

Evolution and Differentiation of OLED Microdisplay

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Abstract

This report reviews the evolution of OLED microdisplays and explains the unique features and technologies that support their differentiation. OLED microdisplays have garnered attention in various fields due to their compact form factor and ability to deliver high-resolution and high-quality visuals. Additionally, the report discusses the trends in evolution aimed at further enhancing customer experience value.

Author Keywords

Microdisplay; OLED; EVF; AR; VR; MR; XR; High Resolution; High Luminance; High Optical Efficiency; Large Color Volume; On Chip Color Filter; Microlens On Glass; On Chip Microlens

1. Introduction

Microdisplays are very small, high-resolution display technologies used in various applications. In particular, OLED microdisplays are adopted in electronic viewfinders (EVF) for consumer and professional cameras and camcorders due to their excellent image quality. Recently, they have been used in a wider range of applications, such as glasses for augmented reality (AR) and virtual reality (VR). To realize these applications, microdisplays require various performance characteristics, such as high resolution, high brightness, large color volume, high contrast, fast response time, high refresh rate, and low power consumption. Therefore, high-resolution technology has been achieved by using silicon as the driving substrate instead of glass and combining it with OLED layers¹⁻³. This report explains the evolution of OLED microdisplays and the technologies that enable them.

2. Required Performance

Among the various performance characteristics required for OLED microdisplay panels, Sony Semiconductor Solutions Corporation (hereinafter referred to as SSS) has focused on developing three key technologies: high resolution, high brightness and large color volume. The priority of these performance characteristics varies depending on the application of the panel, but SSS considers "High resolution" and "High brightness" to be particularly important.

The importance of "High resolution" and "High brightness" technologies is explained. Display resolution has a certain target, and it is required that pixel dots are not recognized by the human eye. The required resolution is determined based on the necessary Field Of View (FOV) and human visual acuity. For example, in the EVF for cameras, an FOV of about 30 degrees is required, and if the angular resolution of the human eye is about 60ppd, it can be seen that the panel resolution needs to be UXGA or higher (Fig. 1). On the other hand, the required resolution varies depending on the FOV required for other applications. In the case of VR, where immersion is a critical factor, a horizontal FOV exceeding 110 degrees, for instance, necessitates the use of panels with a resolution of 6K or higher.

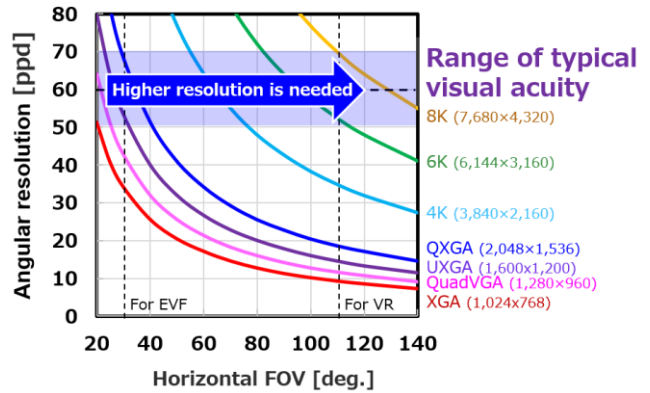


Figure 1. FOV and human angular resolution

In addition, OLED microdisplays are used with magnification, but if magnified too much, the image appears coarse and dark (Fig. 2). For this reason, "High resolution" and "High brightness" are important.

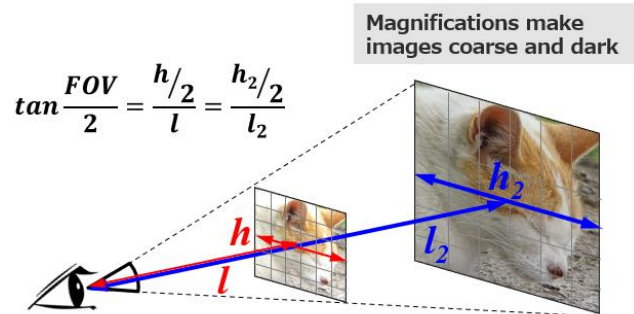


Figure 2. The impact of image enlargement

For these reasons, SSS has been providing panels with both "Higher resolution" and "Higher brightness" for over 10 years. The panels started with the first generation released in 2011 and have evolved to the fourth generation with the evolution of technology and panel performance. During this period, the pixel size, which was 9.9 μm in 2011, was reduced to 5.1 μm as of 2024, and the maximum brightness improved from 200 cd/m² to 10,000 cd/m² (Fig. 3). The technologies that achieved these performance improvements are explained.

