Ultraviolet and visible light detection characteristics of amorphous indium gallium zinc oxide thin film transistor for photodetector applications

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Abstract

The ultraviolet and visible light responsive properties of the amorphous indium gallium zinc oxide thin film transistor have been investigated. Amorphous indium gallium zinc oxide (a-IGZO) thin film transistor operate in the enhancement mode with saturation mobility of 6.99 cm^2/Vs, threshold voltage of 7.6 V, subthreshold slope of 1.58 V/dec and an on/off current ratio of 2.45×10^8. The transistor was subsequently characterized in respect of visible light and UV illuminations in order to investigate its potential for possible use as a detector. The performance of the transistor is indicates a high-photosensitivity in the off-state with a ratio of photocurrent to dark current of 5.74×10^2. The obtained results reveal that the amorphous indium gallium zinc oxide thin film transistor can be used to fabricate UV photodetector operating in the 366 nm.

1. Introduction

Transparent oxide semiconductors, such as zinc oxide (ZnO), indium tin oxide (ITO), zinc tin oxide (ZTO), gallium doped zinc oxide (GZO) indium zinc oxide (IZO), and indium gallium zinc oxide (IGZO) have attracted many researchers with their great potential in optoelectronic applications such as flat panel displays, transparent electrodes in solar cells, transparent thin film transistors (TFTs), and flexible transparent TFTs [1-6]. They have amorphous phase or poly-crystalline phase, oxide semiconductors have higher mobility than a-Si. Especially a-IGZO, has attracted wide attention with its notable advantages over other semiconductors including room-temperature process availability, good-uniformity, high transparency in visible region (400 - 700 nm), and high mobility. High mobility of a-IGZO is originated from the larger *ns*-orbital of the metal cation than *2p*-orbital of oxygen anion [1]. Moreover a-IGZO thin film transistors also can be used to detect the ultraviolet (UV) which is higher wavelength than 400 nm. In previous arts, Keun Woo Lee *et al.* reported the photosensitivity of solution processed single walled carbon nanotube blended a-IGZO thin film [7]. This property of a-IGZO thin film is very useful to apply the UV-detector. In present study, we fabricated a-IGZO thin film transistor to investigate the photo-sensing characteristics of the transistor under the illuminations of visible light and UV.

2. Experimental details

Thermally oxidized p-Si (100, ρ=0.005 Ωcm) are used as substrates. These substrates are cleaned by acetone, methanol, and de-ionized water in ultra-sonic bath, respectively. As the gate-electrode, silver (Ag) is deposited onto the backside of p-Si substrates by using thermal evaporator. Thermally oxidized SiO_2 of 300 nm are used as the gate-insulator. And then, we deposited a-IGZO thin film by using radio-frequency (RF) magnetron sputtering. In this process, initial vacuum is evacuated to be about 2.0×10^{-6} Torr by turbo-molecular pump. And then, ambient gases of O_2 and Ar are injected to the chamber. Working pressure and RF-power density are maintained to be about 1.0×10^{-2} Torr and 1.86 W/cm^2 while the a-IGZO of 80 nm is deposited. Also, sputtering process is carried out at room-temperature. Active layer is patterned by photolithography and lift-off process. As the source-drain (S/D) electrodes, molybdenum (Mo) of 100 nm is deposited by using direct-current (DC) sputtering at room-temperature. S/D electrodes are also patterned by photolithography and lift-off process. Our devices have channel width (W) of 150 μm and channel length (L) of 20 μm. Finally, to enhance the device performance, devices are annealed at 200℃ in tube-furnace. Ambient gas and annealing time are nitrogen (N_2) and 2 hours.

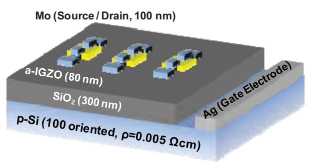

Figure 1. Schematic diagram of a-IGZO TFT

Figure 1 shows schematic diagram of a-IGZO TFT. Electrical characteristics are measured by semiconductor parameter analyzer (Keithley 4200). In electrical analysis, threshold voltage (V_{th}) is defined by the gate-voltage when induced drain-current of W/L ×10 nA is induced [9]. Also, the field effect mobility is estimated by linear fitting the square root of drain-current versus gate-voltage curve at a drain voltage of 10.1 V. The photoresponse properties of the transistor were performed under UV and visible light illuminations by semiconductor parameter analyzer (Keithley 4200) using a white lamp (200 W) and UV lamp with 366 nm.

