DEVELOPMENT AND PERFORMANCE EVALUATION OF A HIGH-EFFICIENCY MICRO LED DISPLAY USING PLANARIZATION AND ELECTRODELESS SHIELDING TECHNIQUES

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GENERAL INFORMATION

Received date: 24/04/2024

Revised date: 24/06/2024

Accepted date: 04/07/2024

KEYWORD

Electrodeless shielding;

High efficiency;

Micro LED display;

Planarization;

Uniform forward voltages.

ABSTRACT

This paper presents the development and performance evaluation of a novel micro LED display achieved through innovative planarization and electrodeless shielding techniques. The study focuses on achieving uniform forward voltages across the entire display panel, ensuring consistent performance and optimal light output. Through meticulous measurement and analysis, the study demonstrates impressive results, with variations of only 2.7% in column pixels and 1.08% in row pixels. Additionally, the micro LED display exhibits remarkable luminance capabilities, achieving a brightness of 430 nits when biased at a pulse-width modulated voltage (PWM) with a frame rate of 105 Hz and a duty cycle of 1/32. Furthermore, the display showcases outstanding power efficiency, with an output power reaching 847 μW at a direct current (DC) of 3 mA. These findings underscore the potential of the developed micro LED display for various applications, including consumer electronics, automotive displays, and augmented reality/virtual reality (AR/VR) systems, where high brightness, efficiency, and uniformity are paramount.

1. INTRODUCTION

In recent times, liquid crystal displays (LCDs) have emerged as pivotal components across diverse fields, owing to their commendable luminous efficiency and expansive color gamut (Lai et al., 2023; Pandey et al., 2023). However, despite these advantages, LCDs suffer from notable drawbacks such as heightened power consumption. A particularly challenging issue arises from the exceedingly low light utilization efficiency (LUE) of the backlight systems within LCD panels, thereby complicating endeavors to achieve further reductions in power consumption (Gou et al., 2019a; Zhu et al., 2023).

The micro-LED displays have garnered significant attention, offering superior brightness, contrast ratio, and response speed. By capitalizing on the strengths of LCDs while circumventing their shortcomings, micro-LED displays present a compelling alternative

(Hsiang et al., 2020; Wu et al., 2018). Notably, micro-LED displays can be propelled by multi-electrode addressable control circuits, leveraging passive matrix programming methodologies characterized by ease of fabrication and cost-effectiveness (Anwar et al., 2022; Huang et al., 2020).

This study focuses on the development of a passive matrix micro-LED display, a pioneering endeavor in this domain. To bolster current spreading and mitigate light-shading issues stemming from metal electrodes, indium tin oxide (ITO) is ingeniously employed as both the ohmic contact layer on the p-GaN and the transparent conducting film (Ryu et al., 2023). Furthermore, the adoption of flip-chip LEDs and anisotropic conductive film for bonding micro LEDs to integrated circuits underscores the innovative approach taken in device fabrication. The display system is driven by a passive integrated circuit, while pixel control on the matrix display is facilitated through a multi-electrodes addressable method. This concerted effort culminates in the successful visualization of images on the display, marking a significant stride towards advancing display technology (Gou et al., 2019b; Meng et al., 2021).

2. EXPERIMENTAL

The fabrication process of the micro LED display began with a meticulous deposition of indium tin oxide (ITO) onto a GaN epitaxial wafer. This initial step was crucial for establishing a foundation conducive to subsequent layers and functionalities. Following this deposition, a critical annealing process was undertaken in atmospheric ambient conditions, subjecting the assembly to a temperature of 525°C for a duration of 10 minutes. This annealing step played a pivotal role in enhancing the structural integrity and electrical properties of the deposited ITO layer, thereby laying the groundwork for the subsequent stages of fabrication.

Subsequent to the annealing process, a meticulous lithography process was initiated to delineate the micro LED arrays' emitting area and the intricate network of n-GaN wires. This process required precision and accuracy to ensure the proper alignment and definition of these critical components. Sequentially, the n-GaN layer was exposed, and a meticulous process of dry etching was employed to precisely define and form the n-GaN wires. This step was crucial for establishing the intricate electrical pathways necessary for the operation of the micro LED display.

