High-Performance AlGaN-Based flip-chip Ultraviolet Light-Emitting Diodes with epitaxial ITO/Al reflective mirror and Symmetry Electrode arrangement

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ABSTRACT

AlGaN-Based flip-chip Ultraviolet Light-Emitting Diodes at 365 nm with epitaxial ITO transparent ohmic contact layers and Al reflective were fabricated. The epitaxial ITO thin film exhibits higher transmittance than that of sputter ITO thin film at 365nm, which is 93.6% and 85%, respectively. The epitaxial ITO thin film is more suitable for 365nm UV-LED. And the reflectance of the ITO/Al layers is 81.2% at 365nm, much higher than that of the ITO/Ag layers, which is only 53.2% at 365nm. When the current injection is 350mA, the forward voltages are 3.43V and 4.05V for flip-chip UV-LED and conventional UV-LED, respectively. The forward voltages of flip-chip UV-LED is much lower than that of conventional UV-LED, because the series resistance (*R*s) of the flip-chip UV-LED is 0.73 Ω, much lower than 2.98 Ω of conventional UV-LED. The flip-chip UV-LED with epitaxial ITO/Al reflective mirror and Symmetry Electrode arrangement is more suitable for high power application.

GENERAL

NITRIDE-BASED wide bandgap semiconductors are widely used in electronic and opto-electronic devices such as light-emitting diodes (LEDs), laser diodes and photodetectors [1], [2]. Over the last decade, AlGaN-based near-ultraviolet (near-UV) LEDs with operating wavelengths ranging from 365 nm to 410 nm have drawn increasing attention because of applications that include UV curing of dyes, solid-state lighting, laser security, and medical sterilization [3]. Most applications require UV LEDs to provide the highest possible optical power density. However, the current performance of near-UV LEDs, particularly at the wavelength of 365 nm, is still too low for many applications because of the poor crystal quality and low hole density of AlGaN [3], [4]. Consequently, it is necessary to improve the optical efficiency of near-UV LEDs to be as high as possible.

EXPERIMENTS

AlGaN-based Ultraviolet LED epitaxial structures were grown on 2-inch c-plane patterned sapphire substrate by MOCVD with an emission wavelength of near 365-nm. The LED structure in this study consist of a 20-nm AlGaN buffer layer, a 4-μm-thick unintentionally doped AlGaN template, a 2-μm-thick Si-doped n-AlGaN layer, a 150-nm-thick strain-compensated AlGaInN/AlGaN superlattice layer, a 250-nm-thick 9-pair of AlGaInN/AlGaN multiple quantum well, a 40-nm thick electron blocking layer, a 100-nm-thick Mg-doped p-AlGaN layer, and 3-nm-thick p^+-GaN for contact layer. Then, a 50-nm-thick ITO was grown as transparent conductive layer on the surface of the LED epitaxial layer by MD 600A 38×2” MOCVD system with Turbo-disc chamber manufactured by S. C. Tech. Co. The detail growth condition of ITO was described as follows. Trimethyl Indium (TMIn), Tetrakis-Dimethylamino Tin (TDMASn), Oxygen and Argon were used as the precursors of In, Sn, O precursors and carrier gas, respectively. The growth temperature and chamber pressure were 500 °C and 12.5 Torr, respectively. The structure of our AlGaN-Based flip-chip ultraviolet light-emitting diodes with epitaxial ITO/Al reflective mirror and symmetry electrode arrangement is shown in Figure 1，and the LED chip is fabricated by the following processes. First, the ITO layer was partially removed by HCl and HNO_3 solution, 10:1, followed by inductively coupled plasma (ICP) etching to form the mesa structure, and the etch depth used was 1.35μm in order to expose the n-AlGaN surface. Then the n-fingers metal layers Cr/Al/Ni/Au/Cr (50/2500/200/600/200A) was deposited on the n-AlGaN surface to extend current and the metal reflective layers Cr/Al/Ni/Au/Cr (2/2500/200/600/200A) was deposited on the ITO surface to form a good ohmic contact with ITO, as well as a UV high reflective interface. And the insulation layer, 1-μm-thick SiO_2, was deposited on the above structure using plasma-enhanced chemical vapor deposition (PECVD). The SiO_2 on top of n-fingers and reflective layer was partially removed by 7:1 buffered oxide agent, and then the symmetry electrode metal layers Cr/Al/Ni/Au (50/2500/500/600A) was deposited, which is respectively connected to n-fingers and reflective layers through the holes in the insulating layer. The symmetry electrode was thickened by electroplating 1 μm Au layer to strengthen the electrical connection and is conducive to heat conduction. Finally, the chip was soldered to ceramic sub-mount by SnAgCuX welding materials.