3. Figures and Tables

Figure 2 shows the drain current-drain voltage characteristics of a-IGZO transistor under various gate voltages. The drain current increases at positive voltages. This indicates that the electrons are generated by the positive gate voltages due to n-type FET characteristics with good gate controllability. The drain current reaches the saturation regime, when the entire channel region is depleted of electrons, i.e, channel is pinched off. The mobility and threshold voltage parameters of the transistor can be determined by the following relation [10-11],

$$I_{ds} = \frac{W}{2L}\mu_{FE}C_i(V_g - V_{th})^2 \tag{1}$$

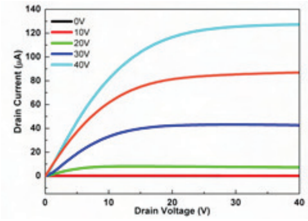

Figure 2. Output characteristics of a-IGZO thin film transistor

where μ_{FE} is the saturation mobility, C_i is the capacitance per unit area of the insulator, I_{ds} is the drain-source current, W is the width of channel, L is the channel length, V_g is the gate voltage, and V_{th} is the threshold voltage. The field effect mobility and threshold voltage values were determined from the plot of drain source current vs. gate voltage under V_{ds}=10.1 V, as shown in Fig. 3.

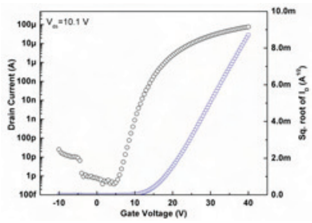

Figure 3. Transfer characteristics of a-IGZO thin film transistor

The field effect mobility, threshold voltage, on/off ratio of a-IGZO transistor from $I_{ds}^{1/2}$-V_g plot are given in Table 1. The obtained μ_{FE} for the a-IGZO transistor is higher than that of a-IGZO transistor fabricated by Tze *et al.* [12]. We have evaluated that the difference between the mobilities is due to higher quality of the film and better interface between the channel layer and insulator. The transistor exhibited an on/off ratio of 2.45×10^8 and this value is considerable high. The sub-threshold swing value which is a measure of the turn-on speed of the transistor can be determined by the following relation,

$$S = \left[\frac{d(\log I_{ds})}{dV_g}\right]^{-1} \tag{2}$$

The S value for the transistor was determined from Fig. 3 and was given in Table 1.

Table 1. Electrical parameters of a-IGZO thin film transistor

Parameters	Value
Threshold Voltage (V)	7.6
Subthreshold Swing (V/decade)	1.58
On-to-off Ratio	2.45×10^8
Field Effect Mobility (cm^2/Vs)	6.99

The S value indicates the presence of trap behavior and interface quality between the dielectric and a-IGZO active layer. The interface trap density for the transistor can be calculated by the following relation [13-14]:

$$D_{it} = \left[\frac{S\log(e)}{kT/q} - 1\right]\frac{C_i}{q} \tag{3}$$

where C_i (11.5 nF/cm^2 for SiO_2) is the capacitance of dielectric layer, *k* is the Boltzmann constant, q is the electronic charge and T is the temperature. The D_{it} value for the transistor was found to be 1.83×10^{12} $cm^{-2}eV^{-1}$. We have evaluated that this D_{it} value is considerable higher. This high D_{it} value makes a contribution to the capacitance of the dielectric layer and in turn, the mobility of the transistor increases. Ultraviolet and visible light detection characteristics of a-IGZO thin film transistor were investigated under white light and UV illuminations. Figure 4 shows the I_{ds}-V_{ds} curves obtained white light and UV illumination (366 nm) with V_g=30V. The drain current under these illuminations increases due to photogeneration of electron–hole pairs in the active layer of the transistor. The effect of UV illumination is higher than that of white light illumination. The UV illumination increases strongly the drain current, because the photon energy of UV illumination at 366 nm is higher than the a-IGZO optical band gap.

