# Flexible/Stretchable TFT Backplane Technologies for Deformable Displays

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## ABSTRACT

*In this paper, we describe our recent work on the development of flexible/stretchable thin-film transistor (TFT) backplane technologies for deformable displays. A flexible bezel-less TFT backplane with through-plastic-vias and dome-shaped stretchable TFT arrays with acrylic adhesive were developed.*

## 1 INTRODUCTION

Deformable displays have been attracting attention for use in various applications due to their high flexibility and stretchability, in contrast to conventional flat, rigid displays [1-4]. Figure 1 shows possible future viewing styles where viewers can enjoy content using deformable displays such as newspaper-type, wallpaper-type (Fig. 1(a)), and dome-shaped displays (Fig. 1(b)) [5].

Tiling [6-8] with a variety of panel units is a promising approach to customizing displays in terms of size, shape, and aspect ratio. This approach is also effective for deformable displays; however, tiled displays with conventional panel units have a major drawback in that they suffer from noticeable seams due to bezels. The bezels cannot be eliminated in conventional panel units because wires are formed on the bezels to input signals into the thin-film transistors (TFTs) in pixel circuits. If these signals could be input into the TFTs from the back side of the panel units instead of from the bezels, then bezel-less panel units could be realized. This would enable seamless tiling for deformable displays, as shown in Fig. 2. Large flexible tiled displays could then be realized by tiling flexible bezel-less panel units (Fig. 2(a)), while dome-shaped tiled displays require stretchable bezel-less panel units (Fig. 2(b)).

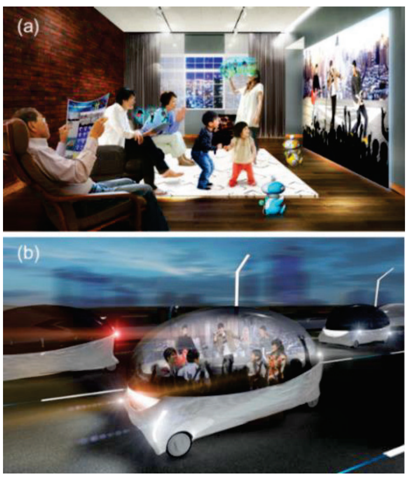


**Fig. 1. Wide variety of future viewing styles: (a) living rooms and (b) vehicle interiors [5].**

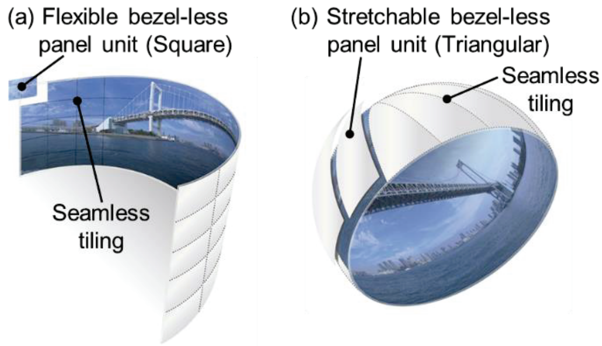


**Fig. 2. Seamless tiling with bezel-less panel units: (a) large flexible tiled display and (b) dome-shaped tiled display.**

Here we describe our recent work on the development of a flexible bezel-less TFT backplane and dome-shaped stretchable TFT arrays for deformable displays with seamless tiling.

## 2 FLEXIBLE BEZEL-LESS TFT BACKPLANE

We have developed a flexible bezel-less TFT backplane where oxide TFTs in pixel circuits are driven from the back side of a polyimide (PI) film substrate using

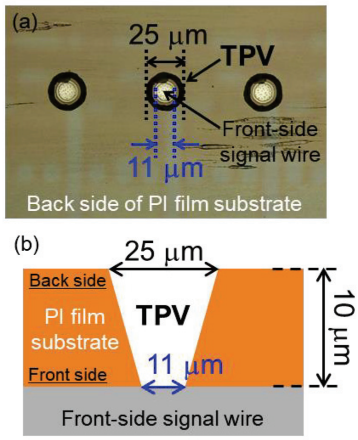


**Fig. 3. (a) Micrograph of through-plastic-vias (TPVs) taken from the back side of PI film substrate. (b) Cross-sectional view of TPV structure.**

