Monolithic Integration of *p*-type MOSFET and MicroLEDs for AR/VR/XR Display

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Abstract

We report a monolithically integrated voltagecontrolled p- type metal-oxide-semiconductor field effect transistor (p-MOSFET)-Micro-LED device based on commercial GaN LED epitaxial wafer. By adjusting the Gate voltage, the effective control of Micro-LED injection current is realized. The I_{ds} on/off ratio is around 10^4, and the gate leakage current (I_{gs}) remains below 10^{-9} A as V_{gs} increases up to -25 V.

Author Keywords

Micro-LED, MOSFET, Monolithic integration, GaN;

1. Introduction

Recent advances in microelectronics and optoelectronics have spurred significant breakthroughs in monolithic optoelectronic integrated circuits, offering advantages over traditional off-chip packaging such as reduced size, minimized parasitic effects, faster operation, enhanced multifunctionality, and greater reliability [1-4]. Particularly, GaN-based transistors have become integral to the monolithic integration of Micro-LEDs due to their superior optoelectronic properties, including high mobility and thermal conductivity. In order to avoid the process complexity brought about by massive transfer technology, more and more researchers have begun to study the monolithic integration technology of MOSFET and Micro-LEDs. Limited by the quality of epitaxial chips, current research focuses on the monolithic integration of *n*-MOSFET and Micro-LEDs. There have been no studies on the monolithic integration of *p*-MOSFET with Micro-LEDs.

This study pioneers the monolithic integration of p-type MOSFET (*p*-MOSFET) with Micro-LEDs, employing a commercial GaN LED epitaxial wafer without necessitating additional ion implantation or epitaxial growth. This work not only advances the field of monolithic integration technology but also paves the way for the development of active matrix Micro-LED displays based on a monolithic integration approach, where each subpixel incorporates two transistors (*n*-type and *p*-type) and one capacitor (2T1C).

2. Results and Analysis

The integrated device layout, depicted in Fig. 1(a), features a *p*-MOSFET on the left and a Micro-LED on the right, interconnected by metal (Ti/Al/Ti/Au) from the *p*-MOSFET's source to the Micro-LED's positive electrode. The *p*-MOSFET measures a gate-to-source distance (L_{GS}) of 3 μm, a gate length (L_G) of 1.5 μm, and a gate-to-drain distance (L_{GD}) of 3 μm, with the Micro-LED sized at 5 x 5 μm². Device characterizations, detailed in Figs. 1(a), reveals the effective modulation of Micro-LED operation by the *p*-MOSFET's gate and drain voltages. The *p*-MOSFET operates in the "normally-off" mode, exhibiting a typical threshold voltage (V_{TH}) of approximately -12 V (defined at Ids = 1 μA/mm). This relatively higher V_{TH} effectively prevents unintended operations. However, an excessively high threshold voltage can hinder the device's energy efficiency. The I_{ds} on/off ratio is around 10^4, and the gate leakage current (I_{gs}) remains below 10^{-9} A as V_{gs} increases up to -25 V. At V_{ds} = -5 V and V_{gs} = -25 V, the maximum I_{ds} is 13 μA. showing robust control capabilities. Meanwhile, the output characteristics of the integrated *p*-MOSFET-Micro-LED device is measured, as depicted in Fig. 3(c), at V_{ds} = -6 V and V_{gs} = -25 V, the maximum Micro-LED current density reaches 20 A/cm². This current density value enables the prepared Micro-LED device to achieve optimal luminous performance.

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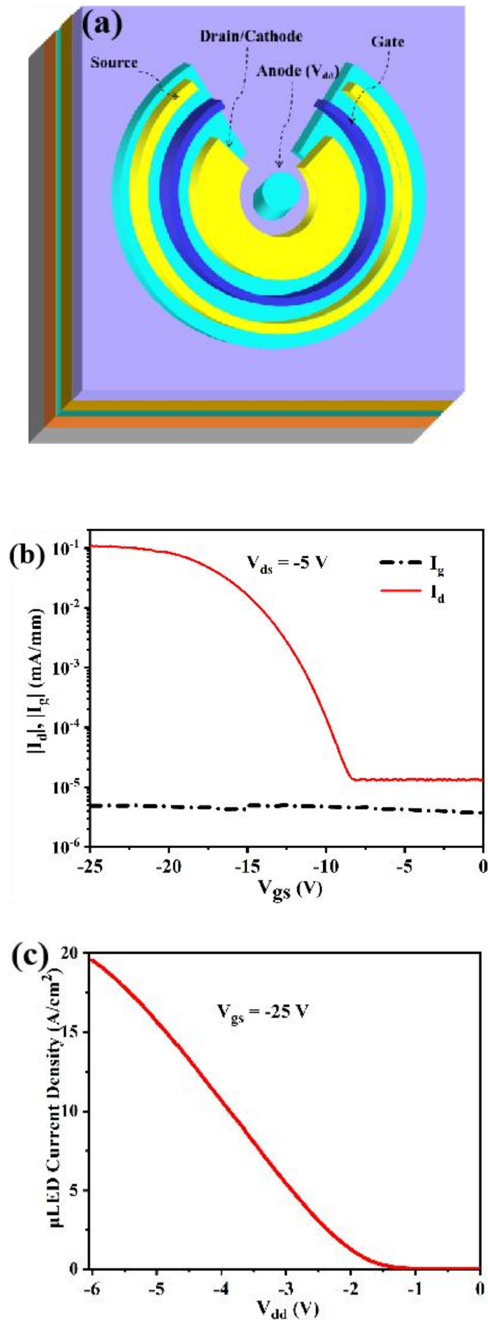

Fig. 1. (**a**) Structure schematic of the monolithically integrated *p*-MOSFET-Micro-LED device. **(b)** Transfer characteristic curve of the *p*-MOSFET when V_{ds} = -5 V. **(c)** Output characteristic curve of the monolithically integrated *p*-MOSFET-Micro-LED device.

3. Conclusion

In this study, we successfully monolithically integrated a 5 μm blue Micro-LED with a *p*-MOSFET on a commercial GaN LED epitaxial wafer, thereby maximizing LED performance. By adjusting the Gate voltage, the effective control of Micro-LED injection current is realized. The I_{ds} on/off ratio is around 10^4, and the gate leakage current (I_{gs}) remains below 10^{-9} A as V_{gs} increases up to -25 V.

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