6.5L: *Late-News Paper:* AMLCDs using Organic Thin-Film Transistors on Polyester Substrates

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Abstract

We have fabricated and demonstrated active-matrix liquid-crystal displays using organic thin-film transistors (OTFTs) on polyester substrates. This is the first reported demonstration of an OTFT active-matrix liquid-crystal display, and also the first demonstration of a TFT active-matrix liquid-crystal display of any type fabricated on a polyester substrate.

1. Introduction

Organic thin-film transistors (OTFTs) are attracting attention as a technology that enables active-matrix displays to be fabricated using low-cost processing on plastic substrates. The entire fabrication process can be performed at temperatures of about 100°C or less, allowing great freedom in the choice of substrate materials. Plastic substrates, in particular, allow rugged, flexible displays to be built using an OTFT active-matrix, with liquid crystal or organic light-emitting diodes (OLEDs) as the electro-optic elements. Plastic substrates also open up the possibility of rapid, high-volume web processing of active-matrix displays.

The goal of our work is to build quarter VGA (320 x 240 pixels) and larger AMLCDs using OTFTs on plastic, for use as rugged, lightweight, flexible video displays. Here we report the successful operation of 16 x 16 pixel displays that serve as a preliminary test vehicle for a quarter VGA display. In other published work on OTFTs, single "smart pixels" have been fabricated by combining an OTFT with an OLED on a glass or silicon substrate [1,2]. The first organic circuits on polyester film were reported recently; they consisted of single one-transistor smart pixels and two-transistor inverters [3]. We recently reported higher complexity analog and digital circuits using OTFTs on polyester film [4]. In other published work on AMLCDs on polymer substrates, AMLCDs using amorphous silicon (a-Si) TFTs on high-temperature polymers such as polyethersulfone (PES) have been proposed [5], AMLCDs using metal-insulator-metal (MIM) elements have been demonstrated on PES [6], and work has been done toward building AMLCDs using transferred polysilicon TFTs on PES [7]. Here we describe the first reported demonstration of an OTFT active-matrix liquid-crystal display, and also the first demonstration of a TFT active-matrix liquid-crystal display of any type fabricated on a polyester substrate.

2. Fabrication

Each of our substrates contains eight 16 x 16 active-matrix displays with 250 µm square monochrome pixels, together with test transistors and yield structures, on a 2.5" square, 75 µm-thick transparent, flexible polyethylene naphthalate (PEN) film (Fig. 1). After the film undergoes an initial 150°C heat treatment to ensure thermal dimensional stability, it is laminated to a removable glass support for ease of processing, and the maximum processing temperature is 110°C. The active organic layer is pentacene, a linear polycyclic aromatic hydrocarbon. A description of our pentacene OTFT process can be found in Refs. [4] and [8]. To pattern and passivate the pentacene layer without exposure to solvents, a process using photosensitized polyvinyl alcohol (PVA) was developed. This process isolates the OTFTs from one another effectively without significantly modifying device characteristics. The PVA that remains over the OTFTs plays an important role in our AMLCDs, because we have found that pentacene OTFTs are severely degraded when they come into contact with typical liquid-crystal materials.

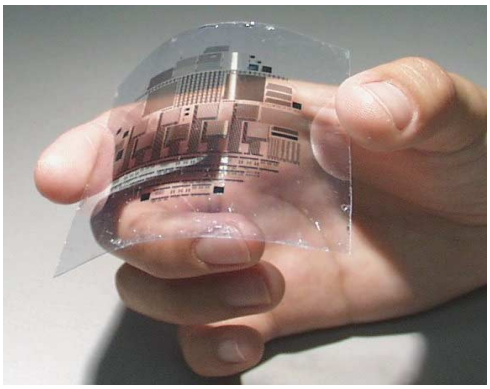

Figure 1. Flexible active-matrix display substrate.

For our reflective displays we use polymer-dispersed liquid crystal (PDLC) material. PDLC assembly is performed by depositing a mixture of Merck TL205 liquid crystal and PN393 pre-polymer on completed OTFT substrates, then laminating an ITO-coated polyethylene terephthalate (PET) cover sheet on top. The 16 µm cell gap is set by plastic spacer balls dispersed within the cell. Large-area PDLC cells fabricated in the same way were tested in front of a black felt absorber and were found to have 30% white-state reflectivity, on-axis contrast ratio of 7:1 at +/- 20V drive voltage with 30° off-axis illumination, and a response time of 20 msec. The contrast ratio was limited by diffuse

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reflected light from the plastic substrates and the black absorber, not from the PDLC material.

