Characteristic of BCE Type IGZO Thin Film Transistor Device with Mo-alloy Serving as a Barrier Layer for Cu Electrodes

Yuhao Zhai[1],Xiaobo Hu, Yupei Wang,Jinming Li,Jun Zhang, Qifeng Jiang,Wei Huang,Conglong Zhang,Yifeng Yang

zhaiyuhao@tcl.com

[1]TCL China Star Optoelectronic Technology Co., Ltd. Guangdong, China

Keywords：Mo-alloy, barrier layer, material properties,electrical properties.

Abstract

This paper demonstrates the performance of different materials used as source and drain barriers in amorphous In–Ga–Zn-O (a-IGZO) thin-film transistors (TFTs)semiconductor. The barrier materials are Mo，MoTi and MoTiNi, respectively. The results show the a-IGZO TFT with MoTiNi/Cu as S/D electrode exhibits lower V_{TH} *and improved performance of avoiding Ti oxidation compared to MoTi/Cu devices. The TEM and linescan of EDS are also used to analyze material properties of samples, which is in close agreement with the obtained electrical properties. Furthermore, comparing the Mo content in the two different barriers samples, the MoTiNi as barrier layer exhibits greater ability to block Cu diffusion,henceit is a good choice for MoTiNi as barrier layer in TFT devices.*

1. Introduction

Recently, amorphous In-Ga-Zn-O (a-IGZO) thinfilm transistors (TFTs) have attracted much attention as active- matrix backplanes for next-generation displays. They have several advantages such as high field-effect mobility, large value of on-current, low-cost fabrication, and low-temperature processing. The a-IGZO TFTs with excellent properties has become one of the reseatch hotspotsfor large area, high resolution active matrix liquid crystal display products. However, there are still some technical issues that need to be solved, such as the signal distortions , which is caused by RC delay. Therefore, source(S) and drain(D) with low-resistance are necessaryto reduce RC delay. Copper (Cu) is considered to be an excellent alternative electrode material for TFTs due to its small resistivity and relatively low price. However, there are limitations in using Cu as a single layer because Cu easily diffuse into a-IGZO,which can result in deterioration of the electrical performance. So the double-layer structure with a barrier layer is an effect method to protecte electrode away from the influence of Cu diffusion. At present, Molybdenum(Mo), Molybdenum titanium (MoTi), MoTiNi ,titanium (Ti) andtitanium nitride (TiN) are offen used as the barrier layer of Cu electrode in TFT devices, . However,on the one hand,some of those materials will degrade the reliability of the a-IGZO TFTs device, which result from the chemical reaction between barrier metal and oxide semiconductor layer at interface .On the other hand,Ti and TiN are difficult to be etched, which affect the preparation of TFT devices and are not suitable for actual production

Based on the above description, in this letter, Mo、MoTi and MoTiNi are selected as three different barrier layers to explore the influence of different materials on the performance of a-IGZO TFT devices. The physical s properties of the fabricated samples were characterized by transmission electron microscopy (TEM) and the line scan of the energyEdispersive spectroscopy (EDS).And the transfer characteristic was measured by TEG to characterize the influence of different barrier layers on the electrical performance of a-IGZO TFT devices

2. Experiment

The schematic cross-sectional view of BCE a-IGZO TFT is shown in **Figure 1**. The fabrication procedure for the a-IGZO TFT is as follows. The Mo/Cu bilayer was deposited on the glass substrate.Then patterned by wet etching process as gate electrode. Following this, gate insulator (SiNx/SiOx bilayer) was deposited by plasma enhanced chemical vapor deposition (PECVD). The a-IGZO film was deposited by RF sputter and then annealed in a furnace with CDA atmosphere at 350℃for 1 hour, after patterning the a-IGZO film as an active channel by wet etching process, Mo, MoTiNi(Mo at>60%) and MoTi (Mo at<50%) with various thickness (5/10/20/30nm) are prepared by DC magnetron sputtering. Next, the500-nm-thick Cu is stacked on top of each barrier layers , using as source/drain electrode. The passivation layer (SiOx) was deposited by PECVD. After that, RIE process was used to establish the contact via, and ITO was deposited subsequently as pixel electrode. Finally, the whole device was annealed in CDA at 250 ℃ for 1h. The electrical characteristic test was performed on keithley 4200 semiconductor analyzer in air.

