TFT Technology for Flexible Display Applications

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Keywords : flexible display, TFT, metal foil, plastic, electrophoretic display

Abstract

The key development issues in the flexible displays are TFT backplane technology for their various applications, which requires competitive device performance as well as its low temperature process. In this paper, with shortly reviewing recent flexible display development status, we describe technical trends of low-temperature a-Si TFTs. Our TFTs show good device characteristics enough to apply LCD and electrophoretic display.

1. Introduction

Flexible displays are very attractive as the displays in the future with ubiquitous and creative era, because of their highly rugged, lightweight, and conformable or rollable properties [1]. In recent years, many interesting and technically progressive prototypes of flexible displays have been reported [2-4], which makes us to have expectations for the flexible display products in the near future. However, it is seen that there are several hurdles to open the flexible display market. For example, most flexible displays are fabricated on the plastic or metal foil substrates, of which thermal stabilities hardly enable us to adopt the conventional process conditions. Instead, low temperature processes should be developed, but nevertheless the resultant thin-film transistors (TFTs) are required to have similar quality as conventional a-Si TFTs. In addition, it is desirable to be able to use the conventional equipments for dealing with the flexible substrates in the flexible display fabrication processes, which reveals some technical difficulties. Many efforts have been made to solve the above problems, including the research area of flexible substrates, low-temperature TFTs, and display modes.

In this paper, the technical trend in the flexible display development is briefly reviewed. And our recent progress in this area is also introduced, which includes the development of a prototype of 14.1" VGA color e-paper using the metal foil substrate and a prototype of 12.1" SVGA flexible AMLCD using the plastic substrate, respectively [5]. These displays are based on the low-temperature a-Si TFT backplanes. Some important process techniques and device characteristics are described together with the photo images of each display.

2. Low-temperature a-Si TFT Trends

a-Si:H TFTs are a mature technology to use in low cost and large sized displays. Making the a-Si TFTs compatible with flexible substrates such as Stainless Steel (SS) metal foil and plastic substrate needs to reduce the process temperature from 320°C to 150°C or below, mainly due to the distortion of flexible substrates from high temperature process steps, which results in a rather poor stability of a-Si:H TFT like threshold voltage shift (ΔV_{TH}) under bias temperature stress (BTS). However, SS substrate has advantages such as thin thickness, ruggedness, and excellent barrier against oxygen and moisture [6]. Thus, these SS substrates are the most promising candidates for flexible and eventually rollable displays [7,8]. In addition, it has been the solution that is enabled by the reflective nature of electrophoretic material [9].

In case of plastic substrate, since there are some merits such as a lower moisture absorption, good chemical resistance, more rugged, and lighter weight, many reports about STN-LCD and MIMLCD using plastic substrates have been published [10,11]. However, overcoming issues such as low Tg and dimensional stability requires additional processing steps.

3. Low-Temperature a-Si TFT Characteristics

3.1 TFT on SS substrate

Relatively high process temperature and excellent dimensional stability of metal foil allow us to be able to make transistors without any pre-processing such as pre-annealing and encapsulation using conventional TFT manufacturing technology. The backplane was designed with a new TFT structure on metal foil for electrophoretic-ink frontplane.

The backplane comprises a-Si thin film transistor array fabricated using a conventional 5 mask process. A multi-barrier structure was developed in order to reduce the surface roughness of the metal foil and to both protect chemical damage and the parasitic capacitance between the metal foil and the gate metal before the a-Si TFT array fabrication. RMS value of the bare metal foil was around 1000 Å. After forming a multi-barrier, RMS value of surface roughness approaching 50 Å was obtained. The a-Si TFTs were made in the bottom-gate back channel etch configuration. The gate metals, source/drain metals, pixel ITO were deposited by dc magnetron sputtering. The a-Si:H, n+ a-Si, and SiN_x layers were deposited by plasma-enhanced chemical vapor deposition (PECVD) without breaking the vacuum. SiN_x layers were deposited using a SiH_4 and NH_3 mixture; a-Si was deposited using SiH_4; and n+ a-Si was deposited using a mixture of PH_3, SiH_4, and H_2. The maximum processing temperature was about 150°C. A final passivation layer was applied to the array to passivate the exposed a-Si back channel. The semiconductor and insulator layers were patterned by reactive ion etching while the metal layers were patterned with wet etching. The smallest patterned dimension, the transistor channel length, is 5 µm with a width/length (W/L) ratio of 16:1.

