OPTOELECTRONICS AND ADVANCED MATERIALS – RAPID COMMUNICATIONS Vol. 8, No. 7-8, July – August 2014, p. 659 - 662

The influence of SiO_2 and Al_2O_3 gate insulator to the performance of In-Ga-Zn-O thin film transistors

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The authors report on the fabrication of IGZO thin film transistor with SiO_2 or Al_2O_3 gate insulator. Effects of SiO_2 and Al_2O_3 gate insulator for TFT have been investigated. The TFT with SiO_2 gate insulator shows a field effect mobility of 3.6 cm^2/Vs, a threshold voltage of 4.7 V, an I_{on}/I_{off} ratio of 1.6×10^7, and a subthreshold swing of 0.46 V/decade; The TFT with Al_2O_3 gate insulator shows a field effect mobility of 5.2 cm^2/Vs, a threshold voltage of 3 V, an I_{on}/I_{off} ratio of 3.4×10^7, and a subthreshold swing of 0.37 V/decade respectively. TFTs with low-k insulator have low on-current due to the low-capacitances of the materials. The experiment results show that the type of gate insulators plays an important role in both the field effect mobility and bias stability of the devices. Using high-k insulator is an effective way to decrease the drive voltage for TFT devices.

(Received March 26, 2013; accepted July 10, 2014)

Keywords: IGZO, Thin film transistor, SiO_2; Al_2O_3, Gate insulator

1. Introduction

Thin-film transistors (TFTs) have received considerable attentions and increasing interests because of their potential application in displays [1, 2]. For the past 10 years thin film transistors (TFTs) made with amorphous and poly silicon have been extensively applied in flat panel display industry [3]. But these TFTs (especially the amorphous silicon ones) actually have some problems: such as light sensitivity and light degradation, low effect mobility and small drain current (typically about 10 µA), which limit their application to other types of flat panel displays such as the organic light emitting diode display (OLED) [4]. Oxide semiconductor thin film transistors (TFT) have recently attracted attention in various electronic device applications [5-7]. Because of their low temperature and low cost process, transparent (wideband gap), and good electric properties (high mobility). Indium gallium zinc oxide (IGZO) have been attracted by many researchers due to their high mobility even thought it has amorphous-phase.

As an important part of a TFT, the gate insulator plays an important role in the TFT performance. TFTs using low-k oxide as the gate insulator have low on-current which is originated from the low capacitance of the low-k oxide [8]. As a conventional low-k dielectric for TFTs, SiO_2 possessing excellent electric stability and leakage current characteristics. However, obtaining low driving voltage TFT based on SiO_2 insulator is still a challenge due to rather low dielectric constant of SiO_2 [9]. Using high-k insulator is an effective way to decrease the drive voltage for TFT devices. It is well known that the output current of a TFT is proportional to the product of the induced carriers (*N*c) in the channel and the mobility (μ). The induced carriers (*N*c) is determined by the relation of $Nc=(\varepsilon\varepsilon_0/ed)/V_{GS}$, where $\varepsilon\varepsilon_0$, d and V_{GS} are the dielectric constant, gate insulator thickness and applied gate voltage, respectively. As a result, by using high-k insulator, the large carriers' density can be produced in even at low applied gate voltage, resulting in low drive voltage TFTs [10-16]. Therefore, we have investigated the use of Al_2O_3 which is one of the most promising high-k materials with high capacitance to improve the TFT performances. Here we report the fabrication of IGZO TFTs with SiO_2 or Al_2O_3 as the gate insulators to compare their performance.

2. Experiments

The TFTs with low-k SiO_2 (named SiO_2-TFT) and high-k Al_2O_3 (named Al_2O_3-TFT) gate insulators are fabricated on the n-Si respectively. The TFTs structure used in this study is shown in Fig. 1.

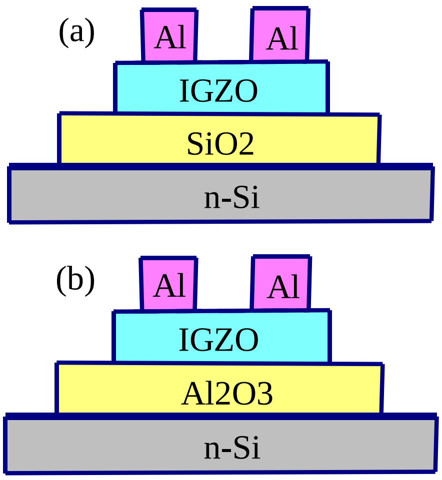

Fig. 1. Schematic structure of the TFTs. (a) SiO_2-TFT; (b) Al_2O_3-TFT.

