Novel Backplane for AM-OLED Device

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Keywords : Oxide TFT, backplane, OLED, flexible display

Abstract

IGZO TFTs were fabricated by conventional photo-lithography and wet-etching processes on metal substrates for the flexible display. The characteristics of TFTs on metal substrates were comparable to those of TFTs on glass substrates. Moreover, AM-OLED panels based on IGZO TFT arrays on metal substrates were successfully driven, for the first time.

1. Introduction

Recently, oxide thin film transistors (TFTs) have attracted a considerable attention because of their superior material properties including wide bandgap and high field effect mobility [1-7]. There have been a number of recent reports on oxide TFTs such as zinc oxide [1, 2], zinc tin oxide (ZTO) [3], indium zinc oxide (IZO) [4] and indium gallium zinc oxide (IGZO) [5-7] as active layers. In the previous work [6, 7], we have fabricated 3.5 inch full color $QCIF^+$ AM-OLED panels on glass substrates and moving images were successfully driven by IGZO TFTs.

Nowadays, a mobile electronic device is the most important business item and there are many interests in the display which is flexible, unbreakable, foldable and light-weight. It is believed that the next generation display will be fabricated on flexible substrates such as plastic and metal foils. To meet the demand for the flexible display, we fabricated IGZO TFTs on metal substrates and investigated their characteristics. Moreover, 3.5 inch $QCIF^+$ AM-OLED panels using IGZO TFTs on flexible metal substrates were also fabricated for the future application, for the first time. In this research, we used the conventional photolithography and wet-etching processes [6, 7]. We believe that our research will provide a possibility of the flexible AM-OLED display using IGZO TFTs.

2. Experimental

TFTs were fabricated on 100 mm × 100 mm glass and insulator-coated metal substrates with a top gate structure. Indium tin oxide films (ITO, 50 nm) deposited by DC magnetron sputtering were used as source and drain electrodes. IGZO films with the thickness of 30 nm were deposited by RF (13.56 MHz) magnetron sputtering at room temperature as active layers. Then, silicon oxide films were deposited as gate insulators by plasma enhanced chemical vapor deposition (PECVD) at the temperature of 300^oC. 100 nm thick Mo gate electrodes were also deposited by DC magnetron sputtering. All the patterning processes were performed by the conventional photolithography and wet-etching techniques. Atomic force microscopy (AFM) was used in order to investigate the surface morphology of active layers and its scan area was 20 μm × 20 μm.

3. Results and discussions

3.1 Issues in metal substrates

Stainless steel foils were used for our flexible substrates because of their low cost and high elasticity. However, considering the flexibility of display, the thickness of stainless foils must be less than 200 μm. In this study, 100 μm thick stainless foils were used for substrates of our device. On the other hand, the surface flatness of the substrates is very important to get proper characteristics of TFTs because very thin films which were 30 nm thick IGZO films, were used as active layers. Since the metal substrates were so rough and conductive, firstly, we coated organic layers of 3 μm using a spin-coater on stainless foils, which serve as electrical insulators and surface planarization layers. Stainless steel foils with planarization layers, showed very flat morphology with root mean square (RMS) and peak-to-peak ($R_{p\text{-}v}$) values of 1.7 nm and 17.5 nm, which are very low compared to those of 22 nm and 258 nm in bare metal substrates, respectively.

The occurrence of crack during processes is also a key issue of a flexible display. The crack of the film was initiated owing to the difference of coefficient of temperature expansion (CTE) and the stress of thin films. Crack formation could be reduced and prevented by decreasing the process temperature and controlling the stress of thin films. In this study, the highest process temperature was 300 °C and the stress of SiO_x gate insulators was a compressive stress of 300 MPa.