Here, U type dual TFT was applied to conventional design rules with W/L of 80/5 and storage capacitor of 2.35pF as shown in the inset of Fig. 1.because of better characteristics in the mobility and I_{on}/I_{off} ratio. Fig.1 shows the transfer curves of the U-type dual TFTs. The drain current vs. gate voltage plots of a TFT in an active matrix array on a metal foil were measured at V_D = 0.1~10V with gate voltages ranging from –20 to 30V. The TFTs have a threshold voltage of 3.2V, the linear mobility of 0.41㎠/Vs, and the saturated mobility of 0.46㎠/Vs. The subthreshold slope of 1.31 V/dec and the On/Off current ratio is over 10^8

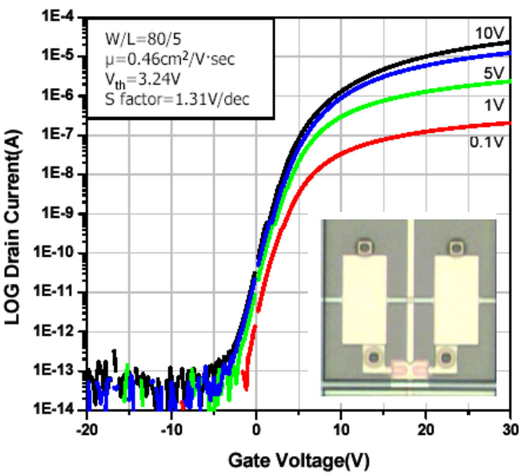

Fig. 1. Transfer curves of U-type dual TFT

3.2 TFT on plastic substrate

Since there is dimensional stability problem due to thermal expansion and shrinkage of plastic substrate during the TFT thermal process, the plastic substrate was pre-annealed to allow shrink before starting the TFT process. Then, the multi-barrier layers was applied to planarize the surface of the plastic substrate as well as to passivate it against chemicals. The fabrication process of TFTs on plastic substrate was almost the same as that on SS substrate except the pre-annealing processing.

The TFT on plastic substrate was designed to implement a large size flexible device. The resolution is 1024x768 (91ppi) with a unit pixel size of 279㎛ and W/L of 20/5 as shown in the inset of Fig.2. And the aperture ratio of the pixel is 65%. U-type TFT structure of the array was also used to obtain good device performance.

As we can see in the Fig.2, TFTs on plastic substrate have effective mobility of 0.41 cm^2/Vs, threshold voltage of nearly 0V, subthreshold slope of 0.46 V/dec and leakage current of 10^{-12} that are similar to good quality devices on glass fabricated at higher temperatures.

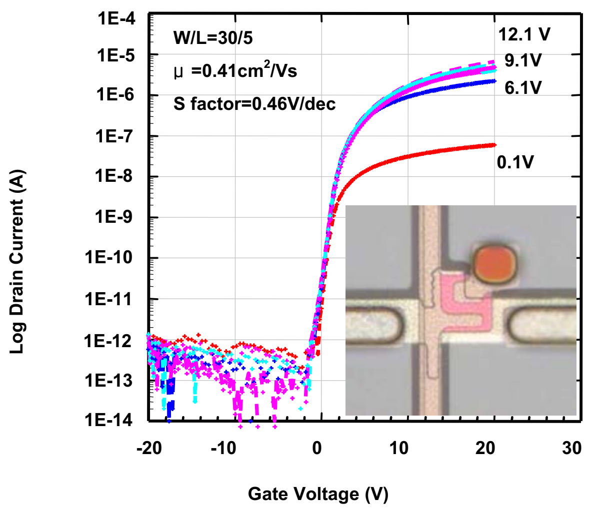

Fig. 2. Transfer curves of U-type TFT on plastic Substrate

4. Display performance

In order to implement flexible color EPD and flexible LCD, flexible color filter process should be developed on plastic substrate. However, there are some issues of color filter process on plastic substrate such as the dimensional stability due to thermal process, the moisture absorption, and surface roughness. So, we have to apply pre-annealing process at the first stage, then to apply the multi-barrier layer structure, finally to optimize the sequence of curing process of color filer resist at below 150 ℃.

