based wide band gap semiconductors have recently attracted considerable interests due to their applications for optoelectronic devices such as light-emitting diodes (LEDs) and laser diodes (LDs) in the blue and violet region[1-3]. Also, they have the potential for fabricating electronic devices operating high temperature up to 300 °C because of their excellent physical properties such as wide band gap, high break-down electric field, and thermal conductivity[4,5]. Especially, their applications has been expanded recently into exterior of automobiles and illuminative lightings, as the brightness of GaN-based LEDs[6].

In conventional GaN-based LEDs, both p and n metal pads should be placed on the epitaxial planes of the LEDs because they use a sapphire substrate which is an insulator with high resistivity.

Most GaN-based LEDs commonly have a passivation layer on the surface of chips in order to avoid electrical short problem during assembly process and surface leakage current between p-electrode and n-electrode due to the location of two electrodes on chips. The materials of the passivation layer are usually silicon nitride or silicon oxide thin films deposited by CVD method[7].

In plastic encapsulated LED lamps, three separate loss mechanisms contribute to reduce the quantity of emitted photons: 1) loss due to absorption within the LED chip material, 2) Fresnel loss and critical angle loss. When light goes from a medium whose refractive index is n_1 to a medium whose refractive index is n_2, a portion of the light is reflected back to the medium interface. This loss of light is called Fresnel loss. Reflection coefficient is:

$$R = \left(\frac{n_2 - n_1}{n_2 + n_1} \right)^2$$

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Therefore Fresnel loss can be reduced by the control of refractive index. This method is called "Anti-reflection Optical Coating"[8]. We have been considering that passivation layer can function as not only the electrical insulation between n metal pad and p metal pad but also the reduction of Fresnel loss which is controlled by the refractive index of passivation layer.

In this study, the thin Al_2O_3 films deposited to the passivation layers by RF magnetron sputtering have been investigated. We considered that the thin Al_2O_3 films are good insulators and their refractive indices are about 1.76 which are good materials as passivation layers. The index value of 1.76 is located between the refractive index of NiO (2.18) used by normally transparent conductive oxide and the silicon epoxy (1.3~1.5) used by packaging material at assembly process[8].

2. EXPERIMENT

To investigate the effects of passivation materials such as Al_2O_3 or SiO_2 and also, the thickness effects of Al_2O_3 passivation layers, we performed 2-inch wafer process up to passivation deposition process. Before depositing passivation layer, the 2-inch wafer was separated into quarter-sized wafers to avoid the deviation of electrical and optical properties by wafers. We used ICP dry etching in the window opening process in order to form an n-electrode on an n-type layer after the first photolithography. A transparent electrode on a p-type top layer consists of Au/Ni whose thickness is 50 Å/50 Å. The first thermal annealing for ohmic contact between the transparent electrode and the p-type top layer was performed. The n and p bonding pads were made of Au/Ti by E-beam evaporator. Our transparent electrode and bonding pad were patterned by lift-off method. After bonding metal was patterned, the second thermal annealing was performed to make ohmic contact. After the 2-inch wafer was broken into 4 pieces, one quarter-sized wafer had about 75 nm SiO_2 thin films deposited by PECVD whose passivation process is being normally applied in Blue LED market and others, three quarter-sized wafers had Al_2O_3 thin films which were deposited by RF sputtering system and whose thicknesses were 50, 70 and 90 nm respectively. RF magnetron sputtering condition is showed at Table 1. Our Al_2O_3 thin films had about 1.62 of refractive index and about 16.8 Å/min of deposition rate which were analyzed by ellipsometer. Also, the etching rate of Al_2O_3 thin films was about 160 nm/min in 2 % HF.

Table 1. Process conditions of RF sputtering to deposit Al_2O_3 passivation layer.

Parameters	**Conditions**
Sputtering Target	Al_2O_3 3N
Base Pressure	2.0×10^{-6} Torr
Process Gas	N_2 5N
Work Pressure	15 mTorr
RF Power	1.5 kW × 2 gun
Pre-sputtering Time	5 min
Deposition Rate	16.8 Å/min
Substrate Temp.	200 ℃

3. RESULTS AND DISCUSSION

Figure 1 is a map data of brightness (Iv) from the bare chips after scribing process and measured by the WPS3000 of Optosystem Inc. at 20 mA forward voltage. We compared four kinds of bare chips in only dot line with red color, For minimizing the deviation of electrical and properties according to the positions on the same wafer, we compared 4 types of bare chips from the area of red dot circle in Fig. 1. On the dot line, the chips with 75 nm SiO_2 and 50 nm Al_2O_3 as passivation layer were distributed in the Iv range from 70 and 75 mcd which was higher than Iv value of the chips with 70 and

