Manufacturing and Electrical Performance of TFTs

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Abstract

This research is to discuss the sputtering of zinc tin oxide (ZTO) thin film under different oxygen flow conditions in the RF sputtering chamber to conduct a series of verifications and inferences and try to find the best sputtering conditions. Next, we deposited hafnium dioxide (HfO_2) as an insulating layer, and processed zinc tin oxide (ZTO) thin film transistors. By measuring the electrical properties for material analysis, we found that the thin film transistors made of ZTO thin films with an argon-oxygen ratio of 45:5 have a better saturation zone. At the same time, we observe that the transmittance of the film will increase with the increase of the oxygen flow rate, and the transmittance is above $80\sim85\%$ at the wavelength of visible light. By measuring the Hall effect, we can see that under the condition of an argon-oxygen ratio of 45:5, there is a better carrier concentration of 6.45×10^{11}. This is because the oxygen vacancies in the ZTO film will provide the film carrier. Therefore, when the oxygen concentration is high, the original oxygen vacancies will be filled, thereby alleviating the problem of excessive carrier concentration, and reaching a saturated and cut-off state.

Keywords: Zinc Tin Oxide (ZTO), Hafnium Dioxide (HfO_2), Insulating Layer, Channel Layer, Thin Film transistor (TFT), Oxygen vacancy and RF Magnetron Sputter

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DOI：10.53106/222344892023101302002

1. Introduction

In recent years, with the rapid development of the optoelectronic industry and media industry, people have found many materials related to research from traditional CRTs to Active Matrix Liquid Crystal Displays (AMLCD), Flat-Panel Displays (FPD), Light Emitting Devices (LED) and Organic Light Emitting Devices (OLED). However, consumers highly and continuously require the performance of the electronic product, so lowering the weight and thickness is the first priority. Also, low cost and energy consumption are important. As a result, display technology needs fine Transparent Conductive Oxide (TCO). Especially, with the rapid development of TFT-LCD displays, the usage of TCO is largely increased. Therefore, it plays an important role in the optoelectronic industry.

Since 2004, people have had a huge interest in the TFT made from Ionic Amorphous Oxide Semiconductors (IAOS). This kind of membrane is appropriate for special applications, because its characteristics can be controlled by changing chemical composition [1]. Although people have extensively researched Amorphous silicon (a-Si: H) and organic semiconductors, IAOS has a few advantages including higher mobility, wider bandgap, and better uniformity in manufacturing. Thence, IAOS will possibly become an alternate material for the next generation TFT or even flexible electronics [2-4].

According to the types of thin film transistors mentioned above, it can be found that the thin film transistors with metal oxide semiconductor as the channel layer have both high uniformity of amorphous silicon and high carrier mobility of poly-silicon, so this experiment uses amorphous Zinc Tin Oxide (α-ZTO) as the material of the thin film transistor channel layer.

Zinc Tin Oxide semiconductor is based on zinc oxide, has a wide energy gap (>3.6eV), and has high transparency in the visible light range. Therefore, compared with other semiconductor materials, although it is generally believed that high transparency and high carrier transmission ability cannot be combined, because the large gap causes electrons to transition from the valence band to the conduction band becomes very difficult.

In addition, the electrical properties of metal oxide thin film transistors are mainly related to the following three factors: (1) The interface defects of the insulating layer: it will grab electrons and holes so that the concentration of the carrier changes (2) The channel layer material itself of the defect density (3) Amorphous Indium Gallium Zinc Oxide Oxygen Defects: Since metal oxide semiconductors will form oxygen defects due to lack of oxygen or the influence of the external environment when depositing thin films, it will provide additional film The equation of the carrier is as follows:

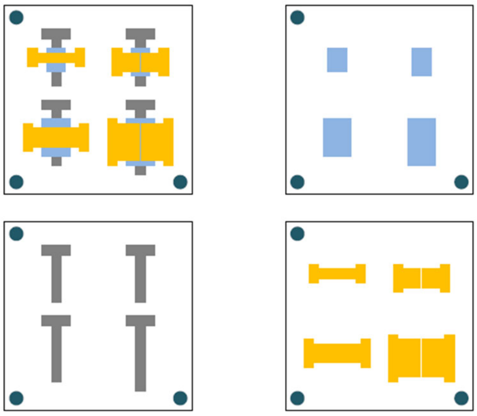
$$O_0^X \rightarrow \frac{1}{2}O_2 + V_O" + 2\mathrm{e}^-$$

Although amorphous ZnO membrane can be manufactured under 80°C [5], it is still not suitable for tender photoelectrical components so far. amorphous In_2O_3 doped in Zn or ITO can be applied on a transparent electrode [6.7]. Despite the good performance on optics and electricity of those thin films, In2O3 is still expensive and poisonous. Therefore, a new kind of amorphous Zinc Tin Oxide (ZnSnO3-ZTO) is a good candidate for tender photoelectrical components [8.9]. In this study, we made a ZTO membrane using an RF magnetron sputtering system and analyzed its properties. Find the best thin film characteristics in different gas flows and make TFTs.