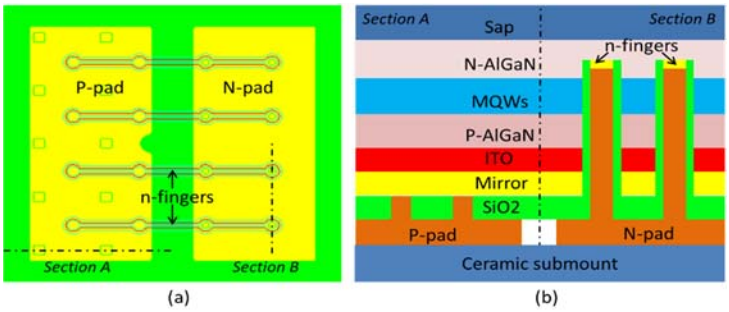

Figure 1 Structure of the flip-chip LED with metal reflective layer and symmetric electrode. (a) Symmetric electrode side up. (b) Cross-sectional view.

The transmittance of epitaxial ITO thin films and the reflectance of the ITO/Al and ITO/Ag reflective mirror were also measured. The epitaxial ITO thin films were grown on c-plane sapphires substrates for this experiment and the thickness of Al and Ag layers was 250nm. In order to study the effect of symmetry electrode structure on LED chip performance, a convectional UV LED was also fabricated. The chip sizes of convectional UV LED and the flip-chip LED are both 45mil×45mil. The transparent conductive layer of the convectional UV LED is the epitaxial ITO thin film, and the positive and negative electrodes of the convectional UV LED is Cr/Pd/Au(200/400/2000A).

RESULTS AND DISCUSSION

The transmittance of the ITO thin films and the reflectance of the ITO/Al and ITO/Ag layers were measured by a Shimadzu UV-2550, and the results are shown in Figure 2. The epitaxial ITO thin film exhibits higher transmittance than that of sputter ITO thin film at 365nm, which is 93.6% and 85%, respectively. This proved that the epitaxial ITO thin film is more suitable for 365nm UV-LED. And the reflectance of the ITO/Al layers is 81.2% at 365nm, much higher than that of the ITO/Ag layers, which is only 53.2% at 365nm.

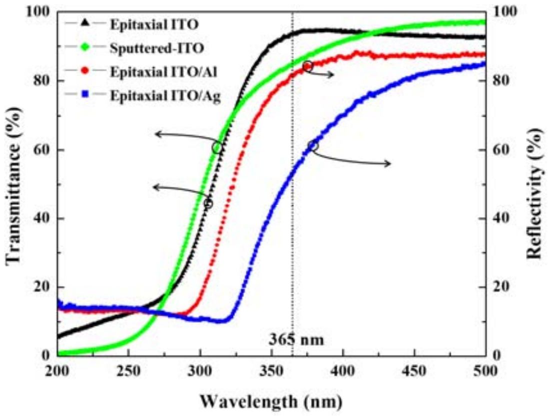

Figure 2 Transmittance of the ITO film and reflectivity of the ITO/Al and ITO/Ag layers.

