Efficient Use of Uniform GaN HVLEDs for Small-Flicker General Illumination Applications with Converter-free LED Drivers

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***Abstract* — GaN high voltage LED (HVLED) chips designed and fabricated for low-flicker converter-free LED drivers are reported. The HVLED chips show uniform electrical performance (forward voltage at 20 mA varies from 8.5 V to 8.7 V for 3-cell chips, 16.7 V to 17.4 V for 6-cell chips) and good linearity of output /input power up to 100W/cm^2 input. Both features satisfy the demanding requirements of the novel quasi-constant power control scheme adopted in the converter-free LED driver circuit. After bonding a total of 60 LED cells (eight 6-cell chips and four 3-cell chips) and a converter-free LED driver on a silicon carrier, a compact and low-flicker lighting system integration is demonstrated.**

Keywords: GaN high voltage LED; converter-free LED drivers; general illumination applications; uniform LED characteristics

GaN LEDs have been widely utilized in display and general illumination due to their high internal quantum efficiency and long life time. At the same time, new designs in LED driver development set new requirements for the LEDs. Recently, Gao *et al.* reported a novel converter-free LED drivers with very low flicker (~18%), high efficiency and power factor (88.2% and 0.92) [1]. The key idea of the driver relies on the quasi-constant power control scheme, which requires stable, uniform LEDs with high output linearity to have little optical power variation, powered by an $110V_{AC}$ mains power input. In this paper, we present uniform electrical and optical performance of high power flip-chip high voltage LED (HVLED) chips made to work well with the converter-free LED driver for a compact and potentially low-cost lighting system. Instead of using discrete single-junction LEDs connected in series either by bond-wires or chip-on-board, single HVLED chip is a more cost effective solution in packaging for a reliable system.

Fig.1 shows the microscopic images of high voltage LED chips with 3 cells (Chip A) and 6 cells (Chip B) connected in series, compared with a conventional single-junction LED (Chip C). Different from conventional high power LED fabrication, the HVLED used a curable photoresist-filled-trench technique [2] to achieve side-wall passivation and facilitate metal connection between cells as shown in Fig.2.

According to the LED driver design, a total of 60 LED cells in series are required and a variable number of LEDs on the string are selected to be lit up as the input voltage changes. Thus it is preferable to have little voltage variation on the constituent LEDs. Fig. 3 (a) shows the typical IV characteristics of all three chips. At 20 mA, the forward voltages for 3-cell and 6-cell HVLEDs are 8.6 V and 17.1 V. The distribution of forward voltages is also displayed in Fig. 3 (b). The forward voltages vary only from 8.5 V to 8.7 V and from 16.7 V to 17.4 V for 3-cell HVLEDs and 6-cell HVLEDs, respectively. The small variation of the forward voltage from the HVLED chips guarantees a confirmative number of LEDs that are designed to be lit.

Another unique feature of Gao's LED driver is the quasi-constant power control scheme in which a higher input voltage will power up more LEDs on the string, but will decrease the current on each LED cell. In order to have stabilized optical power, the light output power of the constituent LED chips is demanded to have good linearity with the input power. It is well known that single junction chip cannot satisfy this requirement due to the "efficiency droop" phenomenon, as shown in Fig. 5. The HVLED chips in this work, with their high voltage/low current operational mode, could greatly mitigate the efficiency droop issue and provide excellent optical power linearity up to 100 W/cm^2 input power for either 3-cell chips or 6-cell chips. It is also noted that the 3-cell and 6-cell chips have almost the same optical efficiency. Thus, given any input voltage, the optical power would be maintained nearly constant, which is independent on the number of lit LED cells, achieving a small flicker lighting system. Fig. 6 shows a LED string (four Chip A & eight Chip B) and a converter-free LED driver bonded on a Si carrier forming an integrated and compact lighting system. As shown in the waveforms of Fig. 7(a) that as the voltage exerted on the LED string was increased, the current on the lit-up LED cells decreased, and vice versa. It is also shown that the input power at any given input voltage was typically constant with little variation. Thus, a stabilized optical power output from the 60-cell LED string could be obtained as shown in Fig.7 (b) with $110V_{AC}$ mains power input without using any power inductors or electrolytic capacitors. The integrated system reported here paved a practical path for applications where compact, large area, and low flicker lighting is needed.

References

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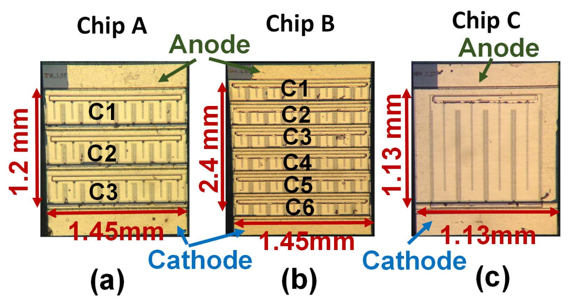

Fig. 1. Microscope images of the three types of high power LED chips: (a) Chip A with current flowing from C1 to C3, (b) Chip B with current flowing from C1 to C6 and (c) Chip C.

