Research on the Improvement of Light Leakage Current of TFT Based on LTPS LCD High-Brightness Projector

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Abstract

Based on the LTPS LCD high brightness projector application scenario, this paper studies and analyses the reasons for the high TFT photo leakage current. The article from two aspects of the light mode into optical machine and the design of panel device, put forward to the improvement approach of the photo leakage current in the bright projector applications, effectively solve the bright projector optical machine due to light leakage current triggered by the vertical crosstalk problem. The above improvement scheme plays an important role in optimizing the image quality of high brightness projectors and effectively promotes the rapid development of LCD high brightness projectors.

Author Keywords

Light-entry mode; High-brightness projector; Photo leakage current; Photoelectric effect; Vertical crosstalk

1. Introduction

Currently, the projection technologies with market scale and more mature technology include DLP (Digital Light Processing) projection technology, LCD (Liquid Crystal Display) projection technology and LCOS (Liquid Crystal on Silicon) projection technology. Among them, benefiting from the mature and stable technical solutions of LCD panels, relatively low cost and high image quality and other advantages, LCD panels are more and more widely used in projection equipment (e.g., projectors), and at the same time, the user's performance on LCD projection equipment (including but not limited to image quality, brightness, and service life) also put forward higher requirements.The structure of LCD projector is roughly divided into five modules: light source, optical system, LCD screen, projection lens and circuit board [1].The display principle of LCD projector is: through the circuit board to control the LCD screen to display different images, the light source irradiated on the LCD screen, and through the projector system to project the corresponding images on the curtain or wall; in order to achieve high brightness projection effect, the major brands of clients continue to improve the The brightness of the light source of the optical machine. However, the high brightness of the working environment requires the LCD screen to have better light resistance, which means lower off-state current for TFT devices.

2. Approach

In contrast to the traditional application of LCDs as displays, LCDs appear as optical components in LCD projectors. The image seen by the user is the result of secondary processing by the projection system. In the projector's optical machine, the LCD screen is subjected to a long period of ageing with high brightness of the light source and high temperature. In the above working environment, not only does the LCD screen material need to be light and heat resistant, but the effective display area of the TFT device also needs to have good switching characteristics. If the TFT is affected by high temperature and bright light, it will generate a lot of light and heat carriers, which will cause the leakage current to increase and affect the screen display.

It is well known that light leakage current is an important cause of vertical crosstalk in displays [2]. In this paper, we will analyze and discuss the display problems such as vertical crosstalk caused by light leakage current in high brightness projector applications from the following three aspects:

A. From the structure of the projector's optical machine and application scenarios, we will study the projector's unique light entry mode to reduce the impact of the high-brightness light source on the pixel TFTs and improve the poor projected image quality caused by pixel leakage current.

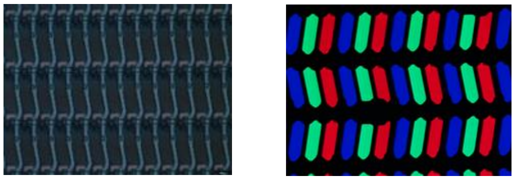
B. Starting from the LTPS material, based on the light input mode of the LCD projector from the color film substrate, use the color film to maximize the filtering of high-energy light, inhibit the generation of photo generated carriers and reduce the photo leakage current.

C. Starting from the pixel TFT structure, optimize the design of the TFT shading layer to maximize the light avoidance of the channel and improve the pixel photo leakage current.

3. Experiments and Results

3.1 Study of the light entry mode of LCD projector

The basic components of LCD liquid crystal display are divided into array substrate, liquid crystal layer and color film substrate [3]. Liquid crystal layer in the array substrate electric field driven by the rotation and light transmission, light through the color film substrate to display a different image. As shown in Figure 1(a), the array substrate has a high transmittance rate, with the transmittance level $\geqslant$ 80%, because on the array substrate is an array of TFT switches formed by metallic and non-metallic stacks, and on the other side of the switches is a pixel storage capacitor composed of transparent ITO electrodes. The color film substrate, on the other hand, corresponds to the array substrate and is designed to prevent metallic light leakage from the lattice-like BM pattern and to fill each BM window area of the RGB color resistor, as shown in Figure 1(b); therefore, the transmittance of the color film substrate is relatively low, generally around 28%.



