Design and Fabrication of InGaN/GaN MQWs Blue LED on Sapphire Substrate For High Voltage Operation

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***Abstract*—In this paper, we report design, fabrication and demonstration of alternate current (AC) operated GaN blue light emitting diodes. In this design, 42 micro-LEDs are connected in series for high voltage operation. The size of each micro-LED chip was ~ 250 µm x 220 µm and total size of monolithic blue LED chip was ~ 2.4 mm x 1.8 mm. The threshold voltage of fabricated monolithic GaN blue was achieved ~ 119 V DC. The ACLED chip was operated successfully at 155 V DC and AC supply.**

Keyword; Light emitting diode, alternate current, GaN, quantum wells, reactive ion etching, high voltage

I. INTRODUCTION

In last few years, GaN-based light emitting diodes (LEDs) have been widely used in various applications such as lighting, traffic signals [1-2] etc. For conventional direct current (DC) LEDs, various electronic components such as rectifiers, transformer etc, are essential components. These various electronic components are the major hurdle for reliable, efficient and compact light source. Therefore, a design of LED chip which can be operated by alternate current (AC) directly is appropriate solution for LED lighting market. AC LEDs have various advantages such as more efficient (because of non conversion of AC into DC), less bulky (no transformer is required for AC to DC conversion) over the conventional DC LED based light source. In the monolithic ACLED chip, various micro-LEDs on one insulated substrate such as sapphire are fabricated by standard compound semiconductor process method. In ACLED chip design, various micro-LED chips are arranged in various manners such as series connected, Wheatstone bridge configuration [3-7] etc. Moreover, for lighting applications, more LED power is needed. Generally to obtain more LED output power, the LED chip size is enlarged to bear high injection current. However, to operate LED at higher current, the efficiency droop is occurs. Therefore, series connected GaN micro-LED chips with high operation voltage and low injection current offer to reduce the probability of efficiency droop [8].

In this paper, we present design and fabrication of series connected GaN based blue ACLED chip under high voltage operation.

II. CIRCUIT DESIGN FOR HIGH-VOLTAGE OPERATION

To operate LED at high voltage, numbers of micro-LED chips should be connected in series as shown in fig.1. In this design 42 micro-LED chips are connected in series. The operation voltage of LED chip will be equal to sum of voltage drop across each micro-LED chip.

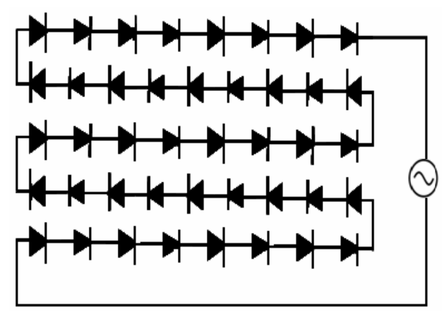

Fig.1 A circuit diagram of a series LED array for AC operation.

III. MATERIAL AND ACLED CHIP FABRICATION

The epitaxial material used for fabrication of blue ACLED chip was grown on c-plane sapphire substrate. Fig. 2 shows the schematic diagram of InGaN/GaN MQWs blue ACLED chip structure. The LED structure consists of a low temperature (~ 500 ^{0}C) grown ~ 25 nm thick nucleation layer, 3 µm thick n-GaN (Si-doped), five InGaN quantum wells (~ 3 nm thick) with 12 nm GaN barrier, a ~ 20 nm thick $Al_{0.2}Ga_{0.8}N$ electron blocking layer (EBL) with Mg doped and a 100 nm thick p-GaN (Mg-doped) contact layer. The thickness and fraction of indium in InGaN QW were optimized to get emission wavelength ~ 460 nm. To activate magnesium (Mg) in p-GaN, sample was annealed in rapid thermal annealing system in nitrogen atmosphere.

To fabricate AC blue chip first, micro-LED chips were isolated using BCl_3 and Cl_2 chemistry based reactive ion etching (RIE). A ~ 600 nm thick low temperature (300 ^{0}C) plasma enhanced chemical vapor deposition (PECVD) deposited SiO_2 and shipley-1818 photoresist were used as mask for micro-LED chip isolation. For complete isolation of each micro-LED chip, an isolation trench (25 µm) was etched up to sapphire substrate (fig. 3). After micro-LED chip isolation, GaN layers were etched up to expose of n-GaN using reactive ion etching for formation of n-ohmic contact. Transparent conducting layer (TCL) of Ni/Au (5/5 nm) was evaporated by e beam evaporation. This transparent electrode also served as p-electrode and annealed in nitrogen and oxygen ambient at 550 ^{0}C in rapid thermal annealing system (RTA) to reduce contact resistance. A low temperature (300 ^{0}C) PECVD deposited SiO_2 of thickness ~ 500 nm was deposited for passivation. The SiO_2 was etched from n and p-electrode using reactive ion etching. A Cr/Au (20/300 nm) metal was evaporated on samples which act as n-contact and metal interconnection between n-pad of one micro-LED chip to the p-contact pad of other micro-LED chip as shown figure 2. Fig. 4 shows the detailed process flow chart of fabrication of GaN monolithic blue LED chip.

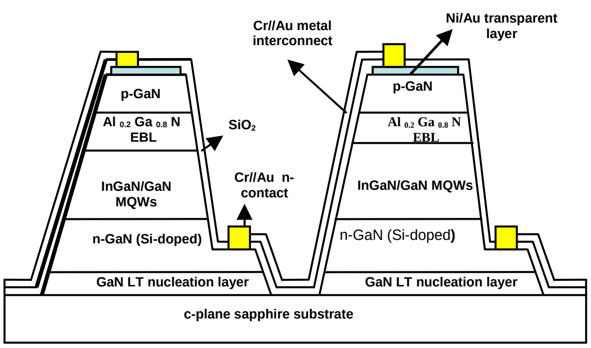

Fig. 2. A schematic structure of monolithically integrated GaN blue LED series arrays.