The photoresponse of the transistor under visible light can be analyzed by the following relation [15],

$$R_{L/D} = \frac{I_{photo}}{I_{dark}} = AP^{\gamma} \tag{4}$$

where I_{photo} is the drain source current under illumination, I_{dark} is the drain source current under dark, *A* is a constant and *P* is the illumination intensity and *A* is a constant. The plot of $R_{L/D}$ vs illumination intensity for a-IGZO thin film transistor was plotted via Fig.4 and in the ON-state, it was seen that the drain current increases linearly with illumination intensity. The γ value for the transistor was found to be 0.12. This value for the a-IGZO transistor indicates the participation of a recombination path.

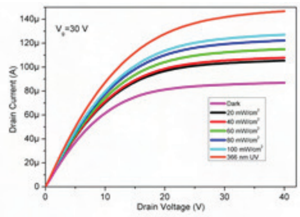

Figure 4. Output characteristics of a-IGZO thin film transistor under white light and UV illuminations

For analysis of UV detection of the transistor, the output characteristics of a-IGZO thin film transistor under UV illumination of 366 nm were measured and are given in Fig. 5. As seen in Fig.5, the UV illumination increases the drain current for various gate voltages. In order to analyze the photovoltaic effect and photoconductivity of the transistor, we measured drain current under dark and UV illumination for various gate voltages, because when the transistor is illuminated, photovoltaic and photoconductivity effects may occur in the active layer of the transistor. When the transistor is in the ON-state the photocurrent is dominated by the photovoltaic effect. Whereas, in the OFF state, photoconductivity effect is significant for the transistor. As seen in Fig.5, the a-IGZO transistor follows both the photovoltaic effect in the turn-on state and the photoconductive effect in the turn-off state.

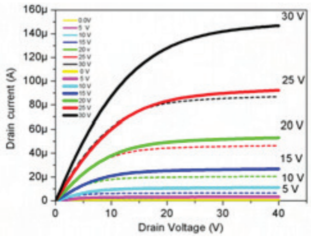

Figure 5. Output characteristics of a-IGZO thin film transistor under UV illumination of 366 nm

In order to analyze photovoltaic or photoconductivity effects on photoresponse properties of the transistor, we plotted the photoresponse as a function of gate voltage. As seen in Fig.6, the $R_{L/D}$ value for the transistor was obtained at the switch-off voltage. But, the lowest $R_{L/D}$ occurs at 30 V gate bias. We have evaluated that the photogeneration is maximum at zero gate bias, at off-state of the transistor; the carrier injection and thermal generation have the smallest contribution to photogeneration and in turn photogenerated current is have highest contribution. Whereas, the photogeneration is minimum at 30 V gate bias, because at this bias, the dark current also increases. The obtained results show that the photoresponse properties of a-IGZO transistor are modulated by gate bias.

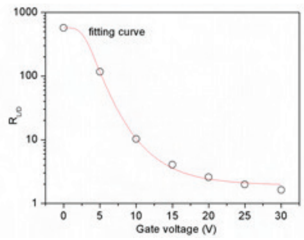

Fig. 6 Plot of photoresponse versus gate voltage for UV illumination of 366 nm

The photoresponse of a-IGZO transistor was analyzed and the following function was obtained as

$$R_{L/D} = A_2 + (A_1 - A_2).(1+(V_g / V_{go})^{-p} \quad (5)$$

where A1, A2, V_{go} and p are constants. For the transistor, the constants in Eq.5 were found to be A_1=574.14847, A_2=1.88469, V_{go}=3.54488 and p=4.03234. We have evaluated that the transistor shows a high photoresponse at off-state of 5.74×10^2. This suggests that the IGZO transistor can find use in two-terminal photodetector applications.

4. Conclusions

The photoresponse properties of the IGZO transistor was investigated under visible light and UV illuminations. The electrical parameters like mobility, threshold voltage, photoresponse, voltage swing, and ON/OFF current ratio were extracted from experimental data. The studied thin film transistor is expected to find application as UV photodetector in the UV region at 366 nm.

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5. References

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