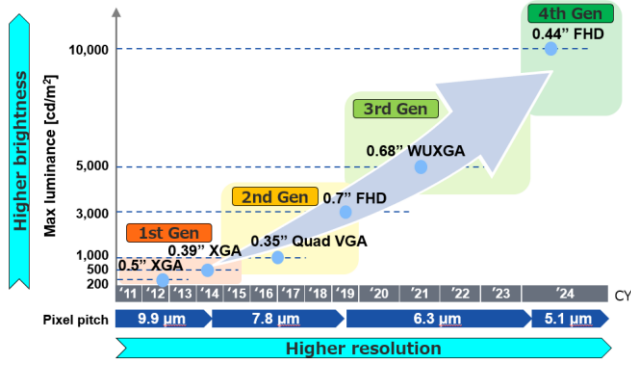


Figure 3. Evolution and achievements of SSS' OLED microdisplays

3. Core Technologies of OLED Microdisplays

The evolution of OLED microdisplay technology, particularly the efforts and advancements in "Higher resolution" and "Higher brightness", are explained in detail.

3-1. 1st Generation Panel

The first-generation panel was born from the combination of a backplane using a silicon wafer and OLED technology. It was important not only to have a smaller pixel pitch than direct-view displays but also to develop a new silicon backplane, OLED device structure, pixel design and layout, and pixel driving circuit specifically for OLED microdisplays.

3-2. 2nd Generation Panel

The second-generation panel introduced technologies to improve resolution and brightness based on the technology of the first-generation panel. As a high-resolution technology, a "Driving circuit with self-correction function" was adopted. "Microlens on glass" and an Indium Zinc Oxide (IZO) high-transmittance cathode electrode were implemented to enhance brightness.

- Driving Circuit with Self-Correction Function

To elucidate the "driving circuit with self-correction function" adopted as a higher resolution technology, Fig. 4 presents the circuit diagrams and image examples with and without the brightness self-correction function. Conventional circuits without the function exhibit variations in the threshold voltage (V_{th}) of transistors in the pixel driving circuit. Consequently, this leads to deviations in the current supplied to the OLED device, resulting in brightness non-uniformity. Two transistors and one capacitor were added to each pixel as a correction circuit to mitigate this brightness non-uniformity. The challenge was to integrate the driving circuit with the correction function within the limited space of the pixel size. Ultimately, Pch 4Tr + 2C circuit with a self-correction function was developed for each pixel, effectively suppressing brightness variations between pixels and achieving high-quality images⁴.

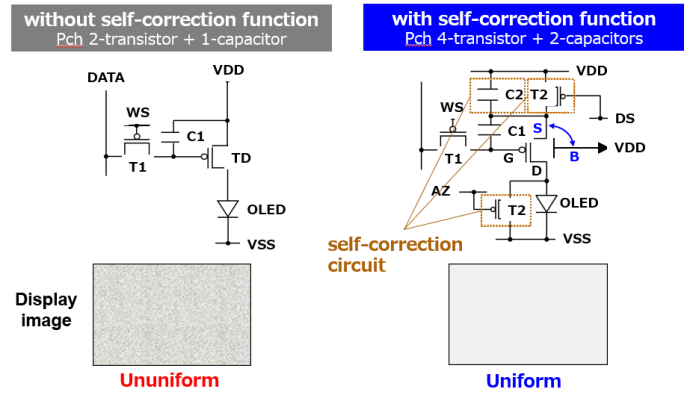


Figure 4. Pixel driving circuit with self-correction function

- Microlens On Glass

The mechanism of light collection using microlens is that light emitted from the OLED is refracted at the interface between the microlens and resin with different refractive index and extracted forward (Fig. 5). This technology improved brightness by 1.8 times⁶ (Fig. 6).

