Full-Color Micro-LED Near-Eye Display Technology Based on Quantum Dot

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Abstract

Augmented reality (AR) smart glasses have garnered significant interest and are often regarded as the future alternative to smartphones. Micro-light emitting diodes (micro-LEDs) offer numerous advantages, including compact size, high efficiency, and excellent reliability, making them ideal for display applications in AR glasses. In this work, we present both monochrome and monolithic full-color micro-LED displays designed for the application of AR glasses. The monolithic full-color micro-LED display incorporates quantum dots into blue micro-LED pixels. A high color conversion efficiency of 40% has been achieved by QDs embedded into a nanoporous GaN as the color conversion layer. Full-color micro-LED display has been demonstrated.

Author Keywords

Augmented reality, micro-LEDs, monolithic, full-color, quantum dots.

1. Introduction

Recent years, micro-light-emitting didoes (micro-LEDs) has been represented as the next-generation display, particularly attractive for transparent displays and high luminance displays.[1-4] Micro-LEDs exhibit superior brightness, contrast and efficiency in comparison to conventional display technologies, for instance, liquid crystal displays and organic light-emitting diodes. Among the various colors crucial for achieving vibrant and energy efficiency displays, green micro-LED displays have been developed mostly mature due to their essential role in accurate color reproduction, high wall-plug efficiency (WPE) and overall image quality. Besides the green micro-LED displays, high-resolution, full-color micro-LED displays have also attracted lots of attention. However, the full-color micro-LED displays with small size and high resolution remain challenging in both academia and industry. Several approaches have been developing to overcome the challenges in fabricating full-color micro-LED displays, including x-cube combinator, quantum dots (QDs) color converter, vertical stacking of micro-LEDs with three different colors, etc.[5-7]

Recently, color conversion has been considered as a promising method to achieve full-color micro-LED displays, accomplished by patterning red and green QDs onto blue micro-LED mesas. Inkjet printing and photolithography have been widely used to fabricate wafer-scale patterning of QD pixels. Usually, a thick layer of QD color conversion is required to achieve high conversion efficiency and high color purity. To address this issue, we have demonstrated using QDs embedded in a nanoporous GaN (NPQD) as a color conversion layer to achieve high conversion efficiency.

In this paper, we first demonstrated the fabrication and mass-production of monochrome micro-LED displays. High brightness green micro-LED displays have been implanted in AR glasses. Besides the green micro-LED displays, we have proposed a new structure of fabricating monolithic full-color micro-LEDs with applying the NPQD color conversion on blue micro-LED mesas.

2. NPQD color conversion

NPQD consists of QDs embedded inside a nanoporous GaN layer. The nanoporous GaN is formed by the electro-chemical (EC) etching process.[7, 8] The porosity and size of the nanopores can be tuned by varying the doping level or applied voltage during EC etching process.[8, 9] Figure 1(a) shows a SEM image of nanoporous GaN loaded with red QDs. The thickness of NPQD is around 7 μm. The particles can be clearly seen, which are clusters the QDs. The conversion efficiency has been measured by photoluminescence (PL). Figure 1(b) shows PL spectrum taken from a blue light excitation source and a red NPQD, respectively. The blue curve is the PL spectra from a blue LED source used to excite the red NQPD. The red curve was measured from w red NPQD which was excited by the same blue LED attached to the red NPQD. The red power conversion efficiency was estimated to be around 40%, by the integrated red light power divided by the integrated blue light power. The high color conversion efficiency by NPQD is due to the enhanced blue light randomization and strong scattering effect by nanoporous GaN, which significantly increases the light absorption by QDs inside nanoporous GaN.[10, 11]

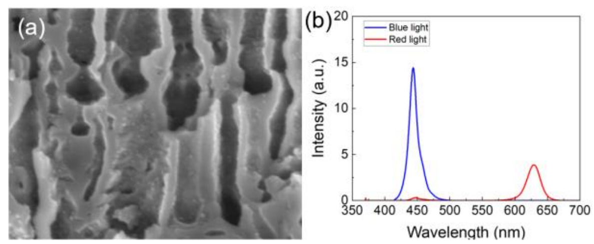

Figure 1(a) SEM image of QDs embedded inside nanoporous GaN. (b) PL spectrum of a blue LED and a red NPQD excited by the blue LED.

3. Monochrome micro-LED displays

The micro-LED display structures were processed on 6-inch wafer. The LED structure was grown on 6-inch Si substrate. Figure 2(a) shows a picture of a 6-inch 0.12" micro-LED wafer after finishing the process. There are more than 1000 micro-LED display dies on each 6-inch wafer. The resolution of each micro-LED display is 640 × 480, with PPI of 6773. After processing, the micro-LED display die was diced frow the wafer. Later, the micro-LED display die was wire-bonded on a flexible printed circuit board (FPC). Figure 3(b) shows a picture of 0.12" micro-LED die packaged on FPC.

