The Novel Technology Development of 7mask for LTPS-LCD

Dandan Yan, Xuexin Lan, Bingping Liu, Yanshan Huang, Xiaoxiao Wu, Xiangkang Wei, Honghong Nie, Keshi Yang, Chao Deng, Guozhao Chen, and Xianyan Yang

dandan_yan2@tianma.cn

Research and Development Center, Xiamen Tianma Microelectronics Co., Ltd., Xiamen, China

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ABSTRACT

Liquid Crystal Display with 7mask was developed and fabricated successfully for production. We found and solved three key questions, which include the M2 taper, the short circuit of M2 and the thorn-like residue in PV1 and PV2 hole.

1 Introduction

Compared with traditional amorphous silicon transistors, low temperature polycrystalline silicon thin film transistors (LTPS) have more advantages, such as high field effect mobility (~ 100 cm2/Vs) and high current switching ratio. Therefore, LTPS-LCD has been widely used as pixel switching or driving devices of LCD in the market of small and medium size displays. With the continuous market share increasing and costs decreasing of the organic light-emitting diode (OLED) products, LTPS-LCD technology needs to further reduce production costs on the premise of maintaining good performance, which has become the mainstream trend of LTPS-LCD development in the future. In the early days, the array substrate of LTPS-TFT (thin-film transistor) required 14 mask to achieve a good liquid crystal display effect. At present, with the development of technology, the mainstream mass production process is 10mask technology (called 10mask as follows) and 9mask technology (called 9mask as follows). 10 mask uses metal M2 instead of M3 to achieve touch function. Self-alignment LDD technology (SALDD) was applied in the 9mask and ND mask was removed. At the same time, the device can still maintain excellent performance.

On the basis of 9 mask technology, we have developed the 7 mask technology by removing the shading layers and using the inorganic film passivation layer 1 (PV1) instead of the organic layers PLN (Fig.1). This technology not only removes the masks of the shading layers, but also removes the mask of the PLN organic layers, and increases the production capacity of the exposure machines. Although the cost can be effectively reduced, there are several process problems related to the removal of organic film that need to be solved: 1. The inorganic film layer breaks at the M2 climbing position, resulting in abnormal contact between ITO2 and M2, and dark spots in VT, which will seriously lead to disordered display; 2. There is a slight short circuit between the two M2, and the gray screen appears purple during the VT electrical measurement; 3. The thorn-like residues appear during the etching of the PV2 layer.

In this paper, the defects of PV1 crack, the short circuit between two M2 and the thorn-like residues in the holes of PV1 and PV2 are systematically studied, the root causes are determined, the methods to improve the defects are discussed, and finally the problems are successfully solved, which lays a foundation for the wide application of 7 mask technology in the field of LTPS technology.

(a) The design structure of PV hole in the PLN layer

(b) The design structure of PV hole in the PV1 layer

Fig. 1 The design structure of PV hole with different layer

2 Analysis and Mechanism Study of PV1 Cracks

Cracks were firstly discovered during the analysis of the TEG test anomaly. We discuss the process of PV1 deposition. Using PECVD machine, SiH_4 and N_2O are used for silicon oxide film formation, SiH_4, N_2 and NH_3 are used for silicon nitride film formation, and the main reaction equations are as follows:

$SiH_4+N_2O \rightarrow SiO_x:H$ (1)

The essence of chemical reaction: SiH_4 mainly ionizes Si•, H•, N_2O ionizes O• and N•, Si• combines with O• to form SiO_x, a part of H• and N• form NH_3 gas. volatile gases are evacuated from the reaction chamber during vacuum evacuation. A part of the H• left in the chamber forms SiO_x:H.

$SiH_4+NH_3+N_2 \rightarrow SiN_x:H$ (2)

The essence of the chemical reaction for silicon nitride is the same as that of silicon oxide, and finally SiN_x:H is formed[1].

The EPD mode is used for the etching of the M2 film layer. Chlorine and oxygen are used as the main etching gases. The etching process is divided into three steps.

In the first step, the metal without photoresist protection is etched by high flow gas. Chemical reaction equation is as follows:

$Al+Cl_2 \rightarrow AlCl_3$ (3)

In the second step, in order to achieve the uniformity of the etching at every positions of the entire glass, the etching uses low-flow gas to reach the etching end between the bottom of Ti and the substrate to ensure the metal M2 at all positions is etched cleanly.

In the third step, the main gases for etching are carbon tetrafluoride and oxygen, ionized F• with $AlCl_3$ is reacted and generates AlF_3 compound.