3.2 Characteristics of IGZO TFTs on metal substrates

IGZO TFTs were fabricated with 50 μm channel width (W) and 20 μm channel length (L) on metal substrates and SiO_x layers were used as gate insulators. Except the planarization layer and SiO_x gate insulators, the fabrication processes on metal substrates were the same as those on glass substrates [6, 7]. Figure 1 (a) is the typical transfer curves of the IGZO TFTs with SiO_x gate insulators on glass and metal substrates. TFTs on glass and metal substrates showed the sub-threshold swings (S) of 0.25 V/decade and 0.61 V/decade, the off-currents of 20 pA and 90 pA and on/off ratios of 1.8×10^6 and 3.5×10^5. From the analysis of the curve, the field effect mobility was 8.5 cm^2/Vs and 6.7 cm^2/Vs, and the threshold voltage was 0.2 V and 0.4 V, respectively.

Figure 1 (b) and (c) show the output and hysteresis characteristics of IGZO TFTs on metal substrates. Figure 1 (b) shows good saturation characteristic even at high drain voltage. Moreover, it had very excellent hysteresis characteristics. As shown in Figure 1 (c), the threshold voltage shift (ΔV_{th}) was less than 0.1 V which indicates a good interface between an IGZO film and a gate insulator on metal substrates. (The transfer curve in reverse direction is shown by dotted

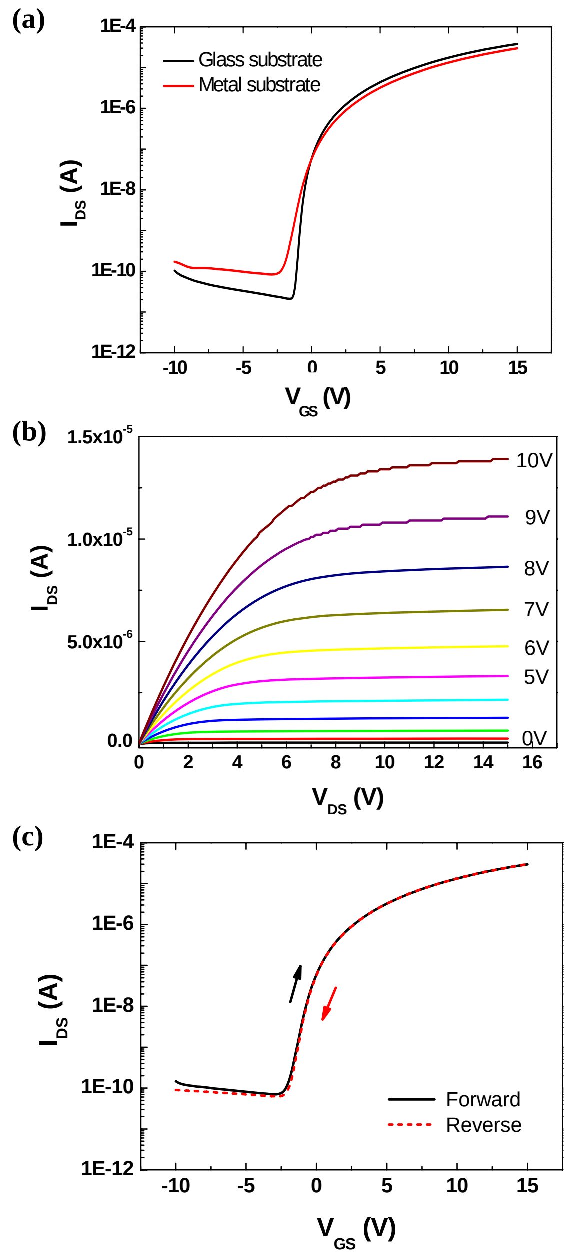

Fig. 1. Typical characteristics of IGZO TFTs on a metal substrate; (a) transfer, (b) output and (c) hysteresis (The transfer curve on a glass substrate was inserted into (a).)

line.) TFTs on glass substrates also showed similar output and hysteresis characteristics to those of TFTs on metal substrates. In the case of TFTs on metal substrates, the mobility was slightly lower than that on glass substrates. The off-current on metal substrates was somewhat higher (~ 90 pA) than that on glass substrates, which resulted in low on/off ratio of 3.5×10^5.