The electrical and optical characteristic of the ultraviolet light-emitting diodes was measured by IPT 6000-LED Probing System with Integrated Tester at room temperature. Figure 3 shows the I-V characteristics of the fabricated flip-chip UV-LED and conventional UV-LED, and when the current injection is 350mA, the forward voltages are 3.43V and 4.05V for flip-chip UV-LED and conventional UV-LED, respectively. The forward voltages of flip-chip UV-LED is much lower than that of conventional UV-LED, because the series resistance (*R*s) of the flip-chip UV-LED is 0.73 Ω, much lower than 2.98 Ω of conventional UV-LED. The low series resistance of flip-chip UV-LED proved that the contact between ITO and p-GaN shows good ohmic characteristics, and the difference between flip-chip UV-LED and conventional UV-LED can be attributed to the chip structure. The structure of flip-chip UV-LED has better current extensibility.

The inserted map is the photograph of the bare LED chip, lit by 20mA current. The photograph shows that the light intensity distribution of the flip-chip UV-LED is relatively uniform, which proved that the structure of flip-chip UV-LED has better current extensibility.

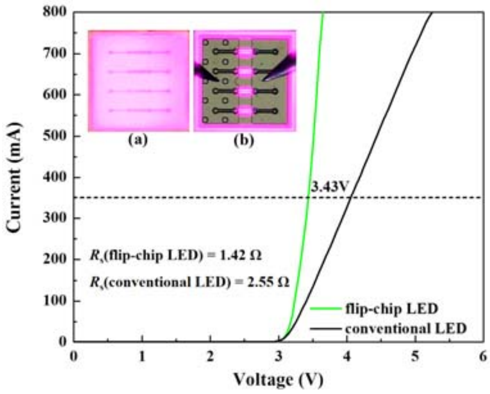

Figure 3 I-V curve and physical picture of the flip-chip UV-LED (FC-LED) and conventional UV-LED (C-LED). (The inserted map: (a) sapphire side up (b) symmetrical electrode side up)

Figure 4 shows the Light output power (LOP) and Wavelength Peak (WLP) of the fabricated flip-chip UV-LED and conventional UV-LED under different input current. As the current increases, the output power of the flip-chip UV-LED almost increases linearly and slightly slows down until the input current reaches 700mA, while the output power of conventional UV-LED sharply slows down when the input current reaches 600mA. This result proved that the flip-chip UV-LED with epitaxial ITO/Al reflective mirror and Symmetry Electrode arrangement is more suitable for high power application. The wavelength peak of the flip-chip UV-LED is 368.19nm under 350mA. And when the current changes from 100mA to 800mA, it slightly shifts from 367.53nm to 369.71nm, while the wavelength peak of the conventional UV-LED shifts from 367.51nm to 370.38nm. This means that the emitting wavelength of the flip-chip UV-LED that we have fabricated is relatively stable, and it can be attributed to the better heat dissipation performance of the flip-chip UV-LED with Symmetry Electrode arrangement.

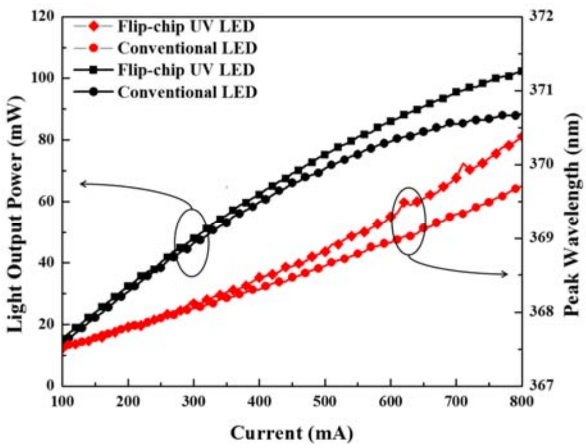

Figure 4 LOP and WLP of the flip-chip UV-LED (FC-LED) and conventional UV-LED (C-LED)

under different input current

In this paper, we fabricate the 368nm LED with a novel ITO contact layer and analysis the performance of this kind of flip-chip LED with Symmetry Electrode.

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