Organic Transistor Materials for bezel-free Plastic Liquid Crystal Displays

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ABSTRACT

Active matrix backplanes on glass almost exclusively use hard ceramic based materials as the basis for the fundamental transistor technology. To enable flexible displays and electronics, FlexEnable has pioneered an alternative manufacturing approach which replaces the hard ceramic materials with soft, flexible organic materials. By folding the borders behind the display our technology enables bezel-free displays for mass market applications such as notebooks and tablets.

1 INTRODUCTION

Hard ceramic based materials are most commonly used as the fundamental transistor technology in active matrix backplanes[1]. In practice this often limits the choice of substrate to glass which is almost exclusively true for backplanes used in active matrix liquid crystal displays. This limits the form factor of products that use these displays. For example, glass-based LCD displays are still the dominate technology for large screen portable devices like tablets and laptops. To make these products truly bezel-free the interconnections of the display must be folded behind the display, which is obviously not possible with glass backplanes[2].

To enable flexible displays and electronics, FlexEnable has pioneered an alternative manufacturing approach which replaces the hard ceramic materials with soft, flexible organic materials. FlexiOM™ is the name for the key organic materials that enable this manufacturing approach which are supplied by FlexEnable. The FlexiOM materials has been specifically engineered so organic thin film transistor (OTFT) backplanes can be fabricated in standard flat panel display factories which are repurposed for the novel material set. The primary benefits for using OTFT is the reduced processing temperature allowing a wider range of suitable substrate materials and the inherent durability that comes from removing the brittle ceramic layers. This paper will discuss the FlexiOM material set, the electrical performance of a state- of-the-art OTFT device, and process steps that require special consideration when using OTFT as a foundation for a plastic or organic liquid crystal display (OLCD). Finally, it will show how the interconnections for a plastic OLCD display can folded behind the device which enables truly bezelfree form factors using liquid crystal technology.

2 OTFT STACK

The best way to introduce the OTFT materials is by describing a basic top-gate OTFT device structure as shown in Figure 1. The three terminal device starts with the first two metal electrodes patterned on a flexible substrate. The first organic layer (FE-S500) is then coated on top which is a near amorphous semiconducting polymer with a low degree of energetic disorder. The next organic layer is FE-D320 which is a low-k dielectric material that has been engineered to ensure a pristine interface with the semiconductor. The final organic layer is a crosslinkable dielectric material (FE-D048X) which is used to increase the electrical robustness. All three materials are available pre-formulated for spin, slit, or various types of printing deposition techniques. The slit or spin formulations are most commonly used in flat panel display factories. The device is completed by adding a metal gate.

An example IV curve from a simple OTFT test structure as described above using FlexiOM materials can be seen in Figure 2. The p-type device exhibits a threshold close to 0V and an on/off ratio greater than 10^6. The field effect mobility is greater than 1.5 cm^2/Vs which is higher than an amorphous silicon-based device. Therefore, from an electrical performance prospective, OTFT is an ideal candidate technology for controlling pixels in a liquid crystal display.

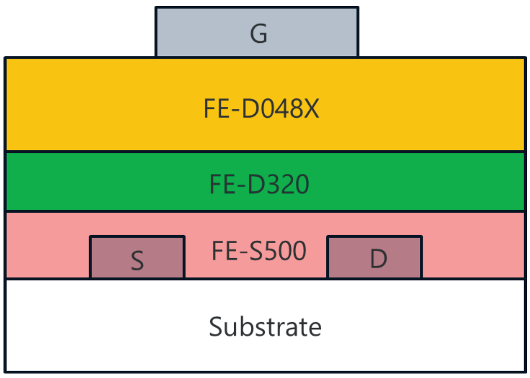

Fig. 1. Cross-section of basic OTFT device using FlexEnable's FlexiOM material set.

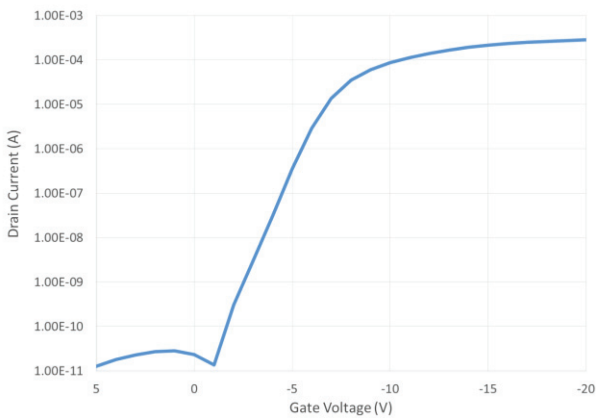

Fig. 2. IV curve from OTFT device

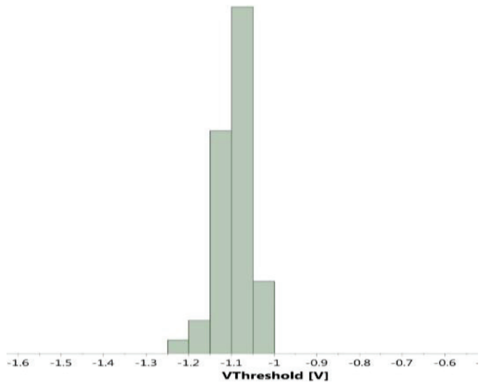

Fig. 3. Threshold voltage distribution for 100 OTFT devices across 356 x 356mm plate

3 OLCD MANUFACTURING PROCESS

The manufacturing process for making a liquid crystal display is more complex than the simple OTFT device. It is important that we maintain the device performance during the whole manufacturing process and display operation. There are three primary risks to the device operation presented in the OLCD application. First, additional layers are added to the simple device architecture to achieve the switching fields required for the liquid crystals. Secondly, the backplanes for OLCD require sputtered metals, plasma etching, and exposure to a wide variety of lithography chemicals, so it is important that the OTFT materials are resilient to these process steps. Finally, the OLCD devices are subjected to constant electrical stress during operation, so the device operation must be stable to this stress.