The Al_2O_3 gate insulator (230 nm) is deposited at 300 ^oC using alternating exposures of $Al(CH_3)_3$ and H_2O vapor at a deposition rate of 0.66 Å per cycle by atomic layer deposition. The SiO_2 gate insulator (260 nm) is deposited by thermally oxide grown. 30 nm thick IGZO film are deposited by rf-magnetron sputtering at room temperature using a IGZO target (99.99%, In_2O_3, Ga_2O_3, ZnO = 1:1:1 mol%) at input power of 50 W, gas mixing ratio of Ar:O_2 (30/1), and total pressure of 0.8 Pa. After deposition of IGZO layer, about 200 nm Al was deposited by thermal evaporation to form the source and drain electrodes through a shadow-mask with the channel width (W) of 1000 μm and channel length (L) of 50 μm. Thermal annealing was carried out at 300 ^oC for 40min in atmosphere. The thickness of the film was measured by the alpha step (Dektak 3st). The electrical characteristics of IGZO TFTs with SiO_2 or Al_2O_3 dielectrics were measured using Agilent E3647A Dual output DC power supply and Keithley 6485 Picoammeter and related software. The capacitance characteristics were measured using Agilent E4980A LRC meter.

3. Results and discussion

Fig. 2 shows the leakage current characteristics as obtained from 1 mm diameter n-Si/SiO_2/Al and n-Si/Al_2O_3/Al dots. Al is used as the top-electrode and n-Si as the bottom-electrode. As is well known, thinner gate insulator may produce serious gate leakage current and low breakdown voltage, which make the I_{on}/I_{off} ratio poor and the device instable, while much thick gate dielectric will lead to low capacitance and more fixed oxide charges, resulting in lower mobility and higher threshold voltage. From Fig. 2 we can see that the leakage current is small both the two devices, the leakage current density of is 1.8×10^{-6} mA/cm^2 and 2.1×10^{-5} mA/cm^2 at 2 MV/cm for n-Si/SiO_2/Al and n-Si/Al_2O_3/Al which indicates that both gate insulator shows good leakage property.

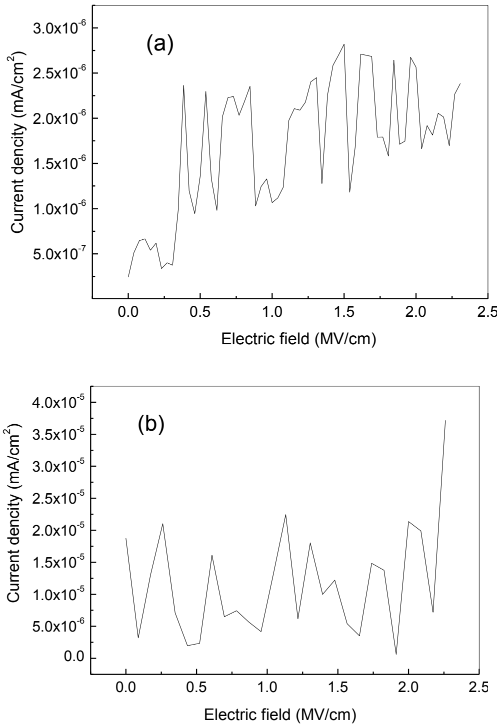

Fig. 2. The leakage current characteristics. (a) n-Si/SiO_2/Al; (b) n-Si/Al_2O_3/Al.

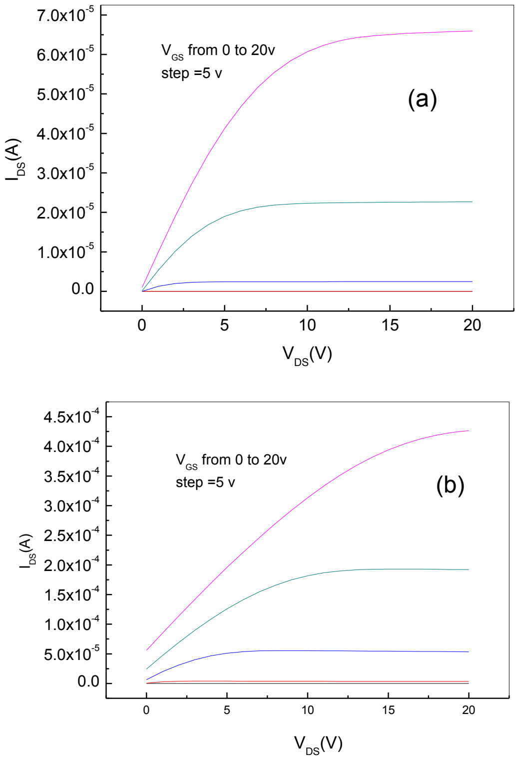

Fig. 3. The output characteristics. (a) SiO_2-TFT; (b) Al_2O_3-TFT.

