Flexible Bezel-less Micro-LED Display Driven from Substrate Back Side Using Through-plastic Vias

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ABSTRACT

Flexible bezel-less micro-LED displays are developed on polyimide film substrates using through-plastic vias (TPVs). Mask misalignment in the TPV formation process is reduced by accounting for substrate shrinkage. The developed displays provide clear moving images with video signals input from the substrate back side through the TPVs.

1 Introduction

Tiled displays, which consist of multiple display units, allow customization of display size, shape, and aspect ratio [1-3]. However, bezel-less display structures are required to realize seamless tiling without noticeable seams. Figure 1 compares conventional and bezel-less display structures. In the conventional structure (Fig. 1(a)), all wiring is formed only on the front side of the substrate, including the periphery of the display screen. Therefore, bezels cannot be eliminated from conventional displays. To realize a bezel-less structure (Fig. 1(b)), it is required to form wiring on both the front and back sides of the substrate and to connect the front- and back-side signal wires [4,5].

In this work, we have developed flexible bezel-less micro-LED displays on polyimide (PI) film substrates using through-plastic vias (TPVs) while accounting for substrate shrinkage. Figure 2 shows a schematic diagram of a TPV. Front- and back-side signal wires were connected using three-dimensional (3D) signal wires that pass through the TPVs. We also demonstrate that the developed bezel-less displays provide clear moving images when driven from the substrate back side through the TPVs.

2 Experiment

A flexible bezel-less micro-LED display was fabricated as follows. An oxide thin-film transistor (TFT) backplane was formed on an 8.5-μm-thick PI film substrate fixed to a glass plate (denoted as the 1st glass plate) using a conventional photolithography process. Figure 3 shows an optical micrograph of the pixels taken from the front side. Back-channel-etched In-Sn-Zn-O TFTs [6] with channel lengths of 10 μm were used as switching and driving TFTs in the pixel circuits. Green micro-LEDs with a size of *ca.* 20×40 μm were bonded onto the oxide-TFT backplane using solder.

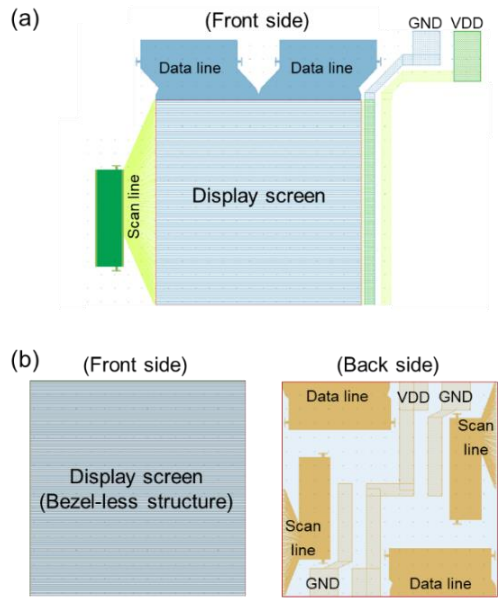

Fig. 1. (a) Conventional and (b) bezel-less display structures.

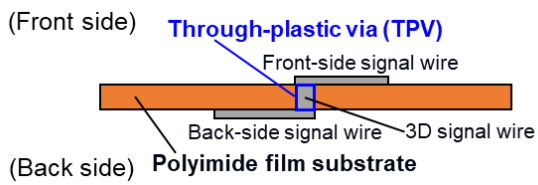

Fig. 2. Schematic of through-plastic via (TPV).

An adhesive film and another glass plate (denoted as the 2nd glass plate) were then attached to the top of the PI film substrate. The film substrate with the 2nd glass plate was then delaminated from the 1st glass plate to expose the substrate back side using a laser lift-off process. Note that shrinkage of the PI film substrate occurs during this process, which causes mask misalignment in the next process of TPV formation. The substrate shrinks by approximately 10 μm in both the vertical and horizontal directions. Computer-aided design (CAD) data for the TPV pattern were corrected to reduce the influence of this shrinkage. As shown in Fig.

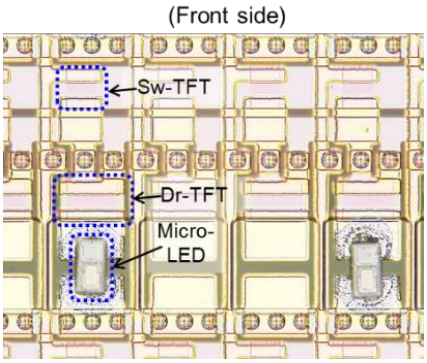

Fig. 3. Optical micrograph of pixels taken from front side. Sw- and Dr-TFTs represent switching and driving TFTs, respectively.

