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# Fabrication low-voltage amorphous indium zinc oxide(a-IZO) thin film transistors using high dielectric $HfO_2$ as gate insulator at room tempature

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## 1. Introduction

Recently, transparent electronic circuits offer the opportunity to create new transparent electronics applications[1]. Transparent oxide semiconductors (TOSs, heavy metal cations with $(n-1)d^{10}ns^0$ electronic configuration) with high optical transparency is due to a wide band gap (~3eV). Hoffman et al. have reported the ZnO-based transparent thin film transistors (TTFTs) in 2003[2] .In next year, transparent thin film transistors fabricated on the flexible PET substrates using amorphous $(InGaZn)O_4$ deposited at room temperature were reported by Nomura et al. [3]. Among transparent oxide semiconductors, IZO-based thin film transistors have attracted a great deal of attention on its high carrier mobility, amorphous phase and smooth surface[4]. To our knowledge, the high-k dielectrics in TFTs have the lower operation voltage range, attributing to the high capacitive coupling between the gate and channel layer [5]. The carriers concentration of the IZO film can be tuned primarily by the oxygen content in the sputtering gas[4,6]. In this work, we presented IZO-bases TFTs using high dielectric $HfO_2$ as gate insulator and deposited the active layer in the different oxygen content of sputtering gas. The operation voltage was below 4V, field effect mobility could exceed 10 $cm^2$/V-s, and on/off ratios approximated to $10^6$.

## 2. Device structure

We demonstrated a TFT with a staggered bottom gate configuration, in which the channel layer are based on an amorphous oxide semiconductor from the $In_2O_3$-ZnO ($In_2O_3$:ZnO, 90:10 wt%, indium zinc oxide - IZO), where the electronic performances can be presented by controlling only the amount of oxygen. The percentage of $O_2$ were calculated by the gas flow of $O_2/(O_2+Ar)$.

Fig. 1 shows the active layer (15 nm) based on IZO, deposited at room temperature by DC magnetron sputtering, using a IZO target. The sputtering power was 50 W, the $O2/(Ar+O_2)$ flow percent range from 5% to 10%, a target-substrate distance of 17 cm and the total deposition pressure was 5 mtorr. The gate electrode (220 nm) based on ITO, deposited at room temperature by DC magnetron sputtering, and the patterning of the gate electrode regions were performed by standard photolithography and etch techniques. The patterning of the insulator regions were performed by shadow mask with a 80 nm sputtered $HfO_2$ film. The patterning of the source/drain regions were performed by lift-off with a 100 nm evaporated aluminum, and the width-to-length ratio (W/L) was 200, with 0.02 mm length. Using α-step (Kosaka ET3000) for measuring the film deposition thickness. Fig. 1 depicts the a-IZO TFT structure with the indication of the layer thicknesses.

X-ray diffraction measurements were performed in air at RT, using the Siemens diffractometer D5000. When the sputtering gas was below 10% oxygen content, the IZO films that deposited at room temperature keep amorphous phase (Fig. 2(a)). The optical transmittance measurements were performed with a Hitachi UV–Vis U3300 spectrophotometer in the wavelength from 300 nm to 800 nm. The optical transmittance of $IZO/HfO_2/ITO$/glass exceed 80% in the Fig. 2(b). The TFTs were electrically characterized by semiconductor parameter analyzer (HP 4145 A) in air at RT.

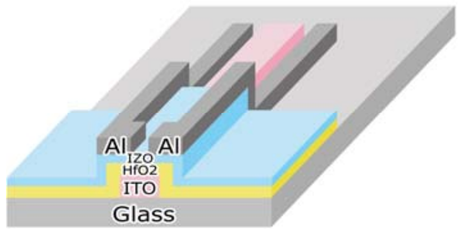


Fig. 1 Schematic illustration of the IZO based TFT structure deposited on g,lass substrate, the thicknesses of each layer, Al(100nm)/IZO (20 nm)/$HfO_2$ (80 nm) / ITO (220 nm) / glass, respectively.

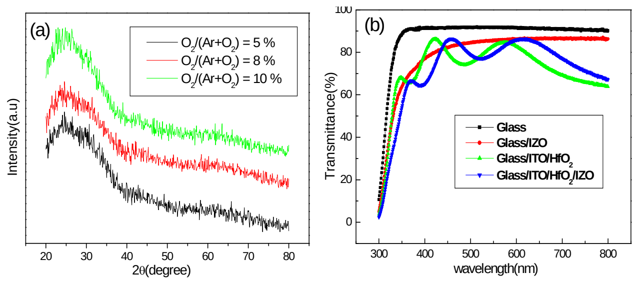


Fig. 2 (a) XRD spectrophotometer taken from IZO thin films deposited on glass substrates depending upon different oxygen content. (b)Optical transmittance of the indicated structures as a function of wavelength in IZO (20 nm)/$HfO_2$ (80 nm) / ITO (220 nm) / glass.

## 3. Device characteristics

When the active layer sputtered in the sputtering gas of 10% oxygen content, we can obtain a optimized characteristics of IZO-based TFT. Fig. 3 (a) shows typical output source-to-drain current ($I_D$)–voltage ($V_D$) characteristics of the IZO TFT. The drain current markedly increases as $V_D$ increases at a positive gate bias ($V_G \geqq 4$V), indicating that the channel is n-type and the TFT operates in the enhancement mode with the accumulation of electrons. The $I_D$ reaches values up to about 3 mA, at $V_G$=8V. The $I_D$–$V_D$ output characteristics exhibit a clear pinch-off voltage and a hard saturation current.