Each of our substrates includes a 1 cm^2 array of 200 identical transistors with W = 25 µm and L = 20 µm. Drain-current characteristics of a typical PVA-passivated OTFT are shown in Fig. 2. The pentacene OTFTs are *p*-channel devices. Transistor yields are high, with recent substrates reaching 99.5%. A high degree of device uniformity is possible. On one array the average threshold voltage was +3.2V and the average field-effect mobility was 0.45 cm^2/V-s, with a standard deviation of 0.2V for threshold voltage and 0.03 cm^2/V-s for mobility. These characteristics are comparable to those of a-Si TFTs used in conventional glass-based AMLCDs, and are adequate for use in plastic-based high-resolution video displays.

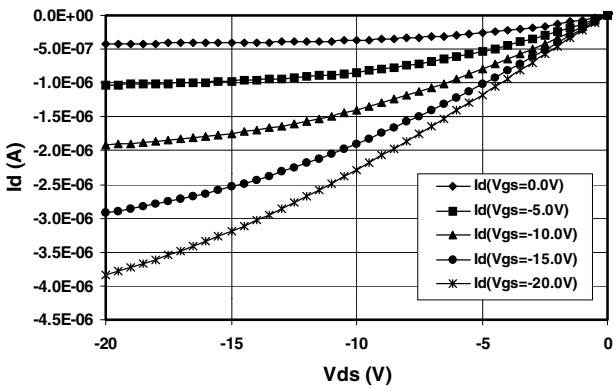

Figure 2. Drain-current characteristics of a typical passivated pentacene OTFT (W = 25 µm, L = 20 µm).

3. OTFT AMLCDs on Plastic

In Fig. 3 we show the layout of a pixel. Like a-Si TFT pixels, each OTFT pixel contains an access transistor with the source/drain metallization on one side connected to the data line. In the pixel in Fig. 3, this source/drain metal has a "wrap-around" shape, which minimizes the source/drain metal area on the other side of the OTFT, which connects to the ITO pixel electrode. This geometry minimizes charge injection leading to pixel voltage "push-up" when the pixel is deselected, improving display uniformity and reducing voltage requirements of the pixel transistor. Storage capacitance for each pixel is provided by an extra line of gate metallization on each row, running under the ITO pixel electrode and separated from it by gate dielectric. Every fourth select line is connected together, as is every fourth data line. This makes testing easier, although it constrains the test patterns to repeat every 4 x 4 pixels.

Since our goal is to build quarter VGA and larger AMLCDs with video capability, the 16 x 16 displays were tested using data and select waveforms appropriate for a quarter VGA video display: 69 µsec line time with a 60 Hz refresh rate. Figure 4 shows different patterns displayed on an array that uses the pixel of Fig. 3 with these waveforms. This display had 100% pixel yield. Illumination was provided by an incandescent lamp 45° off-axis, with a black absorber behind the display, and viewing on-axis. The data voltage was +/-20V for "on" (black) pixels, with a select voltage of –30V and a deselect voltage of +25V. The contrast ratio, obtained by averaging the reflected light over a large area containing many pixels, was 2:1. The aperture ratio (ITO area divided by total pixel area) for this display is 58%. The contrast ratio would be higher if a black-matrix layer were used to reduce reflection from areas outside the ITO area, particularly from the reflective metal lines in the display, as is apparent from Fig. 4. This is the first reported demonstration of an OTFT active-matrix liquid-crystal display, and also the first demonstration of a TFT active-matrix liquid-crystal display of any type fabricated on a polyester substrate.

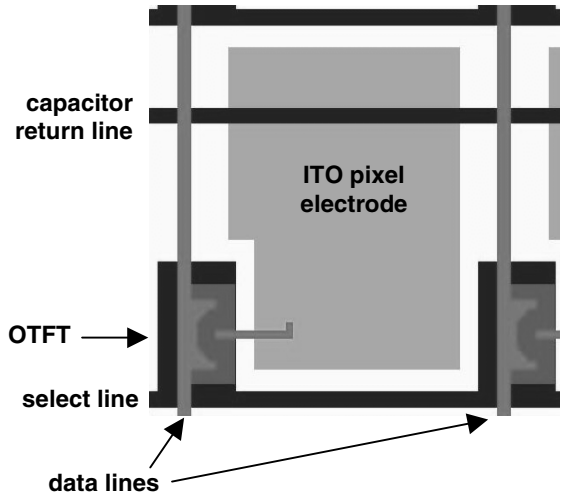

Figure 3. OTFT active-matrix pixel with "wrap-around" source/drain region.