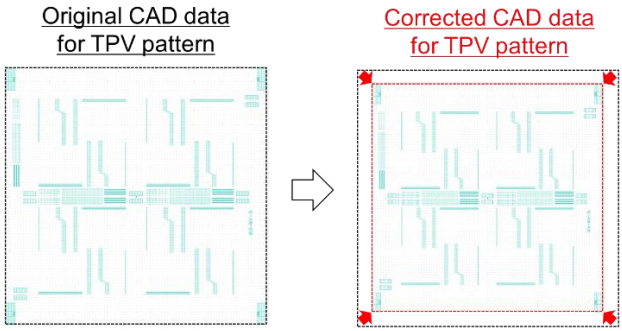

Fig. 4. Schematic diagram of corrected CAD data for TPV pattern accounting for substrate shrinkage.

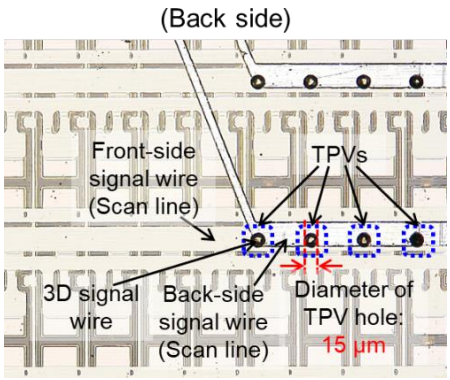

Fig. 5. Optical micrograph of front-side, back-side, and 3D signal wires and TPVs.

4, the TPV pattern was scaled uniformly by accounting for the shrinkage. This is a simple approach that worked well in this work. TPVs were formed with this approach from the back side of the substrate by dry etching using a CF_4/O_2 gas mixture [4,5]. The diameter of the TPV holes measured at the back side was approximately 15 μm. 3D signal wires that pass through the TPVs and back-side signal wires were then formed by sputtering to electrically connect the front and back sides of the film substrate. Figure 5 shows an optical micrograph of the front- and back-side signal wires used for scan lines, which were connected using 3D signal wires that pass through the TPVs. Front- and back-side wires for the other lines (data, power, and ground lines) were also connected in the same manner. Finally, by cutting around the display screen with a laser, a bezel-less display structure was obtained, as shown in Fig. 6. The bezel width was as narrow as 6 μm.

3 Results

Figure 7 shows a photograph of a developed flexible bezel-less micro-LED display with a size of 3×3 cm. Only green micro-LEDs were bonded onto the oxide-TFT backplane with a resolution of 133 ppi. The number of pixels was 160×160.

Figure 8 shows photographs of images rendered on a flexible bezel-less micro-LED display. The display clearly shows moving images produced by inputting video signals from the substrate back side. Note that although only a quarter of the screen area shows images due to the limitations of the experimental setup, this will be improved in future work.

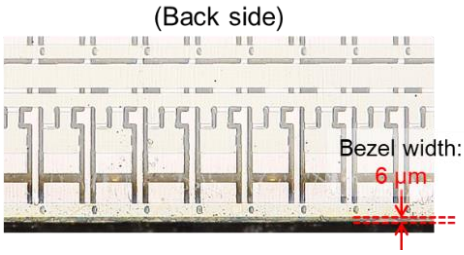

Fig. 6. Optical micrograph of back side of developed bezel-less display structure. The bezel width was as narrow as 6 μm.

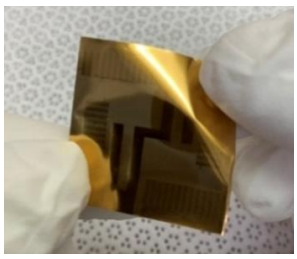

Fig. 7. Photograph of developed flexible bezel-less micro-LED display taken from front side.

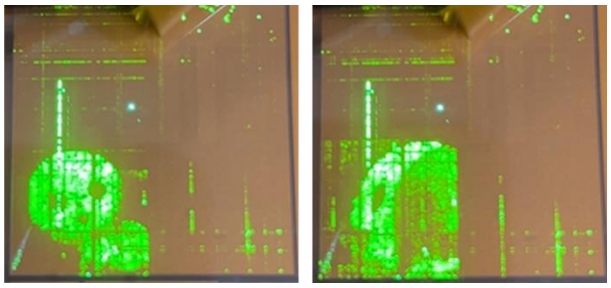

Fig. 8. Photographs of images rendered on developed flexible bezel-less micro-LED display. The video signals were input from the substrate back side.

4 Conclusions

Flexible bezel-less micro-LED displays were developed using TPVs. Mask misalignment in the TPV formation process was reduced by taking substrate shrinkage into account. It was demonstrated that the developed displays clearly show moving images by inputting video signals from the back side through the TPVs. These developments are promising for the realization of seamless tiled displays.

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