However, the off-current could be lowered by some appropriate post processes, as shown in Figure 2. The transfer curve after post processes is presented by a solid line. The figure shows an appreciable decrease of the off-current (~ 0.1 pA), which results in high on/off ratio of 2.2×10^8 after the post processes. On the other hand, there were a slight degradation of mobility (6.2 cm^2/Vs) and a considerable enhancement of a sub-threshold swing property (0.38 V/decade) after post processes.

3.3 Characteristics of IGZO TFTs with a curvature

Before, during and after bending, transfer characteristics of IGZO TFTs were also measured as shown in Figure 3. Firstly, the transfer characteristic was measured after post processes. After that, the stainless steel foil was bent into a curve with a surface radius of 40 mm and then, the transfer characteristic was measured. Finally, the stainless foil was restored, and the transfer characteristic was re-measured. Figure 3 exhibits that there is no significant difference in threshold voltages, sub-threshold swings, off-currents and mobility with the regardless of the bending status of substrates.

3.4 AM-OLED panel on metal substrates driven by IGZO TFT arrays

Using the same processes of AM-OLED panels on glass substrates [6, 7], 3.5 inch diagonal $QCIF^+$ full-color AM-OLED panels on metal substrates were fabricated using the IGZO TFT array. Stainless steel foils were used as substrates and organic planarization layers were deposited before electrode deposition. OLED devices were fabricated with top emission structures. Figure 4 shows a typical cross-sectional schematic structure of the AM-OLED device on a substrate. AM-OLED panels had the conventional 2T1C pixel circuit. The driving TFT had 50 μm channel width (W) and 20 μm channel length (L), and the switching TFT had 50 μm channel width (W) and 10 μm channel length (L). The capacitance of the storage capacitor was 0.4 pF. The resolution was 176 (x 3 (RGB)) x 220 pixels, and the sub-pixel size was

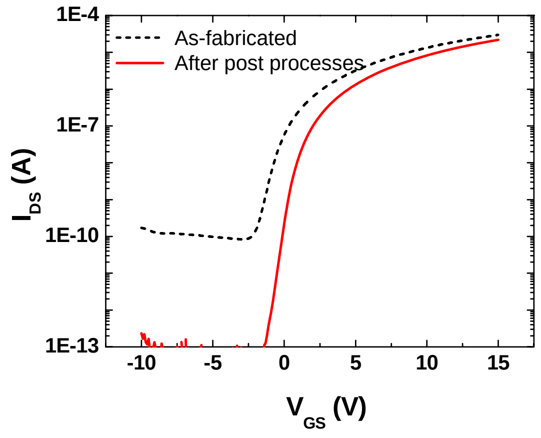

Fig. 2. Transfer characteristics of TFTs, as-fabricated and after post processes

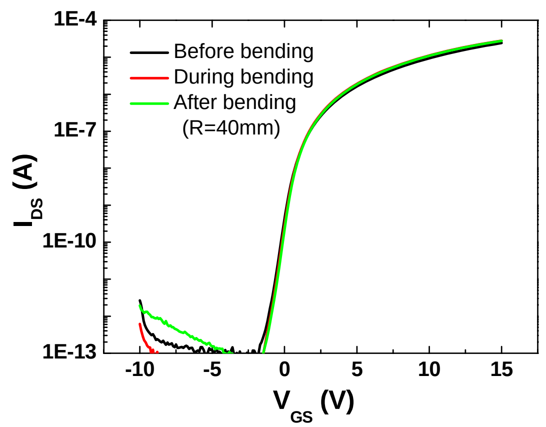

Fig. 3. Transfer characteristics of TFTs, before, during and after bending (R = 40 mm)

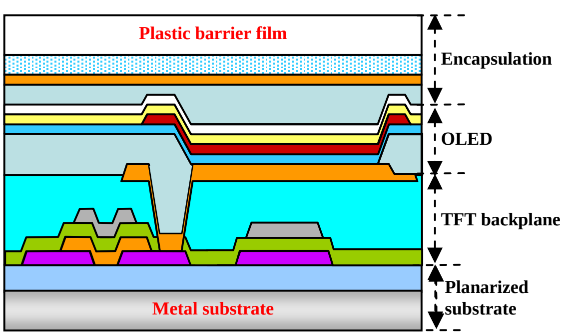

Fig. 4. Cross-sectional schematic structure of a 3.5 inch $QCIF^+$ AM-OLED device

0.316 mm × 0.105 mm. Specifications of AM-OLED panels were summarized in Table 1.

