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Blue light-emitting diode fabrication of an InGaN/GaN epilayer bonded on a Si substrate by laser liftoff

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Absract: We report that a blue LED was successfully fabricated on a bounded InGaN/GaN/Si wafer, in which the InGaN/GaN epilayer was originally grown on a sapphire substrate then bonded and transferred to a Si substrate by laser liftoff technique.

GaN technology has attracted strong attention in the past decade [1,2], mainly due to its important applications in the optical storage, blue as well as full-color display. Since the available substrate for high quality GaN crystal growth is limited to sapphire that is nonconductive, the InGaN/GaN LEDs/LDs have to be made in a horizontal structure with both the p- and n-type contacts on the same topside. This horizontal structure imposes some difficulties on the device fabrication and results in compromise performances, such as higher serious resistance and poor current spreading. GaN grown on a conductive substrate Si was attempted but the fabricated LEDs were inferior to the regular devices due to the poor GaN quality grown directly on the mismatch Si substrate. One method to take the full advantages of existing GaN/sapphire and Si based technologies is to have high quality LED epilayer originally grown on sapphire, then transferred and bonded onto Si substrates. In the recent years, GaN was first demonstrated that it can be separated from the sapphire substrate using the laser irradiation from the sapphire side [3,4]. In this letter, we report that a blue LED was successfully fabricated on a InGaN/GaN/Si bonded wafer, in which the InGaN/GaN epilayer was originally grown on a sapphire substrate and then bonded and transferred onto a Si substrate by a metal to metal bonding and the laser liftoff technique.

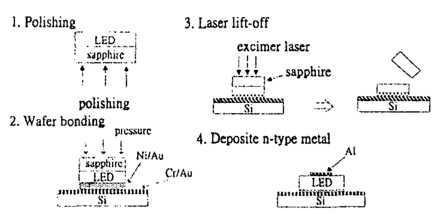

Fig. 1. Major steps for the blue LED fabrication of an InGaN/GaN/Si bonded wafer.

Fig. 1 shows the major steps for the InGaN LED fabrication of the bonded InGaN/Si wafer. The as-grown InGaN/GaN wafer was first polished on the bottom side and deposited with Ni/Au on the top. A p-type Si (100) substrate was deposited with Cr /Au. Then both wafers were pressed together with the metal to metal contacting using a clamp and put it into a 550℃ furnace for 15 min. After the heat treatment semiconductor/metal and metal/metal were alloyed together to form a single bonded wafer. After the bonding the wafer was irradiated from the sapphire side using a KrF excimer laser with a 20ns single pulse of ~600mJ/cm^2. The sapphire substrate instantly popped out by only one pulse laser irradiation resulting in the GaN surface exposed to the air. At the final step, an Al film with ~300 μm diameter was deposited on the exposed GaN and alloyed at 500 ℃ for 1 min to achieve an n type ohmic contact. Fig. 2 shows the current-voltage characteristics of a LED made on the bonded wafer. The turn-on voltage is between 3 and 4 V, which is comparable to that of the most regular InGaN

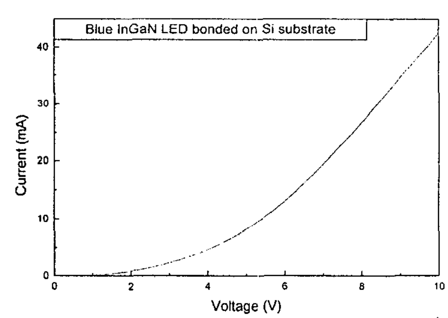

Fig. 2. Current-voltage characteristics of a LED with a 300 μm diameter made on an InGaN/GaN/Si bonded wafer.

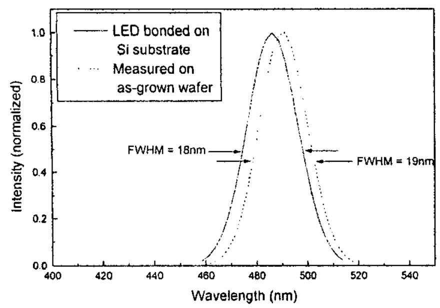

Fig. 3. Room temperature EL spectra measured from the blue LED made on the bonded wafer and by probing directly on the as-grown wafer respectively.

LEDs. But the differential resistance measured at 20 mA is about 150 Ω, which is much larger than the normal value. The possible causes can be the surface damage on the n-type GaN induced by the laser etching, or the poor p-type contact resulted from the bonding. There is a leaky current before turn on, which is possibly due to some microcracks induced by the strong laser heating. Only a low output power of ~20 μW is measured at 100 mA dc current on the LED, which can be also attributed to the leaky current through the microcracks. Further studies are necessary to address the above issues. Fig. 3 exhibits both the room temperature EL spectra of the blue LED made on the bonded wafer and measured by probing directly on the as-grown wafers respectively. The peak wavelength difference (~4 nm) between the two spectra was mainly due to the variation on the original wafer. Both the spectral widths (FWHM) were similar, indicating there was no significant degradation or stress occurred to affect the optical property of the crystal due to the bonding and laser liftoff.

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