Reflective-Type Plastic Color TFT LCD

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Abstract

A reflective-type color TFT-LCD was fabricated on a newly developed plastic substrate. By using the plastic substrate, the 4.4-inch display has realized only 0.65mm in thickness and 9 grams in weight. There is a great possibility that the display will change the future-forms of mobile apparatuses. This paper describes the TFT array process, TFT design technology and the novel plastic materials.

Introduction

Recently, as downsizing and the integration of electronic components advance, size has been reduced and performance improved increasingly rapidly in mobile information equipment such as notebook PCs, PDAs, and mobile phones.

However, while many electronic components are being downsized, for LCD that is an interface, a still larger display area is required. In the future, with the advance in wireless PCs and displays, and keyboardless features by adopting touch-pens, size reduction of image processing circuits, increased battery capacity, and other technological innovations, the ratio of weight and volume of the LCD that accounts for the entire apparatus will inevitably increase. Under these conditions, development of a plastic LCD is anticipated to achieve still lighter and thinner LCDs. STN and MIM plastic LCDs have already been achieved[1)2)]. However, considering the recent rapid development of communication infrastructure, video display capability that supports large-capacity multimedia content is required for mobile devices, and a plastic LCD using a TFT active matrix drive system is required.

1. Formation of a TFT Array on a Plastic Substrate

As methods of forming TFT arrays on plastic substrates, a transfer method and a direct method are proposed[4)7)]. The transfer method is a process that temporarily forms a TFT array on a glass substrate, and that removes only the glass substrate, affixing the TFT array layer to the plastic substrate. The TFT array manufacturing process is nearly same as the conventional process, but there is a higher manufacturing cost.

The direct method is a process that directly forms a TFT array on a plastic substrate in place of a glass substrate. Compared to the transfer method, the challenges for the TFT manufacturing technique and the substrate material are greater, but if this is realized, a manufacturing cost equivalent to or lower than that of glass substrate TFT LCDs can be achieved. Therefore, we undertook development using the direct method, which is more suitable for mass production[3)5)6)].

2. Problems of Forming the TFT Array

To form the TFT array directly on the plastic substrate, the following three problems must be solved.
The first problem is to lower the process temperature. The process temperature of conventional amorphous silicon TFT is 300 to 350℃ at maximum, but the temperature withstood by general plastic substrates is only about 100 to 200℃.
The second problem is how to meet the large dimensional change of plastic substrates. Because plastic substrates are highly susceptible to heat and moisture and tend to change dimensions, position alignment between photo-layers is a problem.
The third problem is the curvature of the substrate. The plastic substrate has a low elasticity modulus, and the substrate easily curves due to stress of the film formed on the substrate. This hinders handling during the process in addition to the flatness when the plastic substrate is applied in products.
By taking measures against these three problems, we have succeeded in forming TFT arrays onto plastic substrates, and a prototype 4.4-inch plastic TFT LCD was successfully produced. The remainder of this section discusses these techniques.

2.1 Lowering Process Temperature

General plastic materials provide a heat-resistance temperature of about 100 to 200℃. However, in manufacturing TFT arrays, the temperature reaches its highest peak at 300 to 350℃ in the CVD film-forming process of the gate insulation film and the amorphous silicon semiconductor layer. The CVD film-forming process is the process most sensitive to temperature, and an insufficient film-forming temperature may lower the transistor current driving capability, lower the ON/OFF ratio, and lessen reliability.
To solve this problem, a new substrate was developed for plastic TFT, whose heat-resistance temperature is 250℃ or higher. In addition, the CVD film-forming conditions around 220℃ were optimized.
Fig. 1 shows the TFT switching characteristics when a gate insulation film and an amorphous silicon layer were formed on the novel plastic substrate under the optimized CVD film-forming conditions. The new TFT achieved 0.32 for mobility, 1.7V for threshold value, 6 or more digits for the ON/OFF ratio, and provides satisfactory characteristics as the driving element of an LCD. In addition, even after a long-term aging test, there was no change in characteristics, nor was there degradation of the switching characteristics.

