Transparent AMOLED Display Derived by Metal Oxide Thin Film Transistor with Praseodymium Doping

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ABSTRACT

Praseodymium-doped indium zinc oxide (Pr:IZO) have been employed as the channel layer of thin film transistors (TFTs). The TFTs with Pr doping exhibited a remarkable suppression of the light induced instability. A negligible photo-response and remarkable enhancement in negative gate bias stress under illumination (NIBS) were achieved in the Pr:IZO TFTs. Meanwhile, the Pr:IZO TFTs showed reasonable characteristics with a high field effect mobility of 18.4 cm2/Vs, SS value of 0.15 V/decade, and I_{on}/I_{off} ratio of 10^9. A prototype of fully transparent AMOLED display was successfully fabricated to demonstrate the potential of Pr-doping TFTs applied in transparent devices.

1. INTRODUCTION

To date, several models were proposed to reveal the mechanism of light-induced instability in AOSs TFTs. The carrier trapping and ambient interaction model are commonly used to expound this deterioration,[1-3] but they can hardly explain the remarkable photo-response of AOSs TFTs under the visible-light irradiation ($h\upsilon<E_g$, band gap of the AOSs) even the TFTs with an optimized passivation. The oxygen vacancies (V_o) photo-ionization model claimed that holes generated by the light ionized the deep sub-gap state of neutral V_o above the valence band maximums (VBM),[4-6] that were trapped at the interface of channel/dielectric or further injected into the bulk of dielectrics, resulting in the degradation of the TFTs performance. Meanwhile, the various oxygen vacancy-related defects in the AOS films, such as meta-stable peroxide defects (O_2^{2-}),[7] oxygen interstitials (O_i) and hydrogen-related complex were also reported as the origins of this light-induced instability.[8-10] Based on the above understanding of light-induced degradation, several approaches in view of defects reduction were proposed to improve the stability of metal oxide TFTs, such as the gate insulator modification, channel layer treatment and passivation matching. Other methods can be also employed to avoid the light-induced instability, such as light-shielding layers or pixel compensation circuits, however, leading to raising both cost and complexity. Herein, a different strategy was proposed in this work to improve the light-induced instability of the metal oxide TFTs by deliberately introducing lanthanide oxide in the channel.

In this study, a powerful oxide semiconductor channel material with praseodymium (Pr) doping were developed to improve the light-induced instability. The effects of the Pr concentrations on the performance of Pr-doped Indium-Zinc-Oxide (Pr:IZO) TFTs were systematically investigated with conventional co-sputtering system. A distinct mechanism for the enhancement of bias illumination stability in Pr:IZO TFTs was proposed with trap-assisted recovery model. A prototype of fully transparent AMOLED display was successfully fabricated to demonstrate the potential of Pr-doping TFTs applied in transparent devices.

2. EXPERIMENT

Bottom-gate staggered structure was employed in this study as shown in Figure 1. A gate metal (Mo, 200 nm) and stacked gate insulator (SiO_2/Si_3N_4, 50/250 nm) were deposited subsequently by DC sputtering and plasma enhanced chemical vapor deposition (PECVD). For the channel deposition, the 30 nm-thick IZO and Pr-doped IZO (Pr:IZO) thin films were deposited using RF magnetron sputtering system with two targets of IZO (In/Zn=2/1 at%) and PrIZO (Pr/In/Zn=0.2/2/1 at%). Both the ceramic targets of IZO and Pr:IZO were sintered with purity of 99.99 %. The films were deposited using Ar and O_2 mixing gas ($Ar:O_2$=10:1) at 5 mTorr, and patterned by wet etching process. Then, a 300 nm thick SiO_2 was grown by PECVD served as etch stop layer (ESL) and patterned by dry etching. 200 nm thick Mo source (S) /drain (D) electrodes were formed by DC sputtering and patterned by wet etching. After that, 200 nm thick SiO_2 as passivation was grown by PECVD. Finally, the fabricated TFTs were annealed at 300 °C in air for 30 min.

