Improvements in High-Voltage LEDs and Applications

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Recently, the high-voltage light-emitting diode (HV-LED) fabricated with series connection of micro-cells on a large area chip can reach a high forward voltage with a low injection current, solving the current crowding problem and decreasing the efficiency droop [1, 2]. Another advantage in the HV-LED is the direct employment of the regular wall plug outlet without further voltage conversion. Via the combination of HV-LED and fewer wire-bonding process, the devices will be more attractive for commercial applications. In this study, we have proposed several techniques to fabricate various types of HV-LEDs and improve their optoelectronic performance. Moreover, the optical and electrical characteristics of HV-LEDs were investigated both experimentally and numerically. These techniques consist of laser lift-off, metal bonding, self-aligning contact, phosphor coating, and so on.

Through the laser lift-off and metal bonding processes, the thin-film HV-LED can be prepared on Cu metal substrate with highly thermal conductivity. In the thin-film HV-LEDs, the effect of micro-LED geometry on the device performance was analyzed in detail. Several micro-LED geometries including square, rectangle, triangle, and L shape were designed to form the thin-film HV-LEDs with 2×2 cells. As the square cells are combined in the HV-LED, a worse device performance is obtained owing to the obvious current crowding phenomenon occurred near its electrodes. Although the HV-LED connected with L-shaped cells has better current spreading effect and lower surface temperature, its light extraction is relatively low because of the electrode-shading loss effect. When the triangular cells are used to prepare the HV-LED, the device can reach a better optoelectronic performance than that with other cells due to its lower current crowding effect and more uniform light emission. After the epoxy package process, the lower forward voltage of 14.9 V and higher output power of 353.2 mW are obtained in this HV-LED, under an injection current of 80 mA. Meanwhile, the wall-plug efficiencies (@20 and 80 mA) of this device are 41.1% and 29.7%, respectively. The results confirm the design of triangular cell is beneficial for the enhancement in the HV-LED performance.

Additionally, after performing the self-aligning contact technique, the chamfer angle structure was formed in the side wall of each micro-LED, which can enhance the light extraction of conventional HV-LED with 4×2 cells. The influence of the u-GaN thickness on the performance of HV-LED with the chamfer angle structure was also characterized. Based on the measurement of surface light emission, the light extraction of the HV-LED with the chamfer angle structure is more uniform than that without the chamfer angle structure. Especially for the trench region between the cells, the light extraction can be saturated even at a low injection current of 10 mA. At an injection current of 80 mA, the output power of the HV-LED without the chamfer angle structure is 538.1 mW. After forming the chamfer angle structure, the output powers (@80 mA) of HV-LEDs with the u-GaN thicknesses of 3, 5 and 7 μm were increased to 555.3, 573.1 and 561.6 mW, respectively. Obviously, by introducing the chamfer angle structure, the HV-LED with a 5-μm-thick u-GaN possesses the highest enhancement in the output power.

Furthermore, the fabrications and device performances of flip-chip type and ultraviolet HV-LEDs will be presented in this research. Moreover, by employing the phosphor coating process, the white HV-LED was fabricated. These HV-LEDs proposed in our work can be practically applied for automobile lighting, high-power solid state lighting, and medical lighting.

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