Plastic Displays Made by Standard a-Si TFT Technology

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Abstract

We have developed EPLaR^{TM}, a new way of making flexible electrophoretic displays. The TFTs have the same good performance, reliability and mature manufacturing processes as TFTs used in LCD monitors and LCD-TVs. We are working with partners to show that plastic displays can be made in existing TFT-LCD factories alongside glass LCDS. In this talk we describe the EPLaR process and show results for TFT arrays on plastic made in a factory by standard a-Si TFT processing.

1. Introduction

Plastic active matrix displays were first demonstrated more than ten years ago, and since then many groups have made a wide variety of different plastic displays. The electronic devices used to multiplex the displays have included Thin Film Diodes [1], amorphous silicon Top Gate [2] and Bottom Gate TFTs [3], Low Temperature Polycrystalline Si TFTs [4], [5] and organic TFTs [6]. Different display effects have also been demonstrated, including LCDs [7], electrophoretic displays [6] and organic LEDS [8]. Despite the large body of work done over many years plastic displays have not yet reached mass production.

The methods used to produce most plastic displays can be divided into three main categories. The first to be developed was to fabricate TFT arrays on pre-formed plastic sheets. The TFT processing was carried out on freestanding sheets, or ones temporarily fixed to glass carrier plates. The second was to fabricate TFT arrays on glass plates and then transfer them to plastic sheets [5]. This has the advantage that the TFT processing can be carried out in standard factories with no modifications to substrate handling, fabrication equipment or process temperatures. The third method, which is often quoted as the ultimate low cost manufacturing process, is roll-to-roll manufacturing [9].

However, TFT plate processing is only part of the complete manufacturing process and normally rear-end processing of plastic displays (integrating the display medium onto the TFT array and forming interconnects to display drivers) has been carried out on plastic sheets. These processes cannot then be done in standard display manufacturing equipment because they are designed to use rigid glass substrates that do not change dimensions after heating or moisture absorption. This can be a particular problem for interconnect bonding, which requires accurate alignment between the TFT plate and TCP foils or Chip-on-Glass packages and precise control of pressure and temperature.

To address these issues and produce a robust manufacturing process we developed a new method of manufacturing plastic displays in which a plastic layer is spin-coated onto glass substrates and the composite substrate is then used for standard TFT processing, display making and interconnect formation. The displays can be fully tested while they are still on the glass substrate before the final process step to separate the plastic layer from the glass. We call the entire process for making plastic displays EPLaR, which stands for **E**lectronics on **P**lastic by **La**ser **R**elease. In this paper we report on EPLaR electrophoretic displays with a-Si TFT pixel switches made in a research lab and progress to transfer the EPLaR process to a working a-Si TFT factory.

2. The EPLaR Process

The EPLaR process for making electrophoretic displays is illustrated in Fig. 1. The first step, shown in Fig. 1(a), is to apply a polyimide layer to a glass substrate by spin coating. When the correct pre-treatments and post-treatments are used, in combination with the correct polyimide type, then the polyimide is effectively permanently anchored to the glass substrate. In addition, the cured polyimide can withstand higher temperatures than the maximum processing temperatures for TFT glass and is resistant

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to standard processes and chemicals used in TFT manufacturing.

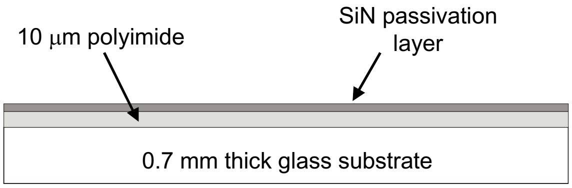

Figure 1(a) Glass substrate with spin coated polyimide and SiN passivation layer.

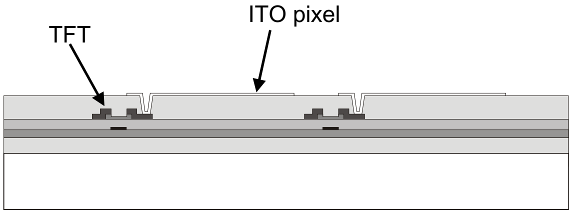

Figure 1(b) Back Channel Etch a-Si TFT fabricated on the composite substrate.

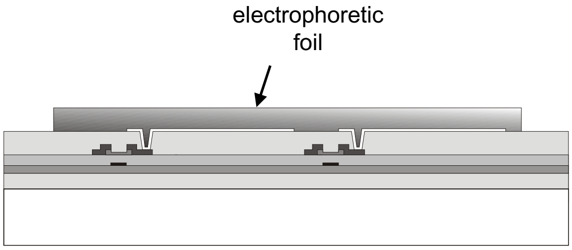

Figure 1(c) Electrophoretic foil added.

