P-24: High-Temperature (250°C) Amorphous-Silicon TFT's On Clear Plastic Substrates

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Abstract

Amorphous silicon (a-Si) thin film transistors (TFT's) were fabricated on free-standing, clear plastic substrates with a maximum process temperature of up to 250℃. An a-Si TFT backplane for active matrix OLED (AMOLED) application was also made on such substrates. The performance of both the TFT's and the AMOLED backplane are excellent. These results will enable the fabrication of flexible AMLCD or AMOLED displays on clear plastic substrates with the TFT processes currently used for glass substrates.

1. Introduction

Amorphous silicon TFT's on plastic substrates are attractive for flexible displays. The plastic substrates for the TFT backplane must be optically clear for the AMOLED or AMLCD displays that require the light to pass through. The properties of the clear plastic substrates available to date have restricted the a-Si TFT fabrication process to temperatures below ~150°C. A widely used clear plastic substrate is poly (ethylene terephthalate) (PET) [1]. Its glass transition temperature T_g of 70-100°C is too low for fabricating high quality a-Si:H TFT's. TFT's deposited at temperatures below 150°C have low electron mobility, high leakage current [2], and show pronounced drift due to charge trapping. Therefore, industry is seeking to keep the TFT process in the temperature range of 250-350°C developed for a-Si TFTs on glass. This high temperature results in the best a-Si TFT performance, particularly because temperatures of at least 250 °C are required for high quality of the SiN_x gate insulator [3]. Therefore, a clear plastic substrate is needed that enables a-Si backplane fabrication at process temperatures similar to those on glass.

High-temperature plastics, such as the DuPont™ Kapton® 200E polyimide, have a T_g of ~350°C. Kapton® has a low coefficient of thermal expansion (CTE), relatively close to device materials, and allows making TFT's with excellent performance at process temperatures of 150-250°C [4] [5]. However, Kapton® is not optically clear. Fig. 1(a) shows that the optical transmission of a 50-µm thick Kapton® 200E substrate cuts off at about 500nm, which gives it an orange-brown color. In this work we present TFT's with excellent performance fabricated on clear plastic substrates at temperatures up to 250°C, suitable for AMLCD or AMOLED applications.

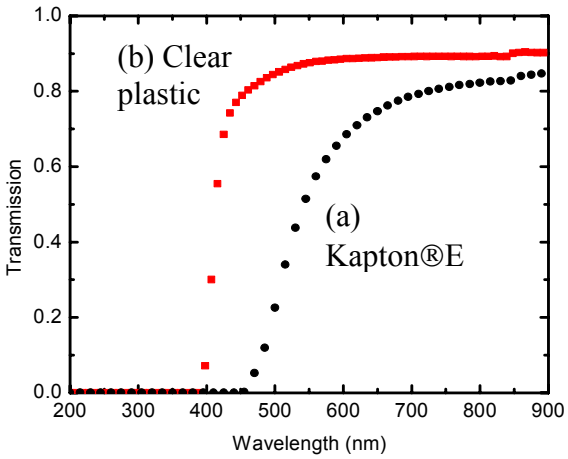

Figure 1. Optical transmission spectra of plastic substrates: (a) Kapton® E (black); (b) High-T clear plastic (red).

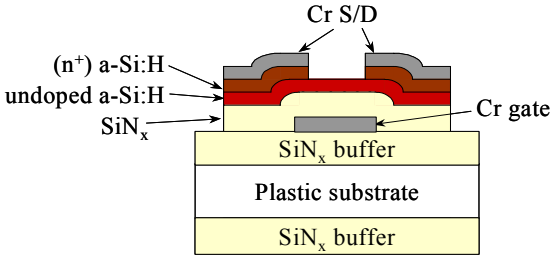

Figure 2. Schematic cross-section of a back-channel cut a-Si TFT on a plastic substrate [1].

2. High-temperature a-Si TFT's on clear plastic

We describe our experiments and results with two new types of clear plastic, each with high T_g. Fig. 2 shows the cross-section of the TFT structure we use on plastic substrates. A thick SiN_x buffer layer on each side of the substrate planarizes the substrate, passivates it against process chemicals, and helps the device layers adhere to the organic polymer substrate. The TFT structure is the standard inverted-staggered structure, with a bottom gate and top source/drain contacts. The TFT channel is defined by back-channel-etch. In contrast to previous work with high temperature plastic substrates that were mounted on rigid carriers for TFT fabrication [5], we kept our substrates freestanding. This is important to avoid separation stress and to keep the back surface optically clean and clear.

