Extended Abstracts of the 2007 International Conference on Solid State Devices and Materials, Tsukuba, 2007, pp. 1006-1007

E-9-4

A Novel Sn-based Metal Substrate Technology for the Fabrication of Vertical-Structure GaN-Based High Power Light-Emitting Diodes

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1. Introduction

In recent years, many efforts have been made to GaN based LEDs as a boost to white light LEDs in the applications of flashlight, backlight source for LCD, and even solid-state lighting [1-2]. Moreover, many substrate transfer techniques by means of laser lift-off with wafer bonding or electroplating [3-4] to fabricate vertical-structure GaN-based LEDs have been developed to solve the severe current-crowding effect and heat-conducting issues encountered by the conventional p-side up lateral LEDs (namely regular LEDs). Recently, the author's group announced the inspiring results of using patterned laser lift-off with selective electroplating Ni (nickel) substrate for the fabrication of vertical-structure metal-substrate GaN-LEDs (namely VM-LEDs) [5]. Advantages including avoidance of metal-cutting, and better electrical and optical characteristics in comparison with regular LEDs have been presented.

In packaging high performance LED chips, tin-based solder materials are widely adopted for its superior thermal and electrical characteristics. To simplify both the device fabrication and packaging process, a novel metal substrate technology to fabricate cutting-free VM-LEDs with tin (Sn) based solder balls is proposed and demonstrated in this paper. Electrical and optical characteristics of VM-LEDs fabricated with the present technology are reported and compared to those of regular LEDs. The advancements and benefits of the proposed novel metal substrate are reported and discussed.

2. Sample preparation

Samples prepared in this work were grown by metalorganic chemical vapor deposition (MOCVD). Figure 1 illustrates key fabrication processes of the VM-LEDs proposed in this work. The oxidized Ni(2.5 nm)/Au(3.5 nm) as an ohmic contact, Ti(15 nm)/Al(400 nm)/Ti(100 nm)/Au(200 nm) as an adhesive and mirror layer, and Ni(200 nm)/Au(200 nm) as a barrier metal layer and a wetting layer for a lead-free Sn-based (a Sn-Ag-Cu alloy) solder-ball [6] were deposited sequentially on p-GaN layer by E-beam evaporator separately [Fig. 1(a)].

A frame-like electroplating area was defined to be 600 μm×600 μm with a cutting-way width of 90 μm by using of thick photoresist. Then, a 10-μm-thick Ni metal frame was formed by selective electroplating under a constant current of 1.7 A for 10 min. After that, Sn-based solder balls of a fixed volume (350 μm diameter) were set in the metal frames individually followed by a reflow treatment with N_2 at around 250°C for 90 s. To be qualified for possible Sn bath soldering process of LED chips mounted on PCBs, the melting point and corresponding reflow temperature of the Sn-based solder balls could be further increased through a variation of the alloy composition. After that, the samples were cooled at a cooling rate 0.45°C/s and the patterned Tin-based metal substrates formed [Fig. 1(b)]. Note that the Ni metal frames were auto-lifted after reflow treatment [Fig. 1(c)] because of the difference in thermal expansion coefficient with respect to those of metal layers and epi-layer underneath. After that, the sample was temporarily bonded to a Si substrate with polyamide and baked at 150°C for 90 min. Through the use of a copper mask to define both size (550 μm×550 μm) and shape of excimer laser beam (248 nm) and an alignment to the patterned Sn-based metal substrate, the patterned LLO process was performed at a reactive energy of 850 mJ/cm^2 [7] [Fig. 1(d)]. Note that the area ratio (AR) of the laser beam size to the chip size should be less than 1 to prevent the edge of epitaxial structure from irregular breach or flaw during the fabrication of device [5]. It is then followed by the removal of u-GaN with ICP dry-etching [Fig. 1(e)]. To improve light extraction and ohmic contact property, a surface roughening with 6-mol KOH solution at 60°C and a cleaning surface process with HF/diluted HCl solutions were made before the formation of a metal pad of Cr(15 nm)/Al(200 nm)/Cr(15 nm)/Au(200 nm) to the exposed n-GaN layer. Finally, cutting-free VM-LED chips with Sn-based metal substrate laid on a blue tape were obtained after the removal of the temporal Si carrier substrate [Fig. 1(f)]. Note that regular LEDs of the same chip size with two electrodes on the same side of the device were also fabricated for comparison.

