Adhesion Improvement for Copper Process in TFT-LCD

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Abstract

The first issue that should be overcome in copper process is its poor adhesive strength between pure copper film and glass substrate. In this study, defining the adhesive strength of pure copper film on various substrates and clarifying the key deposition parameters are presented for the investigation of copper process. First, using different kinds of surface plasma treatments were studied and the results showed that the adhesive strength was not improved even though the roughness of glass substrate surface was increased. Second, adding an adhesive layer between glass substrate and pure copper film was used to enhance the adhesion. Based on the data in the present paper, adopting copper alloy film as an adhesive layer can have capability preventing peeling problem in copper process. Besides, Cu/Cu alloy structure could be etched with the same etchant with better taper angle than the one with single layer of Cu. Unlike Cu/Mo structure, there is no residual problem for Cu/Cu alloy structure during etching process. Finally, this structure was examined in electrical test without significant difference in comparison with the conventional metal process.

1. Introduction

Aluminum Neodymium (AlNd) as a gate metal has several key advantages and has been the predominant gate metal used in thin film transistor liquid crystal display (TFT-LCD). The advantages of AlNd include restraining hillock formation, low material resistivity, good wet-etching capability and excellent adhesive strength to glass substrates. Because of these superior properties, AlNd has been used as gate metal material of TFT-LCD for several years. With the progress of thin film transistor liquid crystal display, however, panel size is continuously scaling up and the RC propagation delay problem during gate signal transferring will become more and more serious [1].

In order to solve this problem, lowering gate metal resistivity is a good way to decrease signal delay problem. The most commonly studied gate metal candidates include aluminum, silver and copper. Among these candidates, pure aluminum has many favorable properties, including low cost and compatible with conventional process. Nevertheless, with panel size increasing or using 120 Hz driving technology, pure aluminum will still suffer the RC propagation delay problem. Moreover, pure aluminum films exhibit a problem of hillock formation easily with glass substrate. The critical issue for silver is its inherent thermal instability during heating process. Besides, the material cost also limits the progress of silver process. Therefore, copper becomes the most suitable material to replace pure aluminum process in next generation. But there are still many problems for copper process, including readily corroding [2], diffusing into silicon rapidly [3] and poor adhesive strength to glass substrate. In this study, we will discuss the adhesive strength of copper films on many kinds of substrates and use different methods to improve its adhesive strength.

2. Experiment

2-1. Adhesive strength by using conventional metal process

Firstly, the value of adhesive strength to pass adhesion test is defined. We used conventional metal process, including aluminum, molybdenum and titanium, to define the criterion of adhesive strength can pass there-working of bonding test in module process. Besides, all the adhesion tests were measured by using 107 Cross Hatch Cutter Operating Instructions with 3M 600 tape. The principle of this testing method is to cut a pattern of right-angled cross cuts into the coating material and through to the substrate. Further information on which cutter to use, the number of cuts to make the lattice and the scale pattern can be found in international standards ASTM D3359-B. Figure 1 shows that the conventional metal process can provide excellent adhesive strength whatever the film thickness is. Besides, as we known, there is also no peeling issue for conventional metal process during bonding/reworking process. Therefore, the adhesive strength of copper process should be improved at least up to 5 to ensure the quality of the adhesive ability.

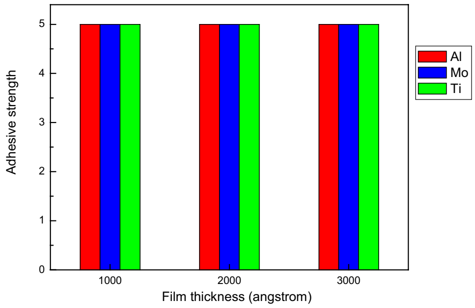

Fig. 1 Adhesive strength v.s. film thickness for the conventional metal film including aluminum, molybdenum, and titanium deposited on the glass substrate at room temperature.