Fig. 3(a) and (b) shows the output characteristics for the TFT with SiO_2 or Al_2O_3 gate insulator, respectively. All the devices have the n-channel, since the electrons are generated by the positive V_{GS}. The TFT with Al_2O_3 shows much lager output (I_{DS}) current compared with the SiO_2-based device. Its saturation current reached 0.43 mA at applied gate voltage (V_{GS}) = 20 V and source to drain voltage (V_{DS}) =10 V, which is 6.5 times larger than 0.066 mA of SiO_2-based device. From Fig. 3 (b), we can see that there are some leakage of the Al_2O_3 based TFT at applied gate voltage (V_{GS}) = 0 V due to the bombardment to Al_2O_3 film from the process of sputtering IGZO film with high power, So adopting a small input power at the beginning of sputtering IGZO will be an effect way to solve this problem.

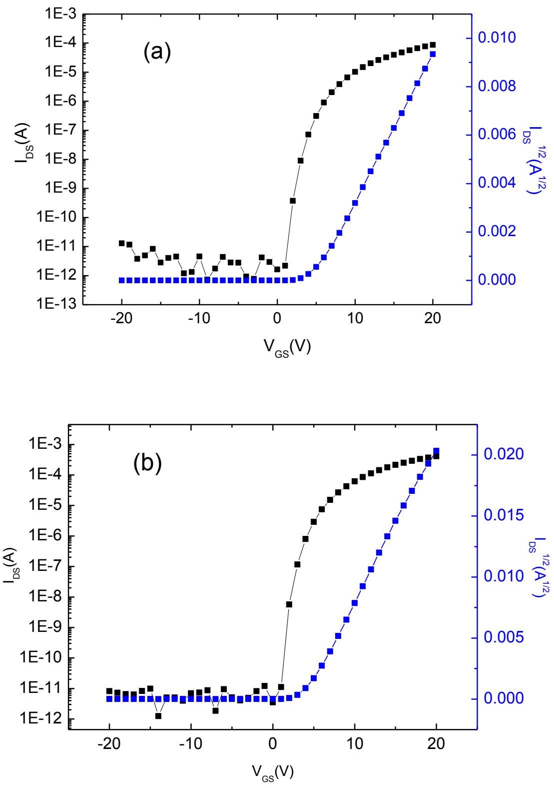

Fig. 4. Corresponding transfer characteristic I_{DS} versus V_{GS} at a fixed V_{DS} 10 V and the $I_{DS}^{1/2}$-V_{GS} curves. (a) SiO_2-TFT; (b) Al_2O_3-TFT.

Fig. 4 shows the corresponding transfer characteristic I_{DS} versus V_{GS} at a fixed V_{DS} 10 V and the $I_{DS}^{1/2}$-V_{GS} curves of TFT with SiO_2 or Al_2O_3 gate insulator. The I_{on}/I_{off} ratio for of SiO_2-TFT and Al_2O_3-TFT are measured to be about 1.6×10^7 and 3.4×10^7, respectively. From the $I_{DS}^{1/2}$-V_{GS} curves shown in Fig. 4, the channel mobility (μ_{sat}) and threshold voltage (V_{th}) can be extracted according to the expression:

$$I_{DS}=\frac{C_i\mu W}{2L}(V_{GS}-V_{TH})^2 \qquad V_{DS}>V_{GS}-V_{TH} \qquad (1)$$

Where C_i is the capacitance per unit area of the insulator layer (C_i ,ε for SiO_2-TFT and Al_2O_3 -TFT are 10 nF/cm^2;3 and 28.7 nF/cm^2;7.5 respectively). W and L are the channel width and length, V_{DS} and V_{GS} are the drain-source voltage and gate-source voltage, respectively. The field effect mobility and threshold voltage of SiO_2-TFT and Al_2O_3-TFT are estimated to be about 3.6 cm^2/Vs, 4.7 V and 5.2 cm^2/Vs, 3 V, respectively. As the result, we confirmed that high-k Al_2O_3 is useful to operate devices at low gate voltage and this result is useful to the current driving devices.