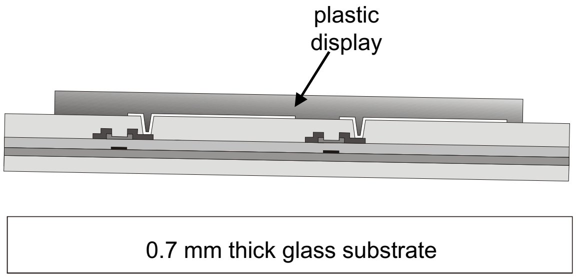

Figure 1(d) Plastic display released from glass by a laser process.

We have processed substrates coated with polyimide layers from 3 to 20 μm thick, but normally use approximately 10 μm. The addition of the polyimide to standard 0.7 mm thick glass increases the thickness by less than 2% and the substrate weight by even less, which means the substrates can still be used in standard TFT manufacturing equipment and automated handling tools. A silicon nitride passivation layer is then deposited over the polyimide and this composite glass/polyimide substrate is used in place of glass substrates for all subsequent processing.

The next step is to make Back Channel Etch a-Si TFT arrays with ITO pixels above a silicon nitride top passivation layer, see Fig. 1(b). After TFT processing electrophoretic foils and TCP driver foils are applied to the array, as shown in Fig. 1(c). At this stage we always test displays while they are still on the glass substrate, to check for yield and display performance. The final processing step is to release the polyimide layer from the glass substrate using a laser release process, Fig. 1(d).

One of the main advantages of the EPLaR process on polyimide is that standard a-Si TFT processing temperatures and design rules can be used. In comparison normal plastic substrates can change dimension during processing, particularly after a high temperature step. For this reason process temperatures are often limited to 150ºC [10], which limits TFT performance, particularly electrical stability. Even at this low temperature substrate compaction during heating can be a problem and alignment tolerant design rules, which suffer from larger overlap capacitances, are often used. During processing of EPLaR TFTs the thin, relatively soft polyimide expands and contracts with the thicker glass substrate and no dimensional changes occur beyond those experienced by normal glass substrates.

3. TFT Arrays by the EPLaR Process.

Figure 2 shows a 50 x 50 mm TFT array on a freestanding 3 μm thick polyimide layer that was made by the EPLaR process in Philips Research. Pre-formed polyimide sheets are normally at least 25 μm thick and opaque. We can see that the sample in Fig 2 is so thin that it is almost transparent. However, it still had some yellow colouring and cannot be used as the substrate for a transmissive display. We are investigating clear plastics that have no birefringence for the EPLaR process to make LCDs.

The electrical characteristics of TFTs on the laser-released polyimide of Fig. 2 were identical to TFTs made on glass, including TFT mobility and stability. This shows that making TFTs on polyimide and the subsequent laser release process did not degrade the electrical characteristics. They were the same as for TFTs made on glass, which have been shown to be reliable by years of use in laptop LCDs and LC-TVs.

Figure 2. 50 x 50 mm a-Si TFT array on 3 μm thick freestanding polyimide layer made by the EPLaR process.

4. EPLaR TFTs Made in a Factory

In 2005 we demonstrated our first EPLaR TFT display made in Philips Research cleanrooms [11]. They were 50 x 50 mm electrophoretic displays with the same high performance for grey-scales and contrast ratio as electrophoretic displays on glass developed in a factory process [12]. However, as we might expect for first demonstrators made in a research lab, they suffered from a significant number of point and line defects. We considered working to improve yield in the lab. However, we had developed the EPLaR process with the promise that it could be used in standard TFT factories so we decided to concentrate our improvement activities on a rapid transfer to a factory and to investigate yield and process improvements there.

After discussions it was agreed that we would investigate the EPLaR process in the Thales-LCD TFT factory as part of the European Community FlexiDis research programme. Thales-LCD manufacture high quality active matrix LCDs for use in avionic applications. The test vehicle we designed for EPLaR development in Thales-LCD was a 5.1" electrophoretic display with 200 μm pixels. At this time we can present results on the TFT arrays, but not on displays.

Fig. 3 shows a pixel after laser release from an EPLaR array made in the factory, . The TFTs have a channel length of 5 μm and the maximum process temperature during fabrication was 280ºC. The pixels were designed using standard factory design rules with no allowance for substrate shrinkage or expansion. The large metal pad in the centre of the pixel is a storage capacitor and the ITO pad, which defines the optically active area, covers most of the pixel area but is difficult to see due to its high transparency.

