Thin film AlGaInP light emitting diodes with different reflectors*

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Abstract: The reflectivity versus incident angle of a GaP/Au reflector, a GaP/SiO_2/Au triple ODR (omni-directional reflector) and a GaP/ITO/Au triple ODR was calculated. Compared to AlGaInP LEDs with a GaAs absorbing substrate, thin film LEDs with a Au reflector, a SiO_2 ODR and an ITO ODR were fabricated. At a current of 20 mA, the optical output power of four samples was respectively 1.04, 1.14, 2.53 and 2.15 mW. The Au diffusion in the annealing process reduces the reflectivity of the Au/GaP reflector to 9%. The different transmittance of quarter-wave thickness ITO and SiO_2 induces different optical output power between the SiO_2 and ITO thin film LEDs. The insertion of Zn in the ITO ODR LED does not affect the light output but evidently reduces the voltage.

Key words: LE; AlGaInP; ODR
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1. Introduction

High brightness AlGaInP red, orange and yellow light emitting diodes (LEDs) in the early 1990s and later the InGaN blue, green and white LEDs have created a lot of new applications, such as traffic signals, automotive lighting and full color outdoor displays for these high efficient solid state lighting sources[1]. In common AlGaInP light emitting diodes, the light-emitting epitaxial layers are grown on conducting GaAs, which absorbs light from the active region. Much research has been done on thin-film AlGaInP LEDs, which transfer the emitting light epi-layer to a Si substrate[2]. In thin-film LEDs, the reflector can be a metal reflector or a triple-layer omni-directional reflector (ODR)[3, 4].

In this paper, the reflectivity versus the incident angle of a GaP/Au reflector, a GaP/SiO_2/Au triple ODR and a GaP/ITO/Au triple ODR was calculated. Four AlGaInP LED samples with an absorbing substrate, a GaP/Au reflector, a GaP/SiO_2/Au ODR and a GaP/ITO/AuZnAu ODR were fabricated and then analyzed.

2. Theoretical calculation

Triple-layer ODRs comprising a semiconductor with a refractive index n_s, a low-refractive index layer (n_{li}) of quarter-wave thickness and a metal with a complex refractive index $N_m = n_m + ik_m$, where k_m is the extinction coefficient, have been introduced in an AlGaInP LED. Both the transparent insulated layer SiO_2 (n_{li1} = 1.45) and the transparent conductive layer ITO (indium tin oxide, n_{li2} = 1.8[5]) are used as a low-refractive index layer to AlGaInP LED incorporating ODR[6, 7].

Figure 1 shows the angular dependence of the reflectivity of a triple layer ODR GaP/SiO_2/Au, GaP/ITO/Au, and Au metal reflector ($n_{Au} = 0.18$, $k_{Au} = 2.7$, $n_{GaP} = 3.3$) at 630 nm[8]. The reflectivity of the Au metal reflector, SiO_2 ODR and ITO ODR is 88%, 97% and 95.8%, respectively, at normal incidence. The average reflectivity from angle 0° to 90° of the three reflector is 96.8%, 97.74% and 93.8%, respectively.

3. Experiment and discussion

The LED epi-layer was grown by MOCVD and it consisted of an etching stop layer GaInP, a heavily doped n-GaAs ohmic contact layer, an n-AlGaInP current spreading layer, active and confinement layers, and a 8 μm p-GaP layer. A conventional structure AlGaInP LED with an absorbing substrate (AS) was made for reference. The SiO_2, ITO, and metal Au Zn layers were deposited, respectively, by PECVD, e-beam evaporation and sputter. Both SiO_2 and ITO low-refractive index layers were quarter-wave thick. The SiO_2 layer was partly etched and

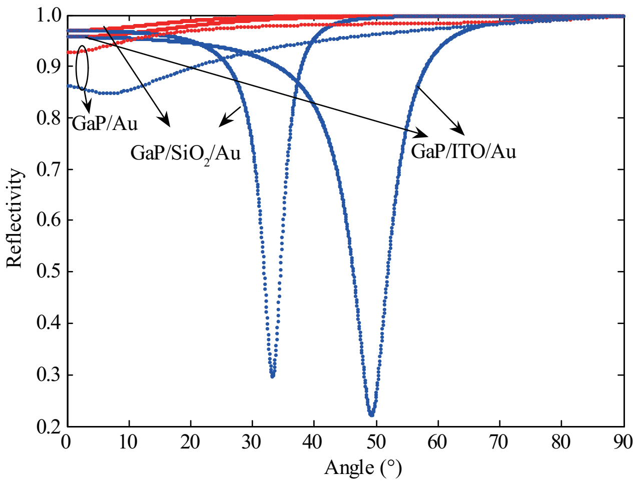

Fig. 1. Calculated reflectivity versus angle of incidence for an Au reflector, a SiO_2 ODR and an ITO ODR.

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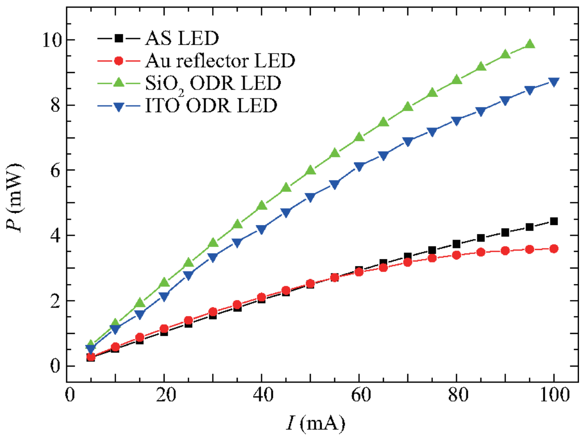

Fig. 2. Characteristic of four samples between current and optical output power.

