Zero-Bezel Flexible MicroLED Display Using Through-Plastic Vias

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Abstract

We have successfully developed zero-bezel flexible active-matrix micro-LED displays (160×160 pixels, 133 ppi) using through-plastic vias (TPVs) with intermediate connecting electrodes (ICEs). By using TPVs with ICEs to connect signal wires patterned on the front and back sides of the polyimide film, we formed signal input lines on the back side of the display screen, instead of in the bezel as in conventional displays, thereby eliminating the bezel. Furthermore, a tiled flexible micro-LED display (320×320 pixels, 133 ppi) was constructed by seamlessly tiling zero-bezel displays, demonstrating the feasibility of flexibly customizing the display in size, shape, and aspect ratio.

Author Keywords

Zero-bezel display; Flexible display; Tiled display; Bezel-less display; Through-plastic via; Micro-LED; Oxide thin-film transistor

1. Introduction

A wide variety of viewing devices will be incorporated into various spaces in the future, enabling people to enjoy their viewing experiences anytime, anywhere. Figure 1 shows examples of future viewing styles where people can enjoy content

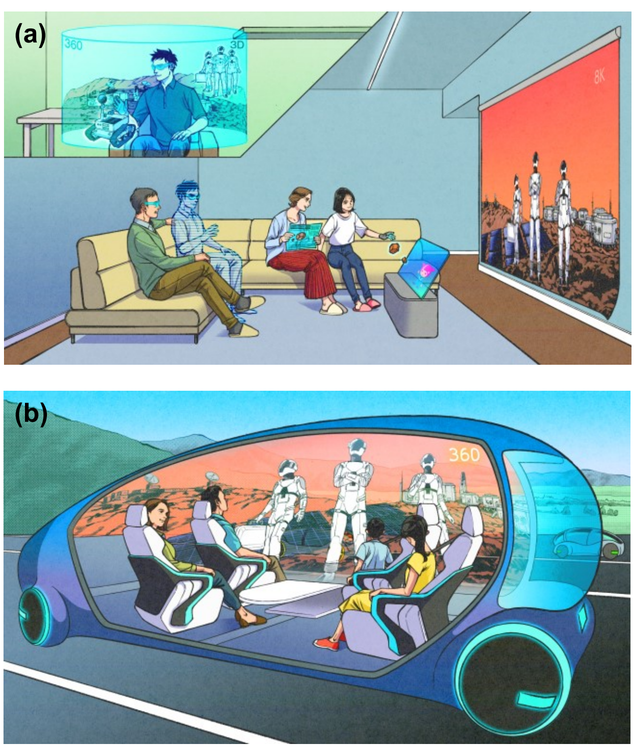

Figure 1. Expected future viewing styles: (a) living room and (b) interior of vehicle [1].

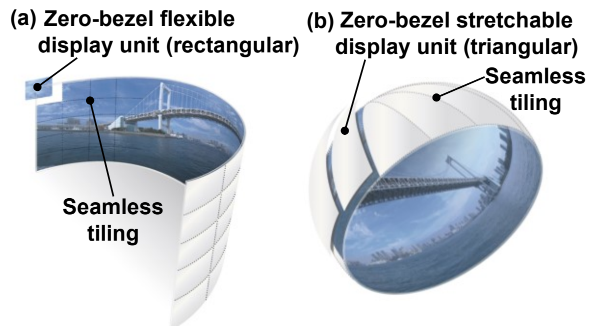

Figure 2. Seamless tiling with zero-bezel display units: (a) large-sized flexible tiled display and (b) dome-shaped tiled display [6].

with a variety of displays such as a large-sized wallpaper display in a living room (Fig.1(a)), and a dome-shaped display in a vehicle (Fig.1(b)) [1].

Tiling [2-4] display units is a promising approach to realize such displays because it allows flexible customization of the display in terms of size, shape, and aspect ratio. However, tiled displays with conventional display units have a major drawback in that they have noticeable seams due to the bezels surrounding the display units [5]. These bezels are required because they contain input signal wires for the thin-film transistors (TFTs) in pixel circuits. If zero-bezel display units can be realized, seamless tiling will be possible for the types of displays shown in Fig. 2 [6]. Large-sized flexible tiled displays can be fabricated by tiling rectangular flexible display units (Fig. 2(a)), while dome-shaped tiled displays require triangular stretchable display units (Fig. 2(b)). These large-sized displays can provide viewers with an immersive viewing experience.

