Combining Al_2O_3 and SiO_2 for nitride semiconductor LED passivation

Patterning of a silicon dioxide/aluminium oxide passivation layer has improved LED light output power by more than 20% at 60mA.

Researchers in China have developed a silicon dioxide (SiO_2) on aluminium oxide (Al_2O_3) passivation for nitride semiconductor light-emitting diodes (LEDs) that offers more than two orders of magnitude reduced current leakage under reverse bias [Hao Guo et al, Appl. Phys. Express, vol6, p072103, 2013]. Further, by patterning the SiO_2 layer with an array of hemispheres, the light output power (LOP) is increased by up to 22% at 60mA.

Table 1. Measured surface etching profiles of patterned SiO_2 / Al_2O_3 passivation layer under different reflow conditions.

Sample	Reflow temperature (°C)	Reflow time (min)	Hemisphere height (nm)	Hemisphere base diameter (μm)
A	0	0	491	1.56
B	160	5	476	1.58
C	160	7	456	1.63
D	160	9	347	1.69
E	160	11	205	1.86

The research was based at Chinese Academy of Sciences' Institute of Microelectronics, Southeast University, and Nanchang University.

The epitaxial material was grown using metal-organic chemical vapor deposition (MOCVD) on patterned sapphire. The pattern of 2.1μm diameter, 0.9μm height and 0.9μm separation was created using photolitho-

