Metal Barrier Design Enables Improving Contrast Ratio and Panel Yield for LCD Display

Jing Liu[1], Yao Sun[1], Li Guo[1], Huang-zheng Liu[1], Zhi-wei Tan[1]

liujing8@tcl.com
[1] R&D Center, TCL China Star Optoelectronics Technology Co., Ltd.,
Shenzhen, Guangdong Province, China
Keywords: Metal barrier material, Light leakage, Contrast ratio, Taper morphology, Panel yield

ABSTRACT

Theoretical and experimental characterizations reveal that the dark light leakage, which is induced by the curved corner at the cross of metal line, can be effectively weakened by decreasing the taper of metal line and increasing the length of barrier tail, finally contributing to 11.7% elevation of panel contrast ratio.

1 INTRODUCTION

For the past of few years, the display quality like contrast ratio, transmittance, visual angle, etc. become competitive elements for high order displays, especially 8K display technology. However, complex array design and metal wires are always needed for these high order display, inevitably leading to certainly crossed metal lines in the open area of panel. Related characterizations reveal that dark light leakage is generally accompanied at these crossed metal lines, where cannot be cover by black matrix, contributing to low contrast ratio for the display (Fig.1). Reducing the light leakage under zero gray so as to increase the contrast ratio is decisive for high image quality of our display, which could also provide significant directions at the step of array design when developing new display products.

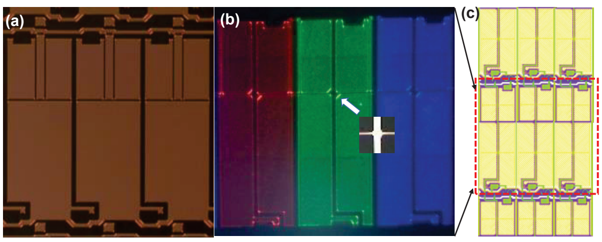


Fig. 1 (a) Light leakage pattern of array panel with only gate lines; (b) Light leakage phenomenon under zero gray of according LCD panel; (c) The array design of this LCD panel, where purple lines represent gate lines and green ones represent source and data lines.

2 EXPERIMENT

Dark light leakage induced by smooth metal corner. It is revealed that light leakage is usually limited at the crossed metal place where the inner corner of the metal line is smoothly cambered as shown in Fig. 1b. As shown in Fig. 2, if the ideal mask is used, the accordingly ideal photoresist pattern can be obtained. However, after isotropically chemical wet etching of the metal layer, the outer corner of the metal line could be perpendicular while the inner corner must be smoothly curved, which is consistent with what we observed in the actual manufacturing process (Fig. 2).

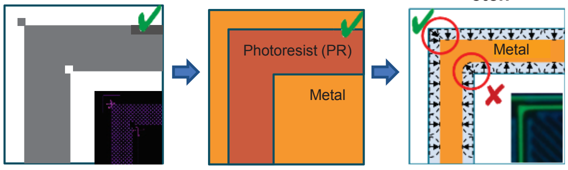


Fig. 2 The formation of cambered metal corner.

This unique dark light leakage phenomenon induced by curved inner corner of the metal line can be explained by surface plasmon polariton (SPP) which is stimulated when the electromagnetic wave travels through a metal-dielectric or metal-air interface.[1] If the electric field direction of the incident linear polarized light is not perpendicular or parallel to the trend of the metal lines (the absorption axises of the polarizer in the panel), SPP will be simulated and thus contributes to the changed electric field of the incident light. When the light with changed electric field direction travels through the liquid crystal and then arrives at the upper polarizer of the panel, the dark light leakage appears, thus leading to decreased contrast ratio of the display.[2] For the design of high order display, the ratio of metal corner in the open area will be elevated, which means the dark light leakage is a more prominent problem that needs to be overcome for these display products.

Taper angle decrease and barrier tail increase both contribute to reduced dark light leakage. Theoretical simulations are conducted to explore the factors that could possibly alleviate the phenomenon of dark light leakage with the detailed results presented in Fig. 3. If the taper of the metal is decreased or the tail of the barrier layer (the metal layer beneath the copper layer) is increased, the dark light leakage can be weakened effectively because of the decrease of effectively interactive metal-air interface area and thus lower extend change of the electric field of the incident light. Just like that shown in Fig. 3b, if the taper is decreased from 60° to 40°, the degree of dark light leakage drops to the half, which exhibits the same effect of elevating the length of the barrier tail from zero to 0.10 um. Further simulations reveal that the overlay of taper decrease to 40° and the tail increase to 0.20 um could almost eliminate the phenomenon of dark light leakage.