Several approaches, such as side wiring and film bending [4], have been proposed to reduce the bezel width in conventional displays. However, although the bezel width can be reduced to about 1 mm [7], the bezel cannot be completely eliminated. Therefore, a new approach is required to completely remove the need for a bezel.

Recently, we have proposed a novel approach to eliminate the bezel by using through-plastic vias (TPVs) that penetrate a polyimide (PI) film substrate to input signals from the back side of the PI film to the front side. Using TPVs, we have developed oxide TFTs that can be driven from the back side of the PI film substrate [8], zero-bezel flexible TFT backplanes with the oxide TFTs [6, 9], and zero-bezel flexible active-matrix micro-LED displays and seamlessly tiled displays using the zero-bezel displays [10, 11]. Here we describe our recent work on the development of the zero-bezel and seamlessly tiled displays using TPVs, focusing in particular on the unique device structure and fabrication process.

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2. Zero-bezel display

Figure 3 compares the computer-aided design (CAD) layout for (a) conventional and (b) zero-bezel displays [10]. In the conventional display shown in Fig. 3(a), scan, data, power (VDD), and ground (GND) wires to input video signals are formed in the bezel around the screen. On the other hand, in the zero-bezel display shown in Fig. 3(b), all the input wires are formed on the back side of the display screen, instead of in the bezel. These back-side wires are connected to the scan, data, power, and ground wires on the front side of the screen using TPVs.

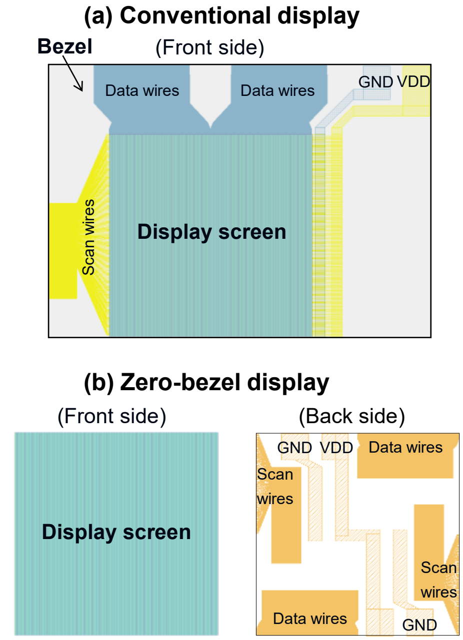

Figure 3. Comparison of CAD layout for (a) conventional and (b) zero-bezel displays [10].

Figure 4 illustrates the fabrication process for the zero-bezel displays [11]. First, an 8-μm-thick PI film is formed on the front side of a glass substrate (denoted as the 1st glass substrate) by coating. Then, an In-Sn-Zn-O (ITZO) thin-film transistor (TFT) backplane is formed on the PI film using conventional photolithography. Back-channel-etched (BCE) ITZO TFTs [12] with a channel length of 10 μm are used as switching and driving TFTs in the pixel circuits. Note that we introduce intermediate connecting electrodes (ICEs) on the same metal layer as the gate electrodes to improve the connection between the front- and back-side signal wires. Then, micro-LEDs with dimensions of *ca.* 20×40 μm are bonded to the TFT backplane using solder. The next step is the attachment of a 2nd glass substrate to the top of the assembly using an adhesive film. The 1st glass substrate is then detached using a laser lift-off process to expose the back side of the PI film, which completes the first half of the fabrication process. This process is almost the same as that used to produce conventional flexible displays, except for the introduction of the ICEs.

The fabrication process for the back side is specifically designed for the zero-bezel displays. TPVs are formed from the back side of the PI film by dry etching using a CF_4/O_2 gas mixture with a 150-nm-thick ITZO hard mask [9]. The use of ICEs eliminates the need to etch the SiO_2 insulating layer from the back side during TPV formation. This significantly suppresses conduction failure between the front- and back-side signal wires. Subsequently, 3D signal wires, which pass through the TPVs, and back-side signal wires are formed by sputtering of Al and Mo alloy. Finally, after laser cutting around the display screen, the 2nd glass substrate and adhesive film are detached.

Figure 5 shows cross-sectional scanning electron microscopy (SEM) images of a TPV, which show that although the TPV is not completely filled with metal, a metal layer is present on the sidewalls, which acts a 3D signal pathway. By testing a TPV chain with 3D signal wires, we confirmed that 1000 TPVs connected in series were fully functional and that each had a resistance as small as 5.9 Ω [11].