The sub-threshold voltage swing (SS) can be determined through the relation:

$$SS=\frac{dV_{GS}}{d(LogI_{DS})} \qquad (2)$$

Here we get a value of 0.46 V/dec and 0.37 V/dec for SiO_2-TFT and Al_2O_3-TFT due to the increase of C_i results in the reduction of the subthreshold swing [8].

From SS we can infer the maximum density of surface states at the channel-insulator interface as:

$$N_{\max}^{SS}=[\frac{SLog(e)}{(kT/q)}-1]\frac{C_i}{q} \qquad (3)$$

and taking into account the value of C_i, N^{SS}max of 4.2×10^{11} cm^{-2} and 9.3×10^{11} cm^{-2} are calculated for SiO_2-TFT and Al_2O_3-TFT, respectively. According to the N^{SS}, we draw a conclusion that the Al_2O_3-TFT has lager charge trapping at the channel-insulator interface which leads to more defects than SiO_2-TFT.

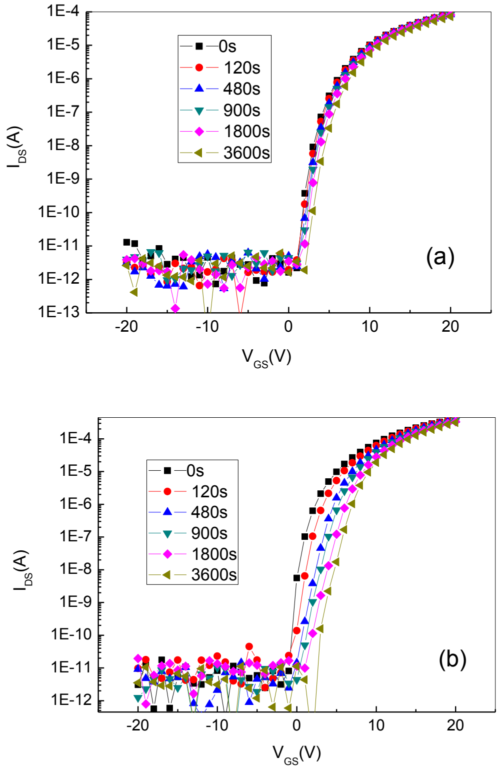

Fig. 5. The transfer curves of TFTs, the gate bias of 10 V was applied for an hour at room temperature in atmosphere (a) SiO_2-TFT; (b) Al_2O_3-TFT.

Fig. 5 shows the transfer curves of TFTs with SiO_2 or Al_2O_3 gate insulator, respectively. The gate bias of 10 V was applied for an hour at room temperature in atmosphere. All the transfer curves show a positive shift by the positive gate voltage stress. The threshold voltage shift is 1 V and 4 V for SiO_2-TFT and Al_2O_3-TFT which indicates that IGZO TFT with Al_2O_3 gate insulator is more sensitive to bias stress than IGZO TFT with SiO_2 gate insulator. The reason is that the Al_2O_3-TFT has more defects than SiO_2-TFT at the channel-insulator interface.

4. Conclusion

In summary, top-contact TFT with SiO_2 or Al_2O_3 gate insulator were fabricated. And the effects of gate insulator on the performances of IGZO-TFT were investigated. In the SiO_2-TFT, mobility, threshold voltage, subthreshold swing, I_{on}/I_{off} ratio, are measured as 3.6 cm^2/Vs, 4.7 V, 0.46 V/decade, 1.6×10^7, respectively. For Al_2O_3-TFT, mobility, threshold voltage, subthreshold swing, I_{on}/I_{off}, are measured as 5.2 cm^2/Vs, 3 V, 0.37 V/decade, 3.4×10^7, respectively. After the gate bias of 10 V applied for an hour at room temperature, threshold voltage shift is 1 V and 4 V which turned out that SiO_2-TFT are very useful to improve the stability of the devices. But, high gate-voltage is necessary to drive the device. Al_2O_3-TFT is very useful to reduce the driving voltage of the device. Whereas, they are not stability enough, it is expected that if problems are solved, realization of the device, which is reliable and low power consumption, would be possible.

Acknowledgement

The authors would like to acknowledge the financial supports of the National Natural Science Foundation of China (61077013, 61274082, 51072111, 51302165), the Project of National Post-Doctor Fund (2012T50387).

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