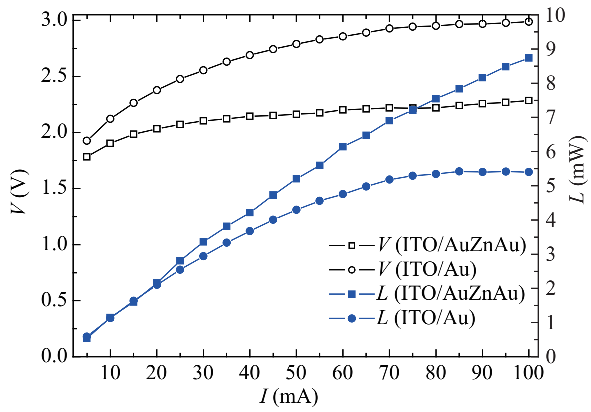

Fig. 3. I–V and L–I curves of ITO ODR LEDs with and without Zn.

filled with an array of AuZnAu micro-contacts for ohmic contact. The ITO layer directly contacts with the AuZnAu layer. The GaAs wafer and Si conductive substrate were bonded together using a 1 μm Au layer by a SUSS SB6 bonder though temperature and pressure. After the GaAs substrate and GaInP etching stop layer were removed, AuGeNi was deposited as an n-type electrode. The GaAs ohmic contact layer was etched except for the part under the shaped electrode. After annealing and cutting into 275 $\times$ 275 μm^2 chips, the LEDs were packaged into TO-18 without epoxy resin.

Figure 2 shows the optical output power versus the drive current characteristic. At a current of 20 mA, the optical output power is 1.04 mW, 1.14 mW, 2.53 mW and 2.15 mW for an AS LED, a Au reflector LED, a SiO_2 thin film LED and an ITO thin film LED, respectively. The voltage is 2.13 V, 2.24 V, 2.03 V and 2.03 V, respectively. Obviously, the light output power of the Au reflector LED saturates at 90 mA because of the high voltage. High current performance and low voltage can be received though a Au bonding process. The metal Au bonding layer has better heat conductivity than silver paste[9]. The light intensity of the LED bonding with silver paste is saturated at 60 mA.

Compared with the calculation result, the Au reflector thin film LED does not show the corresponding performance. The reflectivity of the Au/GaP reflector was low to 9% after a 40 s annealing process at 435 ℃. The insertion of a transparent layer can prevent the reflectivity degradation of the metal reflector because the reflectivity does not change obviously in the annealing process. The purpose of the transparent intermediate layer is to avoid the interaction between the high reflectivity metal layer and the p-GaP in the LED epi-layers during the ohmic contact annealing process.

The light output power of the SiO_2 thin film LED is 1.18 times higher than that of the ITO thin film LED at 20 mA. This is different with the calculated result, which has been shown in Fig. 1. The transmittance of quarter-wave thickness ITO is 93% and that of quarter-wave SiO_2 is almost 100% at 630 nm. The reason for the lower light output power is the enlarged absorption of ITO in the reflected back and forth way. The drawback of the SiO_2 ODR LED is the complicated process, including the etching of the conductive hole and the lift off of AuZnAu.

The ITO ODR comprises AuZnAu (10 nm/10 nm/1 μm), ITO, and GaP. Figure 3 shows the light output power-current-voltage (L–I–V) characteristics of the ITO ODR LEDs with and without Zn. The voltage (@ 20 mA) of the LED without Zn is 2.38 V. The Zn in AuZnAu layer does not affect the light output power, but it could remarkably reduce the voltage of the thin film LED. The diffusion of Zn passes through the ITO layer and reaches the p-GaP layer. So, the voltage could be reduced. At the same time, the diffusion of Zn though the ITO does not affect the performance of the ITO/Au ODR. As shown in Fig. 3, the light output power of the ITO/Au ODR LED became saturated at 80 mA because of high voltage and high series resistance.

In this paper, a roughened surface and some other improving processes have not been introduced in order to compare the reflectors' performance. But a roughened surface can improve the light output more than a conventional LED[10]. Further improvement is expected.

4. Conclusion

The reflectivity versus incident angle of a Au reflector, a SiO_2 ODR and an ITO ODR are calculated. At normal incidence, the reflectivity is 88%, 97% and 95.8%, respectively. Four AlGaInP LED samples with an absorbing substrate, a GaP/Au reflector, a GaP/SiO_2/AuODR and a GaP/ITO/Au ODR are presented. At a current of 20 mA, the optical output power was 1.04, 1.14, 2.53 and 2.15 mW, respectively. The output light powers of the AS and Au reflector LEDs were almost the same because of the Au diffusion in the annealing process. The output light power of an ITO thin film LED was lower than that of a SiO_2 thin film LED because of the absorbing ITO layer. The insertion of Zn in an ITO ODR LED does not affect the light output but evidently reduces the voltage.

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