Prior to building the full display, electrical tests on an OTFT backplane can assess if it is suitable for LCD applications. For this exercise, OTFT backplanes based on the FlexiOM material set, were fabricated on plastic substrate mounted to a 355 x 355 mm glass plate. This mimics the manufacturing approach FlexEnable is pioneering to make OLCD modules. The completed backplanes were then subjected to comprehensive electrical tests for uniformity, leakage, and bias stress stability.

The uniformity of an OTFT backplane is determined by taking several IV measurements across the area of the plate. Figure 3 shows the threshold voltage distribution of 100 randomly selected OTFT devices on the backplane. It shows a tight distribution centered around -1.1V with most measurements within 0.1V of that value. This means the OTFT array provides a uniform platform for switching the LC cell. This is primarily a feature of the absence of crystallinity in the S500 layer which removes many of the common causes of non-uniformities (namely grain boundaries).

Leakage of charge between neighboring pixels is another common yield detractor in LC displays. An electrical test for leakage is to measure the off-state current in the TFT channel. This is often a difficult measurement to take because the off-current in low leakage transistors can be difficult to resolve from the noise in the test set-up. To overcome this issue we fabricated extremely wide TFT devices as test structure on the TFT array. Figure 4 shows IV curves from OTFT devices with a channel width of 50,000 μm and channel length of 5 μm. The off current of the OTFT device is very low (in the pico amp range). Leakage at this level confirms that OTFT can drive LC displays at normal operating frequencies like 60 or 120Hz. It also opens the door to lower frequency driving options, which will reduce power consumption during operation.

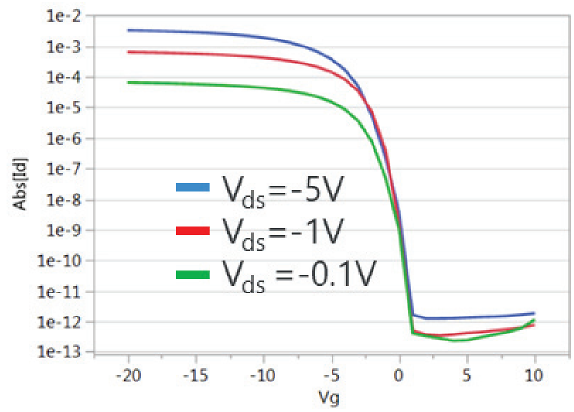

Fig. 4. IV characteristics of 50,000μm wide TFT device.

A final measurement on the OTFT backplane is the electrical stress stability. Conventionally, the electrical stress that is applied to the device is a bias voltage to the gate electrode for several hours at elevated temperatures. The stability of the device is measured by taking IV curves before and after the stress to see if the position of the threshold voltage has moved. Table 1 shows the results of the both the positive gate bias temperature stress (PGBTS) and negative gate bias temperature stress (NGBTS) tests for the OTFT backplane. The relatively small shifts in the threshold voltage indicates that the OTFT array will be resilient to the electrical stress associated with driving the display.

Table 1: Bias stress stability measurements for OTFT devices at 70°C

Test	V	Time	$\lvert\Delta V_{th}\rvert$
PGBTS	+20V	3hr	<2V
NGBTS	-20V	3Hr	<1V

4 SUMMARY

In summary the combination of FlexiOM materials and FlexEnable's proprietary process technology has enabled a viable route to maintaining device performance during OLCD fabrication. Figure 5 shows an image of a 4.7" liquid crystal display made with a FlexiOM-based OTFT backplane. The image also highlights how OLCD enables a bezel-free product form factor. A key feature to the OLCD technology is the flexible nature of the cell. Figure 5 shows how this can be exploited to make a bezel-free display by bending interconnections areas behind the backlight. At FlexEnable we have shown that we can bend cells to about 1 mm bend radius which leads to some very interesting form factor product concepts.

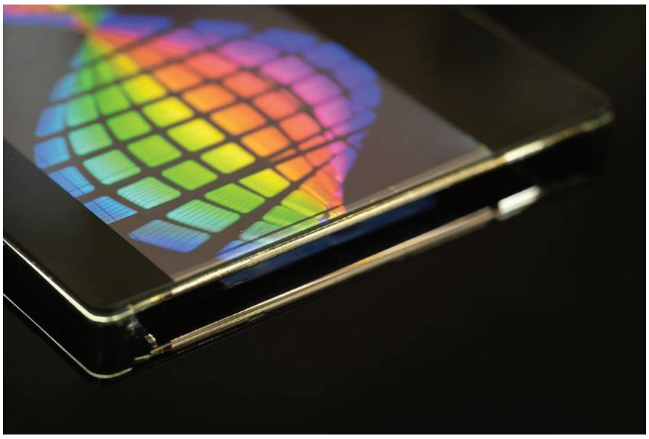

Fig. 5. Bezel-free OLCD display

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[2] J Harding, Information Display, 35(6), 9 (2019).