

High-performance IGZO TFTs with Cu-based Multilayer Electrodes using MoAl Alloy as Buffer Layers

Chuan Liu¹, Zhaogui Wang¹, Yafang Wang¹, Gongtan Li², Shan Li²

¹ State Key Lab of Opto-Electronic Materials & Technologies, Guangdong Province Key Lab of Display Material and Technology and School of Electronics and Information Technology, Sun Yat-Sen University, Guangdong 510275, China

E-mail: liuchuan5@mail.sysu.edu.cn

² Shenzhen China Star Optoelectronics Technology Co., Ltd, Guangdong, China

Abstract

We report high-performance IGZO TFTs with MoAl/Cu/MoAl three-layer electrodes, where MoAl alloy is used as the buffer layer. The multilayer electrode has good thermal stability and can effectively prevent the oxidation and diffusion of the middle Cu layer. On the other hand, the etching conditions of MoAl alloy are compatible with Cu. The multilayer electrode has a good etching profile in the H₂O₂-based etchant solution. Based on the MoAl/Cu/MoAl electrode, vacuum-processed IGZO TFTs exhibit a turn-on voltage as 0 V, an on-off ratio as 10⁷, and a mobility as 13.7 cm²/Vs.

1. Introduction

With the development of display panels in the direction of larger size, higher resolution and faster frame rate, the industry's requirements for RC delay of TFT backplanes are getting higher and higher. To reduce RC delay, we can improve the mobility of TFTs and reduce the contact resistance of electrodes, where oxide semiconductors and copper (Cu) electrode are good candidates. Cu has advantages in mass production for its small resistivity and low price. However, there are some issues that need to be solved, such as: (1) Cu is easily diffused into the semiconductor and affects device characteristics; (2) Cu is easily oxidized; (3) the adhesion of Cu to common substrates (like SiO₂, glass) is poor [1].

In this paper, based on IGZO and Cu, we designed a three-layer electrode structure (MoAl/Cu/MoAl) to solve the above issues, and fabricated high-performance IGZO TFTs. MoAl alloy is used as buffer layer material, the introduction of Al element is to improve the etching rate of buffer layer.

2. Experiments

In order to test the thermal stability and etching characteristics of Cu-based multilayer electrodes, each layer of the electrodes was deposited on the cleaned SiO₂-Si substrate by DC magnetron sputtering with MoAl, MoMn and Cu targets. The sputtering power was fixed at 100 W, the argon flow rate was fixed at 30 sccm, the sputtering time of MoAl and MoMn is 5 min, and the sputtering time of Cu is 10 min. Next, we placed the samples in N₂ annealing furnace at different temperature (180, 250, 300 °C) for 1 h. Finally, we used SEM to observe the electrode morphology of samples.

To fabricated IGZO TFTs, IGZO films were deposited on the cleaned SiO₂-Si substrate by RF magnetron sputtering, where n⁺ Si acted as gate and 100 nm SiO₂ was dielectric layer.

After the active layer was patterned by the photolithography process, the samples were annealed at 400 °C for 1 h. Then, Cu-based multilayer electrode was sputtered onto the IGZO films through the shadow mask. The channel width and length are 1000 μm and 200 μm, respectively. All the devices were electrically characterized by a semiconductor parameter analyzer (Agilent, B1500A) at room temperature in ambient conditions.

3. Results

A. Thermal expansion behavior of Cu-based multilayer electrodes

The cross-section SEM images of the electrode samples after annealing are shown in Fig. 1. From Fig. 1, we can find that the MoMn/Cu/MoMn electrode locally bulged after annealing at 180 °C, and severe detachment after annealing at 250 °C. In comparison, the MoAl/Cu/MoAl electrode performed much better, only a slight local bulge appeared after annealing at 250 °C. The experimental results show that the adhesion between the MoMn/Cu/MoMn electrode and SiO₂ substrate is poor, the electrode is easily thermally expanded and separates from the SiO₂ substrate, and MoMn buffer layer cannot effectively improve the thermal stability of Cu-based electrode. The MoAl/Cu/MoAl three-layer electrode structure composed of the MoAl buffer layer performs well in the annealing process, which can effectively suppress the thermal expansion of the middle Cu layer and meet our requirements. Therefore, we will conduct a more in-depth study based on the MoAl buffer layer material.

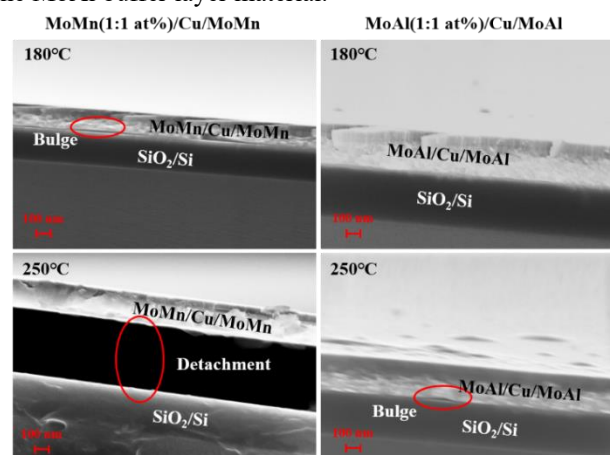


Fig. 1 SEM images of the cross-sections of Cu-based multilayer electrodes under different buffer layer materials after annealing.