$AlCl_3+F\bullet \rightarrow AlF_3 +Cl\bullet$ (4)

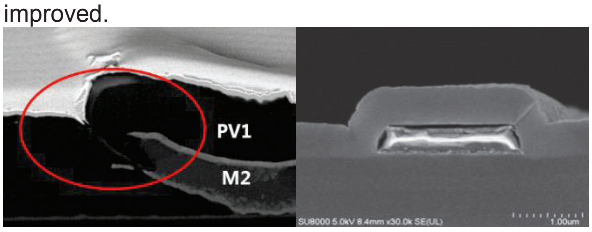
When removing the third step of etching, $AlCl_3$ will react as follow:

$AlCl_3+H_2O \rightarrow Al(OH)_3+HCl$ (5)

The resulting aluminum hydroxide reacts with O_2 to obtain aluminum oxide, which is called aluminum corrosion. The appearance of aluminum corrosion is convex, which will cause a short circuit between two M2, affecting product quality. The M2 etching process may also lead to another undesirable phenomenon, Al lateral etching, which exhibits a concave topography, which also affects product performance. Therefore, aluminum corrosion should be avoided during the M2 etching process.

$Al(OH)_3+O_2 \rightarrow Al_2O_3$ (6)

Figure 2 is the defect of the PV1 film. As shown, the significant PV1 cracks appear at the location of the M2 climb, which morphology is close to that of M2 taper, showing concave M2. This defect leads to high contact resistance, which is harmful for the quality and the reliability of products. Therefore, the process needs to be improved.

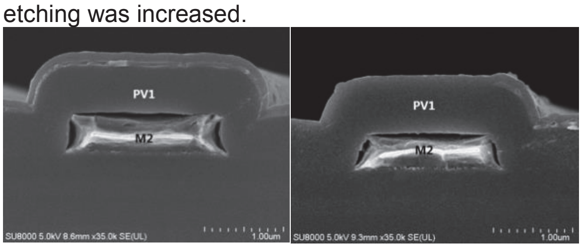


Section diagram of cracked film (a) and good film (b)

Fig.2 the appearance of cracked and good film

In order to clarify the cause of the defect, it is necessary to analyze the structure of the films. The metal M2 are Ti/Al/Ti below the PV1 film. We investigated the structure of the normal PV1 film and found its topography is determined by the M2 taper topography. When the M2 taper is greater than 90° or the Al is lateral etched, the PV1 is more prone to cracks. As the PV1 film layer is uniformly deposited on the top of substrate, when the M2 taper exceeds 90°, the PV1 layer at the M2 taper position cannot be formed continuously by the normal process, resulting in PV1 cracks.

The M2 Al lateral etching is mainly occurred in the second etching process, the physical etching of SiO by chlorine gas. As the SiO under the M2 film is not easy to be etched, the etching rate needs to be low, leading most of the chlorine gas to chemically react with the lateral metal. Because the etching efficiency of Al is faster than that of Ti, the M2 taper has a concave morphology after the second step of etching (Figure 2 (a)). Two methods have been used in 7mask. 1. The structure of ILD deposition was changed from SiN/SiO to SiN/SiO/SiN under the M2. 2. The bias power of M2 etching was increased.



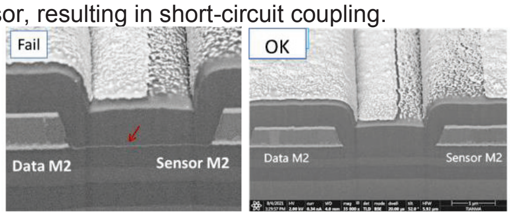
Section diagram of PV1 for (a) adding SiN layer and (b) increasing bias power of etching

Fig.3 The appearance of the PV1 film

It can be seen from Figure 3 that adding SiN layer on the SiO can effectively reduce the lateral etching degree of M2 taper, and the positive effect on the PV1 cracks reducing is obvious. No relevant defects are detected by VT electrical test. The increasing bias power of etching shows that the M2 taper is decreased from 79° to 70°, which is significant to the improvement of PV1 cracks.

3 Analysis and Mechanism Study of Short Circuit between Metal M2 Data and Sensor

7mask products appear defective at the first lighting for the VT electrical test. It was showed that the gray screen appearing purple. The failure mode was analyzed. There is metal residue between M2 data and Sensor, resulting in short-circuit coupling.