We first experimented with the new high-temperature clear plastic substrate A, which is transparent to 400nm as shown in Fig. 1(b). Substrate A has a coefficient of thermal expansion (CTE) that is much higher than that of the a-Si TFT device layers, a problem from which clear high temperature plastics have suffered to date. The stress σ in the device films caused by thermal expansion mismatch is proportional to the product of the difference in CTE, ΔCTE, times the process temperature excursion, ΔT: $\sigma \propto \Delta CTE \times \Delta T$. In the high temperature process (large ΔT) on substrate A, the large CTE mismatch ΔCTE caused a high stress level in the device layers and cracked them. We reduced the process temperature to 150-180°C, modified the TFT device structure and the plasma-enhanced chemical vapor deposition process to improve the adhesion of the SiN_x buffer to the substrate. In this way we successfully fabricated TFT's on substrate A with very good performance (Fig. 3). For a TFT with gate width/length of W/L = 80μm/40μm, the threshold voltage is 3.2 V, the ON/OFF ratio is ~10^6 with gate voltages varied from 0 to 20V, the linear mobility is 0.67cm^2/Vs and the saturation mobility is 0.55 cm^2/Vs. The source-gate leakage current is smaller than 20 pA, which is the sensitivity of our measurement system. With this substrate, the upper limit of the process temperature was well under 200°C. In contrast to processing on

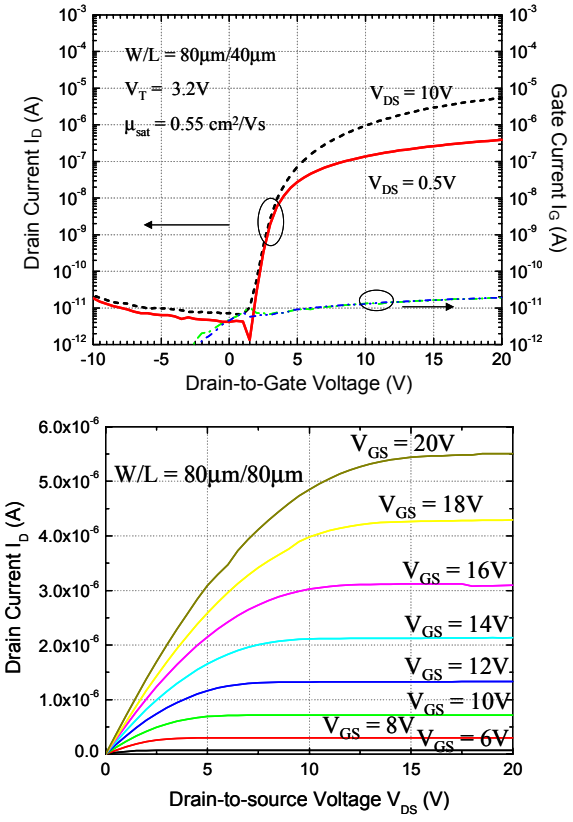

Figure 3. Transfer (top) and output (bottom) characteristics of TFT's processed at ~150°C on clear plastic substrate A.

PET, the limit is not due to T_g of the substrate, but to the CTE mismatch between the substrate and the device layers. Mechanical modeling (omitted here for brevity) confirms that ΔCTE limits the maximum process temperature on substrate A, so that one cannot directly transfer an industrial TFT process to it from glass.

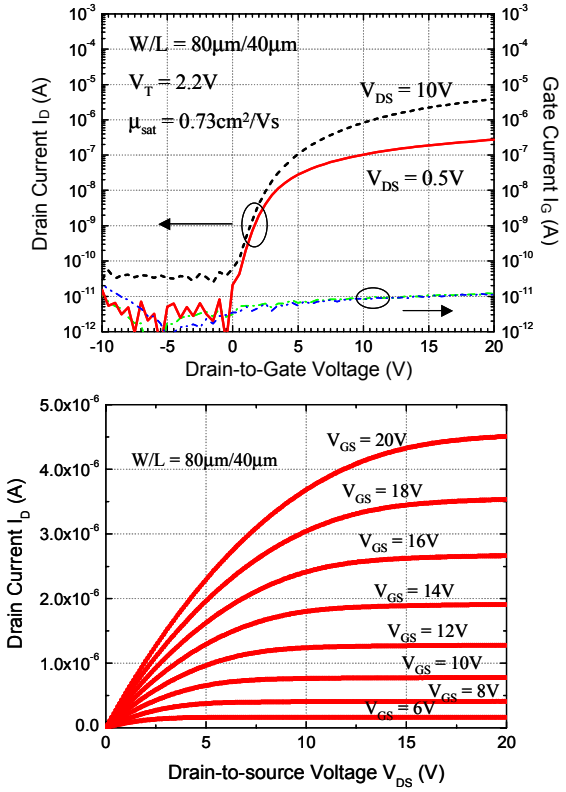

Figure 4. Transfer (top) and output (bottom) characteristics of a TFT on clear plastic substrate B, made at a maximum process temperature of 250°C.

To increase the TFT process temperature, we used a second new clear plastic, substrate B. While its optical transmission spectrum is identical to that of substrate A shown in Fig.1(b), it has a much lower coefficient of thermal expansion than A. The low CTE allows us to fabricate TFT's at a maximum process temperature of 250°C. The characteristics of an a-Si TFT made on substrate B are shown in Fig. 4. For W/L = 80μm/40μm, the threshold voltage is 2.2 V, the ON/OFF ratio is ~5 X10^5 for a gate voltage range from 0-20V, the linear mobility is 0.80 cm^2/Vs, and the saturation mobility is 0.73 cm^2/Vs. The source-gate leakage again is set by the instrument. It is evident that the process temperature of 250°C on substrate B produces TFT's with higher mobility and lower threshold voltage than the 150°C process on substrate A. Both the linear and saturation mobilities of TFT's made on clear plastic substrate B compare favorably to those made on glass substrates at the same process T of 250°C (Fig.5). The mobilities are not corrected for contact resistance, so they decrease at short channel length. Our conclusion is that substrate B enables TFT fabrication like that on glass.