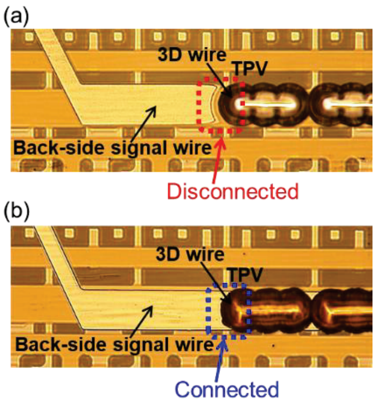


**Fig. 4. Micrographs of back-side signal wires near the edge of TPVs (a) with and (b) without wiring disconnection between back-side signal and 3D wires.**

through-plastic-vias (TPVs). Figures 3(a) and 3(b) show a micrograph of TPVs that penetrate a 10-μm-thick PI film substrate and a cross-sectional view of the TPV structure, respectively. The TPVs were formed from the back side of the substrate by dry etching using a $CF_4/O_2$ gas mixture [9] after the front side of the backplane was fabricated using a conventional photolithography process. One of the advantages of forming TPVs by dry etching is that the processing time is independent of the number of TPVs, whereas in laser drilling it is proportional to the number of TPVs. Furthermore, front-side signal wires can be used as etching stoppers in dry etching but not in laser drilling. The diameter of the TPV holes measured at the front side is approximately 11 μm, which is comparable to or narrower than the width of the front-side signal wires on the backplane.

After TPV formation, 3D wires, which go through the TPVs, and back-side signal wires were formed by sputtering to electrically connect the front and back sides of the backplane. Note that wiring disconnection between the back-side signal and 3D wires could occur at the edge of the TPVs (Fig. 4(a)). This is attributed to photoresist pattern failure induced by burrs at the edge. However, this wiring disconnection can be suppressed through the use of photoresists with higher viscosity (Fig. 4(b)).

Figures 5(a) and 5(b) show photographs of the front and back sides of the fabricated flexible bezel-less TFT backplane, respectively. Note that the back-side signal wires for all the lines (scan, data, power, and ground lines) were formed on just one single layer by placing the signal wires so that they do not overlap with each other, as shown in Fig. 5(b). This simplifies the fabrication process for the back side of the backplane.

Figure 6 shows a micrograph near the bezels of the fabricated TFT backplane. The bezel width is just 8 μm. This ultra-narrow bezel was realized by placing signal wires for all the lines on the back side of the backplane, as shown in Fig. 5(b), instead of on the bezels as in the case of conventional TFT backplanes.