The (a) right location and (b) bad location

Fig.4 the appearance between data and Sensor

The FIB diagram shows that there is a metal-like line between M2 DATA and Sensor. The material of the M2 film is Ti/Al/Ti, and the reaction of Ti during the etching process is as follows: There may be a small amount of $TiCl_3$ and TiF_3 on the surface of the sample after M2 etching. It is known that $TiCl_3$ or TiF_3 is very easy to react with water to form titanium dioxide (reaction equation such as formula 8 & 9). Titanium dioxide is non-conductive and chemically stable, it has good stability in many inorganic and organic media, and is insoluble in water and many other solvents.

$Ti+Cl_2 \rightarrow TiCl_x$ (7)

$TiCl_3+F\bullet\rightarrow TiF_x$ (8)
$TiF_3+H_2O\rightarrow TiO_2+HF$ (9)
$TiCl_3+H_2O\rightarrow TiO_2+HF$ (10)

In order to clarify the composition of the metal between M2 DATA and Sensor, morphology with PV1 layer was investigated. Ti-like substance (Fig.5) was found between DATA and Sensor under the PV1. The failure of "gray screen appearing purple" in the PV1 product demonstrates that some chemical reactions have been occurred after PV1 deposition, which makes it conductive.

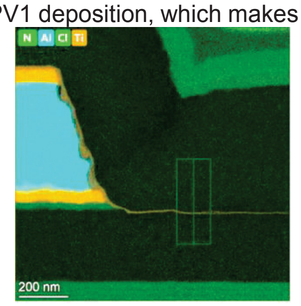


Figure 5: the Mapping image for PV1 layer

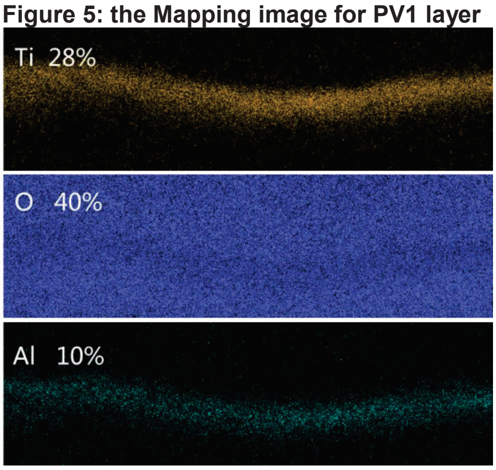


Fig.6 the mapping of image for PV1 layer

For the PV1 product, the substance generated after M2 DET should be non-conductive TiO_2. However, the composition between DATA and Sensor after PV1 film formation was characterized by EDS, and it was found that the ratio of Ti and O elements in the compound was greater than 1:2, indicating that TiO_2 had undergone chemical changes during PV1 film formation, generating substances with weak conductivity, resulting in short circuit between M2 data and Sensor. We analyzed the PV1 film-forming parameters, the SiO film-forming gas is only silane and N_2O. It is speculated that the ionized H ion in silane reacts with titanium dioxide to reduce part of titanium to metallic titanium, which makes it conductive and leads to confused display.

$TiO_2+H\bullet\rightarrow Ti+H_2O$

M2 etching and PV1 depositon were researched to solved this problem. Reducing the reaction pressure of fluorine and chlorine during the M2 etching process can reduce the $TiCl_3$ and TiF_3 formed during the etching process. Reducing the flow rate of gas containing H atoms in PV1 film forming process is also necessary. Both of methods could avoid the generation of reduced Ti. If SiN_x is used as the PV1 layer, the SiN_x film forming gas are silane, ammonia and nitrogen, it is also necessary to reduce the ammonia gas flow rate.

4 Analysis and Mechanism Study of Prickly Residue for the Hole of PV1 and PV2 Etching

The thorn-like residues were found after the etching of PV2. It can be seen from Figure 7 that PV2 has three holes, two of which have thorn-like residues. The SEM cross-section confirms that the height of the thorn-like residues is close to the height of the SiO film layer, resulting in an increase in the contact resistance of M2 and ITO2, which affects product quality.