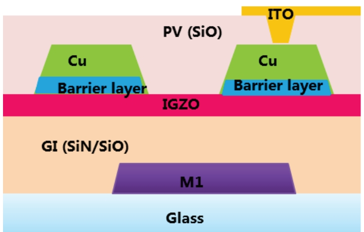

Fig.1. Schematic of TFT structure

3. Results

Figure 2 shows the transfer characteristics of the TFTs with different barrier layer materials, meanwhile, their threshold voltage (V_{TH}) is summarized in **Table I.** It can be seen that all the three devices show the same trend , the increase in the barrier layers thickness from 5nm to 30nm induced a negative shift of V_{TH}. The variation of the V_{TH} in the negative direction implies that Cu diffused into the a-IGZO acts as an acceptor, which result in the decrease of the carrier density in channel[1]. When the thickness of the barrier layer was too thin(<20nm) to prevent Cu diffusion, the Cu oxidization would be formed on the interface with a-IGZO. In additrion, increasing barrier layers thickness above 20nm, the V_{TH} of a-IGZO TFT with MoTi/Cu and MoTiNi/Cu electrodes maintained at the same value, while the V_{TH} of TFTs with Mo/Cu electrodes kept to negative shift, respectively.This performance could be proved by our previous published paper[2]. From what discuss above on ,MoTiNi and MoTi exhibites greater ability to block Cu diffusion.

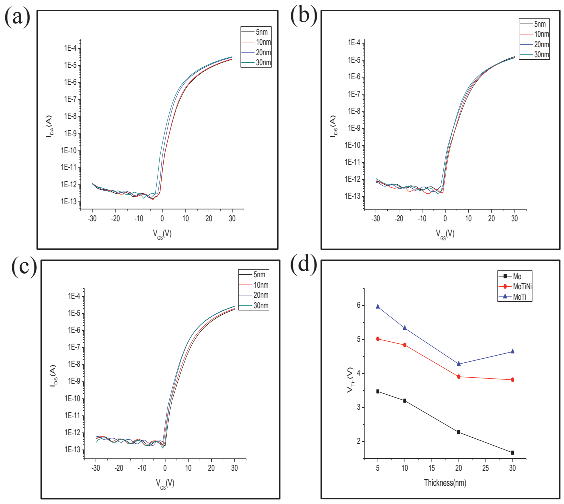

Fig.2. Representative transfer characteristics of the a-IGZO TFT with (a) Mo/Cu and (b)MoTiNi/Cu and (c)MoTi/Cu S/D electrode;(d) Variations of threshold voltage (V_{TH}) for both devices

Table1. Initial threshold voltage (V_{TH}) of the devices.

Thickness	V_{TH} (V)		
(nm)	MO	MTD	MOTI
5	3.47	5.01	5.96
10	3.20	4.83	5.33
20	2.27	3.90	4.28
30	1.67	3.81	4.64

In addition, comparing with the other two TFTs,MoTi/Cu IGZO showes the highest value of V_{TH} according to the Table 1. The differences between devices are only the barrier layer materials, which leads us to consider that the contact between the electrodes and the active layer probably play a major role in influencing transfer characteristics of TFT devices. To investigate the contact properties between a-IGZO and barrier layers , TLM was adopted using a series of TFTs with different, the total series resistance (R_T) can be expressed as follows[3]:

$$R_T = \frac{V_D}{I_D} = R_{CH} + R_C = r_{CH}L + R_S + R_D$$

Where r_{CH} is the channel resistance per unit channel length, R_S and R_D are the series resistances associated with the source and drain, respectively. **Fig3** shows the values of R_T, and R_C (contact resistance) that is calculated from the experimental results of the Mo/Cu and MoTi/Cu electrodes. Here, the y-intercept of the linear R_T in the **Fig3** represents the resistance of the source and drain, and the slope of this linear curves represent r_{CH}. The results shows that the a-IGZO TFT with MoTi S/D exhibits much higher value of R_C than the Mo/Cu TFT. This result could be explained by the foramtion of TiOx interfacial layer, and therefore, leads to V_{TH} toward more positive values. The Ti atom with higher bond enthalpy of Ti-O (672 kJ/mol) is preferred to combine oxygen atom[4]. meanwhile, the TiOx is an excellent insulator material that can prevente charge injection from the source into the IGZO semiconductor[5], and hence the MoTi/Cu device has a higher contact resistance. Moreover, according to previous reports, the Ni is an effective carrier suppressor and easily to be oxidized , forming larger Schottky barrier[6], so the V_{TH} value of MoTiNi/Cu device is higher than Mo/Cu and lower than MoTi/Cu device.

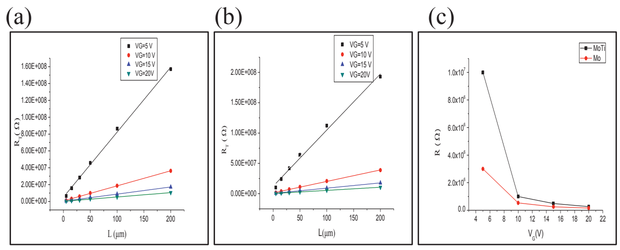

Fig.3. R_T as a function of the channel length (L) at various VG for a- IGZO TFTs with (a) Mo/Cu and (b) MoTi/Cu S/D electrodes; Variation of (c) R_C values for a-IGZO TFTs with Mo/Cu and MoTi/Cu S/D electrodes,respectively.

In order to further study the causes of this phenomenon, TEM and EDS are used to characterize the film structure and element distribution of the sample , respectively.The results of these samples with different barrier layer are shown in Figure 4. Figure 4(a) is images of Mo/IGZO, from these pictures it is clearly noted that no interfacial layer was formed between Mo/IGZO. However, when MoTi/Cu or MoTiNi/Cu as the electrode layer, the Ti will react with oxygen in the IGZO layer and generates a TiOx interlayers, especially with higer Ti ratio in the MoTi/IGZO samples, the TiOx could penetrates to a depth of 40nm. The EDX mapping images show that the In rich layers exist between the IGZO and MoTiNi/MoTi in the devices, suggesting that O is more easily to bond with Ti where O is from breaked In-O in IGZO layer. Therefor, indium atoms at the contact will migrates to form an In-rich region near the contact area[7].

