1. INTRODUCTION

Recently light-emitting diodes (LEDs) have been widely applied for use in a variety of optoelectronic devices such as LCD back light unit, mobile phone displays, signal lamps, automobile and illumination display panels and so on. Normally, a blue GaN LED and fluorescent material (YAG) are used to make a white LED, as the blue GaN LED has the larger energy. Especially, the blue GaN LEDs are attractive due to their high brightness and high power capability in lighting and display applications. The internal quantum efficiency of a Blue GaN LED has been developed to an almost optimum stage.

However, the critical angle is 23.5°, as a consequence of the refractive indexes of GaN (n = 2.5 at 470 nm) and air. Only about 4% of the emitted light radiates through the top and bottom [1]. There are many technologies such as a transparent electrode, a die shaping technology, a wafer bonding technology and an epoxy dome technology and so on for improving the light extraction efficiency of a blue GaN LED with a wavelength of 470 nm. This paper reports on the adoption of a transparent electrode to improve the light extraction efficiency of this LED, and the electrode being used to match refractive index between GaN and air.

Al-doped zinc oxide (AZO) holds advantages in the respects of low cost, being free of toxic materials and stability against hydrogen plasma. Especially, it has a much higher transmittance than that of indium tin oxide (ITO, T = 79%) for the blue GaN LED under investigation. Due to these factors, the AZO film has been considered to be the most potentially viable alternative to ITO.
which has already been extensively adopted as a transparent conducting film material, but is becoming extremely expensive because of the rare metal indium is becoming in increasingly short supply and also it has a low transmittance due to a high absorption ratio at the wavelength of 470 nm [2].

Under the various growth conditions such as work pressure, substrate temperature and annealing temperature, the growth of ZnO-based thin films has been widely investigated [3]. However, studies on light extraction efficiency for the blue GaN LED with a wavelength of 470 nm using AZO-based thin film are rarely found in published literature.

In this paper, a study on the optimal process conditions for an AZO:H₂ thin film was investigated to improve light extraction efficiency of the blue GaN LED of interest, by the use of an radio-frequency (RF) magnetron sputtering system.

2. EXPERIMENTS

The AZO:H₂ thin films were deposited on a sapphire substrate by an RF magnetron sputtering system with a base pressure of 8 × 10⁻⁶ Torr using a AZO (2wt% Al₂O₃) ceramic target [4,5]. The substrates were ultrasonically cleaned sequentially in acetone, alcohol and de-ionized water and dried with nitrogen gas. The H₂/(Ar+H₂) percentage was maintained at 1% [6]. The working pressure was varied from 4 to 13 mTorr. The substrate temperature was changed from 300 to 600°C. The AZO target was pre-sputtered for 10 minutes to remove surface contamination and maintain the system stability. The thickness of the AZO:H₂ films was 410 ± 10 nm [7]. The distance between the target and the substrate and the RF power were 60 mm and 150 W, respectively [8]. The annealing treatments were carried out by changing the annealing temperature from 200°C to 500°C in hydrogen ambient for 60 minutes [6].

The phase and crystal structure of the deposited AZO:H₂ films were determined by X-ray diffraction (XRD: Riraku, Max 2500H; Japan). The film thickness and surface morphology were examined by field emission scanning electron microscopy (FE-SEM: Hitachi, S-4800; Japan). The optical transmittance of the films was measured by a UV-Vis spectrophotometer (Scinco, S-3100; Korea) in the wavelength range of 350-1,100 nm. The electrical properties were examined by the Hall effect system (Ecopia, HMS-3000; Korea) using Van der Pauw geometry. The details of the deposition and annealing conditions of the AZO:H₂ thin films are listed in Table 1.

3. RESULTS AND DISCUSSION

3.1 The micro-structural properties

3.1.1 The working pressure

Figure 1 shows the surface morphologies of the AZO:H₂ thin films deposited in the various working pressures (substrate temperature: 500°C) (a) 4 mTorr, (b) 7 mTorr, (c) 10 mTorr, (d) 13 mTorr.

Figure 2 demonstrates the XRD patterns of the AZO:H₂ films deposited in the various working pressures (substrate temperature: 500°C). H₂/(Ar+H₂) percentage was maintained at 1% [6]. The working pressure was varied from 4 to 13 mTorr. The substrate temperature was changed from 300 to 600°C. The AZO target was pre-sputtered for 10 minutes to remove surface contamination and maintain the system stability. The thickness of the AZO:H₂ films was 410 ± 10 nm [7]. The distance between the target and the substrate and the RF power were 60 mm and 150 W, respectively [8]. The annealing treatments were carried out by changing the annealing temperature from 200°C to 500°C in hydrogen ambient for 60 minutes [6].

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