2-2. Different deposition conditions

In order to obtain the objective data of the adhesive strength, the thickness of copper film was controlled in 3300Å to ignore the effect by various film thicknesses. Pure copper films were deposited on the glass substrate (NEG OA-10) in argon ambient with different kinds of deposition powers and pressures. By comparing with Figure 2 and Figure 3, we found that changing deposition power would not be helpful to enhance the adhesive strength. However, it is necessary to modify a suitable deposition power to obtain a lower resitivity copper film. Figure 4 and Figure 5 show that changing deposition pressure would also not be helpful to improve the adhesive strength. However, increasing deposition pressure would increase the film resistivity significantly.

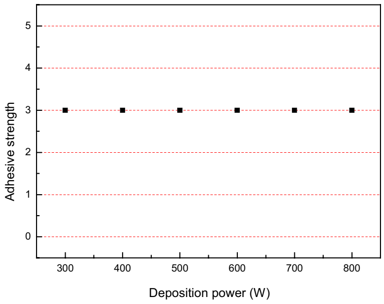

Fig. 2 Adhesive strength v.s. deposition power for 3300Å copper film deposited on the glass substrate in argon ambient at a pressure of 2 mTorr.

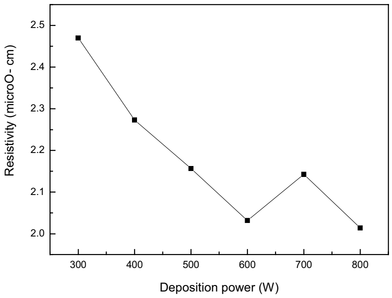

Fig. 3 Resistivity v.s. deposition power for 3300Å copper film deposited on the glass substrate in argon ambient at a pressure of 2 mTorr.

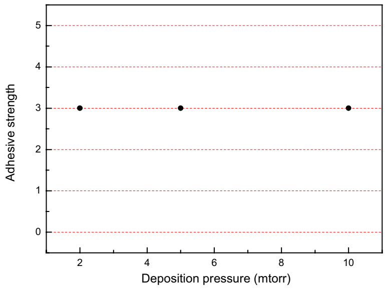

Fig. 4 Adhesive strength v.s. deposition pressure for 3300Å copper film deposited on the glass substrate in argon ambient at a power of 500W.

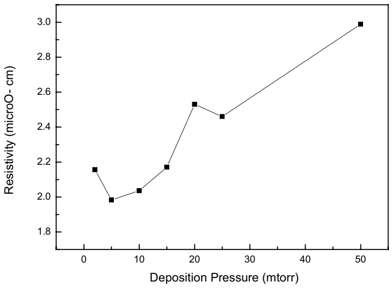

Fig. 5 Resistivity v.s. deposition pressure for 3300Å copper film deposited on the glass substrate in argon ambient at a power of 500W.

2-3. Surface plasma treatment

Six kinds of gas ambient, including N_2, H_2, NH_3, PH_3, N_2O and NF_3, were used for the source of the surface plasma treatment respectively. The treatment duration varied from 20 to 120 sec at a treatment power of 300W. After surface plasma treatment, 3300Å copper film is prepared by using PVD in argon ambient at a pressure of 2 mtorr on a 320×400mm glass substrate (NEG OA-10). Figure 6 shows that the surface roughness increased with increasing plasma treatment duration. The smallest surface roughness of H_2 plasma could be attributed to its light atom weight and the biggest surface roughness of NF_3 presumably due to F radical damage glass substrate and result in severe surface roughness. By comparing with Figure 6 and Table-1, we found that increasing surface roughness did not improve the copper film adhesive strength effectively. Notwithstanding NF_3 roughened the glass substrate effectively, the adhesion degraded significantly. It might be due to the residual of F radical and this F residual would also be harmful to the adhesion of Cu.

