Fully Cu-based Gate and Source/Drain Interconnections for Ultrahigh-Definition LCDs

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Abstract

Low resistivity interconnection and high-mobility channel are required to realize ultrahigh-definition LCDs such as 4k x 2k TVs. We evaluated fully Cu-based gate and Source/Drain interconnections, consisting of stacked pure-Cu/Cu-Mn layers for TFT-LCDs, and found the underlying Cu-Mn alloy film has superior adhesion to glass substrates and CVD-SiO_x films. It was also confirmed that wet etching of the Cu/Cu-Mn films without residues and low contact resistance with both channel IGZO and pixel ITO films can be obtained. It is thus considered that the stacked Cu/Cu-Mn structure is one of candidates to replacing conventionally pure-Cu/refractory metal.

1. Introduction

In order to realize ultrahigh-definition LCDs such as next generation 4k x 2k TVs [1], both low resistivity Cu interconnection [2, 3] replacing widely used Al-based films as well as high electron mobility channel material instead of *a*-Si film are need to be developed. In-Ga-Zn-O (IGZO) film is currently being investigated [4, 5] as a high-mobility channel film for ultrahigh definition LCDs, where effective field mobility over 3 cm^2/Vcm^{-1} is required because of the need to charge the storage capacitors with shorter pulse time to drive the LCD at higher frequency such as 120 and 240 Hz [6].

Although Cu is attractive due to its low resistivity, full-fledged use of the material for interconnection film in LCDs has been hampered because of its poor adhesion to glass substrates. According to Koike *et al*. [7, 8], single-layered Cu-Mn alloy films, with low electrical resistivity and good adhesion to glass substrates, are potentially applicable to gate interconnection. However, the single-layered Cu-Mn films require peculiar annealing atmosphere of 10 ppm or less oxygen to achieve both the high adhesion, and low resistivity comparable to pure-Cu. Conventionally, stacked pure-Cu/refractory metal films are investigated. Nevertheless, the characteristics and reliability of electrical contact between IGZO and pure-Cu films have not been reported yet in detail.

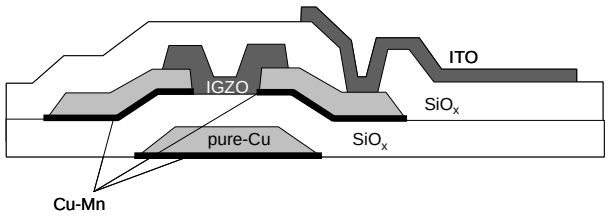

Fig. 1. Schematic of a coplanar-type Oxide-TFT for ultrahigh-definition LCDs.

In this paper, we evaluated wet etching, adhesion to glass substrates and gate insulator SiO_x films, and contact resistance with both channel IGZO and pixel ITO films, intending to realize a coplanar-type IGZO TFT using the stacked-layered Cu/Cu-Mn films as gate and Source/Drain (S/D) interconnections such as shown in Fig. 1.

2. Experimental

We prepared various kinds of stacked-layered films,

including pure-Cu/Cu-(2-10 at.%) Mn, pure-Cu/Mo, and pure-Cu/Ti with the thicknesses of 300-500/10-100 nm, deposited on glass substrates (Corning, Eagle2000) for gate and CVD-SiO_x films for S/D by DC magnetron sputtering. After pattering these stacked films using Cu etchants (acid, H_2O_2 + acid, and H_2O_2 + alkaline), their taper angle and total resistivity after annealing were measured. Furthermore, to investigate their adhesion to the glass substrates and CVD-SiO_x films, we carried out the 3M-tape (8422B) test of these blanket stacked-layered films after short-time (5 min) annealing at 320 ^oC or 270 ^oC, comparable to gate or S/D insulator deposition processes, respectively.

Finally, we evaluated the contact resistance between highly-conductive (*hc*)-IGZO (In:Ga:Zn = 1:1:1, 100 nm thickness) and pure-Cu films, and between ITO (50 nm thickness) and pure-Cu films using test element groups called Kelvin Pattern. The *hc*-IGZO was deposited by sputtering with only Ar discharge gas. The stacked Cu/Cu-Mn films on the glass substrate were observed by cross-sectional transmission electron microscopy (TEM), and Mn-compounds formed at the glass interface were analyzed by electron energy loss spectroscopy (EELS).