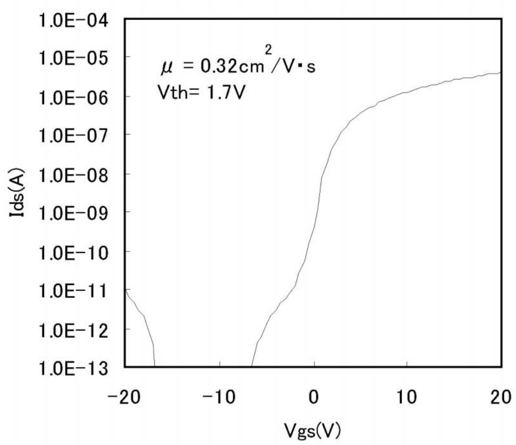


Fig. 1 Switching characteristics of the a-Si TFT on the plastic substrate

2.2 Measures Against Changes in Substrate Dimensions

Plastic substrates change greatly in dimension due to heat and moisture absorption. The linear expansion coefficient is 60 to 100 ppm/℃ for general plastic substrates, compared with 4 ppm/℃ for glass. In addition, substrate contraction and expansion caused due to moisture absorption reaches more than 3,000 ppm. A general TFT array substrate has an alignment margin as small as about ±30 ppm between the photo-layers. **Fig. 2** shows the structure of a conventional TFT array substrate. To solve this problem, we controlled the contraction and expansion of the plastic substrate and increased the alignment margin of the TFT array.

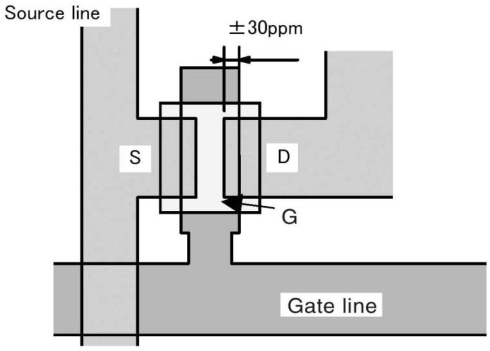
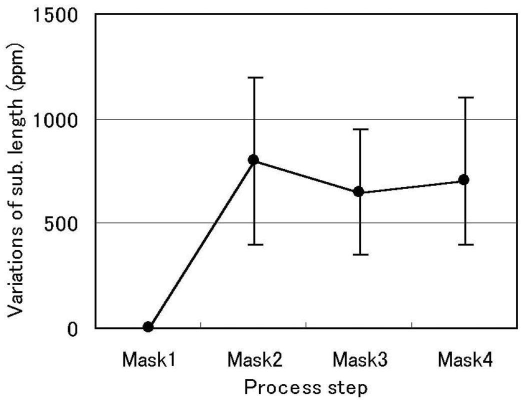
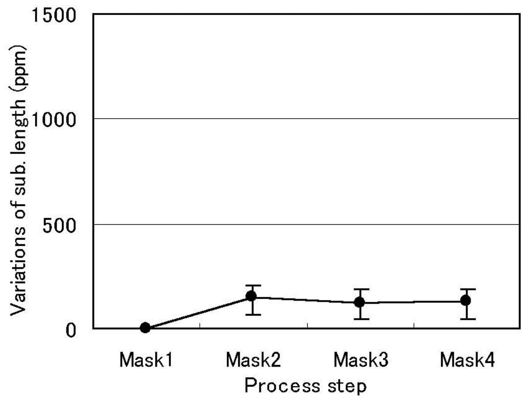


Fig. 2 Conventional TFT array structure



(a) Conventional plastic substrate without base coat film



(b) Novel plastic substrate with base coat film

Fig. 3 Variations in plastic substrate length in the actual TFT manufacturing processes

Fig. 3 shows the dimensional changes in the substrates in the actual TFT array process. In this experiment, to suppress contraction and expansion of the substrates, changes in temperature and humidity were minimized at each process step. However, as can be seen from **Fig. 3 (a)**, in the conventional plastic substrate, the dimensional changes exceeded 1,000 ppm. Therefore, we improved the linear expansion coefficient and moisture absorption ratio of the substrate material itself. Furthermore, to suppress moisture from entering the substrate, a base coat film comprising SiNx was deposited on both surfaces of the substrate. **Fig. 3 (b)** shows changes in dimensions in the novel plastic substrate with a base coat film. By this measure, dimensional changes can be suppressed to about 200 ppm.