2. Experimental steps

This experiment can be mainly divided into two parts. The first part is thin film deposition and analysis. We initially deposited a channel layer on the transparent glass by operating an RF Magnetron Sputtering system. The target we chose was Zinc Tin Oxide (ZTO). After analyzing the characteristics of the material, we embarked upon manufacturing a thin film transistor.

The second part is about the manufacture and electrical measurement of thin film transistors. The thin film transistor produced in this experiment has a lower gate structure. We used a metal mask to define the shape of each layer of the thin film transistor and deposited 70nm of aluminum as the lower gate at the first step by the thermal evaporation machine. Next step, we deposited 200nm of Hafnium Oxide (HfO_2) as the insulating layer. Afterward, we deposited the ZTO membrane in different proportions of oxygen flow on the insulating layer. Finally, by using thermal evaporation machine, we evaporated 70nm of aluminum as the drain and source of the thin film transistor. The complete metal



mask diagram is shown in Figure 1.

Fig. 1 (a) Complete transistor (b) Channel layer
(c) Gate layer (d) Drain and Source

3. Results and discussion

This chapter can be divided into two parts, the first part is checking whether ZTO thin film conforms to paper content by analyzing the characteristics of ZTO thin film under different conditions during sputtering. Afterward, find an appropriate environment for depositing the ZTO membrane. The second part discusses the effect on the electrical properties of ZTO TFT by manufacturing in different oxygen flows after depositing the insulation layer.

3.1 ZTO Thin Film Analysis

3.1.1 UV-VIS

The wavelength of visible light is from 380nm to 750nm and its energy gap is from 1.8eV to 3.1eV approximately. According to the papers, we can find that there are defects in the ZTO thin film called oxygen vacancy. We could find that the transmittance is improved when the proportion of oxygen is improved during sputtering ZTO in Figure 2. Figure 2 shows the transmittance of thin film deposited in different oxygen proportions under the same sputtering time. We found that the deposition rate was affected by the oxygen flow. However, the transmittance is not completely the same in different oxygen flows. We could still find that the transmittance is higher than 80 percent in the visible spectrum. As a result, ZTO thin film is a good choice for TCO material.

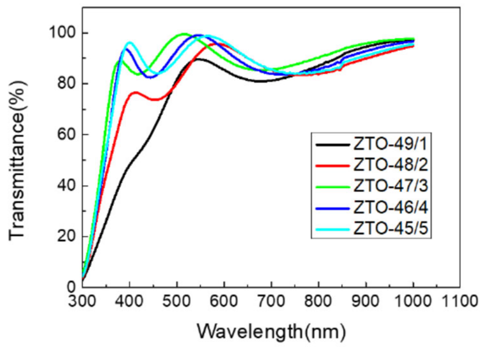


Fig. 2 Transmittance in different oxygen flow during the same sputtering time

3.1.2 XRD

Figure 3 is the result of XRD patterns, which shows Ar/O_2 ratios are 2%, 4%, 6%, 8%, and 10% (Ar/O_2 = 49/1, 48/2, 47/3, 46/4 and 45/5). There wasn't any obvious peak on XRD patterns, which indicated that the ZTO thin film is amorphous. The advantages of amorphous membranes are uniformity in large areas, low electron defect, smooth surface, and low interface state density. Those are indispensable for making components.