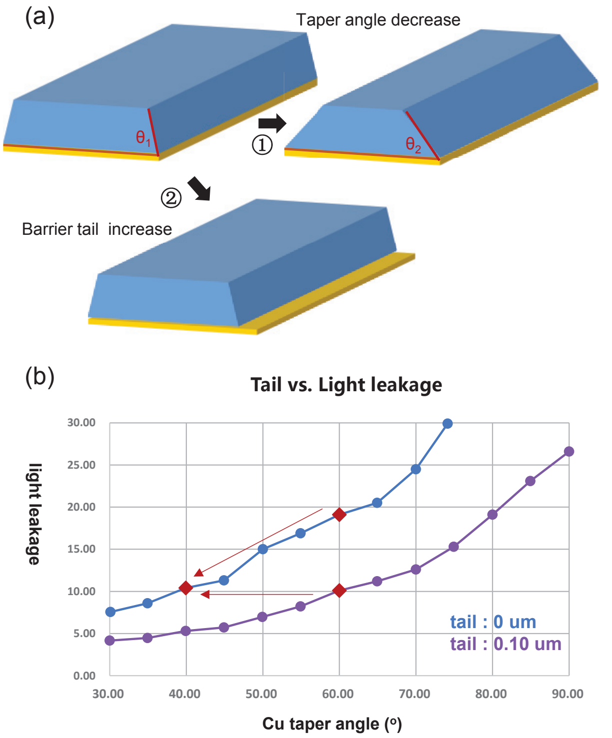


Fig. 3 The result of light leakage simulations: (a) taper angle decrease and barrier tail increase both lead to reduced light leakage of LCD panel; (b) for the contribution to light leakage, the effect of reducing taper angle from 60° to 40° resembles increasing the barrier tail from zero to 0.10 um.

On the basis of theoretical simulations, four array samples with different taper angle and tail combinations (0 um tail and taper 60°, 0 um tail and taper 45°, 0.12 um tail and taper 45°, 0.18 um tail and taper 45°) have been intentionally made for exploring the experimental effects of these two critical factors on dark light leakage as shown in Fig. 4. One thing needs to be figured out here that due to the poor resistance to oxidation and corrosion of barrier molybdenum (Mo), it is very difficult to make barrier Mo-based samples with tails. Instead, molybdnum alloys like MoTi is applied as the new barrier layer so as to get tails with different length. The dark light leakage of these array panels with only gate line pattern are quantitatively measured using the polariscope meter. If the light leakage of the sample with 0 um tail and taper 60° is regarded as the reference (100% light leakage), only reducing the taper from 60° to 45° could effectively weaken the degree of light leakage to 49%, which is in accordance with the simulated results. Then increasing the tail to 0.12 um while keeping the taper angle unchanged of 45° can reduce the light leakage to 29%. Further increase of the tail length to 0.18 um with 45° taper could reduce the light leakage to a lower degree of 21%. If the tail is keeping increasing to 0.20 um and the taper angle is further reduced to 40°, the light leakage is estimated to remain only 6% compared with the reference, which keeps well with the theoretical results.

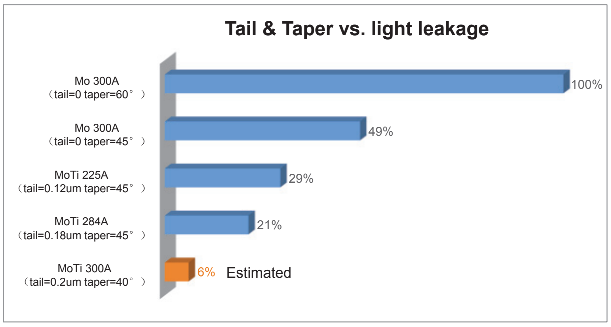
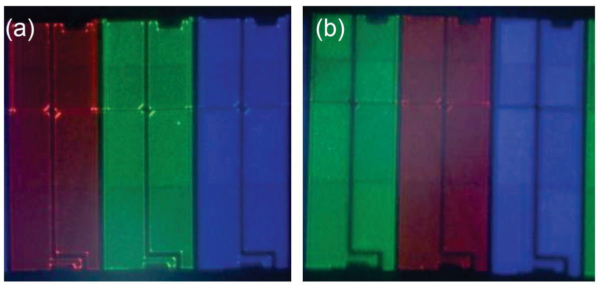


Fig. 4 The measurement of light leakage for different tail & taper combinations.