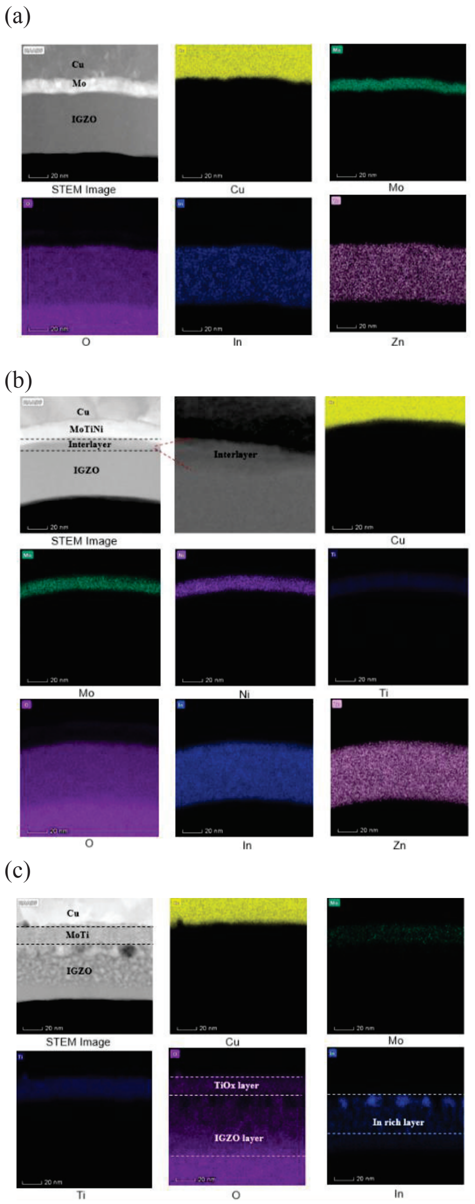

Fig4. Cross-sectional STEM image of the a-IGZO TFT and the EDX mapping with (a)Mo/Cu;(b)MoTiNi and (c) MoTi S/D

Fig. 5 depicts the depth profile of elemental distribution in the S/D contact region. We can naturally observe the rapid decrease of the Mo signal and increase of O signal at the interface between Mo and IGZO layers in the Fig. 5(a) . However, as shown in the Fig. 5(c), O signal remains at the same level throughout the MoTi layer reveals that there are kinds of Ti-oxides at the interfacial layer in the MoTi/Cu device. On the other hand, the variety of In-intensity with the depth can also be observed in fig 5(c); it is greater at the top of the IGZO, which is corresponding to the result of EDX mapping. Furthermore, MoTiNi device shows broad intersections revealing deeper diffusion, but the oxidation of Ti element is weaker and not obvious compared to the MoTi device.

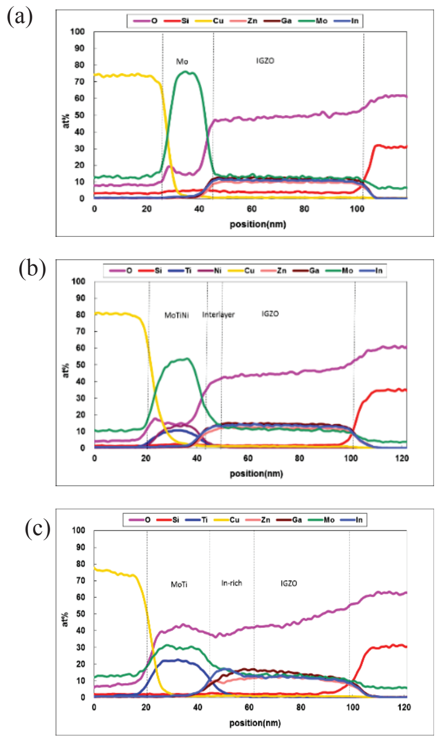

Fig.5. EDS line scan showing the depth profile of the elemental distribution of the a-IGZO TFT with (a)Mo/Cu;(b)MoTiNi and (c) MoTi S/D

Finally, the Etch-related properties of these three materials with triple layers structure were also investigated under the same etching condition, as show in Fig.6. As we all known, N_2O plasma treatment is a common method to improve the electrical performance of BCE IGZO type. However, N_2O gas may cause the Cu electrode to be easily oxidized,resulting in an increase in the contact resistance between the pixel and the source/drain. Therefore, triple layers structure (barrier/Cu/barrier) electrode is usually used to slove this problem. According to the corresponding SEM images, it can be known that the taper angle of Mo/Cu/Mo is too small to be used as electrode in TFT structure. In contrast,the MoTiNi/Cu/MoTiNi is a good choice for acting as barrier layer in the triple layers structure,because of the good taper angle and the property of no tip after etching. In order to further verify its substitutability, the contact resistance between the pixel and the source / drain were also investigated.And the results iss shown in Fig.6.(d),the contact resistance of Mo/Cu deivces are increased from 5360Ω to 29800Ω because of N_2O plasma treatment. However, when we use MoTiNi/Cu/MoTi/Ni as the source and drian electrode, N_2O plasma treatment can not cause Cu oxidation and the contact resistance is keep at around 3000Ω.