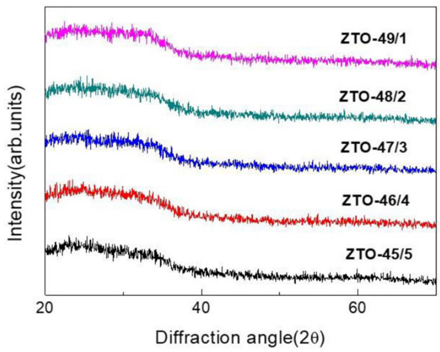


Fig. 3 XRD patterns of ZTO

3.1.3 α-step analysis

The result of the sputtering rate tested by α-step is shown in Figure 4. This experiment was bombarding the target by Argon ion and making the target dissociate. The target atoms would deposit on the substrate. According to the result, we found that the higher the proportion of oxygen flow, the lower the sputtering rate. When we improved the proportion of oxygen flow, the argon percentage would reduce with the gas amount we aerated was same. The argon ions would collide with oxygen atoms in the cavity during sputtering, so the probability of bombarding the target by argon ions would reduce. Therefore, the thickness of deposition is reduced, which indicates that the sputtering rate lowers down.

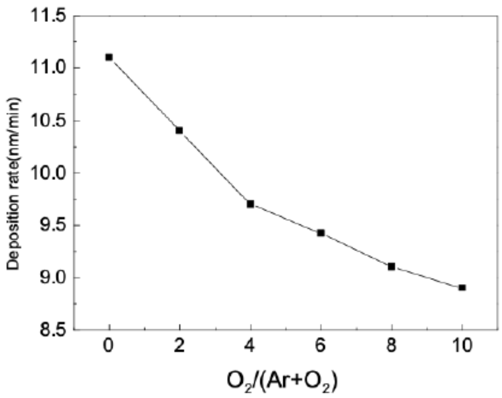


Fig. 4 Sputtering rate in different oxygen ratio

3.1.4 Hall Effect

Table 1 indicates the resistance of ZTO thin film in the different gas flows (Ar : O_2) according to the Hall Effect. When the oxygen flow improved from 2% to 10%, the resistance increased from 3.8 x102 (Ω/ cm) to 2.8 x10^3(Ω/ cm). We found that the transmittance would improve, and the conductivity would reduce when the oxygen flow was increased. In the ZTO membrane, the oxygen vacancies would give the membrane carriers. Therefore, the oxygen vacancies would be reduced during the flow of more oxygen. As a result, the carrier concentration will be decreased by filling the oxygen vacancies [10].

Ar : O_2	49:1(2%)	48:2(4%)	47:3(6%)	48:2(8%)	45:5(10%)
Bulk Resistivity	3.81×10^2	4.12×10^2	1.86×10^3	2.1×10^3	2.8×10^3
Carrier Concentration	3.62×10^{13}	7.74×10^{12}	6.3×10^{12}	8.89×10^{11}	6.45×10^{11}
Mobility	22.6	24.2	25.9	33.6	36.8

Table. 1 Electrical property of different gas flow ratio

3.1.5 Micro-PL Spectrometer

Figure 5 shows the PL result of ZTO under different ratios of oxygen flow. This testing data is obtained from samples illustrated and excited by a 325nm He-Cd laser beam at room temperature. According to previous reports, the emission band of zinc oxide can be divided into a few intervals, which are located at UV emission (3.06eV), Green emission (2.34eV), and Red emission (1.62eV). Nowadays, UV emissions and Green emissions are widely discussed [11.12].

UV emission usually belongs to intrinsic characteristics of material, the others are related to the energy level transition of electrons. As the figure showed, there was a peak at 405nm due to the intrinsic transition of ZnO between the energy gap at 373nm. However, the result is a Red Shift, which is due to metal atoms diffusion on the surface [13.14].

There is a peak at the center of the spectrum (green light 540nm), which is caused by the defects of the zinc oxide structure. According to the result, with the increase of oxygen, the peak value declined, which showed that the intensity of green light is proportional to oxygen vacancy. Also, when the oxygen vacancies decreased, the carrier intensity would decrease, which is consistent with the result of the Hall effect. There was a wide peak belonging to oxygen vacancies of ZnO 1.62eV at 700nm including the formation of the substitutional oxygen vacancies between metal and oxygen.