4.1 Flexible Color EPD on thin metal foil

The display was designed to provide high-information in e-book displays relevant to A4 size, which had resolution of 1280x800(103dpi) sub-pixels, a unit sub-pixel size of 255㎛, and the aperture ratio of 96%.

This display uses electronic ink between Thin-Film Transistors (TFT) on a thin SS metal-foil substrate and Color Filter Array coated onto the plastic substrate, allowing it to recover its original shape after being bent as well as to produce color images. We focused on the designs of the color filter structure and TFT, as well as color filter lamination technology. This allowed us to overcome processing difficulties inherent in the lack of heat resistance in metal foil and plastic substrates. This display prototype is very flexible and has a true paperlike look with wide-viewing angle and high contrast ratio as shown in Fig.3.

This reflective-type display can reproduce 4096 colors, including 16 shades of gray. Its high resolution and omni-directional viewing angle make it as easy to read as a printed page. Using a reflective foil substrate eliminates the need for a backlight, making this display thin, lightweight and easy on the eyes. It also means that the display is extremely energy-efficient, only drawing power when the image changes. The display performance and characteristics are summarized in Table 1.

Fig. 3. Photograph of 14.1" Flexible Color E-paper

Specifications	
size	14.1-inch (diagonal)
Thickness	~300um
Resolution	1280 × 800 sub-pixels
Sub-pixel density	103 dpi
Number of colors	4096 colors
Viewing angle	180° (omni-direct.)
Illumination mode	Reflective
Driving voltage	± 15V
Application	Mobile e-paper

Table 1. Summary of flexible color e-paper display performance

4.2 Flexible LCD on plastic substrate

The TFT on plastic substrate was designed to implement 12.1-inch flexible AMLCD. The resolution is 1024x768 (91ppi) with a unit pixel size of 279㎛ and the aperture ratio of 65%.

To solve the problems involving the plastic substrate's heat sensitivity such as dimensional stability, stress optimization, and misalignment between the two plastic substrates for TFT and CF, we developed a low-temperature processing technique to fabricate the thin-film transistors, color filters and liquid crystals at process temperatures much lower than standard a-Si technology on glass substrate.

Fig.4 shows this flexible active matrix LCD, which reveals the features of full-color, high-resolution, lightweight, and bendable flexible LCD display. And, the display performance and specifications are summarized in Table 2.

Fig.4. Photograph of 12" Flexible AMLCD

Specifications	
size	12.1-inch (diagonal)
Thickness	~600um
Resolution	800× RGB × 600
Pixel density	83 dpi
Number of colors	262114 colors
Color Method	Color Filter (RGB)
Display mode	Liquid Crystal (TN mode)

Table 2. Summary of flexible AMLCD performance

5. Conclusion

Technical trends of flexible display based on low-temperature a-Si TFTs and our recent progress in this area were described. Both SS substrates and plastic substrates, despite of their limitations, are useful for the several flexible displays depending on their modes and applications. For the case of plastic substrate, additional process steps were required to overcome the issues such as low T_g and dimensional stability. The fabricated color e-paper on the SS substrate was very flexible and has a true paperlike look with wide-viewing angle and high contrast ratio. And the flexible AMLCD fabricated on the plastic substrate revealed full-color, high-resolution, lightweight, and bendable flexible LCD. Our research results on the low-temperature a-Si TFTs showed good device characteristics enough to apply flexible LCDs as well as flexible color e-papers .

6. References

[1] M. Robert Pinnel, et al., IMID Digest, p227, 2005.

[2] S.E. Burns, et al., SID DIGEST, p19, 2005

[3] Tetsuya Ohsima, et al., SID DIGEST, p266, 2006

[4] Yoshiro Okada,et al., SID DIGEST, p1204, 2002

[5] C. D. Kim, et al., SID Digest, p1669, 2007.

[6] M. Wu, et al, Appl. Phys. Lett., **75** (15), p 2244, 1999

[7] Shin, H.S. et al. SID Digest, p.1642, 2005.

[8] Chang, J.-F. et al, Proc. of EuroDisplay, p.133, 2005

[9] J. Au, et al., IDW, p223, 2002

[10] S. Aomori et al, SID DIGEST, pp558, 2001

[11] S. J. Hong et al, Asia Display / IDW, p 403,2001