Meanwhile, to expand the TFT array alignment margin, a novel TFT array structure was developed. **Fig. 4** shows a conceptual diagram of the novel TFT array structure.

In Fig. 4, the section in which the drain electrode and gate wiring intersect functions as the TFT. Channel length L is defined by the gap width between the source wiring and the drain electrode, and channel width W is defined by the width of the semiconductor layer. The gate wiring has no rugged portion. Consequently, even if any misalignment occurs in the X direction, no change is generated in the various parameters of the TFT. In addition, the drain electrode extends from the gate wiring in the vertical direction without causing ΔY bends, respectively. Consequently, in the Y direction, the novel TFT array

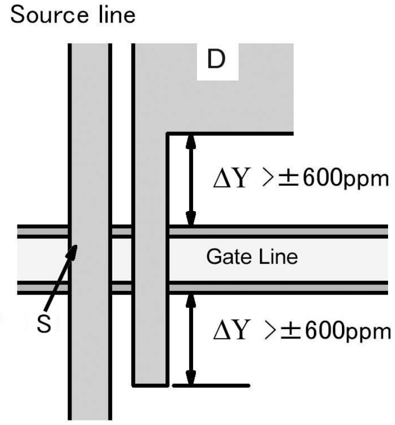


Fig. 4 Novel TFT array pattern

pattern can meet misalignments up to ± ΔY. By adopting this structure, it is possible to handle misalignments exceeding 600 ppm.

By using the above two techniques, it is possible to form a TFT array pattern without problems even with large TFT arrays exceeding 10 inches.

2.3 Measures Against Substrate Curvature

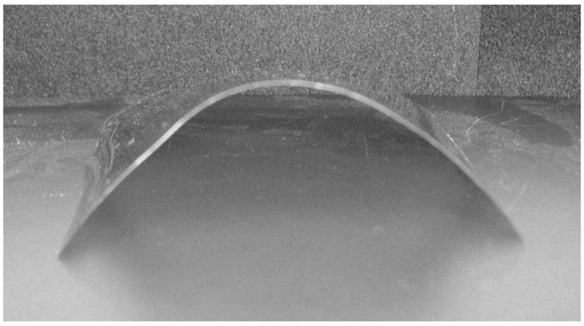
Plastic substrates are softer than glass substrates and are likely to curve due to internal stress or thermal stress of the film deposited on the substrates. It is possible to suppress the internal stress through film-forming conditions, but since the thermal stress is caused by the physical constant difference between the substrate and the deposited film, no improvement can be expected due to film-forming conditions. **Fig. 5 (a)** shows the condition of substrate curvature when a CVD film is deposited on a general plastic substrate. The substrate is 5 inches square and 0.2 mm thick, and the CVD film deposited is a laminated film comprising 350 nm SiNx film and 100 nm a-Si film. By controlling the film-forming conditions, the internal stress of the CVD film is brought to nearly zero, but large curvature exceeding 40 mm was generated due to thermal stress. It is difficult to treat these curved substrates with existing apparatus. Curvature amount d of a substrate caused by thermal stress can be approximated by the following equation using the physical constants of the substrate and the deposited film.