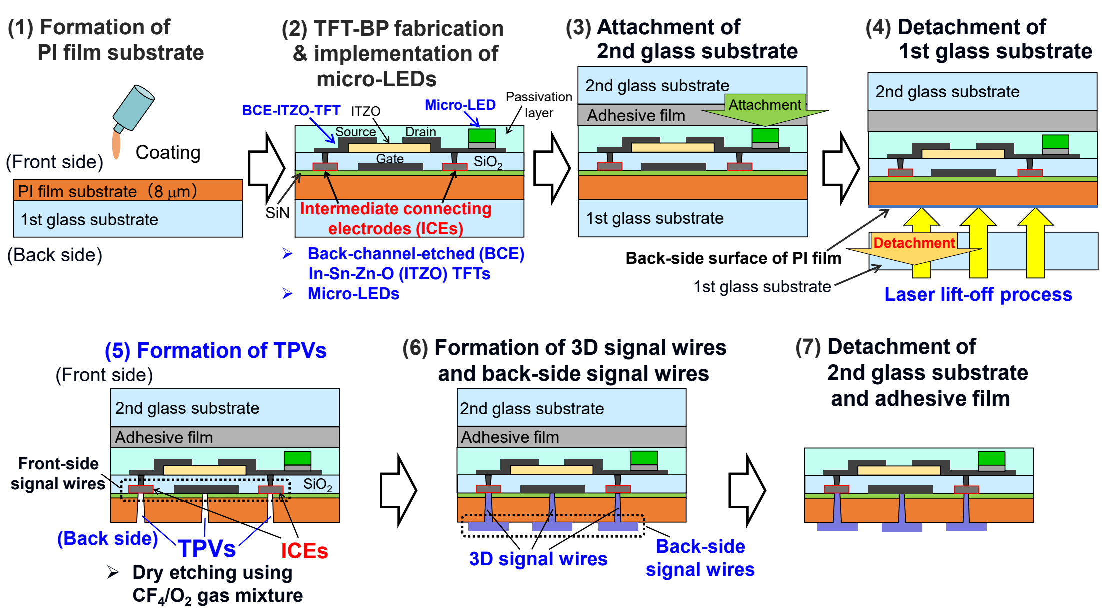

Figure 4. Fabrication process for zero-bezel displays. TPVs and ICEs are introduced to connect signal wires formed on the front and back sides of the PI film substrate.

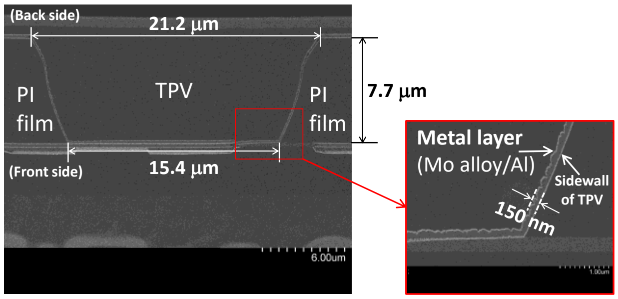

Figure 5. Cross-sectional SEM images of TPV. The TPV is not filled with metal, but a metal layer is present on the sidewalls.

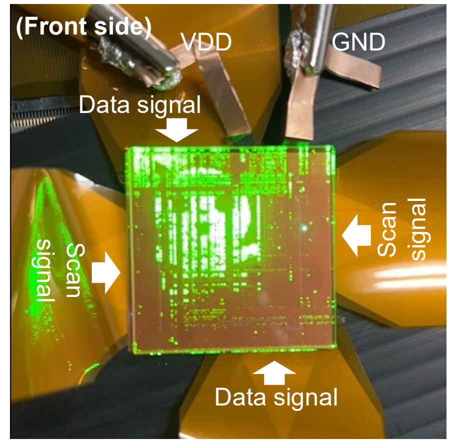

Figure 7. Image rendered on the developed zero-bezel flexible active-matrix micro-LED display.

Table I. Specifications of the zero-bezel display

Display size	3-cm square
Number of pixels	160×160
Pixel size	190×190 µm
Resolution	133 ppi
Driving device	Back-channel-etched In-Sn-Zn-O TFTs
Light-emitting device	Green micro-LEDs (Green monochrome)

Figures 6(a), 6(b), and 6(c) show a fabricated specimen composed of four displays on a single substrate, a zero-bezel flexible active-matrix micro-LED display with TPVs and ICEs after the laser cutting process, and an optical micrograph near the edge of the zero-bezel display, respectively [11]. As shown in Fig. 6(c), the width of the border around the screen is ultra-narrow, with a width of about 13–15 µm, which is negligible compared to the 1-mm bezel width for typical narrow-bezel displays. Although the border width strongly depends on the accuracy of the laser cutting process, we confirmed that it could be narrowed down to 6 µm using a test substrate and our laser cutting machine [10]. The display specifications are summarized in Table I. Note that only green micro-LEDs were bonded to the backplane in this study. We will develop full-color zero-bezel displays in future work.