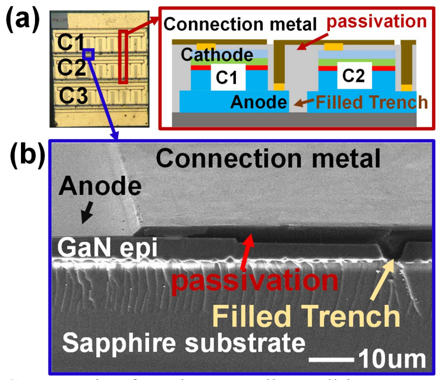

Fig. 2. Cross-session for sub-LED cell-to-cell interconnection (a) cross-session of the C1 to C2, (b) SEM image of the trench filling and metal interconnection.

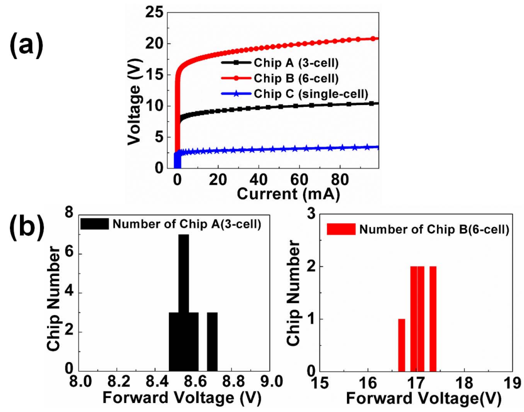

Fig. 3. (a) IV characteristics of three chips and (b) V_F distribution for Chip A and B, respectively.

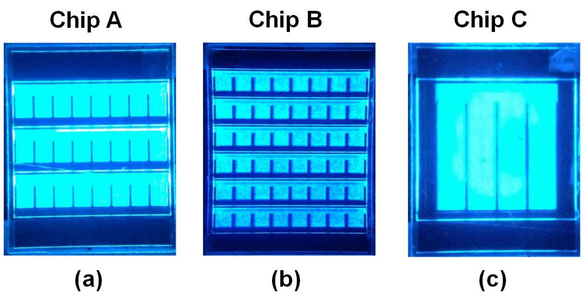

Fig. 4. Light emission of three chips at 1 mA injection current.

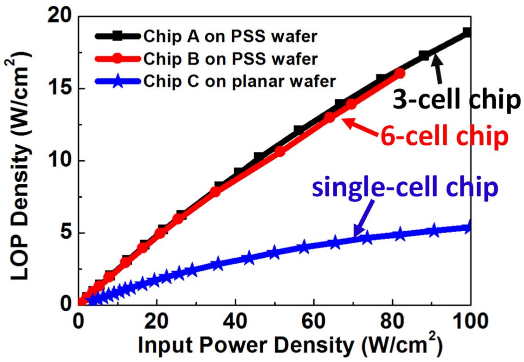

Fig. 5. Light output power density versus input power density for three chips.

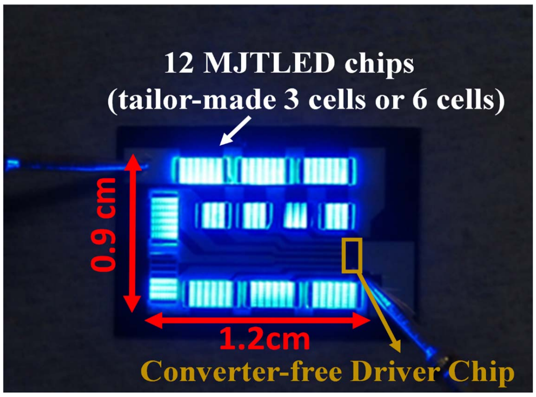

Fig. 6. LED strings on a silicon carrier designed for converter-free LED lighting system integration.

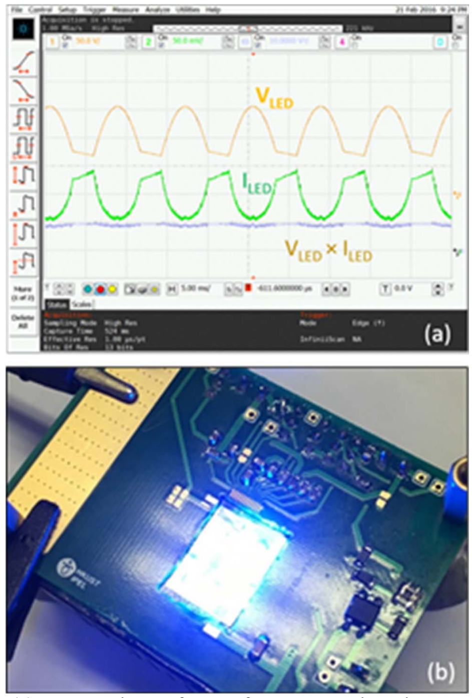

Fig. 7. (a) Measured waveforms of V_{LED} exerted on the LED string and corresponding current (b) Light emission image of the integrated system working at 110V_{AC} mains power input.

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