(a) TFT (b) CF

Figure 1. TFT and CF under the microscope (50x)

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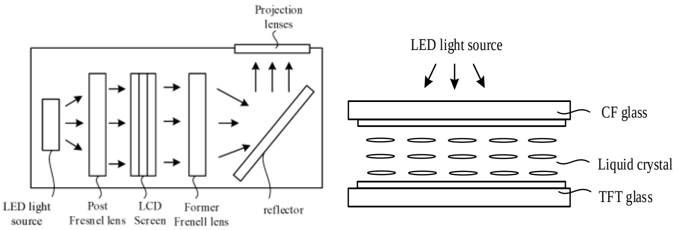
Typically, the light source for LCD liquid crystal displays is located on one side of the array substrate. And in high transmittance projector applications, the brightness of the backlight source is in the thousands or even tens of thousands of lux. In such a high-brightness environment, a different position of the light source on the LCD screen will make a huge difference in the effect. Using the characteristics of that there is a large difference between the array substrate and color film substrate of LCD's transmittance .This paper proposes in the LCD projector, the light source is placed on the side of the color film substrate, more conducive to the theoretical analysis of the projector to display the quality of image . In the mode of the light source on the side of the color film substrate, which has been filtered out up to 70% of the brightness when the light through the color film substrate, so the light intensity irradiated on the array substrate TFT devices will be greatly weakened, and the photo leakage current of TFT is greatly reduced, as shown in Figure 3.



(a) LCD projector structure

(b) The position relationship between the light source and the LCD

Figure 2. Schematic diagram of the direction of entry light of the LCD projector

3.2 Study of the photoelectric effect of LTPS materials

According to the characteristics of semiconductor materials, when light irradiates the semiconductor P-N junction, if the energy of the photon is greater than or equal to the forbidden band width of the semiconductor, the electrons in the valence band absorb the photon and enter the conduction band, generating electron-hole pairs, and this type of carrier is called photo generated carrier [4].According to the photoelectric effect, it is known that when the light energy absorbed by a semiconductor material is greater than its forbidden band width.

$$h*v \geqslant E(g) \quad (1)$$

(v is the frequency of light, h is Planck's constant, E(g) is the forbidden band width)

$$v=c/\lambda \quad (2)$$

$$\lambda \leqslant h*c/E(g)=1240/E(g) \; (\lambda \text{ unit: nm}) \quad (3)$$

Substituting the forbidden bandwidth of different materials into the formula gives the maximum wavelength that can be detected.

Table 1 . Bandwidth and cut-off wavelength of different semiconductor materials

semiconductor material	single crystal silicon	polycrystalline silicon	amorphous silicon	IGZO
bandwidth (eV)	1.12	1.23	1.70	3.50
cut-off wavelength (nm)	1107	1006	729	354

In order to be able to maximize the suppression of photo generated carrier production in the LTPS substrate, the spectrum of the projector light source was analyzed (as Figure.3);

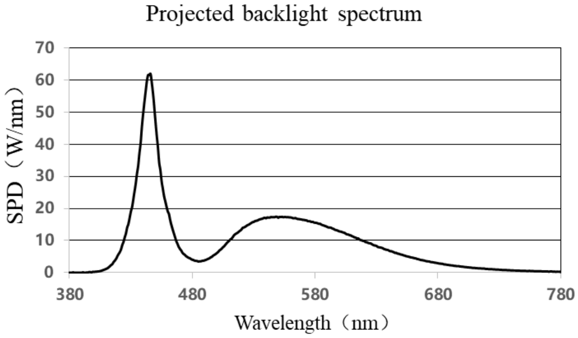


Figure 3. Spectral diagram of the projector light source

The leakage current of the pixel TFT with different wavelength bands is measured: Superimposed the color filter on the light source, then irradiate the TFT and test the transfer characteristics curve of TFT. The test results are shown in Figure 4, the TFT leakage current is highest with the blue light and lowest with the red light.