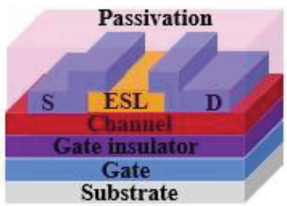

Fig. 1 Schematic cross-section of the TFTs

The fully transparent TFT back panel based on the Pr:IZO channel layer were fabricated by using bottom-gate staggered structure, employing the ITO as gate and S/D electrodes. 2T1C architecture is adopted to drive the

TFT panel. The TFT back panel shows a very high transmittance reaching as high as 80%, and the transmittance of AMOLED display has an obviously decrease due to the absorption of OLED material and Mg/Ag transparent cathode. As shown in Figure 5, we successfully demonstrated a transparent green-light AMOLED display. Notably, the performance of the transparent display shows no degradation under lighting of a white LED lamp even the luminance up to 100 000 cd/m^2. The specifications of the transparent AMOLED display are summarized in the Table 1.

Table 1. Specifications of 2.2-inch transparent AMOLED display.

Item	Specifications
Diagonal Size	2.2 inch
PPI	120
Pixel Size(μm)	70(W) ×210(L)
Pixel Circuit	2Tr+1C
Aperture Ratio	38%
Emission Type	Bottom Emission

3. RESULTS and DISCUSSION

3.1 TFTs Performance

Fig. 2 shows the transfer characteristic curves of the IZO and Pr:IZO TFT on glass substrate. The IZO-TFT exhibits field-effect mobility (μ_{sat}) of ~24.2 cm^2 V^{-1} s^{-1}, a threshold voltage (V_{th}) of 1.2 V, a subthreshold swing (SS) of 0.14V dec^{-1}, and an on/off current ratio (I_{on}/I_{off}) of ~10^9. On the other side, The Pr:IZO-TFT exhibits slightly lower μ_{sat} of ~18.4 cm^2 V^{-1} s^{-1}, a V_{th} of 1.3 V, a sharp SS of 0.15 V dec^{-1}, and an similar I_{on}/I_{off} of ~10^9. The on-current of the TFTs are above 10^{-5} A and the off-current is ~ 10^{-14} A, which demonstrates the promise for the TFTs in the application of high resolution AMOLED displays requiring a large on-current to drive pixels and a small off-current to minimize the power consumption. It is worth to note that there was no hysteresis in both of the transfer curves.

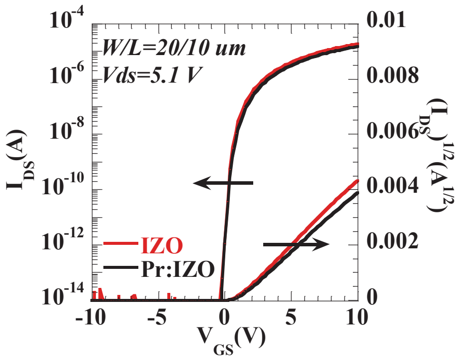

Fig. 2 Transfer characteristic curves of the IZO and Pr:IZO TFTs.

3.2 Photo-response and instability of the TFTS

To investigate the effect of light illumination on electrical properties of TFTs, the characterization of photo-response was carried out by a white LED lamp with the luminance of 12000 cd/m^2. As shown in Figure 3, the performance of the IZO-TFTs device degraded significantly under the LED illumination. However, the photo-response is suppressed significantly in the Pr:IZO-TFTs. In order to clarify this rigid shift, the V_{on} shift ($\triangle V_{on}$), variation of the SS ($\triangle SS$) and the I_{light}/I_{dark} (the ratio of drain current with/without light illumination at a fixed V_{GS} of -5 V) are represented in Figure 3a. It is observed that the TFT devices without Pr doping exhibited an obvious negative shift $\triangle V_{on}$ of -7.5 V, serious change in $\triangle SS$~1.8 V/decade and large I_{light}/I_{dark} more than 10^6. Impressively, in the Pr:IZO-TFT, the changes of V_{on} and SS are negligible ($\triangle V_{on}$~0.1 V, $\triangle SS$~0.04 V/decade), only with a slightly increase of the off-current. According to the previous reports, the V_o photo-ionization model are frequently quoted to explicate the degrade mechanism under light illumination in AOS materials, and the high density fully-occupied V_o states near the VBM which is verified by the first-principle study and experimental observation. Analogously, as for the IZO-TFT devices (Figure 3a), the V_o are excited by the irradiation phones and then created the V_o^{2+} states close to the CBM and donated the delocalized electrons in conduction band, resulting into the larger negative shift in transfer curve and the significant degradation of SS. Fortunately, this inferior phenomenon is greatly alleviated in the thin film transistor once with the Pr doping. So, it is reasonable to claim that the Pr cations play a determinant role in this photo-response improvement.