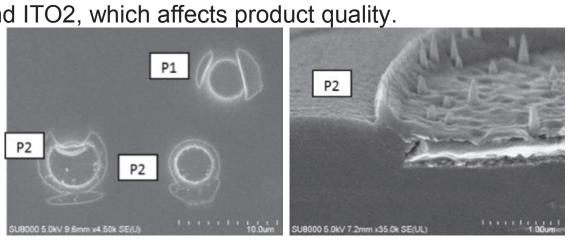


Figure 7: (a) Surface of PV2 hole and (b) Section of PV2 hole

In order to clarify the cause of the failure, it is first necessary to investigate the structure of the PV2 hole (Fig.8). The passivation layer mainly forms two kinds of hole structure. The substrate under P1 hole is ITO1 which thickness is 500A. P1 hole only needs to etch PV2 layer. P2 hole connect to the M2 and ITO2 layer. There are PV1, ITO1 and PV2 layer between M2 and ITO2. It is necessary to etch PV1 and PV2 at the same time to realize the connection between M2 and ITO2, providing electrical signals to the pixels. As Figure7 shown, The P1 hole has a good morphology and no thorn-like residue, indicating that PV1 hole etching is normal. However, the P2 hole appears thorn-like residue. This is related to the relatively complex hole structure, and may also be due to the abnormal etching of SiO.

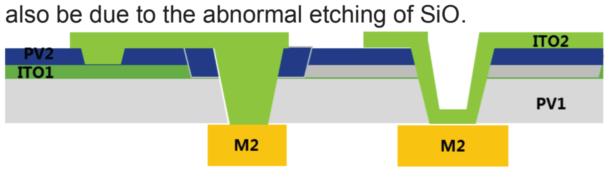


Figure 8: The structure of PV2 hole

The ITO1 was removed and thickness of ITO1 was decreased, which were used for the 7mask layer. The SEM after PV2 etching is shown in the figure 9. After the removal of ITO1, the thorn-like residue in the P2 hole completely disappeared, and at the same time, the thorn-like residue in the P2 hole became worse when ITO1 was thickened. Therefore, the thorn residue for P2 hole is strongly correlated with the ITO1 layer. When the chamber temperature increases during the film formation process, ITO1 crystals are formed above the film layer. In order to reduce the amount of ITO crystal, three methods were verified. The SEM after etching is shown in Fig.9. Firstly, increasing the water treatment process in advance in the process of ITO film formation ensures the crystallization of ITO. Secondly, reduction of ITO1 thickness also obtained the lower crystallization of ITO. Thirdly, extending the etching time makes the ITO crystallization reaction more sufficient. The improvement of ITO1 crystallization significantly improves the P2 porethorn residue, but it still cannot be resolved.

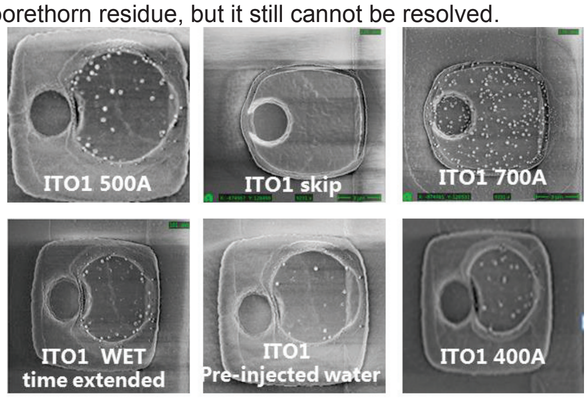


Figure 9: The SEM surface images of different ITO1

Aiming at the poor columnar shape caused by ITO crystallization, try to etch and react the remaining ITO crystals by improving the etching gas ($CF_4/O_2 \rightarrow SF_6/O_2$), so as to form a clean through-hole morphology, the through-hole morphology is clean, and the poor columnar shape is significantly improved.

5 Conclusions

In this paper, the systematic study is carried out on the related problems of 7mask technology. We detail analyzed and resulted the questions, such as: PV1 cracks, short circuit between data and Sensor, and thorn-like residue of PV1PV2 etching for the hole. The root cause of PV1 cracks is the M2 taper morphology, and improving the M2 taper morphology is an effective way. The material that causes the short circuit between M2 data and Sensor is conductive TixOy. The reduction of the etching pressure for M2 and the reduction of the gas flow rate contained H atoms in PV1 layer reduce the formation of TixOy compounds. The thorn-like residues are strongly correlated with the ITO1 crystal. The improvement of ITO1 crystallization is decreased by pre-injected water of ITO1 deposition. And the gases of PV2 etching are changed to SF_6/O_2, which is also an effective way. The adverse phenomenon has been completely improved.

References

[1] A. Kim, B. Lee, H. Kim, J. Bang, S. H. Nam, K. Park, J. Kim, S. Y. Yoon. “Effects of Ar Dilution on N2O/SiH4 PECVD for the Growth of Silicon Oxide Thin Films with Improved Breakdown Voltage Characteristics”, SID, p-11, 1078-1080 (2022).