The transfer characteristics of the devices were investigated in the saturation region of the $I_D$–$V_D$ curves. A series of measurements were made in which the gate voltage was swept from 0 to 8 V at a fixed drain bias of 5 V, as seen in the output curve (Fig. 3 (b)). It shows that the device current in the off state is at the gate current ($10^{-8}$ A) and the on/off ratio is $4\times10^5$, field effect saturation mobility of 10.62 $cm^2$/V-s, on/off ratios was $4\times10^5$, sub-threshold slope of 0.42 V/decade, and threshold voltage was 3.54 V.

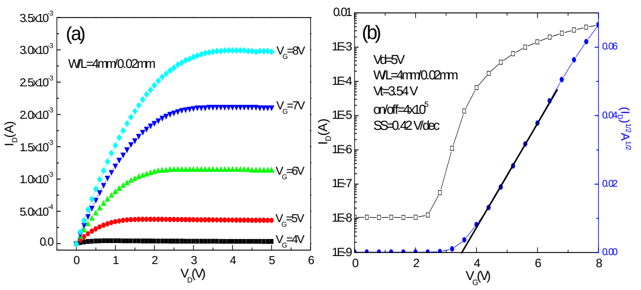


Fig. 3 (a)Output characteristics of an IZO-channel TTFT on glass using IZO (b) Transfer characteristics of the IZO-based TFT with source-to-drain current as a function of gate voltage($V_G$) at a fixed drain voltage of 5 V.

The ITO/$HfO_2$/Al MIM(Metal–insulator–metal) capacitors were fabricated for measureing the leakage current, capacitance density and dielectric constant. The insulator layers were sputtered with a hafnium target in different $O_2$/Ar ratio. It could find the lowest leakage current at 5% $O_2$ of sputtering gas. The leakage current was below $10^{-8}$ A/$cm^2$, the capacitance density was 166 nF/$cm^2$ and the dielectric constant was 14.7.

The carrier concentration of the IZO film can be tuned primarily by the oxygen content in the sputtering gas. The carrier concentration deceased with increasing the oxygen content. Fig. 4 shows the transfer characteristics of the IZO-based TFT at different oxygen content. When using 5% oxygen content, on/off ratio is about $10^2$, suggesting that the channel layer is similar to conductor as a result of its high carriers concentration. Raising to 8% oxygen content, on/off ratio is about $10^3$. The oxygen content get up to 10%, that on/off ratio can be over $10^5$. Nevertheless, the oxygen content exceed 10%, the IZO TFTs can't show typical output characteristics because the IZO films are similar to insulator. Table I shows the characteristics of IZO-based TFT with the active layer sputter in different oxygen content.

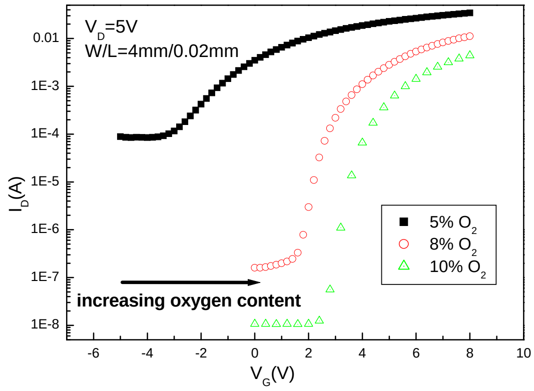


Fig. 4 Transfer characteristics in which the IZO channel layers were sputtered in different oxygen content.

Table I Characteristics of IZO-based TFT with the IZO channel layer of different oxygen content.

| Sputtering gas, $O_2/(Ar+O_2)$ | $I_{D.Sat}$ (mA) | $C_{ox}/A$ (nF/cm²) | W/L(mm) | $V_T$(V) | SS (V/dec) | $\mu$ (cm²/V-s) | on/off |
|---|---|---|---|---|---|---|---|
| 5% $O_2$ | 8.26 | 166 | 4/0.02 | -2.7 | 1.65 | 22.53 | $3.9\times10^2$ |
| 8% $O_2$ | 4.95 | 166 | 4/0.02 | 2.33 | 0.42 | 22.15 | $8.4\times10^4$ |
| 10% $O_2$ | 2.11 | 166 | 4/0.02 | 3.54 | 0.42 | 10.62 | $4\times10^5$ |

## 4. Conclusions

In summary, the data show the IZO films deposited in the sputtering gas of 10% oxygen content, produced at room temperature by DC magnetron sputtering are amorphous phase and optical transmittance in the visible region is greater than 84%, and the IZO-based TFT show typical field effect saturation mobility of 10.62 $cm^2$/V-s, on/off ratios was $4\times10^5$, sub-threshold slope of 0.42 V/decade, and threshold voltage was 3.54 V. The channel regions were designed by changing the reactive oxygen content in the sputter chamber during deposition. The electrical characteristics are clearly visible that increasing the oxygen content, leading to higher on/off ratios, higher $V_T$, lower SS and lower $\mu_{sat}$.

## References

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