Semipolar Micro-LEDs Combined with All-inorganic Encapsulated Perovskite Nanocrystal for Full-color Display Device and Potential VLC Application

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ABSTRACT

In this sudy, we using a SiO_2 coating craft to enhance its stability in ambient conditions and under exposure to blue light. Generally, blue μ-LEDs grown on c-plane GaN own a severe quantum-confined Stark effect (QCSE), To fundamentally solve this problem, we proposed semipolar (20-21) blue μ-LEDs to eliminate QCSE.

1 Introduction

Micro light-emitting diodes (μLEDs) are considered the most promising light sources for next-generation display technology, and are of great interest for display and visible light communication (VLC) due to its high contrast, low power consumption, wide color gamut, high efficiency, wide viewing angle and high bandwidth[1-3]. Currently, the GaN grown on the c-plane has a severe quantum confined Stark effect (QCSE), In order to fundamentally solve this problem, we proposed a semipolar orientation GaN to mitigate polarization fields and increase wave-function overlap[4-6].

A feasible method to realize the full-color display is to use near-ultraviolet or blue light chip combined with color conversion layer[7]. The luminescence materials of color conversion layer, could determine display device performance and thus luminescence efficiency, color purity, and stability need to be taken into consideration when choose a suitable luminescent material[8]. Perovskite NCs (PNCs), especially those that are lead-based, demonstrate significant advantages over conventional semiconductor NC systems, attracting extensive interest from researchers and manufacturers seeking to produce cost-effective and wide-color-gamut displays[9]. Nevertheless, PNCs have some drawbacks, for example, they have exhibited vulnerability under ambient conditions, particularly in the case of red-emitting PNCs that contain iodine[10].

In this article, we report a device that could be used for both display and visible light communication (VLC) applications. The semipolar μLED array exhibits an impressive 652 MHz 3 dB bandwidth corresponding to an injection current of 18 mA. The PNC-μLED device assembled from the semipolar μLED array with PNCs achieved 99.2% National Television Standards Committee (NTSC) space and 93.0% Rec. 2020 in the CIE 1931.

2 Experiment

The structure of full-color display device with the cross-sectional view is vividly presented in Figure 1. It mainly includes two parts, blue semipolar LED and PQDs color conversion layers. As for the preparation of semipolar blue μ-LED, the substrate epitaxial process comes first. (20-21)-oriented GaN layer was grown on a patterned sapphire substrate (PSS) by metal-organic chemical vapor deposition (MOCVD). In order to improve the epitaxial quality and eliminate stacking faults (SFs), a Ge-doped process by selective area growth (SAG) was utilize to realize SF-free semipolar (20-21) μ-LED. Later, the n-GaN layer, MQWs active layer and p-GaN layer were grown consecutively. Next comes the μ-LED process, indium tin oxide (ITO) was deposited on the epitaxial wafer and thermally annealed to form a p-type ohmic contact. After that, n-type electrodes were deposited by electron beam evaporation, μ-LED had done atomic layer deposition (ALD) treatment. (DBR) was deposited on the back of the wafer to reflect the light from the back of the chip. The green and red PQDs color conversion layers were fabricated through spin coating process, the PQDs thin films were covered on semipolar blue μ-LED to realizing full-color display.

