Reliability of AlGaInP light emitting diodes with an ITO current spreading layer*

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Abstract: Three aging experiments were performed for AlGaInP light emitting diodes (LED) with or without indium tin oxide (ITO), which is used as a current spreading layer. It was found that the voltage of the LED with an ITO film increased at a high current stressing, while there was little change for that of the LED without the ITO. The results of the LEDs with different thicknesses of the ITO film show that the LED with a thicker ITO has a higher reliability. The main reason for the voltage increase of the LED with the ITO film might be the current crowding in the ITO film around the P-type electrode.

Key words: indium tin oxide; AlGaInP; light-emitting diode; reliability
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1. Introduction

High brightness light emitting diodes (LED) are used in many areas, such as solid-state lighting, outdoor displays, traffic signals, and automobile indicators[1]. Indium tin oxide (ITO) films exhibit excellent light transmission characteristics in the visible region of the spectrum while maintaining a high electrical conductivity. Because of this unique combination of properties, ITO is widely used in LEDs to improve the light extraction efficiency, both for AlGaInP LEDs and for InGaN LEDs[2–5].

In this paper, the reliability of the ITO in AlGaInP LEDs is investigated in three experiments. A degradation of the ITO is notable at a high current, but there is no degradation at high temperatures. The higher the current is and the higher the junction temperature is, the higher the forward voltage in AlGaInP LEDs induced by the ITO. For a thicker ITO layer, the increment is decreased.

2. Experiments and results

The LED layers are grown on a GaAs substrate by metal-oxide chemical vapor deposition. A schematic drawing of the device structure is shown in Fig. 1. Figure 1(a) shows the schematic of a conventional AlGaInP LED, whose external quantum efficiency is low because of the light absorption by the electrode. Figure 1(b) shows the new LED with higher external quantum efficiency. SiO_2, which is deposited by plasma-enhanced chemical vapor deposition, acts as a current barrier in this design because of its insulating properties and its transparency. The ITO layer, which is used as a current spreading layer, was deposited on top of the LED epi-layer by electron-beam evaporation.

Traditionally, there are two methods to predict the lifetime of an LED, by using a high temperature or by using a high current. In this paper, three groups of experiments were carried out for different samples in order to study the reliability of AlGaInP light emitting diodes with ITO current spreading layers.

2.1. Aging test for conventional and new LEDs

Three kinds of samples were made: a conventional LED without ITO (A1); a new LED with an ITO layer (A2); a new LED with an ITO layer and packaged by an epoxy resin (A3). The thicknesses of the samples A2 and A3 are $\lambda/4$. Here, the symbol λ is the peak wavelength of the LED in the ITO material. Samples A1 and A2 were aged at a constant high current I = 80 mA at room temperature, while A3 was aged in an oven using a current of I = 20 mA and an ambient temperature of 90 °C. The aging result is shown in Fig. 2, where the voltage and the light output were measured with I = 20 mA at room temperature. After the 6000-hour aging test, all three kinds of samples do not show a notable degradation except for the voltage increment of A2.

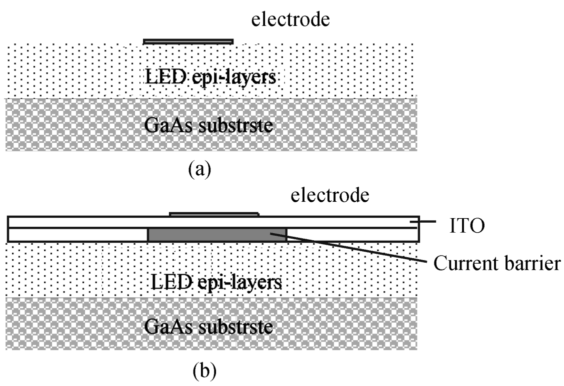

Fig. 1. Schematic of the LED: (a) Conventional LED; (b) New LED with ITO.

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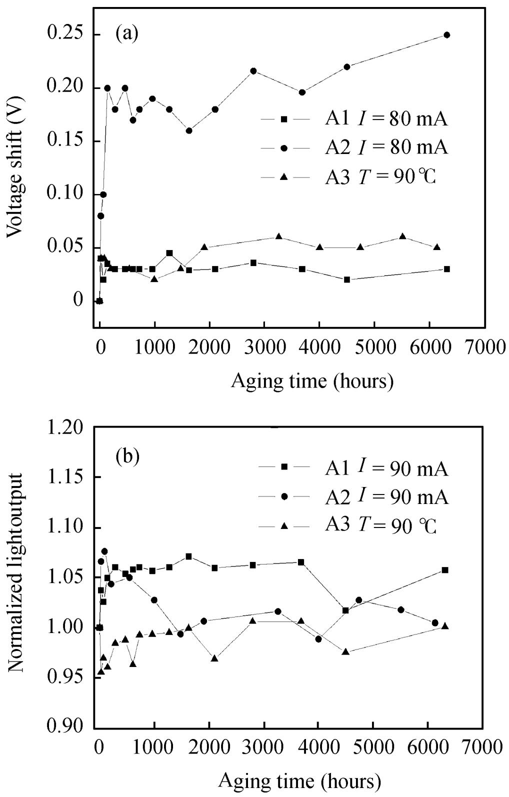

Fig. 2. (a) Voltage and (b) light output aging properties of group A.