3. Results and discussion

The tapered profiles of the pure-Cu/Cu-10Mn, pure-Cu/Mo, and pure-Cu/Ti films of 300/100 nm in thickness, etched by acid, H_2O_2 + acid, and H_2O_2 + alkaline etchants are shown in Fig. 2. As seen in the pictures, the pure-Cu/Cu-Mn films showed good taper angles and no residues while Cu-Mn undercut is seen in the sample etched in the acid without H_2O_2. We do not understand yet whether the undercut is formed due

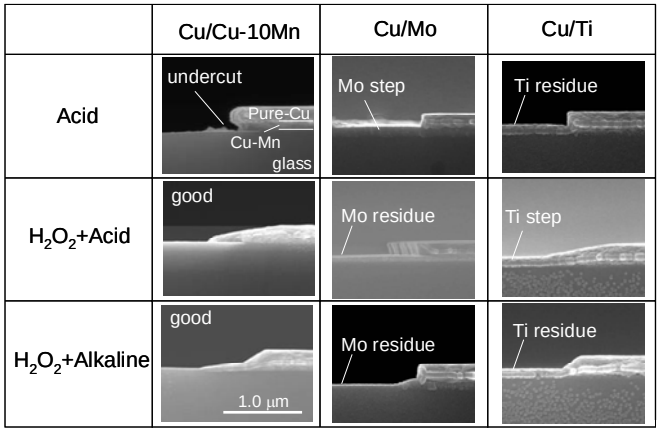

Fig. 2. Taper-etch profiles formed by acid, H_2O_2 + acid, and H_2O_2 + alkaline etchants.

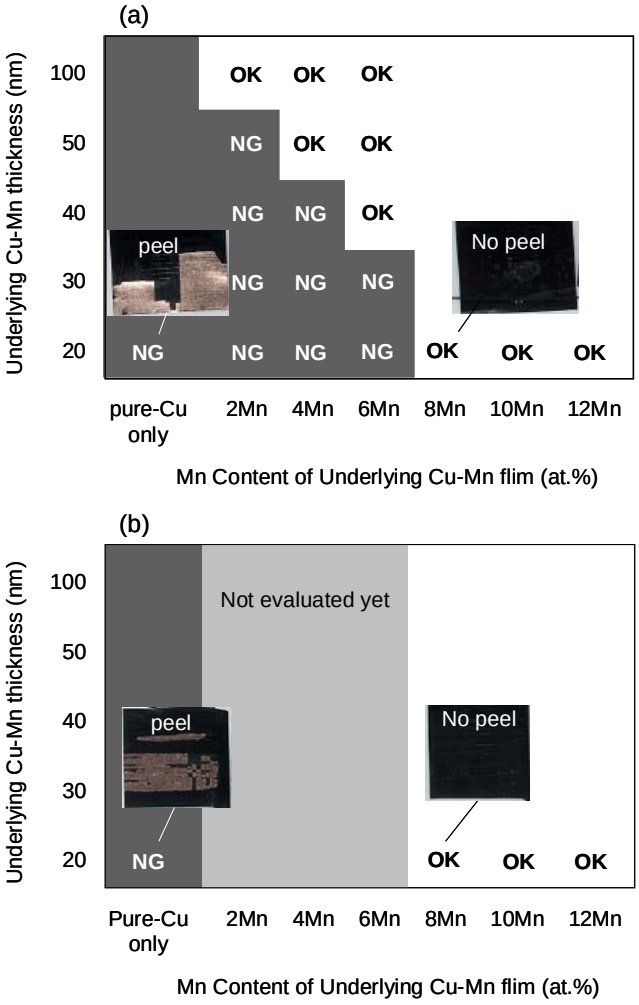

Fig. 3. Test results of adhesion (a) to glass substrates after 320 ^oC for 5 min, and (b) to CVD-SiO_x films after 270 ^oC for 5 min, of pure-Cu/Cu-Mn films of 500/20-100 nm in thickness.

to so-called battery effect or not. On the other hand, Ti steps/residues and Mo steps/residues can be observed in the etched pure-Cu/Ti and pure-Cu/Mo films, respectively.

Results of 3M-tape (8422B) tests of pure-Cu/Cu-Mn films on the glass substrates and CVD-SiO_x films are summarized in Figs. 3(a) and 3(b), respectively. Pure-Cu films of 500 nm in thickness are evaluated in accordance to an requirement of sheet resistance of 0.04 Ω/sq. for ultrahigh-definition LCDs. The Mn contents of 8 at.% or greater are needed to secure adhesion in the case that the Cu-Mn underlying film is 20 nm in thickness as shown in Fig. 3(a). The stacked pure-Cu/Cu-Mn films of 500/20 nm in thickness showed similar adhesion to CVD-SiO_x films as shown