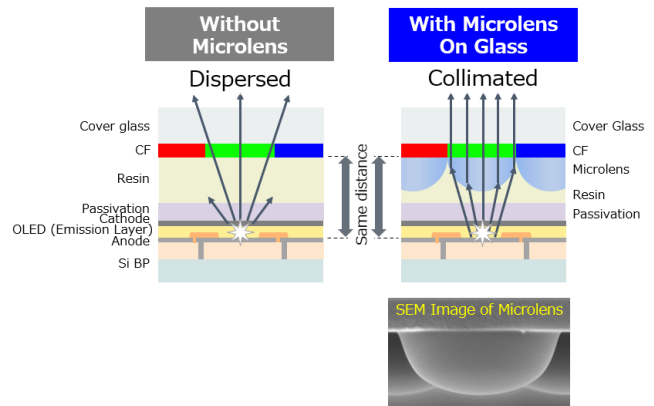


Figure 5. Structure and image of Microlens on Glass

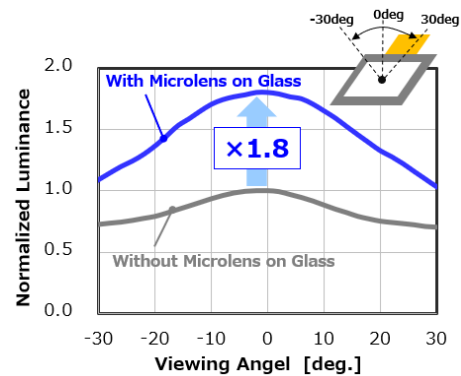


Figure 6. Brightness with Microlens on Glass

- IZO Cathode Electrode

Instead of the commonly used MgAg cathode layer, an IZO cathode layer with higher light transmittance was deposited on the electron injection layer of the OLED using a low-temperature sputtering process (Fig. 7). The change from the process using MgAg was minimized, and the performance of the panel, such as I-V characteristics and lifetime, remained equivalent. Fig. 8 compares the spectra after passing through the color filter. It can be seen that IZO has low absorption in the blue and green wavelength regions from this spectral comparison. This difference can be explained by the different optical properties of these cathode materials. Considering the color balance, it was found that changing the cathode layer improved optical efficiency by 1.3 times⁶. Furthermore, IZO deposited by sputtering is uniform, and it has the advantage that the cathode resistance is not affected by the geometric steps of the Si backplane caused by the anode or pixel design.

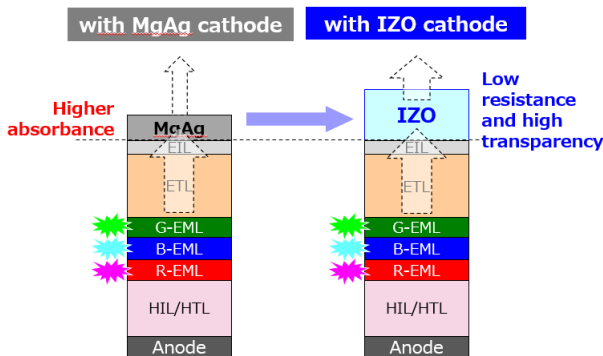


Figure 7. OLED structure with IZO cathode

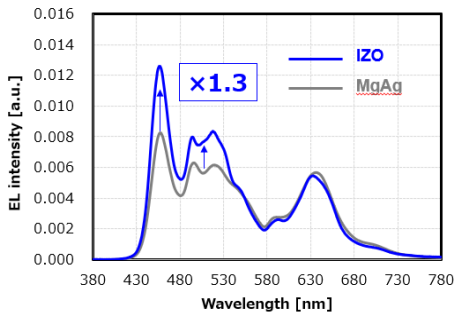


Figure 8. Emission Spectra with IZO cathode

3-3. 3rd & 4th Generation Panel

In the third and fourth generations, "Resolution" and "Brightness" were significantly improved by adding new technologies based on the technologies established up to the second generation. As a high-resolution technology (to miniaturize the circuit), the wiring material of silicon backplane was changed from aluminum to copper, and the wiring width was reduced. Additionally, an "On Chip Color Filter (OCCF)" was adopted to improve process accuracy. A "Proprietary OLED device structure" was also applied to achieve higher emission efficiency. Furthermore, the "Microlens on Glass" technology from the second generation was replaced with "On Chip Microlens," resulting in higher brightness.

- OCCF

Generally, as the pixel size (pixel pitch) decreases, emitted light is more likely to pass through adjacent color filters, leading to color crosstalk. One of the factors is the misalignment between the color filter and the emission position caused by insufficient process accuracy. SSS' OLED microdisplays changed the process of forming the color filter directly on the silicon backplane substrate instead of on the cover glass to minimize this misalignment (Fig. 9). This eliminated the impact of alignment accuracy between the backplane and the color filter, achieving high positional accuracy. Furthermore, this structural change shortened the distance between the emission point and the color filter, further suppressing color crosstalk⁵. However, when forming the color filter directly on the backplane substrate after forming the organic film, it was necessary to consider the thermal impact on the OLED material. Therefore, color filter materials and low-temperature processes were developed to realize this structure.