Figure 7 shows an image rendered on the developed zero-bezel flexible active-matrix micro-LED display. The display clearly shows moving images produced by inputting scan and data signals from the back side. Because of the zero-bezel structure, images and text can be displayed up to the very edge of the screen.

3. Tiled display

Furthermore, we developed a tiled flexible micro-LED display by seamlessly tiling zero-bezel displays [11]. The tiled display was fabricated by first attaching four zero-bezel displays to a temporary glass substrate with a weakly adhesive film, and then attaching them one by one counterclockwise to a transparent plastic substrate with a strongly adhesive transparent film, as shown in Fig. 8. The transfer process used the difference in adhesive strength between the two types of adhesive film. Note that the first three zero-bezel displays were almost perfectly aligned (misalignment was within 3% of the pixel size) while the fourth display, which was the last to be attached to the transparent substrate, exhibited a relatively large alignment error (>10%). We expect to be able to reduce the misalignment to within 10% by methods such as changing the order of tiling.

Figures 9(a) and 9(b) show a photograph of the fabricated tiled display taken from the front side, and an image rendered on the display with all the green micro-LEDs turned on, respectively [11]. The size of the tiled display is 6×6 cm, and the number of pixels is 320×320. LED luminescence is observed even in the region where two zero-bezel displays come together. Note that

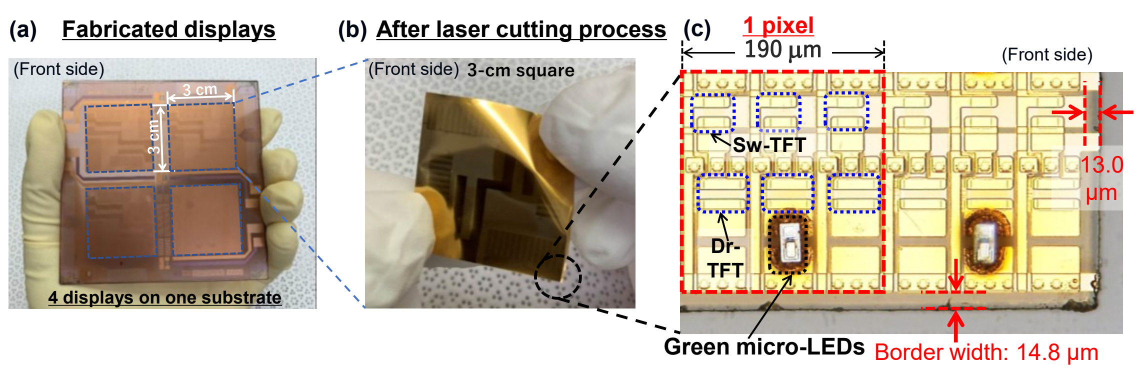

Figure 6. (a) Fabricated specimen comprising four displays on single substrate. (b) Zero-bezel flexible active-matrix micro-LED display with TPVs and ICEs after laser cutting process. (c) Micrograph near edge of zero-bezel display [11].

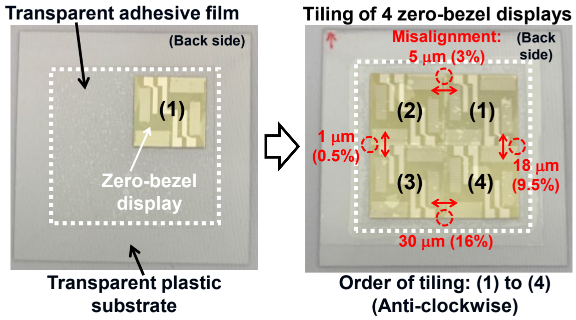

Figure 8. Seamless tiling by attaching four zero-bezel displays one by one to transparent plastic substrate with transparent adhesive film [11].