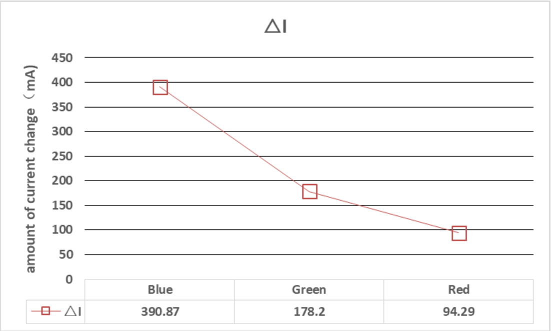
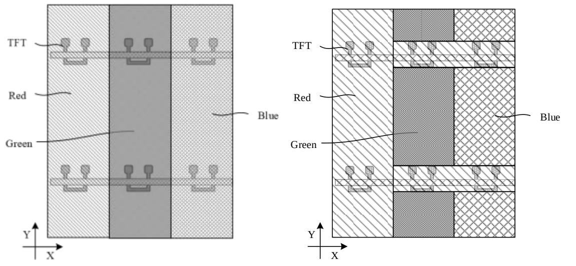


Figure 4. Leakage current level of LTPS TFT under different light sources

In general, in order to display the image without distortion, the RGB ratio is 1/3 of the whole pixel, and the ratio of red light, green light and blue light through the color film substrate is the same. In this paper, based on the experimental conclusions that blue light has the greatest impact on the TFT, red light is the smallest, combined with the spectral analysis of the projector's light source: the color film substrate side of the incoming light, the RGB color resistance restructuring and distribution, can be achieved on the irradiation to the TFT device on the filtering and selection of light.

The implementation of the scheme is as follows: replace the Blue resin with Red resin at the TFT device position, or replace both Green & Blue resin with Red resin at the TFT device position; expand the area of Red on the colored film substrate to enhance the transmission ratio of red light; reduce the energy of light irradiated to the TFT device to weaken the influence of light on the TFT, and improve the light leakage current as shown in Fig.5. Green and Blue pixel position, lateral light resistance, can be filtered and selected on the light irradiated to the TFT device. Blue pixel position, the width of the Red resin should be block the channel of pixel TFT$\geqslant \pm 2.0$ μm. Besides, this area is covered by BM to prevent the Red leakage of light to bring about the problem of the image heterodyne.



（a）before Optimization （b）after optimization

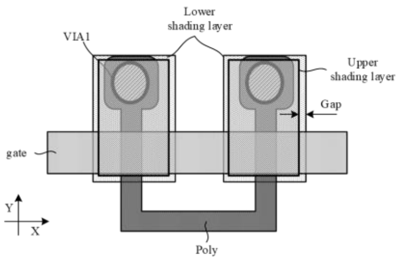
Figure 5 . Schematic design of colored film substrate (without BM layer)

3.3 Optimization of the pixel structure

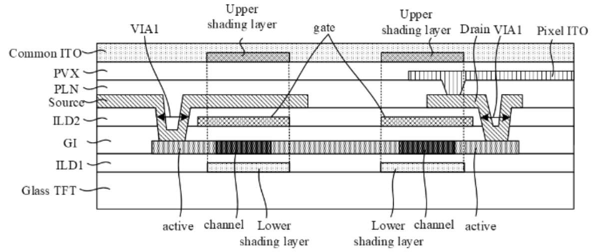
In conventional application products, BM graphics on the color film substrate can solve the problems of light leakage and color crosstalk on the screen. Light leakage: metal pattern will appear rounded after etching, when the light passes through the LCD box will be deflected and light leakage will occur, therefore, there should be a BM blocking design in the position of the metal pattern; Color crosstalk: in order to prevent the mixing of colors between the RGB, there should be a BM pattern design between the RGB.

In the projector applications that the light-entry mode with the CF side into the light, BM in addition to the above role of the light leakage and color crosstalk, a more important role is the shading layer of the TFT device; although the Shading performance of BM is very good, but due to the BM which designing on the color film substrate, and the TFT is designed on the array substrate. In order to achieve the full shielding of the TFT switch channel by the BM, the accuracy of the cell is crucial. When the alignment control is poor, and the BM fluctuates upward or downward relative to the gate of pixel TFT, there is inadequate shading of the TFT trench or even bare, and the incident light from the color film substrate will directly irradiate the device trench, resulting in higher light leakage current; in addition, the misalignment of the BM will also affect the aperture ratio of the pixel , resulting in fluctuations in the transmittance rate of the panel, which will affect the quality of the product.

