Integrated Novel Light-Shield Metal with Sub Pixel Design Technology for High Transmittance Liquid Crystal Display

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ABSTRACT

A novel light-shield material with sub pixel design technology for high transmittance liquid crystal display (LCD) was proposed in the first time. We fabricated and characterized Low-Temperature Polycrystalline-Silicon Thin-Film Transistors (LTPS TFTs) backplane with high reflectivity light-shield metal (SM) embed in new sub pixel designs on a glass substrate, which can be applied to high transmittance display products. And the technology has been integrated to a 16-inch WQXGA (Wide Quad XGA, 2560*1600) LCD for green low-power display application.

Author Keywords

LTPS TFTs, Low-power LCD, Green NB

1. INTRODUCTION

In today's digital and mobile office era, laptops have become a necessity for our daily lives and work. With the advancement of technology, recent notebook computers have significantly improved in display effects and power management. High-transmittance LCD monitors use low-power backlight technology and its power-saving features to bring users benefits such as improved display effects, energy saving, improved heat dissipation, environmental protection and laptop usage cost saving.

And the development of liquid crystal display (LCD) technology aims to provide better electro-optical performance, such as wide viewing angle, fast response time and high contrast, while improving transmittance and liquid crystal efficiency are two key requirements to meet better electro-optical performance and then to increase competitiveness with OLED displays.

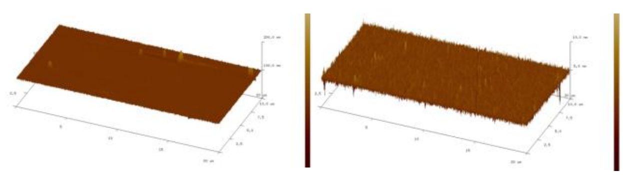
In this study, our new type of light-shield new-Alloy material has added high reflectivity from 53.7% up to 89.6% in average wavelengths scanned from 400nm to 800nm by Perkin Elmer Lambda 800 UV/Vis/NIR Spectrophotometer compared with Molybdenum metal, effectively enhancing the light usage efficiency of backlight and achieving new pixel design driving low brightness backlight of new high transmittance LCD to realize low power consumption application without loss image quality [1]. We also employed Fast-Response AFFS (Advanced Fringe Field Switching) liquid crystal technology and data driver IC using multiplexer circuit, resulting in green low cost and small border architecture platform of laptop introduced recently.

2. Experiment and Results

2-1 Material Properties and Process

High reflectivity new-Alloy metal layer was first deposited by physical vapor deposition (PVD) and patterned on glass substrate as light-shield metal (SM) layer. The buffer layer was deposited by plasma enhanced chemical vapor deposition (PECVD) on glass. N type channel LTPS TFTs were then fabricated on a buffer layer and an amorphous-Si layer of 43nm thick was deposited and crystallized into a polycrystalline silicon film by excimer laser annealing (ELA) [2]. After defining the active region, SiOx and SiNx were deposited as the gate dielectric, and resulted in a dual layer insulator of equivalent oxide thickness (EOT) =122.4nm. Next, the metal gate electrode, Molybdenum (M1), was deposited and patterned. After gate fabrication processes, the N+ and N- regions were defined by ion doping and formed the lightly doped drain (LDD) of 0.8μm. After the deposition process of the inter layer dielectric (ILD), Source/Drain (SD) metals were deposited and formed. The coating and photolithography process of the organic layer (or PL: planarization layer) for high aperture application was subsequently formed. The final steps involve passivation layer deposition and ITOs patterning to form an array backplane for a 16-inch AFFS laptop LCD.

Figure 1 illustrates the surface morphologies of new-Alloy metal by Atomic Force Microscope (AFM) before and after RTP treatment (temperature < 600℃) and the average roughness (Ra) of new-Alloy thin film are 1.49nm and 2.64nm. There is less risk of hillocks causing some damage to worse the interface quality between light-shield metal and buffer layer.



(a) (b)

Figure 1 Images of single thin films with new-Alloy metal before and after RTP treatment. **(a).**The surface average roughness (Ra) with new-Alloy metal film is 1.49nm before RTP treatment. **(b).**The surface average roughness (Ra) with new-Alloy metal film is 2.64nm after RTP treatment.