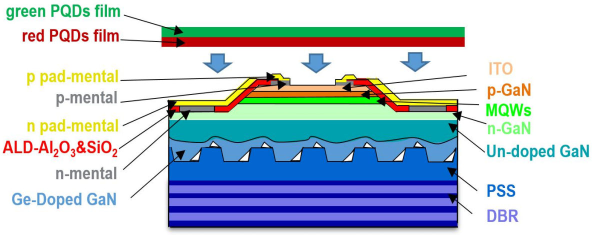

Fig. 1 Schematic diagram of full-color display device

3 Results

Figure 2 exhibits the results for the frequency response measurement. The modulation bandwidth measurement was performed using a vector network analyser (VNA; Keysight E5071C). The blue light passing through the filter was collected using an optical fiber, which was coupled to an avalanche photodiode (APD). The converted signal was traced back to the VNA, where the modulation bandwidth was measured. The 3-dB bandwidth varied from 484 MHz to 652 MHz, with the injection current density increased from 495 A/cm2 (3.5 mA) to 2547 A/cm2 (18 mA), the 3-dB bandwidth increased owing to the higher injected carrier density in the active region as the injection current increases. The semipolar μ-LED got it maximum 3-dB bandwidth (652 MHz) when the injection current density increased to 2547 A/cm2, which was attributed to the built-in electric field screening and high injected carrier density in the active region reducing the carrier lifetime. The 3-dB bandwidth was proportional to the increase of current, which means that the 3-dB bandwidth is not limited by RC delay, but by the recombination lifetime, thus, semipolar blue μ-LED is quite promising for VLC applications.

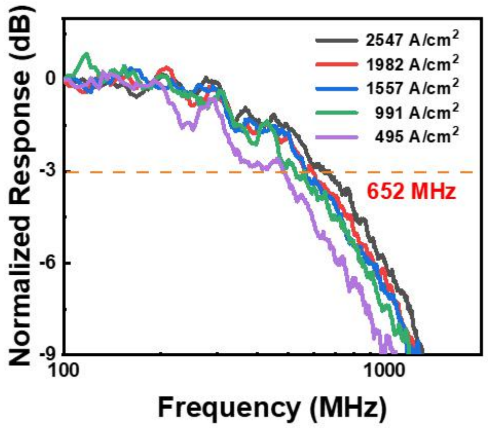

Fig. 2 Frequency response for semipolar blue μ-LED.

Figure 3 exhibits the color gamut of the semipolar GaN based full-color display device. As clear shown in Figure 3(b), the semipolar blue μ-LED color coordinates varied from (0.1667, 0.0549) to (0.1570, 0.0275), when the injection current was increased from 0.54 mA (76 A/cm2) to 6.6 mA (934 A/cm2). The color coordinate offset Δx and Δy in CIE 1931 are 0.097 and 0.0274, respectively. The color gamut of semipolar blue μ-LED device was hardly changed, which is attributed to its wavelength stability of semipolar μ-LED. PQDs exhibit excellent luminescence stability, the color coordinates hardly change. The red and green PQDs color coordinates are (0.1348, 0.7894) and (0.7034, 0.2941), respectively. The full-color display device achieved 99.2% National Television Standards Committee (NTSC) space and 93.0% Rec. 2020 in the CIE 1931, as shown in Figure 3(a), which strongly indicated the application potential of semipolar μ-LED in high quantity display.

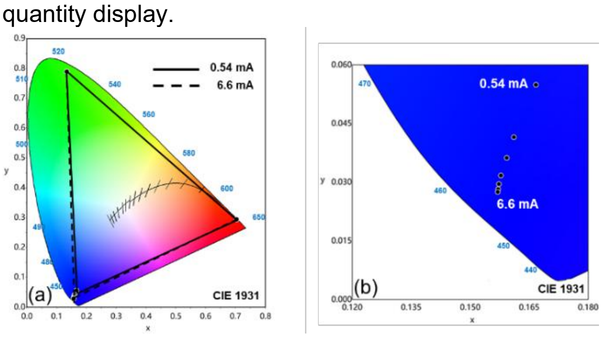

Fig. 3 Color performance of semipolar μ-LED under various injection current on the CIE 1931 color space diagram. (a) The color gamut of full-color display device. (b) Color coordinates of semipolar μ-LED.

Therefore, the device proposed in this study could be used for display applications when operated at low current densities, while at high current densities it could be used for VLC applications.

4 Conclusions

In conclusion, we have successfully grown semipolar μ-LED in patterned sapphire substrate, and the epitaxial quality has been significantly improved through the Ge-doped process, and realized a full-color display device with high color stability and explore its potential application in high-speed VLC. the device presents a wide color gamut of 99.2% NTSC and 93.0% Rec. 2020 with high color stability. Meanwhile, the semipolar blue μ-LED had a highest 3-dB bandwidth of 652 MHz under an injection current density of 2547 A/cm2. All those strongly prove that semipolar μ-LED could have a thrived prospect in full-color display and high-speed VLC.

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