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Performance Enhancement of Calcium-doped Zinc Oxide Thin Film Transistors Fabricated on Glass at Low Temperature

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Abstract

Fully transparent calcium-doped zinc oxide thin film transistors (Ca-ZnO TFTs) have been successfully fabricated on glass at low temperature. The characteristics of Ca-ZnO TFTs and ZnO TFTs are compared and analyzed in detail. The results suggest that incorporation of Calcium element can suppress growing the columnar structure and improve the performance of device. The TFTs with Ca-ZnO active layer exhibit excellent electrical properties with the saturation mobility (μ_{sat}) of 147.1 $cm^2V^{-1}s^{-1}$, threshold voltage (V_t) of 2.91 V, subthreshold slope (SS) of 0.271 V/dec, I_{on}/I_{off} ratio of 2.34×10^8.

1. Introduction

Low temperature poly-silicon (LTPS) TFTs have been widely used as driving devices in active matrix organic light-emitting diode (AMOLED) displays due to the high field effect mobility. However, non-uniform device properties of poly-Si TFTs over large area limit the large-area application of AMOLED displays [1]. Besides, the relatively high processing temperature also limits the use of poly-silicon TFTs for transparent and flexible electronics. Thus, various novel materials have been explored for the channel layer of TFTs. Recently, novel amorphous materials based on ZnO demonstrate excellent performance such as good uniformity, low-temperature processing, high mobility, low sensitivity to visible light, which offer great promise for the high-performance AMOLED displays. In 2004, Nomura *et al.* first introduced gallium (Ga) into a-IZO, where Ga element as carrier suppressor can control carrier concentration and oxygen vacancy effectively [2]. After that, based on strong bonding strength and Lewis acid strength (L), other carrier suppressors such as Si, Hf, Zr and Ta have been incorporated into oxide semiconductors channel layers [3-6].

In this work, the calcium element is incorporated into zinc oxide thin film to improve the performance of TFT. The characteristics of ZnO and Ca-ZnO TFT have been compared and properties of thin films have been investigated electrically and physically.

2. Experiments

In this experiment, bottom gate inverted Ca-ZnO TFTs were fabricated on glass substrate by standard photolithography and lift-off technique. The cross-sectional schematic of device is shown in Fig. 1. The fabrication procedures were as follows. First, the 150-nm-thick In-Sn-O (ITO) was deposited on glass substrate by radio frequency (RF) sputtering in pure Ar atmosphere. Secondly, the 130-nm-thick SiO_2 gate insulator layer was deposited by Plasma Enhanced Chemical Vapor Deposition (PECVD) at 100 ℃. Thirdly, the channel layer was deposited by RF sputtering in pure Ar atmosphere at room temperature. The stack of the insulator layer and channel layer were then lifted off together to simplify the process and optimize interface states. Lastly, ITO was sputter deposited as the source/drain electrodes. In this experiment, the working pressure during the sputter deposition was 1 Pa and the RF sputter power maintained at 70 W.

In order to investigate the effects of Calcium doping on performance of zinc oxide thin film transisitors, two samples with 30nm-thick ZnO and Ca-ZnO deposited as active layer respectively were fabricated at room temperature (referred to sample "S1" and "S2"). In S2, the wt% ratio of CaO and ZnO was 2% : 98%. The electrical characteristics of TFTs were measured by the semiconductor parametric analyzer (Agilent 4156C).

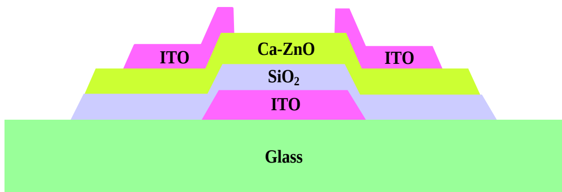

Fig. 1 Cross-sectional schematic of the device.

3. Results and Discussion

The transfer characteristics of S1 (ZnO) and S2 (Ca-ZnO) TFT are illustrated in Fig. 2. The S2 exhibits excellent electrical properties with the μ_{sat} of 147.1 $cm^2V^{-1}s^{-1}$, V_t of 2.91 V, SS of 0.271 V/dec, I_{on}/I_{off} of 2.34×10^8. The experiment results suggest that the performance of TFT is improved effectively due to the incorporation of calcium element into the zinc oxide thin film. The related electrical parameters are extracted and listed in Table I. In amorphous oxide semiconductors, electron mobility is sensitive to defect states. In 2012, Zan *et al.* reported that capping a strong reduction layer on IGZO oxide is a successful method to reduce defects and to increase mobility [7]. In metal-oxygen bonding system of Ca-ZnO oxide,