The light leakage of the panel is caused by many factors, such as particle, black matrix, liquid crystal, polarizer and the metal curved corner described in this paper. Here panels with different taper angles and tail length are made to decide the final contribution of the decrease of metal dark light leakage to the contrast ratio of the display while the other manufacturing processes of these two panels are the same. In Fig. 5a, the barrier material of the gate line is Mo with the 0 um tail and 60° taper angle. The according panel shows severe dark light leakage at the curved corner of crossed gate lines as shown in the picture. If the Mo is replaced with MoTi with a decreased taper of 45° and an increased tail of 0.18 um, the dark light leakage could be effectively weakened as shown in Fig. 5b, which is also reflected in the L_0 values of two panels. The average L_0 of MoTi-based panel is 0.0632 that is 10.5% lower than that of Mo-based one, contributing to 11.7% increase of contrast ratio of MoTi-based panel compared to Mo-based one. The strategy of taper angle decrease and barrier tail



Item	Mo 300Å Taper ~60°, Tail 0um	MoTi 300Å Taper ~45°, Tail 0.18um
	AVE	AVE
CR	4643	5189
L0	0.0706	0.0632
L255	325	325

Fig. 5 The light leakage and CR of (a) Mo- and (b) MoTi-based LCD panels.

increase described in this paper are demonstrated theoretically and experimentally to weaken the light leakage and improve the contrast ratio of the display effectively.

3 DISCUSSION

Normally, the taper of the metal line is determined by the etching acid other than the barrier materials, which is composed of many ingredients. Appropriate tuning of the component type or content could change the metal taper angle according to our own demands. By using two different etching acid, taper ~60° of Mo-based and taper ~45° of MoTi-based metal lines are obtained. However, the length of barrier tail is related to many factors, such as the material of the barrier layer, the component of etching acid and the thickness of the barrier layer. If a certain etching acid is used for MoTi-based metal line etching, the length of the MoTi tail is proportional to the MoTi thickness so that ideal tail can be designed by tuning the thickness of the barrier layer. As shown in the table of Fig. 5, taper ~45° and tail 0.18 um can be intentionally obtained by using a special etching solvent with a MoTi barrier layer of 300 Å.

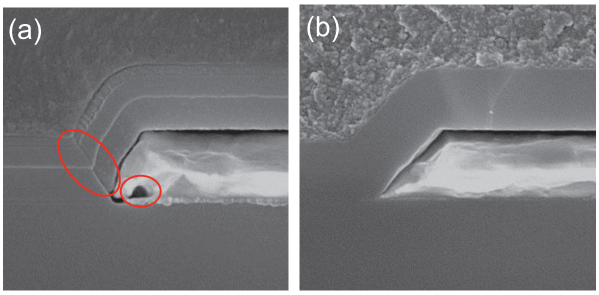


Fig. 6 The taper morphology of gate lines based on (a) Mo and (b) MoTi barriers.

Owing to the poor resistance to oxidation and corrosion of barrier Mo, the Mo-based products usually exhibit severe undercut and empty problems of metal lines， accompanied by poor step coverage like layer crack issues of the following gate insulator and passivation layers (Fig. 6a). By intentionally replacing the Mo barrier with MoTi that is more resistant to oxidation and corrosion, the metal line could maintain perfect taper morphology. Also, the following deposited layers could keep good film covering property. It has already been proven that MoTi-based products show higher panel yield and lower issue problems than Mo-based ones due to the improvement of taper morphology of metal lines.

4 CONCLUSIONS

In this paper, the phenomenon of dark light leakage is fully analyzed in order to improve the image quality of the panel. Theoretical simulations indicate that this phenomenon result from the curved corner at the place of metal cross, which however can be obviously reduced by reducing the taper of the metal and increase the length of barrier tail. Following experiments have been conducted to weaken the light leakage with the results match well with the simulations. Finally, the contrast ratio of the panel is elevated by 11.7% through metal taper and barrier material design. Besides, the panel yield could also be improved due to the curing of Mo undercut and Cu empty issues. This paper provides a novel and effective approach to improve the image quality and thus the product competitiveness for the display.

REFERENCES

[1] Barnes, William L.; Dereux, Alain; Ebbesen, Thomas W. (2003). "Surface plasmon subwavelength optics", Nature. 424 (6950): 824–830.

[2] Li-Xuan Chen; Chao Zhang; Ming-Hui Li; Hsiang-Chi Liu; Hsiao-Hsien Chen; Yung-Jui Lee; (2007). “Improving LCD Contrast Ratio by Modifying Metal Layout Design”, SID 2017 DIGEST. 894-895.