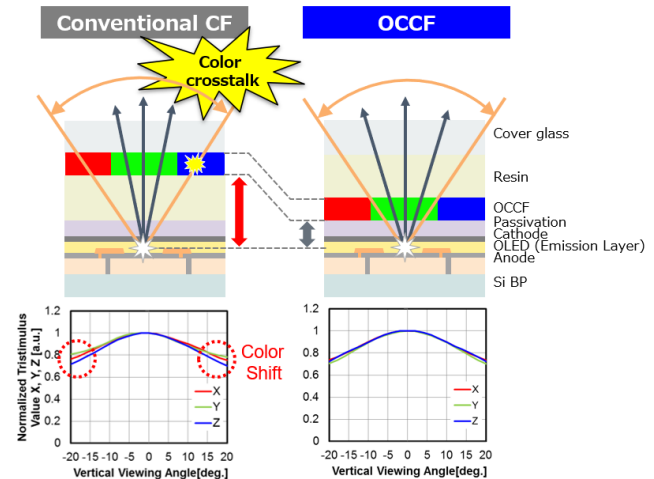


Figure 9. Vertical viewing angle versus Normalized tristimulus value with Conventional CF and with OCCF

- On Chip Microlens

In the second generation, microlens were formed on the cover glass along with the color filters, but this was insufficient to prevent color mixing due to the distance from the OLED emission part. Therefore, similar to the OCCF, a technology to form microlens on the silicon backplane substrate was established (Fig. 10). The principle of utilizing light refraction to improve light utilization efficiency remained unchanged. By forming the microlens directly above the OLED, the distance between the OLED light source and the microlens was shortened, further improving optical efficiency and increasing brightness by 1.7 times compared to the conventional technology (Fig. 11).

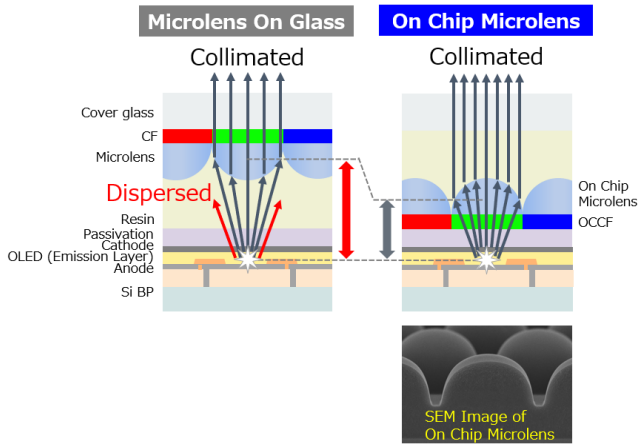


Figure 10. Structure and image of On Chip Microlens

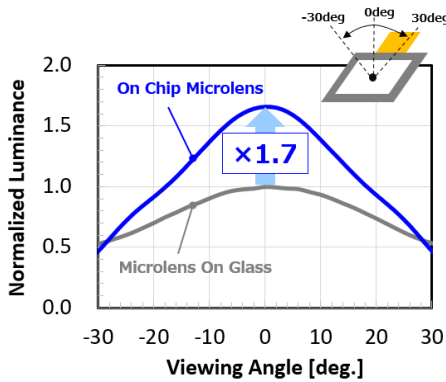


Figure 11. Brightness with On Chip Microlens

Various technologies have been applied to achieve the main two objectives of "Higher resolution" and "Higher brightness" for OLED microdisplays, establishing core technologies along with improving panel performance and quality. As a result, the industry's smallest 5.1 μ m pixels and the highest brightness of up to 10,000 cd/m² were achieved (As of the press release on September 24, 2024).

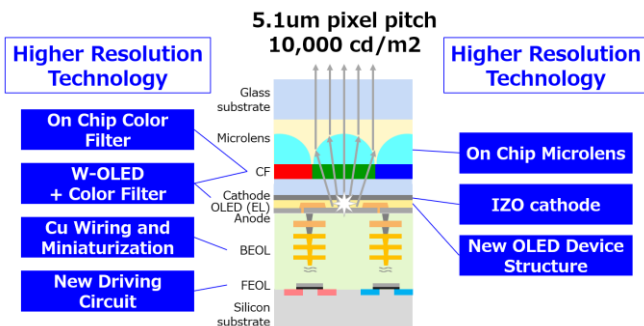


Figure 12. OLED Microdisplay 4th Gen. in 2024

As explained above, SSS has been working on the evolution of OLED microdisplays for over 10 years and will continue to develop new technologies and evolve panels.

4. Conclusion

The evolution and achievements of SSS' OLED microdisplays were introduced. From the perspective of the characteristics and usage of OLED microdisplays, we explained the technologies that improve "Higher resolution" and "Higher brightness", which are considered the most important. We also introduced panels that have evolved by adding technologies based on these technologies. SSS will continue to strive to meet various customer needs in the future.

5. Acknowledgements

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6. References

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