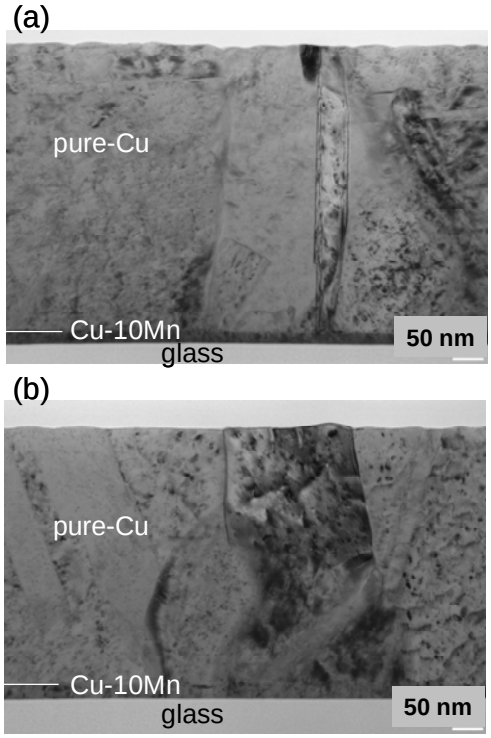

Fig. 4. Cross-sectional TEM images of (a) as-deposited pure-Cu/Cu-10Mn films, and (b) after annealing at 320 °C for 5 min, deposited on glass substrates.

in Fig. 3(b). It was thus found that adequate adhesion can be achieved with pure-Cu/Cu-Mn films of 500/20 nm in thickness and Mn content of 8 at.% or greater. Cross–sectional microscopic images of the stacked pure-Cu/Cu-10Mn films deposited on glass substrates are shown in Fig. 4. In both as-deposited and annealed (at 320 °C for 5 min) samples, it is seen that grain size in pure-Cu on the Cu-10Mn film is larger than 100 nm, and that the pure-Cu grains on Cu-10Mn film are continuous without a trace of voids. We also analyzed a portion of the films adjacent to the glass substrate using EELS. According to Koike *et al*. [7, 8], interface reaction layer of Mn-compounds is formed after annealing at the interface with glass substrates. Figure 5 shows the electron energy-loss spectra collected around the interface (Point 2 is at the very interface, Point 1 in Cu-10Mn and Point 3 in glass substrate are 1.3 nm away from the interface). After annealing at 320 °C for 5 min, Mn-L2 and Mn-L3 peeks at Point 2 are intensified as compared to Point 2 of as-deposited sample as shown in Fig. 5. Although the composition of Mn-compounds can not be determined by the EELS analyses, the Mn-L2 peak could be indicative of Mn

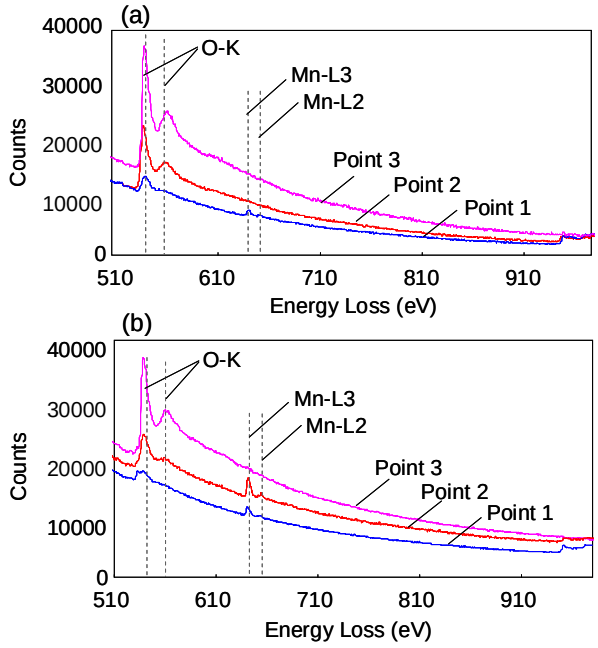

Fig. 5. Electron energy loss spectra at the interface between Cu-10Mn/glass substrates; (a) as-deposited, and (b) after annealing at 320 °C for 5 min.

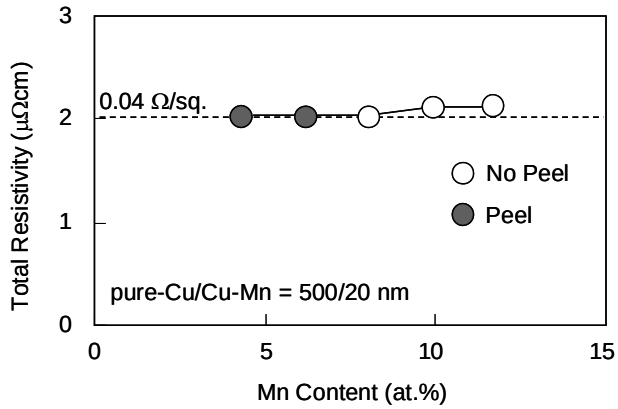

Fig. 6. Total resistivity of stacked pure-Cu/Cu-Mn films after 320 °C for 5 min.

oxide formation by the reaction of Mn in the Cu-Mn film and glass substrate.

