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Fabrication of large-area GaN Vertical Light Emitting Diodes on Copper Substrates by Laser Lift-off

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1. Introduction

III-nitride wide band gap semiconductors have recently attracted considerable interest due to their wide applications for optoelectronic devices such as blue light-emitting diodes (LEDs) and laser diodes (LD). In recent years, white light LEDs using GaN based blue emitter were thought as highly suitable for light sources like backlighting or dashboard illumination. However, illumination applications require dozens, hundreds or even thousands of lumens in a single light source, and hardly be realized by simply accumulating appropriate numbers of conventional size (about 300× 300 μm^2) LEDs. Therefore, to provide high power of the single LED chip would be a tendency. The GaN-based LEDs are commonly epitaxially grown onto sapphire substrate due to its relatively low cost. Nevertheless, high power and high temperature operation are restricted by the poor electrical and thermal conductivity of the sapphire substrate. In addition, electrostatic discharge (ESD) problems would be caused by the insulating sapphire substrate. Therefore, GaN-based LEDs, fabricated on an electrically and thermally conducting substrate by separating sapphire substrate, are most desirable.

Additionally, the p- and n- contact of GaN-based devices are conventionally fabricated on the top of the device. Consequently, the emission area of conventional GaN-based LEDs on sapphire with the p-side up configuration were limited because the p-GaN and MQW layers were required etching away to expose the n-GaN layer for n-type contact purpose. Therefore, the emitting area was typical small. In addition, the conventional LEDs also need a transparent contact on the top of mesa to enhance current spreading and emitting area due to the typically holes mobility and conductivity of p-GaN [1]. For increasing the emitting area and high light output power operation, interdigitated mesa geometry was recently reported [2]. However, the emitting area was still limited by the current spreading length of p-GaN layer. In addition, the interdigitated finger circuit patterns on the top of p-GaN also confine the size of emission area. Recently, the flip chip bonding technique for the backside emission of the GaN LEDs [3] and the 10×10 array of microdisk LEDs technique for enhancing the emission area and the output power were reported [4]. However, the processes of these techniques were still relatively complicated. In our recently report [5],[6] we compared the performance of p-side up and p-side down LEDs on copper substrate using Laser lift-off (LLO) technique with the same p-GaN contact metals, and demostrated that the p-side down configuration of GaN LEDs have superior performances over the p-side up LEDs. The result suggests the p-side down LLO-LEDs can enhance the light output power, high current operation and heat capacity of GaN-based LEDs. In this letter, we report the large-area-emission GaN-based LEDs with a size of 1× 1 mm^2 by using new metal schematism bonding and LLO techniques. The uniform current spreading of both p-and n-GaN without transparent contact and the good current-voltage (I-V) performance of the large-area-emission GaN-based LEDs were observed.

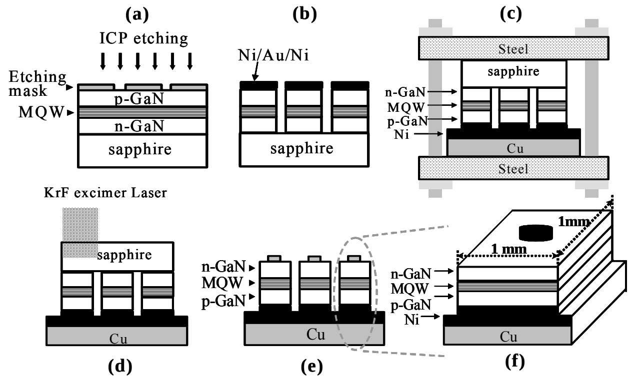

Fig. 1 Fabrication steps of the large-area-emission GaN LEDs with wafer bonding and LLO techniques. (a) Mesa etching by ICP-RIE; (b) Metal deposition; (c) Bonding; (d) Laser lift-off by KrF Laser; (e)n-contact metal deposition; (f) Transferred LED.