$$\delta \propto \frac{\alpha_f - \alpha_s}{Es} \qquad \text{Eq.(1)}$$

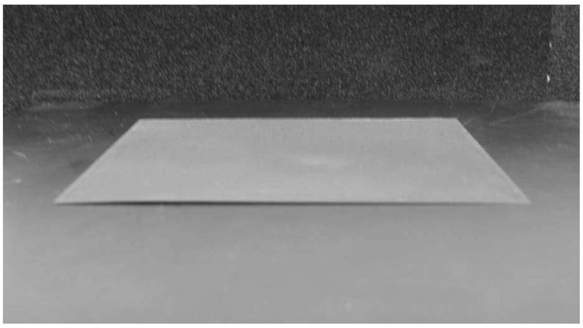
where α_f denotes the linear expansion coefficient of thin film, Es, the linear expansion coefficient of the substrate, and α_s, Young's modulus of the substrate.

Consequently, to suppress the curvature of the substrate, it is essential to reduce the linear expansion coefficient of the substrate and increase Young's modulus. Therefore, in this research, we used a plastic substrate with greatly improved linear expansion coefficient and Young's modulus. **Fig. 5 (b)** shows the novel plastic substrate with a CVD film deposited under the same conditions as in **Fig. 5 (a)**. Curvature is scarcely observed in the substrate.

When the substrate is large, the problem of substrate curvature due to thermal stress further increases to a critical level . **Fig. 6** shows the calculation results of



(a) Conventional plastic substrate



(b) Novel plastic substrate

Fig. 5 Curvature of plastic substrates with PECVD film deposited

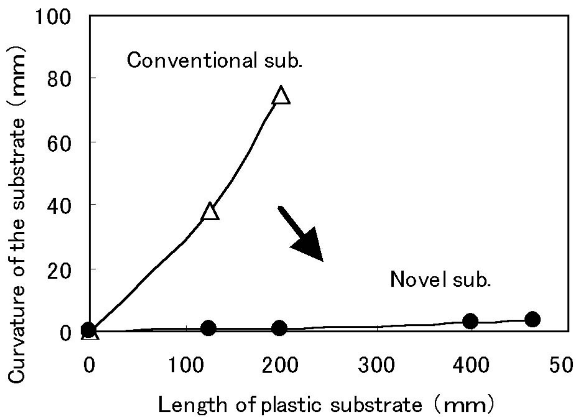


Fig. 6 Relation between the length and curvature of plastic substrates

Table 1 Specifications of the plastic TFT LCD

Display size	4.4-inch diagonal
Display type	Reflective color
Resolution	240×RGB×240
Number of pixels	172,800 pixels
Aperture ratio	92%
Contrast ratio	25 : 1
Panel thickness (with polarizer)	0.65mm
Weight	9g

the relationship between substrate size and substrate curvature due to thermal stress. The △ marks show the curvature when the CVD film is deposited at 200℃ on a conventional plastic substrate, and the ● marks show the curvature when the film is deposited on a novel plastic substrate. The use of the novel plastic substrate suppresses substrate curvature due to thermal stress to 10 mm or lower even if it is a large substrate measuring 360 x 465 mm.

3. Display Specifications

Table 1 shows the specifications of the plastic color TFT LCD we developed and **Fig. 7 (a)** and **(b)** show the external appearance of the display. By using the plastic substrate, an LCD of 0.65 mm in thickness and 9 grams in weight can be achieved with a 4.4-inch display area. This means that the weight has been reduced to one third and the thickness to one half of that when a glass substrate is used. The plastic color TFT LCD has achieved a 6-bit color display with 92% aperture ratio, nearly the same display characteristics as those of reflective LCD panels currently produced.

(a) Front view

(b) Side view

Fig. 7 Reflective plastic TFT LCD

Conclusion

Miniaturization of mobile devices will continue to take place, and it is foreseen that not only display quality but also elements such as light weight, slimness, and sturdiness of display modules will greatly govern the salability of applied products. The plastic TFT LCD we developed unites all these elements and has great potential as a future mobile device display.

We will continue make efforts to develop applied techniques for improving salability and progress with technological developments for mass production to open up new markets for applied products .

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