In the BCE (Back Channel Etching) process, the thermal

expansion issue will also occur between the Cu-based electrodes and passivation layer. In order to further improve the thermal stability of MoAl/Cu/MoAl electrode, we have increased the ratio of Mo to Al in MoAl alloy to 3:1 at%, where Mo element has better thermal stability and smaller thermal expansion coefficient. The SEM images of MoAl (3:1 at%)/Cu/MoAl samples and Cu samples with passivation layer (300 nm SiO₂ by PECVD) are shown in Fig. 2. We can observe that after CDA (Clean Dry Air) 300 °C annealing, the single-layer copper was oxidized, and in the N₂ atmosphere, although no obvious oxidation occurred, there was still a gap between the passivation layer and Cu layer. For MoAl (3:1 at%)/Cu/MoAl samples, regardless of the CDA or N₂ atmosphere, the middle Cu layer was effectively protected without significant thermal expansion. Therefore, the MoAl (3:1 at%)/Cu/MoAl three-layer electrode structure has advantages in the Cu-BCE process.

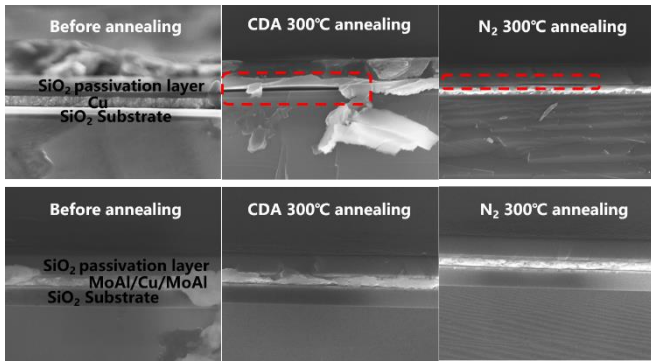


Fig. 2. SEM images of MoAl (3:1 at%)/Cu/MoAl samples and Cu samples with passivation layer.

B. Etching behavior of Cu-based multilayer electrodes

Different optimal pH ranges of Mo (pH < 2 and pH > 8) and Cu (pH < 8), which is chemically ionized in wet etchants, results in their etching rate mismatch and poor etching profile [2]. So, we introduced Al with low standard potential (-1.66 V) to improve the etching rate of Mo-based alloy. We found that the MoAl (3:1 at%)/Cu/MoAl three-layer electrode could be completely etched by the H₂O₂-based etchant solution when soaked for 3 min. The etching profile SEM image of the sample is shown in Fig. 3, where the thickness of MoAl layer and Cu layer is 40 nm and 170 nm, respectively. And the etching profile is trapezoidal, the bottom MoAl layer has a slight drag, which may be caused by metal oxide (alumina oxide, molybdenum oxide) coverage.

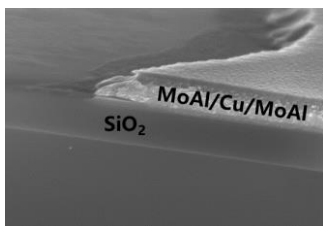


Fig. 3. the etching profile SEM image of MoAl (3:1 at%)/Cu/MoAl three-layer electrode.

C. IGZO TFT device characteristics with Cu-based multi-layer electrode

As we know, the electron affinity of IGZO is 4.16 eV [3], and the work-function of Cu, Mo, Al is 4.65 eV, 4.37 eV and 4.28 eV, respectively. Therefore, compared with Cu, it is easier to form ohmic contact between Mo, Al and IGZO. The electrode thickness was controlled by sputtering time, we tested the electrical properties of IGZO TFTs with various electrode thickness combinations. And the results are shown in Fig. 4. We find that the hysteresis of the transfer characteristic curve of all devices is small, which is mainly due to the good interface characteristics between IGZO and SiO₂. With the thickness of Cu layer increases, I_{on} of the linear region increases. From the mobility vs V_{GS} curves, when the sputter time of Cu layer is 6 min and 7 min, the μ_{linear} drops significantly, which may be related to the larger resistance of the electrode. When the sputter time of Cu layer is 10 min, the device performs well with a turn-on voltage as 0 V, an on-off ratio as 10⁷, and a mobility as 13.7 cm²/Vs.

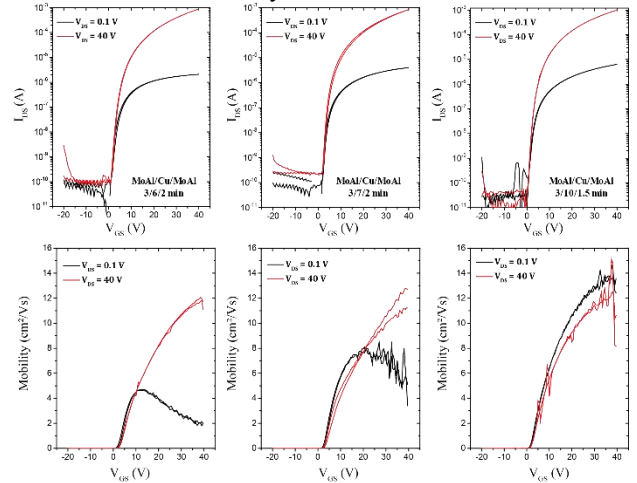


Fig. 4. the electrical properties of IGZO TFTs with various electrode thickness combinations.

3. Conclusions

We used MoAl alloy as the buffer layer for Cu electrode, and studied the thermal expansion and etching behavior of MoAl/Cu/MoAl three-layer electrode. Based on Cu-based electrode, high-performance IGZO TFTs were fabricated. We hope the research may provide a new choice for Cu buffer layer.

References

- [1] LIU X, et al. IEEE Transactions on Electron Devices, 2014, 61 (12), 4299-4303.
- [2] PRESUEL-MORENO F, et al. Journal of The Electrochemical Society, 2005, 152 (9), B376-B387.
- [3] ZHAO C, et al. IEEE electron device letters, 2013, 35(1) : 75 – 77.