Figure 5 shows the image of the full color AM-OLED device on a flexible metal substrate driven by oxide TFT arrays. An operation image shows a clear and good contrast in spite of some point and line defects. Moreover, it was successfully driven with bending in the curvature of 40 mm radius.

Table 1. Specifications of OLED panels driven by IGZO TFTs

Display size	3.5 inch diagonal
Resolution	176 (X 3) X 220
Display mode	Top emission OLED
Driving TFT	W/L : 50 μm /20 μm
Switching TFT	W/L : 50 μm /10 μm
Storage cap.	0.4 pF

Fig. 5. 3.5 inch full color QCIF+ AM-OLED panel on a metal substrate

4. Summary

IGZO TFTs with top gate structures and SiO_x gate insulators were fabricated by conventional photo-lithography and wet-etching processes. TFTs on glass substrates showed the mobility of 8.5 cm^2/Vs, on/off ratio of 1.8×10^6 and sub-threshold swing of 0.25 V/decade. TFTs were also fabricated on flexible metal substrates for future application. The devices worked well and showed the mobility of 6.7 cm^2/Vs, on/off ratio of 3.5×10^5 and sub-threshold swing of 0.61 V/decade. However, the off-current of TFTs has been greatly enhanced by post processes. Moreover, there is no significant difference in threshold voltages, sub-threshold swings, off-currents and mobility with the regardless of the bending status of substrates. For the first time, we developed 3.5 inch diagonal full color QCIF+ AM-OLED panels using IGZO TFTs on the metal substrates. These results demonstrate that the oxide TFT can be one of the promising candidates as a backplane for the AM-OLED flexible display.

5. Acknowledgement

This work was partly supported by IT R&D program of MIC/IITA [2006-S-079-01]. The authors would like to thank LG Chem, Ltd. for supplying plastic barrier films.

6. References

[1] E. Fortunato, P. Barquinha, A. Pimentel, A. Gonsalves, A. Marques, L. Pereira, and R. Martins, Adv. Mater., Vol. **17**, p590 (2005).

[2] Sang-Hee Ko Park, Chi-Sun Hwang, Jeong-Ik Lee, Sung Mook Chung, Yong Suk Yang, Lee-Mi Do, and Hye Yong Chu, Proc. SID'06, p25 (2006).

[3] H. Q. Chiang, J. F. Wager, R. L. Hoffman, J. Jeong and D. A. Keszler, Appl. Phys. Lett., Vol. **86**, p013503 (2005).

[4] P. Barquinha, A. Pimentel, A. Marques, L. Pereira, R. Martins, E. Fortunato, J. Non-Cryst. Solids, Vol. **352**, p1749 (2006).

[5] Kenji Nomura, Akihiro Takagi, Toshio Kamiya, Hiromichi Ohta, Masahiro Hirano, and Hideo Hosono, Jpn. J. Appl. Phys., Vol. **45**, p4303 (2006).

[6] H. N. Lee, J. W. Kyung, S. K. Kang, D. Y. Kim, M. C. Sung, S. J. Kim, C. N. Kim, H. G. Kim and S. T. Kim, Proc. IDW'06, p663 (2006).

[7] Ho-Nyun Lee, Jaewoo Kyung, Sun Kil Kang, Do Youl Kim, Myeon-Chang Sung, Seong-Joong Kim, Chang Nam Kim, Hong Gyu Kim, and Sung-tae Kim, Proc. SID'07, p1826 (2007).