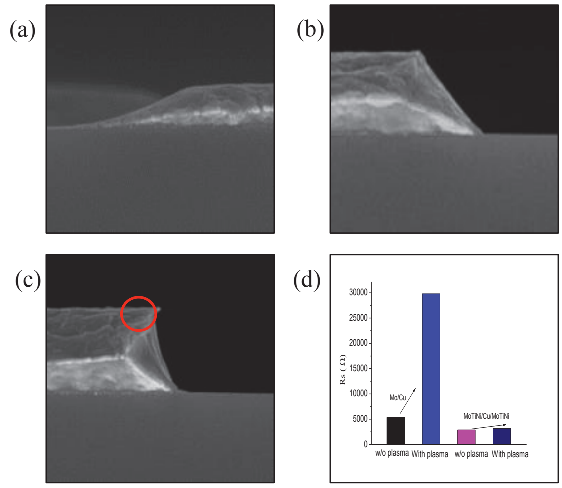

Figure. 6. SEM cross section images of barrier/Cu/barrier triplelayers (a) Mo/Cu; (b) MoTiNi and (c) MoTi S/D; variation of contact resistance between the pixel and the source / drain for a-IGZO TFTs.

4. Conclusion

In conclusion, the electrical characteristics of a-IGZO TFTs using Mo, MoTiNi andMoTi/Cu bilayer electrodes are investigated in this paper. The Mo device exhibits lower value of V_{TH} but the ability of blocking Cu diffuser is poor, and etchability is too poor to apply to Mo/Cu/Motriple layer electrode structure. On the other hand, as the Mo at% of the interlayer decreased to 50%, the TFT employing MoTi/Cu bilayer electrodes presents higer V_{TH} and contcat resistances because of the formation of titanium dioxide film between the barrier layer and IGZO. In addition, the material properties of samples are obtained using the TEM and linescan of EDS. As a result, the MoTiNi/Cu device shows lower V_{TH} and weaker oxidation than the MoTi device. Furthermore, the MoTiNi is a good choice for acting as barrier layer in the triple layer structure, because of the good taper angle and the property of no tip after etching.

REFERENCES

[1] Shi-Ben Hu, Hong-Long Ning, “Low contact resistance a-IGZOTFTbased on Copper-Molybdenum Source/Drain electrode”

[2] Xiaobo Hu, Li Zhan, “A Study and Estimate Method about Mo and MoTi Barrier Endurance for Cu Diffusion , 2018 ,IDW, pp.476-479, 2018

[3] Pedro Barquinha, Anna M. Vilà,"Gallium–Indium–Zinc-Oxide-BasedThin-Film Transistors: Influence of the Source/Drain Material" IEEE Transactions on Electron Devices, VOL. 55, NO. 4, APRIL 2008;

[4] Hsiao-Hsuan Hsu, Chun-Yen Chang,"High Mobility Bilayer Metal–Oxide Thin Film Transistors Using Titanium-Doped InGaZnO"; IEEE Electron Device Letters, VOL. 35, NO. 1, JANUARY 2014

[5] Joon Seok Park, Tae Sang Kim,"Ti/Cu bilayer electrodes for SiN x -passivated Hf–In–Zn–O thin film transistors: Device performance and contact resistance";Applied Physics Letters 97, 162105 (2010);

[6] Dong Lin, Kaiwen Li,"High-Performance Thin-Film Transistors with Nickel-Doped Indium Zinc Oxide Channel Layers"Phys. Status Solidi A 2019, 216, 1900274;

[7] Young Wook Lee,Sun-Jae Kim "Effect of Ti/Cu Source/Drain on an Amorphous IGZO TFT Employing SiNx Passivation for Low Data-Line Resistance", Electrochemical and Solid-State Letters, 15 (4) H126-H129 (2012);