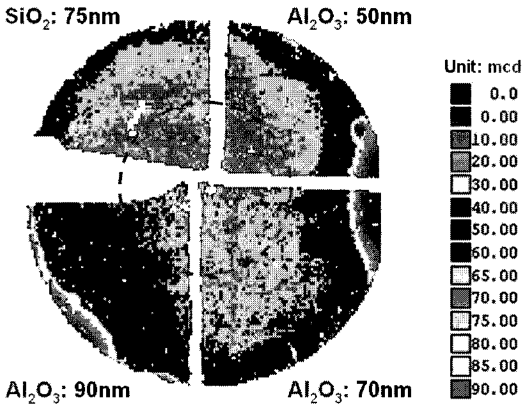

Fig. 1. Iv map data for bare chips after scribing process with passivation layer conditions.

90 nm Al_2O_3. Also, we found Iv was reduced as the thickness of Al_2O_3 passivation layer was increased.

We packaged four types of chips to analyze optical properties at normal LED lamps as shown in Fig. 2(a) and its viewing angle is about 60°. Four kinds of chips were selected on the dot line in Fig. 1. We have packaged 29 LED chips with the same package, Fig. 2(a) for each of four types, and analyzed by Minitab, a statistics tool. Fig. 2(b) shows the Boxplot obtained through the One-way ANOVA in Mintab at 20mA forward current. Iv of lamps with Al_2O_3 passivation layer was increased as the thickness of Al_2O_3 passivation layer was increased. This indicates an opposite trend on bare chips shown in Fig. 1. Lamps with Al_2O_3passivation layer whose thickness was 90nm has average 1012.8 mcd which was the highest Iv among the four kinds of lamps. Also, Iv of lamps with SiO_2 passivation layer was lower than Iv of all kinds of lamps whose passivation material was Al_2O_3.

2-Sample T in Minitab was used to analyze statistically and Iv of lamps with 90 nm Al_2O_3 passivation layer was brighter than those of the conventional lamps whih 75 nm SiO_2 passivation layer. Alternative hypothesis in 2-Sample T was that Iv of lamps with 90 nm Al_2O_3 was higher than Iv of lamps with 75 nm SiO_2 and confidence level was 95.0. The statistical results analyzed at these conditions are indicated in table 2. We could claim that lamps with Al_2O_3 90 nm has higher Iv than lamps with 75 nm SiO_2 according to the analyzed result showed P-Value as 0.000 which is lower than 0.05. Iv. In an average comparison of those 2 types of the lamps, we have improved about 13.6 % (=(1013-892)/892 %) by developing and applying Al_2O_3 passivation layer process.

Figure 3 showed bias current-voltage curves of the four kinds of lamps with passivation layers. The driving voltages of three kinds of lamps

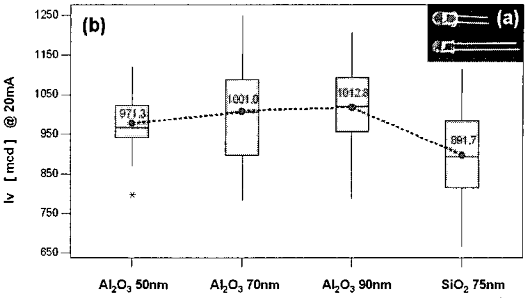

Fig. 2. (a) the image of packaged LED lamps, and (b) Boxplot of Iv for LED lamps with passivation layer conditions at 20 mA forward current.

Table 2. Statistical results of 2-Sample T for Iv with Al_2O_3 90 nm vs SiO_2 75 nm passivation layer.

2-Sample T for Al_2O_3 90nm vs SiO_2 75nm

	N	Mean	StDev	SE Mean
Al_2O_3 90 nm	29	1013	110	20
SiO_2 75 nm	29	892	105	19

Difference = mu 900 - mu normal
Estimate for difference: 121.1
95 % lower bound for difference: 74.0
T-Test of difference = 0 (vs >): T-Value = 4.30
P-Value = 0.000 DF = 55