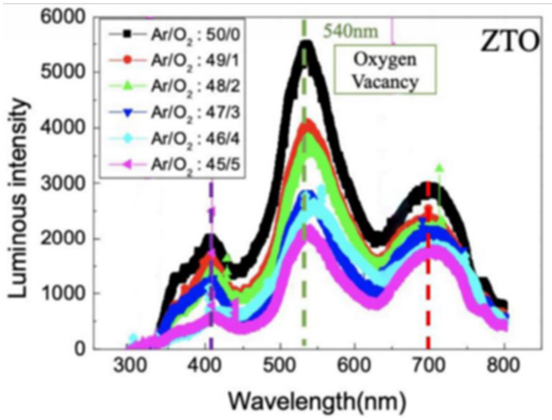


Fig. 5 PL spectrometer of ZTO thin film in different Ar/O_2 flow

3.2 ZTO thin film transistor

Different content percentage of oxygen affects not only oxygen vacancies but also carrier intensity in ZTO thin film, which changes the conductivity in a thin film. If the carrier intensity is too high, it will affect the characteristics of devices and cut off. The width of the active layer is 1mm and the length is 100μm. We discussed the characteristic differences of ZTO thin film transistors made in different gas environments. When the oxygen ratio is 2%, the output characteristic curve (I_{DS}-V_{DS}) shown in Figure 6(a) tells us the conductivity is ohmic linear. I_{DS} doesn't enable ZTO TFT to enter saturation region with fixed V_{GS}. Because the oxygen flow is less, it can't effectively restrain oxygen vacancies and make carrier intensity too high. Also, this component won't have switch characteristics with less oxygen flow. When the oxygen flow ratio was 10% shown in Figure 6(b), we could find that V_{GS} made a transistor as a switch.

With the increasing oxygen flow, V_{GS} can make drain current enter the saturation region for the reason of some inhibitory oxygen vacancies which made carrier intensity lower.

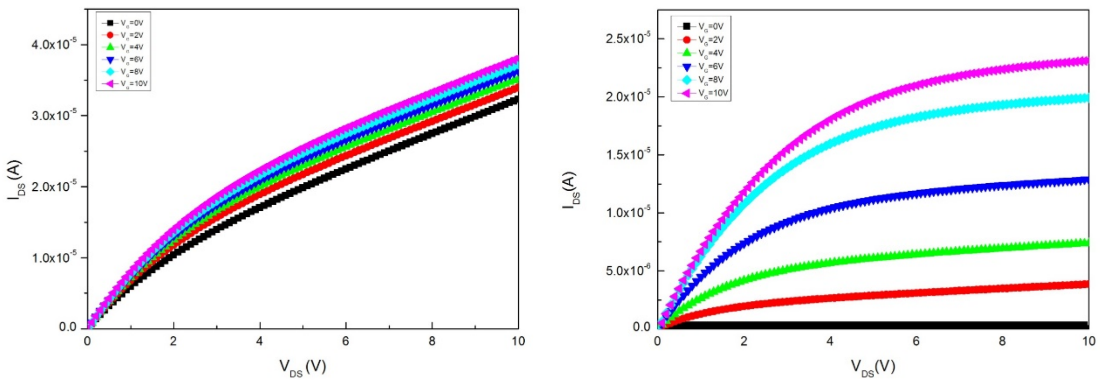


Fig. 6 ZTO TFT output characteristic with different oxygen flow(a) 49:1 (b) 45:5

4. Conclusions

We have analyzed the characteristics of the ZTO film under different argon-oxygen ratios. According to the XRD pattern, we found that the ZTO film has no obvious peak, which shows that the ZTO film has an amorphous structure. According to the PL spectrum, we found that the peak of the ZTO film occurs at a specific interval, the above are in line with the paper. When using the Alpha-Step measurement, we know that the increase in oxygen flow will cause the thickness of the ZTO film to become thinner and the sputtering rate will decrease. Therefore, when the UV-Vis is used to measure the transmittance, the value will increase with the increase in oxygen flow. Finally, by measuring the Hall effect, we found that when the ratio of argon to oxygen is 45:5, the increase in transmittance leads to a decrease in conductivity and an increase in resistance. However, due to the increase in oxygen flow, the oxygen contained in the film is vacant. It is filled to reduce the carrier concentration to 6.45×10^{11}. It can be seen that the film characteristics under this argon-oxygen ratio are the best. Due to the above characteristics, we choose the argon-oxygen ratio of 45:5 as the process parameter for the subsequent channel layer.

Next, we deposit HfO_2 as an insulating layer, fabricate thin film transistors under different argon gas flow rates, and discuss their electrical properties. According to the $I_{DS} - V_{DS}$ diagram, we can find that the increase in oxygen flow rate will lead to the reduction of oxygen vacancies, and the gate voltage (V_{GS}) can control the drain current (I_{DS}) into the saturation zone and use it as a switch. Based on the above, we know that in ZTO thin-film transistors, it is most suitable to use ZTO thin-film with an argon-oxygen ratio of 45:5 as the channel layer.

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