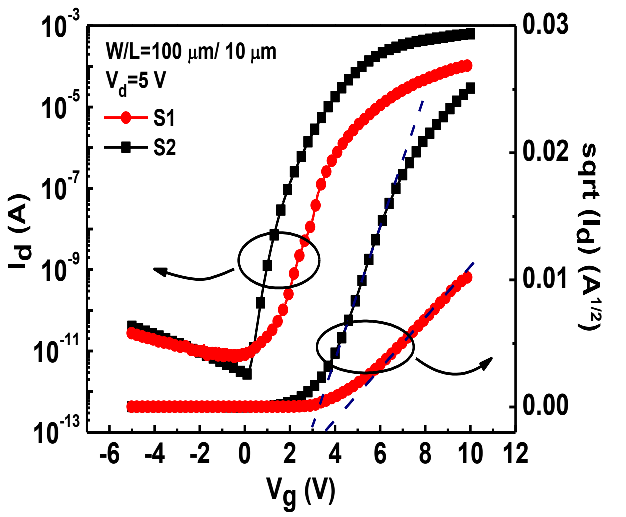

Fig. 2 The transfer characteristics of the ZnO TFT and Ca-ZnO TFT.

Table I Extracted parameters of the ZnO TFT and Ca-ZnO TFT

No.	Channel material	μ_{sat} ($cm^2V^{-1}s^{-1}$)	V_t (V)	SS (V/dec)	I_{on}/I_{off}
S1	ZnO	16.05	3.69	0.331	1.34×10^7
S2	Ca-ZnO	147.1	2.91	0.271	2.34×10^8

the oxygen-binding ability of Ca is higher than that of Zn due to the lower electronegativity of Ca element. Therefore, the number of weakly bonded oxygen atoms and oxygen–related defects density decreases. This defect reduction effect probably causes the improvement of mobility in calcium-doped zinc oxide thin film transistors. In order to investigate the properties of the channel materials, surface morphology of the channel materials were evaluated by atomic force microscopy (AFM) and the scanning electron microscopy (SEM). As shown in Fig. 3, the S2 is smoother and more compact than S1. The root mean square roughness of S1 and S2 are 1.0 nm and 0.7 nm respectively. The particle size of S2 is smaller than that of S1. In general, smooth surface is helpful to suppress interface traps and scattering centres. It is known that interface states play a key role in determining the subthreshold swing and mobility [8]. Therefore, the S2 exhibits better SS and μ_{sat} due to the smoother surface.

Fig. 4 shows the X-ray diffraction pattern (XRD) of the ZnO and Ca-ZnO thin film deposited at room temperature. The S1 is the C-axis aligned crystalline oxide semiconductor with a peek at approximately 34 °. The full width half maximum (FWHM) is measured as 0.363 ° and the average grain size is 21.6 nm calculated by the Scherer formula. However, none peak is observed in S2 when calcium element is incorporated into zinc oxide thin film. It implies that calcium element can prevent columnar growth in the metal-oxide film deposition. Amorphous structure makes it available for the large-area display applications due to the high uniformity.

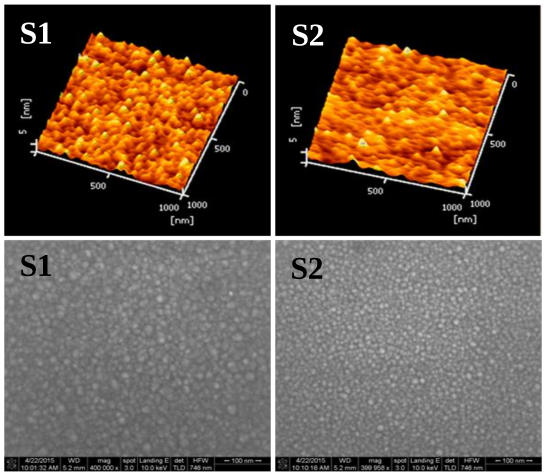

Fig. 3 The AFM and SEM images of the ZnO thin film and Ca-ZnO thin film.

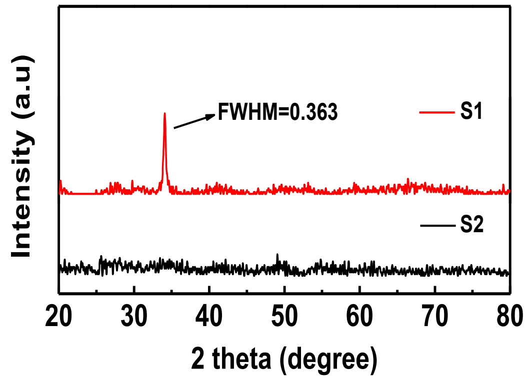

Fig. 4 The XRD pattern of the ZnO thin film and Ca-ZnO thin film deposited on glass substrate.

4. Conclusions

The effects of calcium doping on characteristics of zinc oxide TFTs have been investigated in detail. The incorporation of calcium element can suppress growing the columnar structure and improve the performance of device. The TFTs with Ca-ZnO active layer exhibit excellent electrical properties with the μ_{sat} of 147.1 $cm^2V^{-1}s^{-1}$, V_t of 2.91 V, SS of 0.271 V/dec, I_{on}/I_{off} ratio of 2.34×10^8.

Acknowledgements

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