3. Results and discussion

The surface morphology of the sample before and after the patterned LLO process obtained from scanning electron microscopy (SEM) and optical microscope (OM) were shown in Fig. 2. These photos indicate that both patterned Sn-based metal substrates and the patterned LLO process are quite acceptable for the device fabrication. It is noted that the patterned Sn-based substrates formed from solder-balls could be directly attached to lead frame or heat-sink-slug for LED packaging itself. Hence the fabrication processes are essentially simplified and low-cost. The comparison of current-voltage (I-V) and light output-current (L-I) characteristics of the proposed fabricated VM-LEDs of this work and regular LEDs with the same chip size were shown in Fig. 3 and Fig. 4, respectively. According to experimental results from more than 50 devices, the VM-LEDs with the proposed patterned Sn-based metal substrates in this work and surface roughening, as compared to regular LEDs, were found having an increase in light output power (*i.e.*, ΔLop/Lop) about 342% and a decrease in forward voltage (V_F) drop from 3.88 V down to 3.34 V under an injection current of 120 mA, all in average. Taking both superiority of V_F reduction and light output power enhancement, it is found that the power conversion efficiency (*i.e.*, the ratio of optical output power to input electrical power) of VM-LEDs at 120 mA is about 5.1 times of that in the regular LEDs.

Conclusion

In summary, a novel substrate technology to fabricate cutting-free VM-LEDs with solder-able metal substrate and experimental results have been reported and demonstrated. As compared to lateral-conducting regular LEDs, the proposed VM-LEDs with a surface roughening have been shown having an enhancement in Lop about 342% at 120 mA. It is expected that the proposed fabrication process would not only simplify the fabrication process, but also improve LEDs' performance in package level.

Acknowledgements

This work was supported by the National Science Council (NSC) of Taiwan, Republic of China, under Contract No. NSC 95-2215-E-006-014. Technical assistance in experiments from Uni-Light Technology, Accurus Scientific, and the center for Micro/Nano Technology Research, National Cheng Kung University, Tainan, Taiwan, are appreciated.

Reference

[1] J. J. Wierer et al., Appl. Phys. Lett. 78, p. 3379, (2001)
[2] T. Fujii et al., Appl. Phys. Lett. 84, p. 855, (2004)
[3] W. S. Wong et al., Appl. Phys. Lett. 75, p. 1360, (1999)
[4] D. W. Kim et al., Appl. Phys. Lett. 86, p. 052108, (2005)
[5] S. L. Chen et al., IEEE Photo. Tech. Lett. Vol. 19, No. 6, p. 351 (2007)
[6] C. H. Lee et al., J. Appl. Phys. 72, p. 3808, (1992)
[7] S. J. Wang et al., Appl. Phys. Lett. 87, p. 011111, (2005)

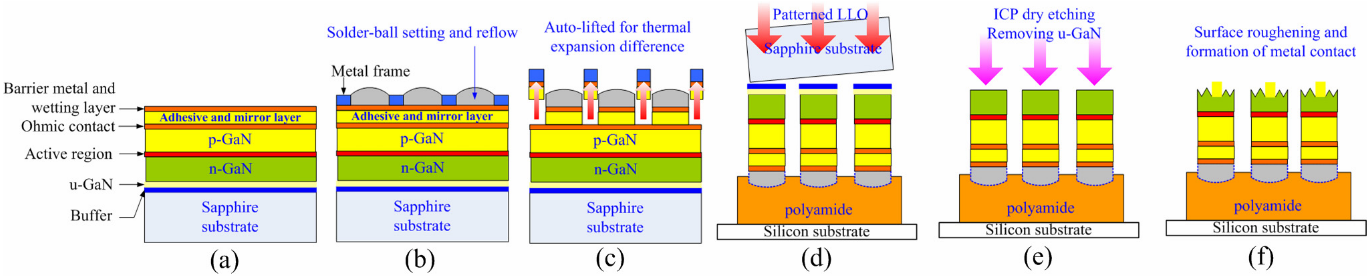

Fig. 1 Key fabrication processes of VM-LEDs employing the metal substrate technology proposed in this work.