High-brightness projectors require extremely high screen transmittance, so in order to enhance the aperture ratio, the size of the BM is constantly compressed, which is contrary to the BM fully shading the TFT channel; this paper proposes an optimization scheme for the pixel TFT structure to address the above issues, and designs a double-shading layer structure on the array substrate, as shown in Fig. 6.



（a）the plan of pixel TFT （dual gate）



（b）the cross section of pixel TFT（dual gate）

Figure 5 . Schematic diagram of the double shading layer scheme

The double shading layer design is to design a shading layer above and below the TFT active layer, and the channel is treated with light, which can effectively prevent the impact of the incident light of the projector and the reflected light generated by the optical system on the TFT device. In addition, the shading layer is designed on the array substrate to better control the alignment fluctuation of the shading layer and the channel, and improve the shading effect. The design scheme of the double shading layer can cancel the BM in the gate direction on the color film substrate, which not only solves the problem of high light leakage current of the LCD screen of the high-brightness projector, but also improves the uniformity of transmittance of batch products.

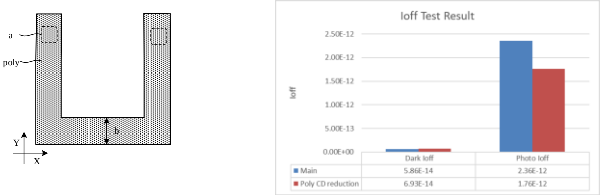
In the double-shading pixel design, the upper shading layer is located after the passivation layer and before the common electrode. It is short-circuited with the common electrode layer, which effectively avoids the problem of floating electrodes above the gate line and affecting the pixel TFT characteristics. The key function of the upper shading layer is to block the stray light in the LC cell and the light source, so the upper shading should ensure that the pixel TFT channel (including the LDD channel of the NMOS TFT) is fully blocked. Considering the fluctuation of CD and layer OL, the upper shading layer is required to cover the LDD channel ⩾ 1.3 μm, on the opposite side of the source drain, and the upper shading layer is required to cover the vias of source and drain.

The lower shading layer is far away from the light source side, but the reflector and Fresnel lens will produce strong reflection in the structure of the projector, the impact on the TFT switch is also great, so the lower shading layer is also a key layer to protect the device channel. The lower shading layer is designed on the first layer of the array substrate and is in direct contact with the glass substrate. Considering the influence of the upper and lower shading layer CD and Overlay on the product opening, the shading layer CD away from the light source side can be appropriately reduced, and when the CF surface enters the light, the upper shading layer CD ⩾ the lower shading layer CD, Gap=1.1 μm (CD and OL fluctuations are controlled according to 0.6um). During implementation, the distance from the shading layer to the active layer < 4000 Å [5].

Considering the requirements of pixel aperture ratio, the size of the shading layer on the array substrate is limited. Based on the root cause of the light leakage current of TFT devices, TFT with different active layer sizes were designed to test the light leakage current. The test results show that reducing the active layer Pad (a) at the source-drain end of the TFT device and the poly connection line (b) between the two TFT can effectively reduce the light leakage current of the TFT device, as shown in Figure 7.

4. Conclusion

In this paper, based on the analysis of the characteristics of projector applications and market demand for LCD projectors, we adjust the entry-light direction of the LCD screen, make reasonable use of the low transmittance of the colored film substrate, reduce the light intensity irradiated to the TFT device by about 50%, and greatly reduce the light leakage current of the pixel TFT. Combined with the optoelectronic properties of semiconductor materials, optimize the openings of different color resistances on the colored film substrate to enhance the penetration efficiency of low wavelength light and reduce the impact of high-energy light on the polysilicon, thus reducing the sensitivity of Poly to light. Reducing the area of the source layer and superimposing the TFT double shading layer design can effectively isolate the impact of the projector's high-brightness light source on the TFT device of the LCD screen, maximizing the reduction of light leakage current, and improving the vertical crosstalk and other picture quality problems caused by high light leakage current.



	Dark Ioff	Photo Ioff
🟦 Main	5.86E-14	2.36E-12
🟥 Poly CD reduction	6.93E-14	1.76E-12

（a）schematic diagram of active layer （b）Light leakage current results

Figure 5. Comparison of optical leakage current before and after active layer area optimization

5. Acknowledgements

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