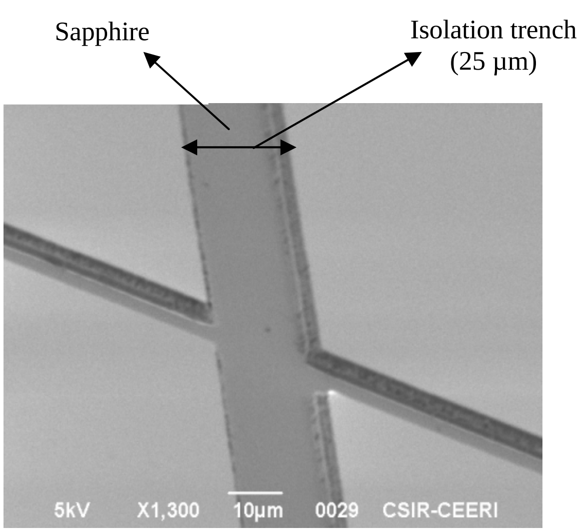

Fig. 3. SEM photograph of isolated micro-LED chip after reactive ion etching.

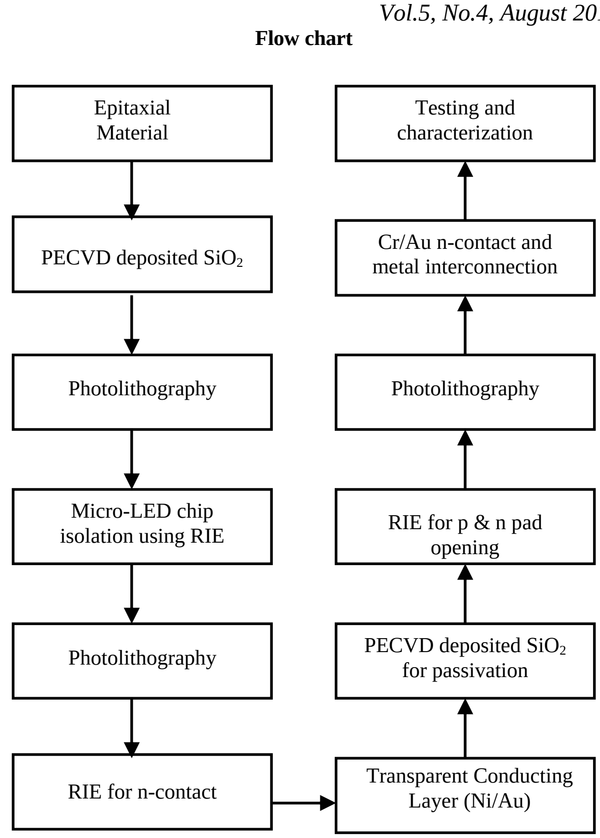

Fig. 4. Fabrication flow of monolithic GaN blue LED chip.

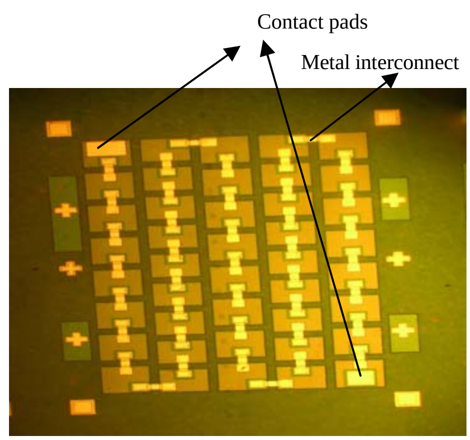

Fig. 4. Microscopic photograph of fabricated monolithically integrated GaN blue LED.

IV. RESULT AND DISCUSSIONS

Fig. 4 shows the fabricated monolithically integrated GaN blue LED chip on c-plane sapphire substrate. For testing the chip at wafer level, two probe tips were contacted to n and p-pads. The dc voltage was applied through probe pins. The measured threshold voltage of fabricated blue AC LED chip was 119 V under DC bias. Therefore, the voltage drop across each micro-LED chip was ~ 2.8 V. Fig. 5 shows the photograph blue light emission from AC LED chip operated at 150 V (DC). The LED chip was also tested at direct alternate current (AC) mode at low current 10 mA.

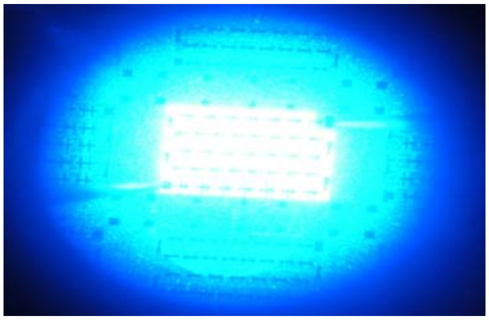

Fig. 5. Photograph of fabricated GaN AC blue LED under 150 V (DC).

V. CONCLUSION

In this paper, we have demonstrated design and fabrication of the single chip AC-LED integrated with a number of micro-LED chips under high voltage operation. In this ACLED chip design, 42 nos. micro-LED chips (size of micro-LED chip ~ 250 µm x 220 µm were internally connected in series. The threshold DC voltage of fabricated blue AC LED chip was 119 V. The AC LED chip was successfully operated at 155 V DC and AC mode respectively. Further, the active layer area utility and thermal burden can be improved by optimizing circuit and layout design. Therefore, monolithic integrated LED may be used as high efficiency, high reliable and more compact lighting solution under high voltage for lighting applications.

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