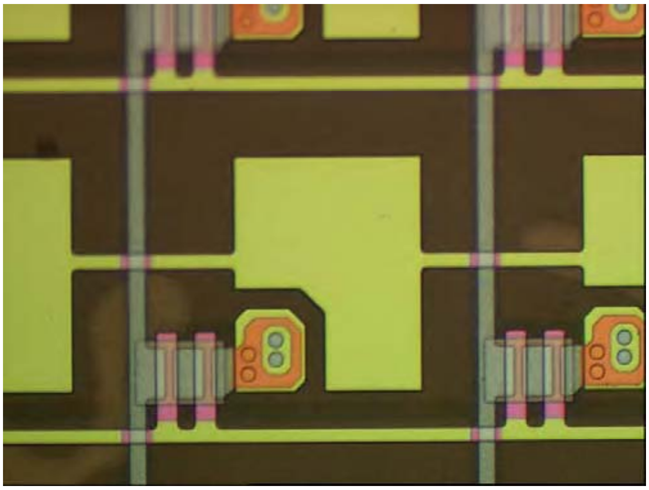

Figure 3 Pixel from an a-Si TFT array on 10 μm thick freestanding polyimide layer made by the EPLaR process in a TFT factory.

We have also carried out electrical measurements on test TFTs of EPLaR arrays before and after laser release. The TFTs had excellent characteristics in terms of mobility, threshold voltage and low OFF-currents, making them ideal for driving electrophoretic displays. The electrical characteristics shown in Fig. 4 came from test TFTs with a channel length of 10 μm. The linear and saturated mobilities were both greater than 0.7 $cm^2/V.s$. By inspection of Figure 4 we can see that there was no significant difference in electrical characteristics before and after laser release. These results are typical for all of the

TFTs we have measured before and after laser release.

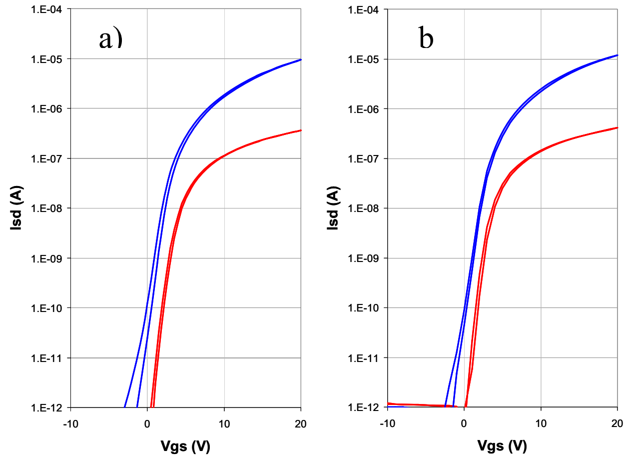

Figure 4 Transfer characteristics from an EPLaR test TFT made in a factory. Results are shown before a) and after b) laser release. The TFT W/L was 60/10 µm and source-drain voltages were 0.25 and 10 V.

5. Discussion and Conclusions

In a research lab we have demonstrated active matrix plastic electrophoretic displays made by the EPLaR process [11]. In this a thin polyimide layer was spin-coated onto a glass substrate and the composite substrate was used for all subsequent TFT processing, display making and bonding of interconnect foils. At this stage of the process we had fully functioning displays on glass substrates, but with a thin polyimide layer between the top of the glass and the bottom of the TFT arrays. After display testing a laser process was used to release the plastic carrying the completed display from the glass carrier plate.

After showing proof of principle in the research lab we began experiments in a TFT factory as part of the European FlexiDis programme. This work has resulted in laser released TFT arrays with good electrical characteristics. We believe that EPLaR will offer a rapid route to a robust process for manufacturing plastic displays. The TFTs on plastic have the same performance and stability as a-Si TFTs in displays on glass.

So far we have demonstrated displays made with polyimide as the plastic substrate, which is suitable for emissive or reflective displays, but which cannot be used for transmissive LCDs. We are working to extend the EPLaR technology to clear plastics, which will allow us to make transmissive LCDs.

6. Acknowledgements

We would like to thank the many people at Philips Research and Thales-LCD who developed the process on glass that we modified to make plastic displays. Laser release was developed and carried out at Philips AppTech in Eindhoven. We gratefully acknowledge the European Commission for funding of this work under contract IST-2004-4354 (FlexiDis).

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