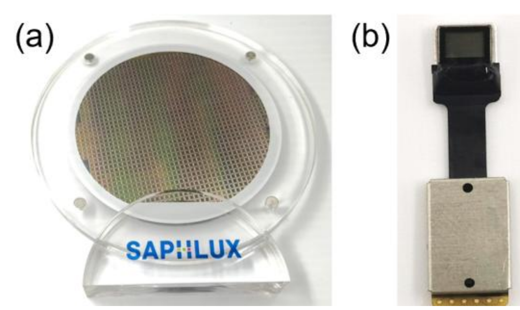

Figure 2. (a) Picture of a 6-inch processed 0.12" micro-LED wafer. (b) Picture of a 0.12" micro-LED display panel on a FPC board.

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Figure 3 shows the lit-up pictures of 0.12” blue, green, and red monochrome micro-LED displays, respectively, with resolution of 640 × 480. The monochrome blue and green micro-LED displays were fabricated on the basis of InGaN-based LEDs grown on Si-substrates. The monochrome red micro-LED displays were made by converting the blue micro-LED pixel mesa with red NPQD as the color conversion layer. The brightness curve of the 0.12” green micro-LED is shown in Figure 4, with 10% active lit-up area of the total display. The brightness can reach up to 2 million nits under injection current of about 25 A/cm^2. The brightness of blue and red micro-LED have also been characterized and can reach above 300,000 nits.

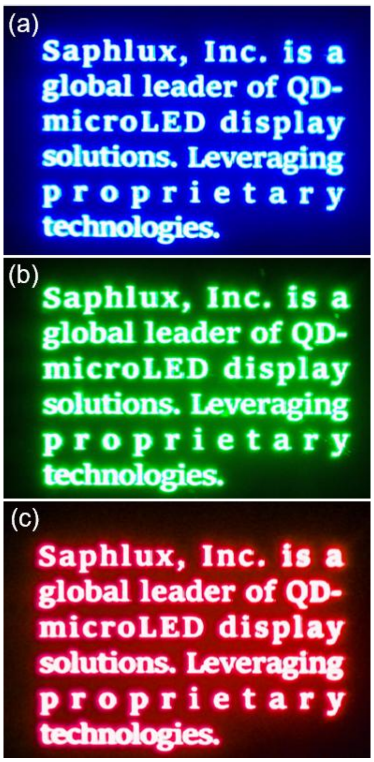

Figure 3. Pictures of (a) blue, (b) green, and (c) red monochrome 0.12” micro-LED displays. The resolution of each display is 640 × 480.

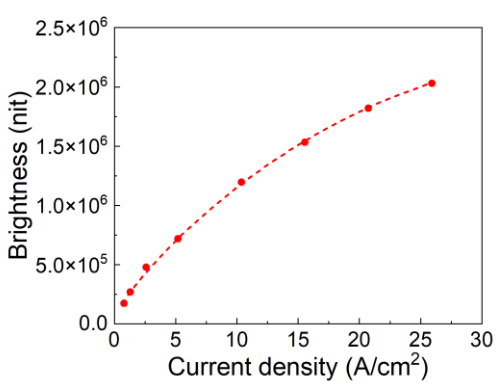

Figure 4. Brightness curve of 0.12” green micro-LED display under different injection current.

4. Monochrome green color AR glasses

AR glasses made with monochrome green micro-LED display have been built up. Figure 4 shows the picture of an AR glasses made with 0.12” green micro-LED display. The brightness entering the eye from the glasses can reach up to around 1000 nits.

Figure 5. Picture of AR glasses made with 0.12” green micro-LED display. The resolution of the micro-LED display is 640 × 480.

5. Monolithic full-color micro-LED display

Monolithic full-color micro-LED display has been fabricated by adopting the NPQD color conversion layer. Blue micro-LED mesas were fabricated first as the excitation source. NPQD with red and green QDs loaded inside different areas were attached on the top of blue micro-LED pixel mesas and excited by blue micro-LED mesas to achieve the red and green emission pixels. Figure 6 shows an image of a monolithic full-color micro-LED display. The resolution of the display is 512 × 384 and the sub-pixel pitch is 7.5 µm. A new version of monolithic full-color micro-LED display with sub-pixel pitch of 4 µm will come out soon. The white color brightness of our new version of monolithic full-color micro-LED display is expected to reach up to above 200,000 nits.

Figure 5. Image of a lit-up monolithic full-color micro-LED display.

6. Conclusion

We have reported the fabrication and mass-production of monochrome micro-LED displays used for the application of AR glasses. AR glasses built up with green micro-LED displays have also been produced. Besides the monochrome micro-LED displays, we have also demonstrated the monolithic full-color micro-LEDs display by applying the NPQD color conversion layer on blue micro-LED pixel mesas. High color conversion efficiency can be achieved up to around 40% from blue to red light power by NPQD.

7. References

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