Total resistivies of the stacked pure-Cu/Cu-Mn films after annealing at 320 °C for 5 min are plotted in Fig. 6. The measured values are nearly 2.0 μΩcm (= 0.04 Ω/sq.). It is found that the total resistivity of pure-Cu/Cu-Mn films, comparable to that of pure-Cu even after annealing at temperatures for conventional gate insulator deposition, is suitable for ultrahigh-definition LCDs.

Finally, we evaluated the contact resistances with

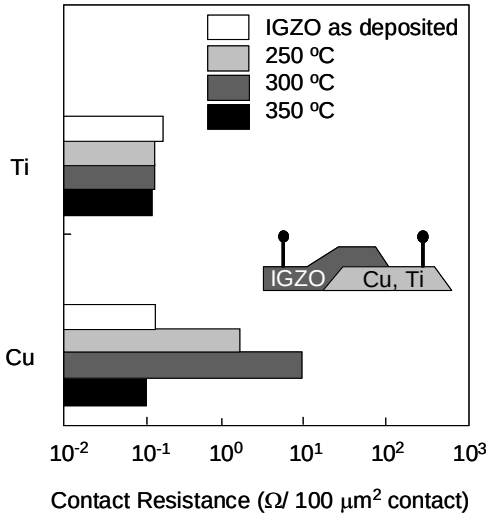

Fig. 7. Contact resistance between *hc*-IGZO and pure-Cu films annealed at 250 – 350 °C for 30min.

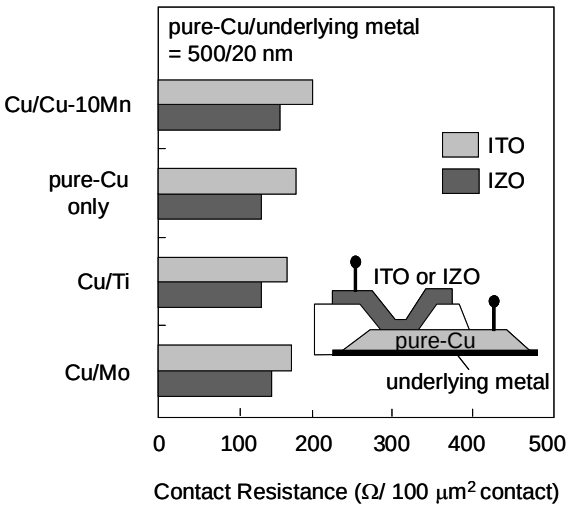

Fig. 8. Contact resistance between ITO and Cu with underlying metal films.

both *hc*-IGZO film without insulator, and pixel ITO film with insulator (*i.e.* through contact hole), using Kelvin Pattern. Figure 7 shows the contact resistance between *hc*-IGZO and pure-Cu films. For comparison, contact resistance of Ti measured using the same contact structure of coplanar-type oxide-TFT is also shown in Fig. 7. For oxide-TFTs, the annealing process is necessary to realize highly uniform V_{th} and high-mobility channel [4, 5]. We evaluated, therefore, the contact reliability after IGZO annealing in the temperature range from as-deposited to 350 °C for 30min. While the contact resistance increased with annealing temperature up to 300 °C, the contact resistance after annealing at 350 °C decreased lower than that of as-deposited sample.

In Fig. 8, we showed the contact resistance between ITO and stacked pure-Cu/Cu-10Mn films, and compared the values with those measured for pure-Cu/Mo and pure-Cu/Ti films. It was found that the contact resistance ITO and pure-Cu films are not very dependent on underlying metals. The ITO/Cu contact is completely different from the behavior of the ITO/pure-Al contact [9].

4. Summary

For the stacked pure-Cu/Cu-Mn films we showed here, any additional processes are not required to be adhesive to glass substrates and CVD-SiO_x films, unlike conventional pure-Cu/refractory metal films. Furthermore, in the case of pure-Cu/Cu-10Mn films with thickness of 500/20 nm, the total resistivity is the almost same (= 2.0 μΩcm, *i.e.* 0.04 Ω/sq.) as single-layered pure-Cu film. And, we also evaluated the contact resistances of pure-Cu/Cu-Mn films with *hc*-IGZO and ITO films. The contact resistances are suitable, especially after annealing at 350 °C in the IGZO film case.

From these results, it was found that the stacked pure-Cu/Cu-Mn films are applicable to gate and S/D interconnections in a coplanar-type oxide-TFT. As the sputtered Cu-Mn thin films occupy little portion of manufacturing cost of displays, the newly developed structure is a viable candidate for interconnection for ultrahigh-definition LCDs such as 4k x 2k TVs.

5. References

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