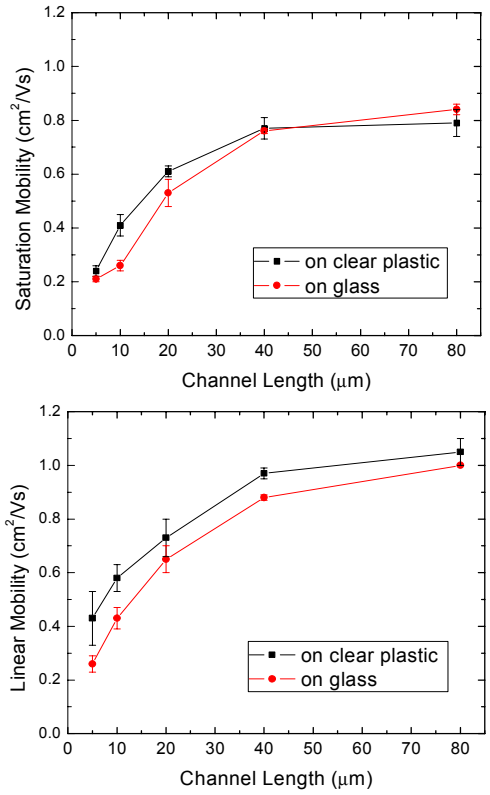

Figure 5. Mobility (uncorrected for contact resistance) vs. channel length for a-Si TFTs fabricated at 250°C on clear plastic substrate B and on glass. W = 80μm. Top: Saturation region; Bottom: Linear region.

3. AMOLED backplane on clear plastic

To test these clear plastics for AMOLED application, we made an AMOLED drive circuit. The pixel design is the simple 2-TFT scheme shown in Fig.6, with the source of the power TFT (T2) connected to the anode of the OLED. The DC current-driving ability of the pixel was measured. V_{DD} of the pixel is connected to 20V, the source of T2 is grounded. A pixel size of 300μm x 300μm, an OLED efficiency of 10 cd/A, and a 50% polarizer loss in the display panel are assumed. As seen in Fig.7, the voltage difference between the data line and the OLED anode needed for 100 nits brightness (~2μA of drive current) is only 9V. Clearly the a-Si TFT's provide sufficient drive current for AMOLED applications.

4. Conclusion

We have successfully fabricated a-Si TFT's with excellent performance at process temperatures of up to 250°C on free-standing high-T_g clear plastic substrates. An active matrix backplane pixel circuit made for AMOLEDs can provide sufficient current at low voltage. These results will enable the fabrication of high performance AMLCD or AMOLED displays on clear flexible plastic substrates with industrial TFT processes similar to those used at present for glass substrates.

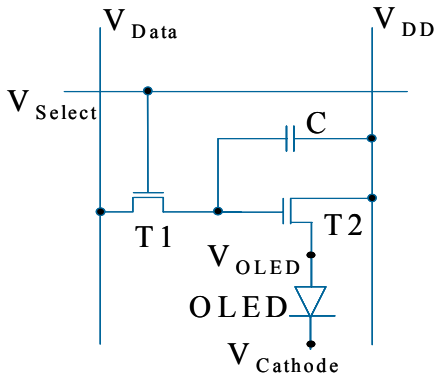

Figure 6. 2-TFT AMOLED pixel circuit.

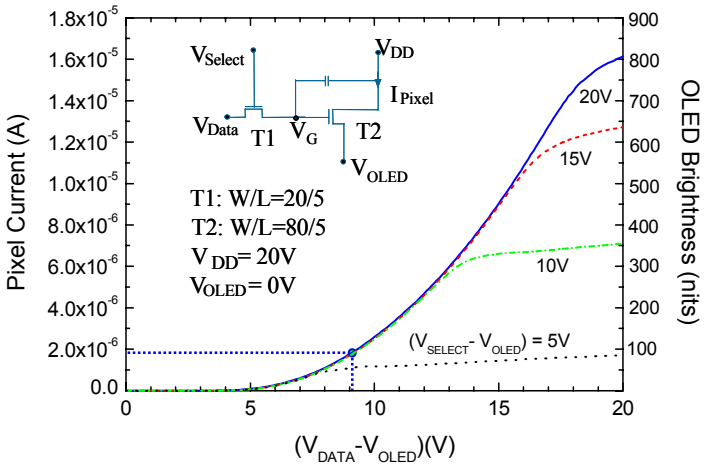

Figure 7. DC test of the drivability of the pixel on high temperature plastic. The dotted horizontal line shows 2 μA pixel current for 100 nits.

5. Acknowledgement

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6. References

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