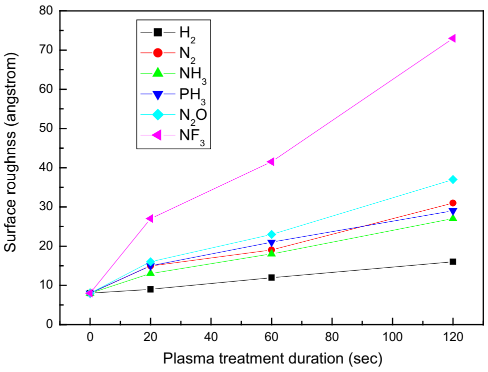

Fig. 6 Surface roughness v.s. plasma treatment duration with different kinds of gas

Plasma treatment gas	Plasma treatment duration (sec)	Adhesive strength	Plasma treatment gas	Plasma treatment duration (sec)	Adhesive strength
H_2	0	3	PH_3	0	3
	20	3		20	3
	60	3		60	3
	120	3		120	3
N_2	0	3	N_2O	0	3
	20	3		20	1
	60	3		60	1
	120	4		120	0
NH_3	0	3	N_2O	0	3
	20	3		20	1
	60	4		60	0
	120	4		120	0

Table-1 Adhesive strength v.s. plasma treatment duration with different kinds of gas ambient including H_2, N_2, NH_3, PH_3, N_2O and NF_3.

2-4. Conventional metal stack structure

400~500Å conventional metal film, including Ti, Mo, MoN, Al and AlNd, is prepared as an adhesive layer between glass substrate and copper film. After depositing the metal film, 3300Å copper is deposited in argon ambient at a pressure of 2 mtorr. Figure 7 shows the adhesive strength versus different kinds of substrate without annealing process. We found that the adhesive layer, including titanium and molybdenum could be an excellent adhesive layer. However, the adhesive strength of samples with Mo substrate will degrade with the increase of Q-time. If Mo substrates were exposed to atmosphere for 1~2 days, the adhesion of Cu degraded form the level of 5 to 2. It would be attributed to the formation of molybdenum oxide. Therefore, after depositing Mo adhesion film, the copper film should be deposited on this substrate as soon as possible to inhibit molybdenum oxide formation.

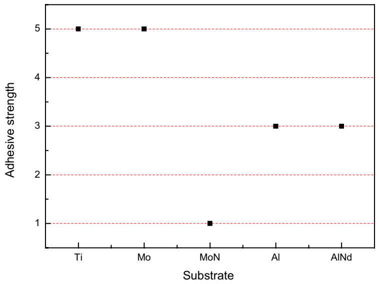

Fig. 7 Adhesive strength v.s. different kinds of substrate

2-5. Copper alloy metal stack structure

400~500Å copper alloy film is deposited by sputtering using a copper alloy target at a pressure of 5 mtorr and a temperature variation from room temperature to 150 ℃. After the deposition of copper alloy film, 3300Å of copper film is subsequently deposited on this substrate. Figure 8 shows film resistivity versus deposition temperature for Cu alloy(A) and Cu alloy(B) film without annealing process. Figure 9 shows adhesive strength versus deposition temperature by using Cu alloy(A) and Cu alloy(B) as an adhesive layer respectively. Increasing the deposition temperature can improve adhesion of Cu/Cu alloy(A) or Cu/Cu alloy(B) structure. Besides, by increasing the deposition temperature up to 150℃, both Cu/Cu alloy(A) or Cu/Cu alloy(B) structure could pass the adhesion test.

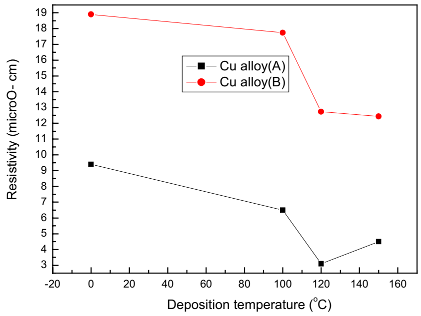

Fig. 8 Film resistivity v.s. deposition temperature for Cu alloy(A) and Cu alloy(B) without annealing process.