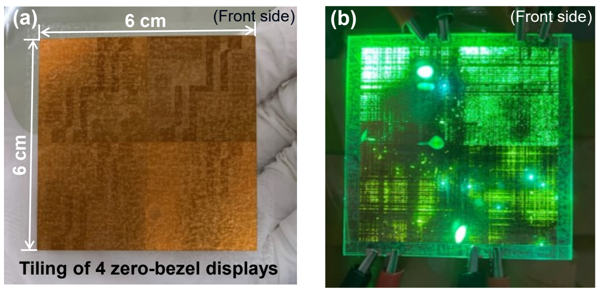

Figure 9. (a) Photograph of the fabricated tiled display taken from the front side. (b) Image rendered on the display with all the green micro-LEDs turned on [11].

Table II. Specifications of the tiled display

Display size	6-cm square
Number of display units	4
Number of pixels	320×320
Pixel size	190×190 μm
Resolution	133 ppi
Driving device	Back-channel-etched In-Sn-Zn-O TFTs
Light-emitting device	Green micro-LEDs (Green monochrome)

since our proposed zero-bezel display structure has no bezel on any of the four sides, there is no limit to the number of zero-bezel displays that can be used for seamless tiling in both the horizontal and vertical directions. Finally, Table II summarizes the specifications of the tiled display.

4. Summary

Zero-bezel flexible active-matrix micro-LED displays were developed by using TPVs with ICEs. We also fabricated a seamlessly tiled flexible active-matrix micro-LED display composed of the zero-bezel displays using a transfer process. Our approach is applicable to displays of various sizes, shapes, and aspect ratios, from small ones such as those used in smartphones to large ones such as wallpaper displays. Thus, it offers benefits in a variety of situations, from personal use to immersive experiences for large groups of people.

5. Acknowledgements

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6. References

1. NHK Science & Technology Research Laboratories, "*Future Vision 2030-2040*". Available at https://www.nhk.or.jp/strl/english/future_vision/
2. Nakamura D, Ikeda H, Sugisawa N, Yanagisawa Y, Eguchi S, Kawashima S, *et al.* An 81-in. 8k x 4k OLED Kawara-type multidisplay that provides a seamless, continuous image. SID 2015 DIGEST. 2015;1031–4.
3. Biwa G, Doi M, Yasuda A, Kadota H. Technologies for the crystal LED display system. SID 2019 DIGEST. 2019;121–4.
4. Chen W-L, Lin Y-H, Chuang H-A, Huang C-W, Cheng T-S. MicroLED display with tiling technology. SID 2022 DIGEST. 2022;1024–7.
5. Ebert A, Thelen S, Olech P-S, Meyer J, Hagen H. Tiled++: An Enhanced Tiled Hi-Res Display Wall. IEEE Trans. Visualization and Computer Graphics. 2010;16:120–132.
6. Tsuji H, Miyakawa M, Takei T, Nakata M. Flexible/ Stretchable TFT Backplane Technologies for Deformable Displays. Proc IDW'22. 2022;1055–7.
7. Niu T-L, Yang C-H, Chen W-S, Wang B-K, Mi X-D, Teng H-Y, *et al.* Glass Solution for Zero Border Design (ZBD) TVs: Advantages and Prevention of Border Light Leakage. SID 2022 DIGEST. 2022;662–5.
8. Tsuji H, Miyakawa M, Nakata M. Oxide Thin-film Transistors Driven from Substrate Backside Using Three-dimensional Wires. Proc IDW'21. 2021;143–4.
9. Tsuji H, Miyakawa M, Takei T, Fujisaki Y, Nakata M. Flexible bezel-less thin-film transistor backplane with through plastic-vias for seamless tiling. J Soc Inf Display. 2025;33(1):18–23.
10. Tsuji H, Takei T, Miyakawa M, Yamamoto T, Motomura G, Fujisaki Y, Nakata M. Flexible Bezel-less Micro-LED Display Driven from Substrate Back Side Using Through-plastic Vias. Proc IDW'23. 2023;1132–4.
11. Tsuji H, Takei T, Miyakawa M, Yamamoto T, Motomura G, Fujisaki Y, Nakata M. Zero-Bezel Flexible Active-Matrix Micro-LED Display Using Through-Plastic Vias and Its Seamless Tiling. 2024 IEEE International Electron Devices Meeting (IEDM), San Francisco, CA, USA, 2024, pp. 1–4.
12. Nakata M, Motomura G, Nakajima Y, Takei T, Tsuji H, Fukagawa H, *et al.* Development of flexible displays using back-channel-etched In-Sn-Zn-O thin-film transistors and air-stable inverted organic light-emitting diodes. J Soc Inf Display. 2016;24(1):3–11.