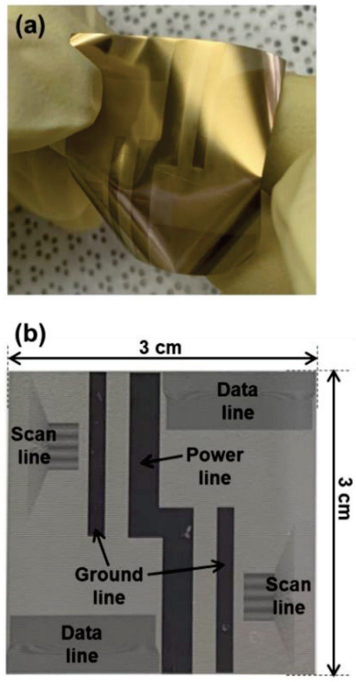


**Fig. 5. Photographs of (a) front side and (b) back side of fabricated flexible bezel-less TFT backplane.**

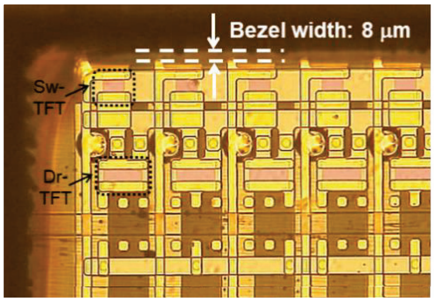


**Fig. 6. Micrograph of bezels in fabricated TFT backplane. The bezel width is just 8 μm.**

Figures 7(a) and 7(b) show micrographs of a test element group for a pixel circuit on the substrate taken from the front side and back side, respectively. The transfer characteristics of the driving TFT (back-channel-etched In-Sn-Zn-O TFT [10]) were evaluated from the back side with TPVs. As shown in Fig. 8, the TFT exhibited clear switching behavior with an on/off current ratio of more than $10^8$, which is sufficient to drive light-emitting devices. As future work we plan to integrate light-emitting devices onto the developed backplane to realize flexible bezel-less panel units as shown in Fig. 2.

## 3 STRETCHABLE TFT ARRAY

Stretchability is required for TFT backplanes to realize displays that can be adapted to various non-flat shapes. Therefore, we have developed stretchable TFT arrays [11] as shown in Fig. 9. An acrylic adhesive structure was used to realize reliable and highly stretchable TFT islands on PI films. The TFTs showed stable switching

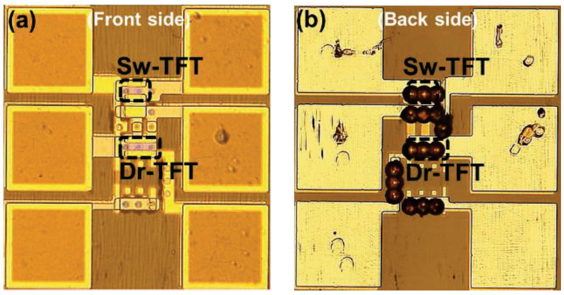


**Fig. 7. Micrographs of test element group in pixel circuit taken from (a) front side and (b) back side of PI film substrate.**

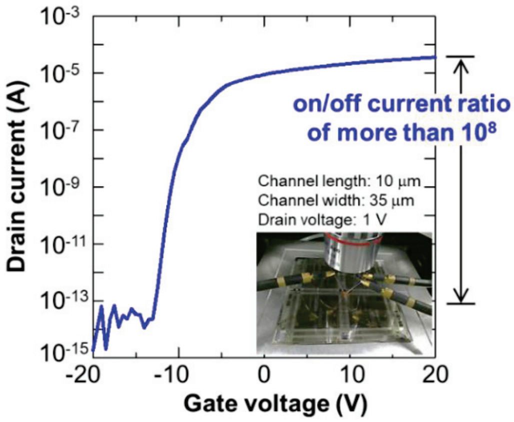


**Fig. 8. Transfer characteristics of Dr-TFT shown in Fig. 7, driven from back side of backplane using TPVs.**

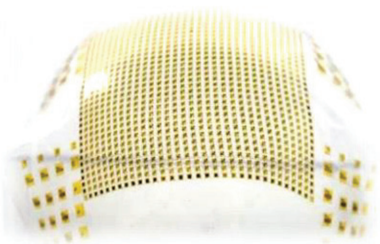

**Fig. 9. Photograph of developed dome-shaped stretchable TFT array [11].**

characteristics with a high mobility of 30 $cm^2/Vs$, even when the substrate was stretched by up to 50% and released to 0%. Therefore, the adhesive structure is promising for realizing highly stretchable displays that can be adapted to shapes such as domes and spheres. Furthermore, this structure is also expected to be used with TPV technology to realize stretchable bezel-less panel units for dome-shaped tiled displays.

## 4 SUMMARY

We have developed a flexible bezel-less TFT backplane with TPVs and dome-shaped stretchable TFT arrays with acrylic adhesive. These developments are promising for realizing deformable displays with seamless tiling.

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