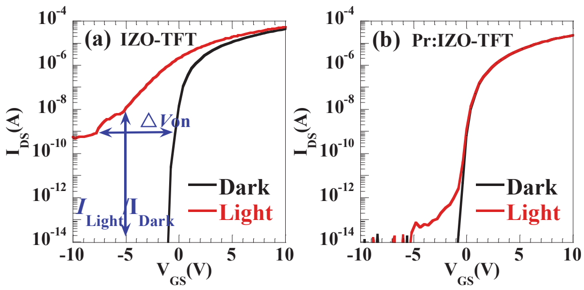

Fig. 3 The photo-response of the (a) IZO and (b) Pr:IZO TFTs, respectively.

As a further certification, the NITBS tests are carried out at V_{GS}=-20 V and V_{DS}=0 V at 70 °C. A commercialized LED is irradiated on top of the device with the white light through an optical fiber, and the light is not turned off while sampling the transfer characteristic. Figures 4a and 4b show the time dependence of the transfer curves under a NITBS for the IZO-TFTs and Pr:IZO-TFTs, respectively. It is obviously that the V_{on} shift of -11.5 V with significant degradation of SS could be observed for the device without Pr doping. However, the Pr:IZO-TFT exhibited a mildly V_{on} shift of -2.2 V. It is worth to note that the NITBS condition is severer than that photo-response test, because of the continual negative bias stress on gate electrode which accelerated the photoionized holes drift to channel/dielectric interface, and the temperature enhanced it. These results strongly reveal that Pr doping can significantly improve the light-induced instability.

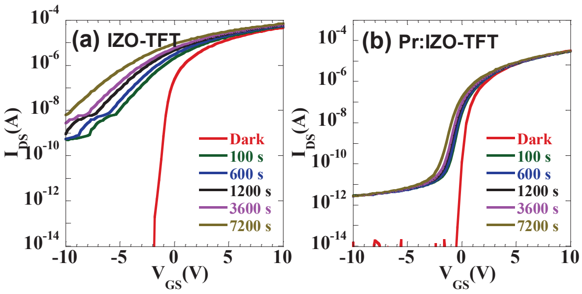

Fig. 4 Stability of the (a) IZO and (b) Pr:IZO TFTs under negative light temperature bias stress, respectively.

3.3 Full Color Transparent AMOLED Display

The fully transparent TFT back panels for AMOLED display are fabricated by using bottom-gate staggered structure, employing the ITO as gate and S/D electrodes. The channel layer is Pr:IZO (30 nm), and 2T1C architecture is adopted to drive the TFT panel. The transmittances of the PrIZO-TFTs array panel and the AMOLED display are illustrated in Figure 5. It is worth noting that the performance of transparent display shows no degradation under illumination with a white LED lamp, even the luminance up to 100 000 cd/m^2, indicating that this material has great potentials for applications in transparent AMOLED, transparent micro-LED displays or transparent photodetectors.

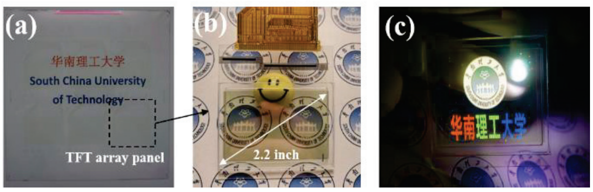

Figure 5. Photograph of (a) the transparent TFT array panel, (b) 2.2-inch AMOLED display and (c) the transparent display with white-LED irradiation.

4. CONCLUSIONS

In summary, a powerful oxide semiconductor channel material with praseodymium doping are developed. The effects of the Pr concentrations on the PrIZO-TFTs performance are comprehensively investigated. The incorporation of the Pr hardly change the phase structure of IZO with the concentration below 2.98 at% and negligibly affect the optical band gap. The photoconductivity response of the PrIZO thin films are well corresponding to the photo-response in the TFTs. A distinct mechanism is proposed with the trap-assisted non-irradiation recovery model. Finally, the common adaptability in oxide semiconductor materials are confirmed, and a prototype transparent AMOLED display is demonstrated with high resistivity to the visible light.

5. ACKNOWLEDGEMENT

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