2. Experiment

The GaN-based LED wafer structure was grown by metalorganic chemical vapor deposition (MOCVD) on a (1000) sapphire substrate. The LED structure consists of a 3-μm-thick n-type GaN layer for better current spreading, a multi-quantum-wells (MQWs) region consisting of five-period undope-GaN 2/5-nm-thick InGaN/GaN multiple quantum wells, and a 0.1-μm-thick p-type GaN layer. Fig. 1(a)-(f) shows the fabrication steps of the large-area-emission GaN LEDs with wafer bonding and LLO techniques. The original LED wafer with backside published sapphire substrate was cleaved to a size of 1.5×1.5 cm^2. The sample was patterned with a size of 1×1 mm^2 by a standard photolithographic process. The 1×1 mm^2 mesas were then etched to the sapphire by inductively coupled plasma reactive ion etching (ICP-RIE) followed by depositing of Ni/Au/Ni (20nm/20nm/150nm) metals as p-GaN contact. The final Ni layer also serves as the bonding metal. The LED sample with a structure of sapphire/GaN-LED/Ni/Au/Ni was then bonded onto a Ni-coated Cu substrate by the fixture in argon atmosphere at 400 ^{o}C for 30 min. The bonded structure was then subjected to the LLO process. A 248 nm KrF excimer laser with a pulse width of 25 ns was used to remove the sapphire substrate. The laser with a beam size of 1.2 mm × 1.2 mm was incident from the polished backside of the sapphire substrate into the sapphire/GaN interface to decompose GaN into Ga and N_2. In this process, the laser beam size was larger than the size of LEDs; therefore, the laser irradiation on the interface of sapphire and GaN was uniform. By heating the irradiated sample at a Ga melting point of about 30^{o}C, the sapphire substrate was easily remove from the LEDs structure. Then the LEDs were transferred on to the Cu substrate and formed an n-GaN/ MQW/p-GaN/Ni/Au/Ni/Cu, p-side down, structure. The transferred sample was dipped into H_2SO_4 solution to remove the residual Ga on the n-GaN. Finally, patterned Ti/Al layers were deposited as the n-type contact without transparent contact layers.

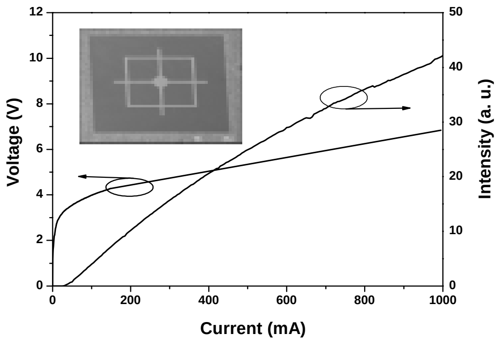

Fig. 3 The L-I-V characteristics of 1×1 mm^2 mesa size LLO-LED. The insertion is the SEM image of the transferred p-side down GaN LED on Cu substrate.

3. Result and discussion

Fig. 2 shows the light output-current-voltage characteristics of the p-side down LLO-LED on Cu operated under continuous-wave (cw), and the insertion is the scanning electron microscope (SEM) image of the transferred p-side down LLO-LED film on Cu substrate. No peeling or crack was observed on the 1×1mm^2 LED film depicts that the GaN-based LED was well transferred onto the Cu substrate without any damage on it. The L-I curve doesn't show rollover even under 1000mA high operation current indicating the LLO-LED possesses superior heat dissipation with the Cu substrate and also allows higher current operation with higher light output. The turn-on voltage for large-area-emission GaN LEDs is about 3V with a forward current of 20 mA. The dynamic resistance is 2.5Ω at 400mA. The current spreading of the LLO-LED without transparent contact on it was investigated by emission pictures. Fig. 3(a)-(d) exhibit the emission pictures of the p-side down LLO-LED under different operation currents. These emission pictures show that the LLO-LED have uniform emission images under small operation current suggesting the LLO-LED have much uniform current spreading performance.

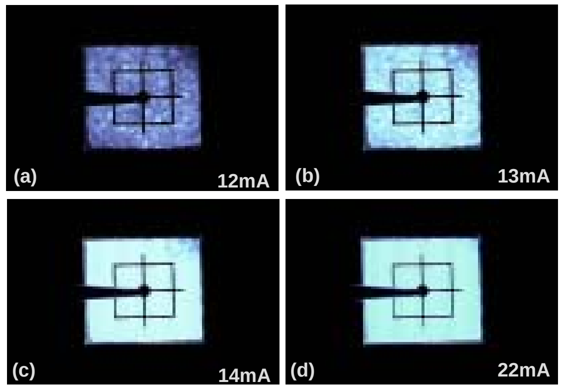

Fig. 3 The emission pictures of the p-side down LLO-LED without transparent contact on it under small operation current, (a) 12mA, (b) 13mA, (c) 14m and 22mA.

4. Conclusions

We demonstrated high performance of large-area as 1×1 mm^2 mesa size GaN-based LEDs on Cu substrate by LLO technique. The LLO-LEDs don't have rollover in light output-current curves under 1000mA high operation current. The LLO-LEDs on Cu substrate also show the uniform current spreading performance without transparent contact. The LLO technique should be a candidate to fabricate single GaN-based optoelectronic device with high operation current and high light output power performances.

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