While the forward current increased from I = 20 mA to I = 80 mA, the peak wavelength of sample A2 shifts from 629 to 639 nm. In other words, the LED with I = 80 mA has a 10 nm longer wavelength. According to the wavelength coefficient K_p = 0.1376 nm/°C for AlGaInP LED, which is the change rate of the junction temperature (ΔT_j) at the peak wavelength ($\Delta\lambda_p$)[6], the junction temperature can be calculated by the equation $T_j = T_a + \Delta\lambda_p/K_p$. Here, T_a is the ambient temperature of the environment. In this experiment, the equation would be $T_j = 23 + 10/0.1376 = 95.7$ °C. So, we can suppose that the thermal effect is almost the same for A2 and A3. In other words, the voltage increment of A2 is mainly induced by the high current. There is little change for A1 and A3. Therefore, the degradation of A2 is induced by the high current in the ITO.

2.2. Different thicknesses of the ITO film

New LEDs with different thicknesses of the ITO films were made. The LED chip size is 225 × 225 μm^2 and they are packaged into TO-18 without epoxy resin. The ITO thickness of the LEDs is λ/4 (B1) and 3λ/4 (B2), respectively. The aging current was 140 mA. The aging result is shown in Fig. 3. The figure shows that if the ITO film thickness increases, the slope of the voltage increase reduces.

2.3. Different aging currents and sizes

Different chip-sizes with new LEDs, packaged into TO-18 without epoxy resin, were made. One chip size is 200 × 200 μm^2 (C1) and another is 225 × 225 μm^2 (C2). After 6000 hours of aging at forward currents of I = 80 mA and I = 90 mA, the voltage increment is shown in Table 1. It can be seen

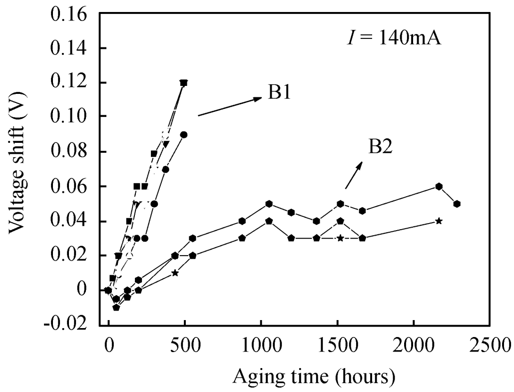

Fig. 3. Voltage aging properties of group B.

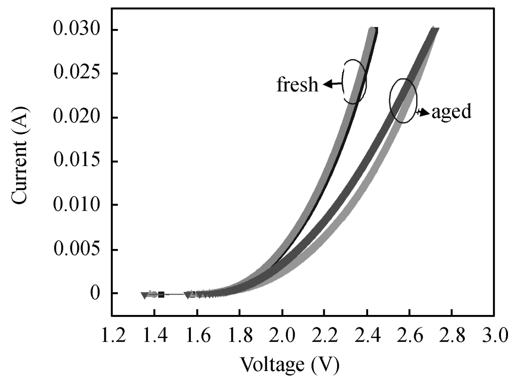

Fig. 4. Current–voltage relationship of the fresh and the aged LED.

Table 1. Voltage increment of group C at an aging time of T = 6000 hours.

	C1 (200 × 200 μm^2)	C2 (225 × 225 μm^2)
I = 90 mA	0.855	0.3125
I = 80 mA	0.407	0.29

from the table, that a smaller chip leads to a larger voltage change; a higher current leads to a larger change. As we know,the smaller area LEDs have a higher junction. So, for the condition of a high current, the high junction temperature accelerates the failure process.

3. Discussion

There is no notable decrease of the light output power for the LEDs in all of the experiments. The current–voltage relationship of the fresh and aged LED is shown in Fig. 4. It reveals that the LEDs' series resistances increase after aging compared to the series resistance of a fresh LED. As the stressing current is constant, the increase of the voltage will induce an increase of the junction temperature. Inversely, the higher temperature accelerates the voltage increase. At last, a failure will happen.

As a current spreading layer, the ITO film transfers the current from the P-type electrode to the whole LED area. The current density on the ITO around the electrode is bigger than that in the other areas. This current concentration may be the main reason of the ITO degradation. Traditionally, along with time, the LED light output power decreases exponentially[7]. From the above experiments, the voltage failure happens before the light drop becomes evident. The exact relationship between voltage, time, current, and junction temperature needs to be studied further.

In 1996, Chao pointed out that ITO damage in polymeric light emitting diodes[8] only depends on the applied electric field strength. The ITO damage results from a self-decomposition reaction. What exactly happens in the ITO film of AlGaInP LED is not known as so far.

4. Conclusion

In this paper, we find that the ITO film in an AlGaInP LED is the main reason of the voltage increment in the aging process. With higher aging currents, the increment accelerates. Compared to what is happening at a thickness of $3\lambda/4$, ITO films with a thickness of $\lambda/4$ fail much faster. At last, the reliability of the AlGaInP LED with ITO was discussed.

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