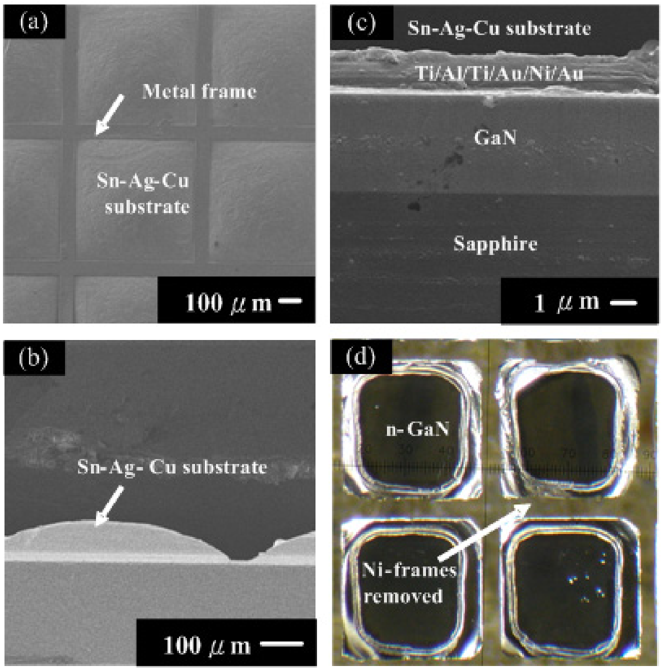

Fig. 2 SEM and OM images of samples at specific process step. (a) Top-view of the sample after the solder-balls reflowed inside the defined metal frames. (b) The side-view of the sample shown in (a) after metal frame removed. (c) An SEM image shows the cross-sectional structure of the sample before patterned LLO process. (d) OM picture the epi-GaN side of the same sample after patterned LLO process.

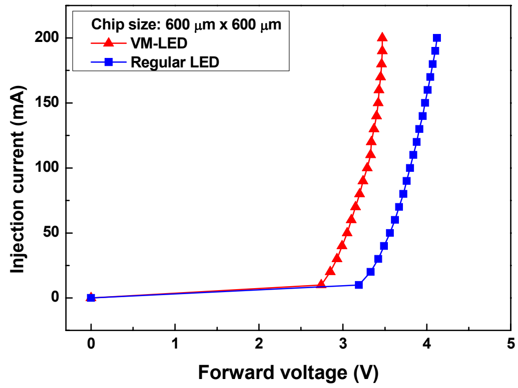

Fig. 3 A comparison of I-V characteristics between VM- and regular LEDs.

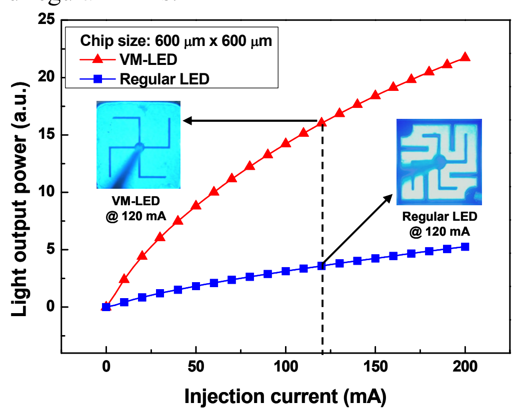

Fig. 4 A comparison of L-I characteristics between VM- and regular LEDs. The inset shows the photos of light emission from VM- and regular LEDs at 120 mA.