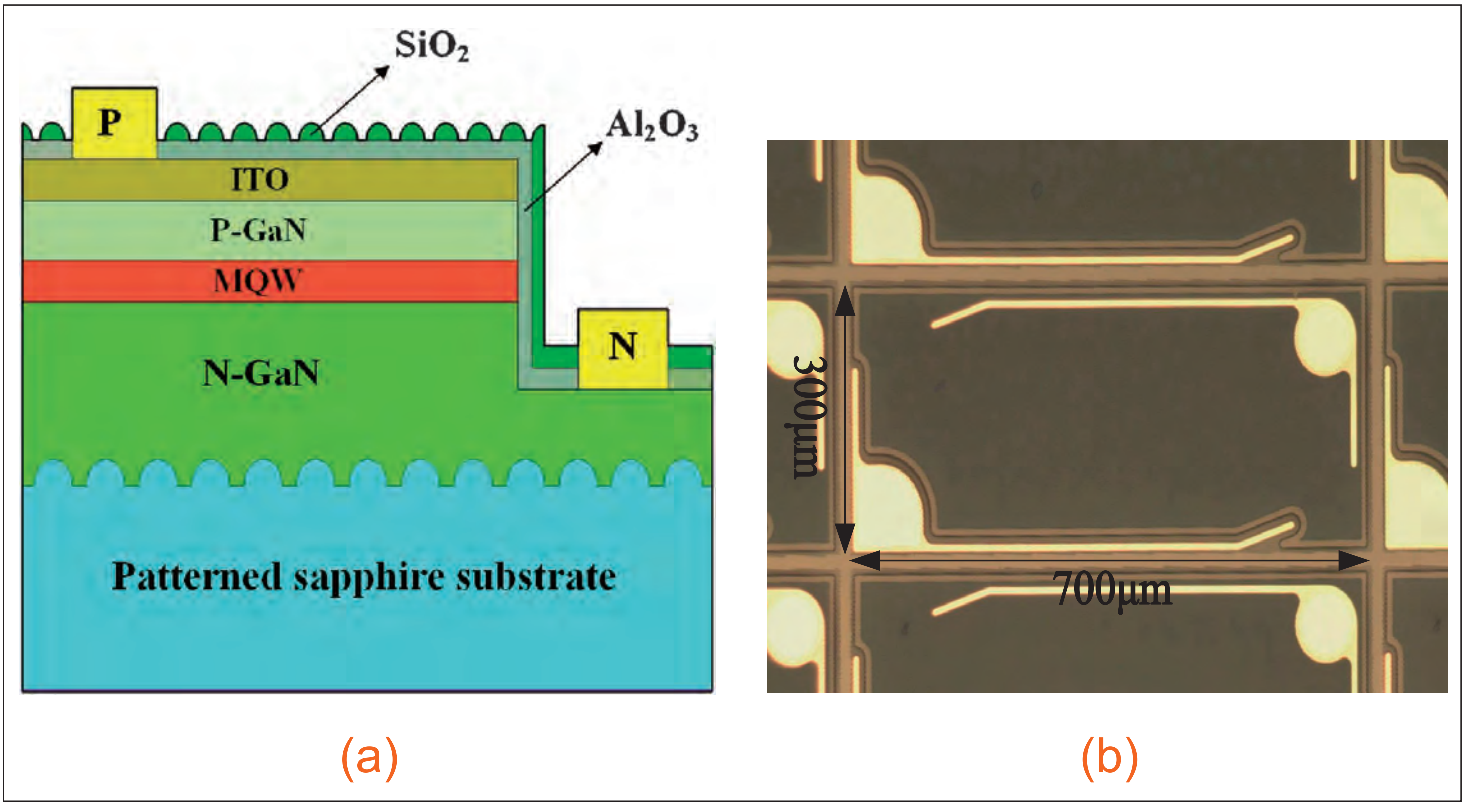

Figure 1. (a) Schematic of LED on patterned sapphire with patterned SiO_2 / Al_2O_3 passivation. (b) Photograph of fabricated 300μm x 700μm LED chips.

graphy and inductively coupled plasma (ICP) etch.

The LED nitride semiconductor layers consisted of a 30nm GaN buffer, 4.5μm n-GaN contact, six-pair InGaN/GaN multi-quantum-well active region, and 0.9μm p-GaN contact. These layers were followed by 240nm of indium tin oxide (ITO) as a transparent conducting layer on the p-contact. Chromium/platinium/gold metal layers for the electrodes were deposited on the n-GaN and ITO. The devices emitted at wavelengths of around 460nm. The fabricated LED devices measured 300μm x 700μm.

After experimenting with various Al_2O_3, silicon nitride and SiO_2 passivation layers for the LED, the researchers decided to develop a combined SiO_2/Al_2O_3 oxide process. The Al_2O_3 was found to have a good surface passivation effect, as evidenced by a very low reverse bias (–5V) leakage current of -9.3×10^{-10}A when applied using atomic layer deposition (ALD). The surface passivation offered by plasma-enhanced chemical vapor deposited (PECVD) SiO_2 was relatively poor, with a reverse bias leakage of -1.8×10^{-7}A. However, the light output power (LOP) from the LED was 45.4mW with SiO_2 passivation, compared with 42.7mW for the Al_2O_3 layer.

The effect of the Al_2O_3 passivation is believed to be a decreased trap density near the surface. Such surface traps provide routes for reverse leakage currents and for non-radiative surface recombination.

In the combined SiO_2/Al_2O_3 passivation (Figure 1), the top SiO_2 was also patterned into a triangular array of 2μm-diameter hemispheres spaced by 1μm, designed to reduce total internal reflection and hence increase light extraction. The Al_2O_3 layer was 10nm and the SiO_2 500nm.

The hemispheres were formed by photolithography into a soft resist, which was then transferred into the SiO_2 via inductively coupled plasma etch. The hemispherical shape was achieved by reflowing the patterned photoresist, i.e. the photoresist is melted and the surface tension of the liquid pulls the material into hemispherical shapes. By varying the reflow time and temperature, different diameters and heights could be achieved (Table 1).