The resulting micro LED displays boasted an impressive configuration of 64 × 32 pixels, each meticulously crafted to possess a uniform pixel size of 50 μm × 50 μm, with a pixel pitch of 100 μm. This uniformity in pixel size and spacing was essential for ensuring consistent and high-quality image reproduction across the display surface. To further enhance the functionality of the display, layers of Ti/Al/Ti/Au were deposited via Physical Vapor Deposition (PVD) techniques to serve as both the p-pad and n-pad electrodes. Additionally, a ring-shaped metal layer was intricately deposited onto the nGaN channel using the same PVD techniques, further augmenting the electrical conductivity and performance of the display.

In order to ensure optimal planarization and passivation of the display surface, a meticulous process involving the use of photoresist was employed to fill the trench. This step not only served to smoothen the surface but also provided crucial passivation to protect the underlying layers from environmental degradation and mechanical stress. Following this, additional layers of Ti/Al/Ti/Au were deposited via PVD techniques to serve as interconnect electrodes, facilitating seamless connectivity among the micro-LED arrays.

For a comprehensive understanding of the intricate fabrication process, interested parties are directed to consult the detailed process flow outlined in Figure 1, which provides a visual representation of each step and its corresponding significance in the overall assembly of the micro LED display.

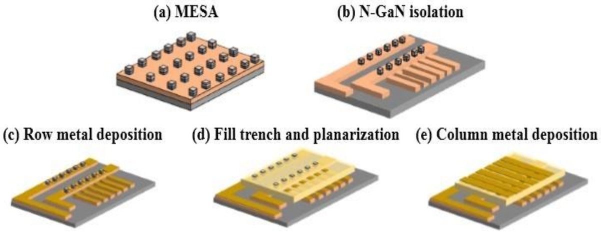

Figure 1. GaN-based micro-LED displays process flow chart

3. RESULTS AND DISCUSSION

The results and discussion section provides comprehensive insights into the performance and characteristics of the micro LED display developed in this study. Through meticulous measurement and analysis, the study delves into various aspects of the display's functionality and compares its performance with existing display technologies.

The measurement process was meticulously divided into three parts, focusing on both the column pixels and row pixels, each driven at a direct current (DC) of 1 mA. In the examination of column pixels, where current transmission relies on metal lines, the forward voltage exhibited a subtle shift from 3 V to 3.081 V, with a variation of 2.7% observed in column 32. Conversely, the row pixels, utilizing a common cathode configuration with the n-GaN channel deposited by ring-shaped metal as transmission lines, showed a marginal shift in forward voltage from 2.99 V to 3.029 V, with a variation of 1.08% observed in row 16. This uniformity in forward voltages across both column and row pixels is pivotal for ensuring consistent light output and optimal display performance, contributing to enhanced visual fidelity and reliability.

The study highlights the superior brightness of the developed micro LED display compared to commercially available OLED displays of similar size. At a pulse-width modulated voltage (PWM) biased at a frame rate of 105 Hz and a duty cycle of 1/32, the display achieved an impressive brightness of approximately 430 nits. This brightness profile exhibits a nearly linear optical power output with increasing forward current, making it highly adaptable for a wide range of applications where luminance consistency is paramount. Additionally, the study showcases the display's remarkable power efficiency, with an output power reaching 847 μW at a direct current (DC) of 3 mA. Furthermore, the efficiency of the $50 \times 50\ \mu m^2$ blue LED is highlighted, boasting a maximum external quantum efficiency (EQE) exceeding 12% at 0.3 mA. These findings underscore not only the clarity and visibility of displayed images but also the display's compact dimensions, measuring 1.5 cm × 1 cm with a thickness thinner than 230 μm. The results presented in this section underscore the exceptional performance and potential applications of the developed micro LED display. By surpassing the brightness and efficiency benchmarks set by existing display technologies, the display emerges as a promising solution for diverse display requirements across various industries and applications.