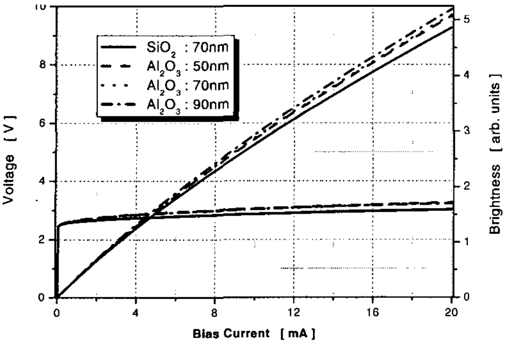

Fig. 3. L-I-Vcurves of packaged LED lamps with passivation layers

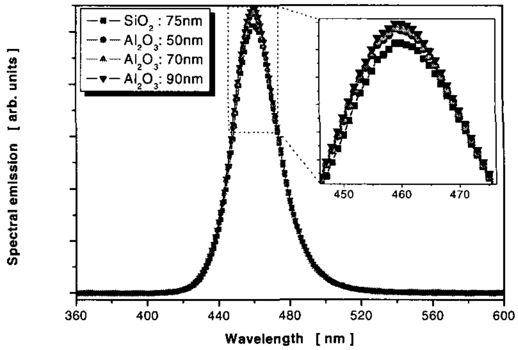

Fig. 4. Emissionspectra of packaged LED lamps with passivation layers at 20 mA of bias current.

with Al_2O_3 passivation layer at 20 mA show about 0.25 V higher values than those with SiO_2. However the driving voltages of our packaged LEDs with Al_2O_3 passivation layers are less than 3.5 V at 20 mA which is the typical value of conventional products being used in applications now. We are thinking that the increase of biasing voltage is from Al_2O_3 deposition process, RF sputtering which still wasn't optimized. So, we are doing an additional investigation that optimizes Al_2O_3 sputtering without increasing driving voltage.

Figure 3 showed emission spectra of packaged LED lamps with passivation layers which is SiO_2 75 nm and Al_2O_3 50~90 nm at 20 mA of bias current. Figure 3 indicates that materials (SiO_2 and Al_2O_3) of the passivation layer on InGaN/GaN LED chips had nothing to do with peak wavelengths which are all about 460 nm. Also, lamps with Al_2O_3 passivation layer showed higher intensity than lamps with SiO_2 passivation layer at peak wavelength and lamps with Al_2O_3 90 nm passivation layer had the highest intensity among the other lamps without the change of peak wavelength.

In this study, we found that the lamps with Al_2O_3 passivation layer were brighter than the lamps with SiO_2 passivation layer. However, bare chips without packaging process showed the opposite trend. Also, the brightness of the packaged LED lamps increased as the thickness of Al_2O_3 layer increased, and in case of 90 nm Al_2O_3 passivation condition, the highest brightness was obtained. For normal incidence, Fresnel reflection at the interface can be reduced to zero, if an anti-reflection coating which is passivation layer at blue LEDs has the following parameters:

$$\textit{refractive index}: \mathrm{n}_{\mathrm{AR}} = \sqrt{\mathrm{n}_{\mathrm{T}} \times \mathrm{n}_{\mathrm{P}}} \quad ,$$

$$\textit{thickness}: \frac{\lambda}{4} = \frac{\lambda_0}{4\,\mathrm{n}_{\mathrm{AR}}}$$

n_{AR} is refractive index of anti-reflection layer (passivation layer), n_T and n_P are respectively refractive indexes of transparent conductive oxide (NiO in this study) and plastic package material, and λ is wavelength. Therefore, ideal refractive index of passivation layer in Blue LEDs has to be located in near 1.75 in order to reduce Fresnel loss between NiO and package material. In this study, refractive indices of SiO_2 and Al_2O_3were 1.50 and 1.62, respectively. So, we are considering that lamps with Al_2O_3 passivation layers show higher brightness than lamps with SiO_2 passivation layers because the refractive index of Al_2O_3 thin film is nearer to the ideal refractive index of about 1.75 than that of SiO_2 thin film. In the second equation, we can find the theoretically ideal thickness of Al_2O_3 passivation layer whose value is about 72.5 nm.

However, the highest brightness was indicated at 90 nm Al_2O_3 passivation layer on lamp condition. We are considering additional study in order to explain and improve the differences between the values from theoretically calculated and actually measured the thickness of the Al_2O_3 passivation layer.

4. CONCLUSION

In this study, we have improved the brightness of lamps which were made of the LEDs with 90 nm Al_2O_3 passivation layer without changing of emitting wavelength, even though LEDs with 90 nm Al_2O_3 passivation layer had lower brightness than normal LED with 75 nm SiO_2 passivation layer which is normally used in LED market on bare chip condition. This brightness has been improved about 13.6 % compare to the lamps made of normal LEDs. We consider that this brightness improve is from reducing Fresnel loss between transparent conductive oxide and package material.

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