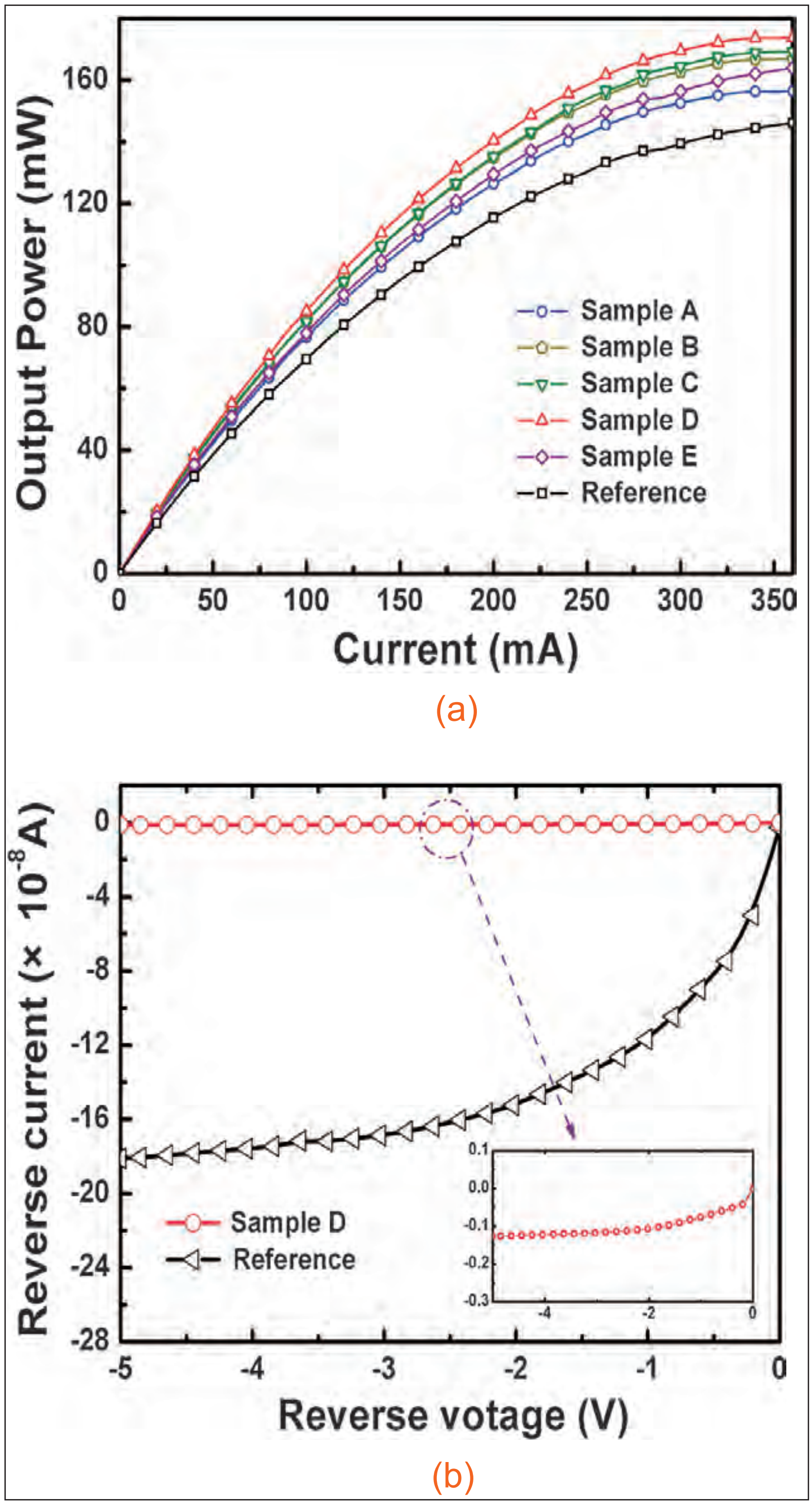

Figure 2. (a) LOP of fabricated LEDs as function of injection current. (b) Reverse leakage current characteristics of sample D and reference.

The resulting LEDs had very similar current–voltage characteristics. At 60mA, the forward voltage was 3.1V for all six devices.

However, the light output from sample D was greatest (Figure 2): at 60mA, the LOP for samples A–E were, respectively, 49.2mW, 52.9mW, 53.5mW, 55.2mW, and 50.9mW. A reference device with conventional SiO_2 passivation had an LOP at the same current of 45.4mW. The sample D value of 55.2mW was 21.6% greater than that of the reference.

Another reflection of the improved performance with Al_2O_3 was increased electrostatic discharge resilience under 2000V reverse voltage stress that yielded 93.67% functioning devices for sample D, compared with 82.69% for the reference device. ■

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