4. Conclusion

Our results demonstrate that active-matrix displays can be fabricated using organic TFTs on low-cost flexible polyester substrates. The technology permits rugged, lightweight, flexible video displays to be built on plastic. These results, combined with our earlier results on analog and digital organic TFT circuits [4], point the way toward active-matrix displays on plastic with organic integrated driver circuits, similar to our previous work on glass-based AMLCDs using a-Si integrated drivers [9].

5. Acknowledgements

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6. References

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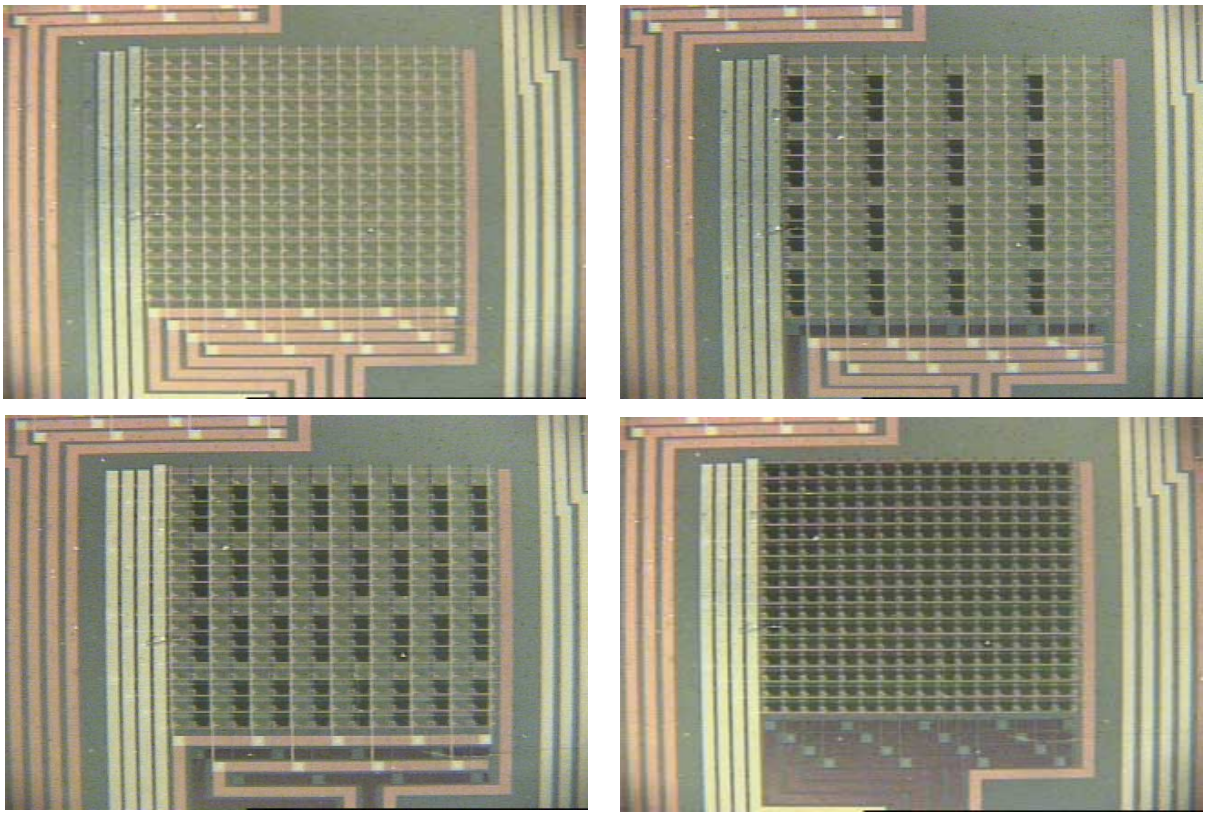

Figure 4. Different patterns displayed on a 16 x 16 reflective organic AMLCD on a polyester substrate.