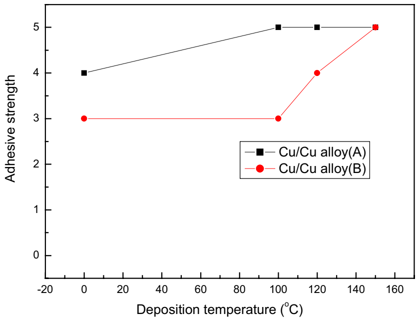

Fig. 9 Adhesive strength v.s. deposition temperature for Cu/Cu alloy(A) and Cu/Cu alloy(B) structure without annealing process.

2-6. Electrical test

Figure 10 shows the applied voltage versus leakage current density for Cu/Cu alloy(A) gate and Ti gate. We found that there was only little difference between copper gate and Ti gate. It means that copper process would not degrade the device lifetime significantly because of the copper diffusion problem. Besides, Figure 11 shows less variation and better performance at off-state ($V_{GS}<0$) in I_{DS}-V_{GS} curve between copper and titanium material. In the adhesion test, the conventional metal stack, Cu/Mo can obtain excellent adhesion. However, during wet etching process, bottom molybdenum layer will suffer serious residual problem and figure 12 shows the results related to bottom molybdenum residual issue. As for the etching of Cu/Cu alloy(A) structure, it is easier to control the taper by using the new etchant, which can be clearly seen in Figure 13 for the taper angle of Cu/Cu alloy(A) structure.

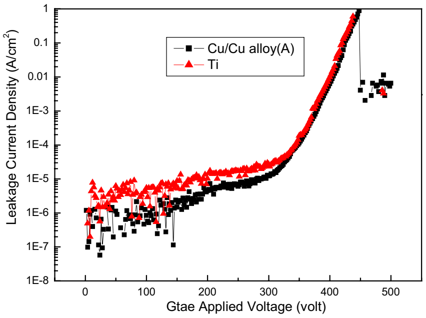

Fig. 10 Leakage current density v.s. gate applied voltage for Ti and Cu/ Cu alloy(A) gate without annealing process.

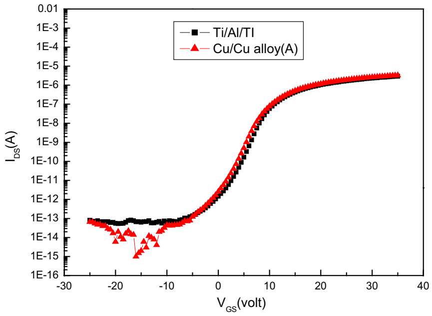

Fig. 11 Current-voltage characteristics for Ti/Al/Ti and Cu/Cu alloy(A) gate at V_{DS}=5 V after annealing process.

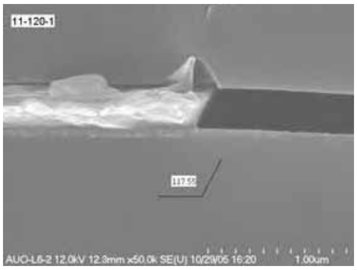

Fig. 12 Bottom molybdenum residual problem for Cu/Mo structure after wet etching process.

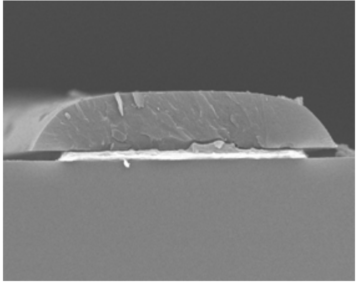

Fig. 13 Taper angle for Cu/Cu alloy(A) structure after wet etching process

3. Conclusion

Increasing surface roughness on glass substrate would not enhance the adhesive strength efficiently. The optimum adhesive strength structure for copper process is to use Cu/Cu alloy(A) structure, in which its adhesive strength can be improved up to level of 5 at high temperature deposition condition. Besides, this structure could be etched easily by using the new etchant without residual problem and provide better taper angle after wet etching process. In electrical test, there is no significant variation between Cu/Cu alloy(A) and conventional metal process.

4. References

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[3] J.D. McBrayer, R.M. Swanson and T.W. Sigmon, "Diffusion of metal in silicon oxide", J. Electrochem. Soc., 133(6) (1986) 1242.