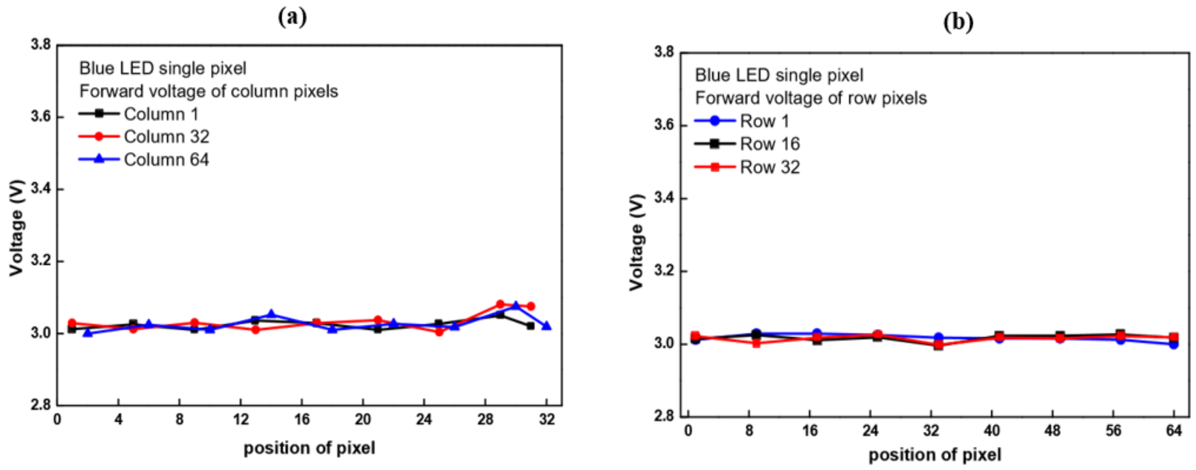

Figure 2. LED forward voltages of (a) column and (b) row

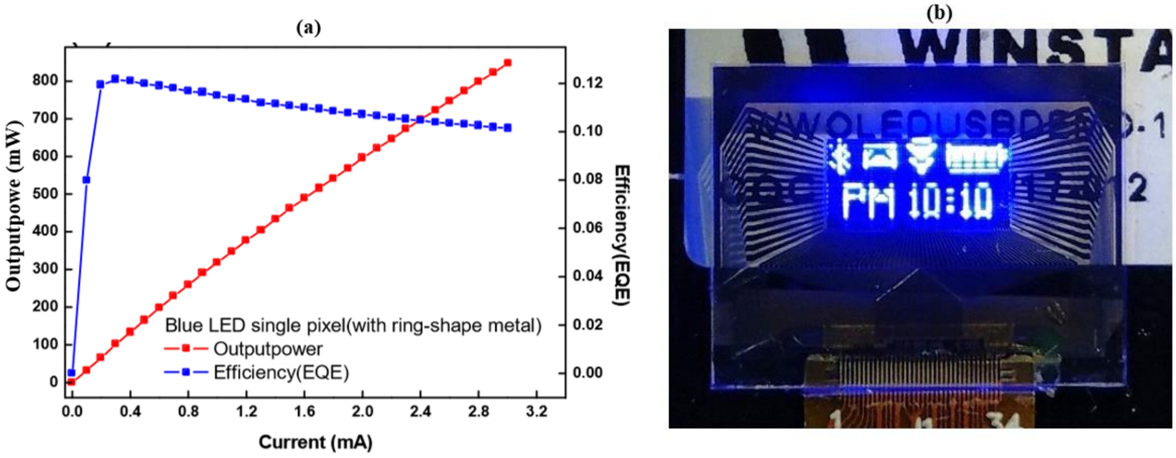

Figure 3. (a) Different drive current under the brightness, (b) Image of the display under driven

4. CONCLUSION

This study successfully developed a micro display utilizing planarization and electrodeless shielding techniques. Notably, the forward voltages across the entire panel exhibited uniformity, with variations of only 2.7% in column pixels and 1.08% in row pixels. This uniformity ensures consistent performance and optimal light output across the display, contributing to enhanced visual clarity and reliability.

The micro display demonstrated impressive luminance capabilities, with the blue LED arrays achieving a brightness of 430 nits when biased at a pulse-width modulated voltage (PWM) with a frame rate of 105 Hz and a duty cycle of 1/32. Additionally, the display exhibited remarkable power efficiency, with an output power reaching 847 µW at a direct current (DC) of 3 mA. These findings underscore the display's potential for a wide range of applications where high brightness, efficiency, and uniformity are essential. The successful development of this micro display represents a significant advancement in display technology, offering enhanced performance and functionality compared to existing solutions. With its uniform forward voltages, impressive luminance capabilities, and efficient power utilization, the micro display holds promise for various applications across industries such as consumer electronics, automotive displays, and augmented reality/virtual reality (AR/VR) systems.

SUPPLEMENTARY INFORMATION

Supplementary Information (SI) is attached to the manuscript and submitted to the journal including tables out of specification, figures, formulas, details of experimental methods, etc. SI saved as a .pdf file and numbered the pages.

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