Figure 2 exhibits the average reflectivity of Molybdenum and new-Alloy metals. The average reflectivity of new-Alloy metal is 89.6%, which is 1.67 times larger than that of Molybdenum metal between 400nm to 800nm wavelengths sutible to collect and reuse light from LCD backlight module. Table 1 shows new-Alloy metal has higher optical density (OD) than Molybdenum metal at the same thickness enough for avoiding light from bottom side to affect thin film transistors (TFTs), especially polycrystalline silicon (poly-Si) of active layers such as light leakage current of TFTs. By means of high reflectivity new-Alloy material reusing light without affecting the electrical characteristicsof the TFTs array, combining LCD sub pixel design will have the opportunity to increase light transmittance of overall display without affecting the aperture ratio of sub pixel.

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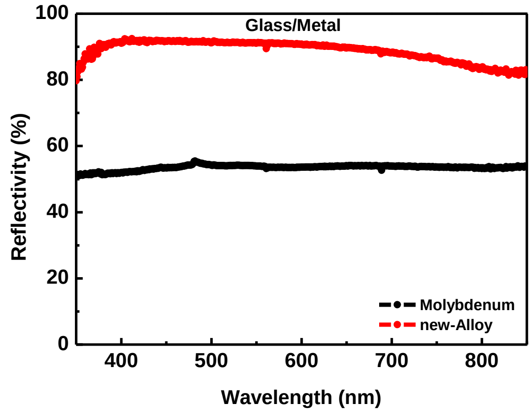
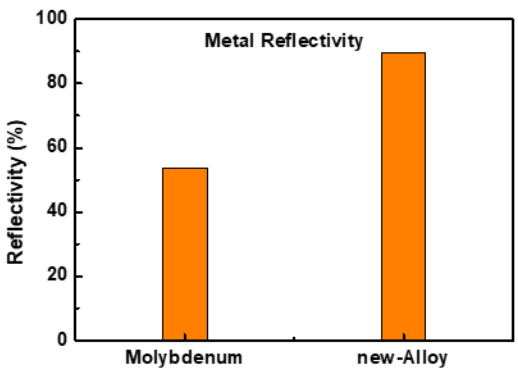


(a)



(b)

Figure 2(a). Reflectivity of Molybdenum and new-Alloy materials on glass substrate with different wavelengths **(b).** Average reflectivity of Molybdenum and new-Alloy materials on glass substrate between 400nm to 800nm wavelengths

Table 1 Comparison of optical density with Molybdenum, new-Alloy and black resin materials on glass substrates

Material	Thickness	Optical Density (OD)
Molybdenum	T< 1000 Å	2.306
new-Alloy	T< 1000 Å	3.307
Black Resin	~1um	4~4.2

Table 2 lists the specification of 16-inch WQXGA LCD product with Low-Temperature Polycrystalline-Silicon Thin-Film Transistors (LTPS TFTs) backplane employed in high resistivity light-shield metal material and new sub pixel design of a liquid crystal display. Next explanation, re-designs of sub pixel of 16-inch WQXGA LCD can achive more high transmittance of display judged by optical simulation of sub pixel and optical transmittance measurement with KONICA MINOLTA CM-2600d.

Table 2 The specification of a 16-inch LCD

The Specification	
Resolution	2560*1600
Pixel Per Inch	189
Border Width (mm)	1.95/1.95/1.95/5.1mm(U/L/R/D)
Brightness	500nits typ.
Contrast Ratio	1800:1
Power Consumption	5.8W typ. (Logic + BLU power @Mosiac pattern)

2-2 Simulation Result

Figure 3 shows the schematic diagram and main optical path of the LCD module [3]. There are two main types of paths, one path goes from the backlight unit (BLU) directly through the pixel unit without being reflected by any metal lines. Another type of light consists of light emitted from the BLU, reflected by a metal wire, and returned to the BLU for reuse. For different types of light passing through, this study call them the 1st optical path and the 2nd (or Nth) optical path. The first light route is defined by passing directly through the LCD cell, and the second or N light route is defined by additional light reflected from the metal wires for reuse.

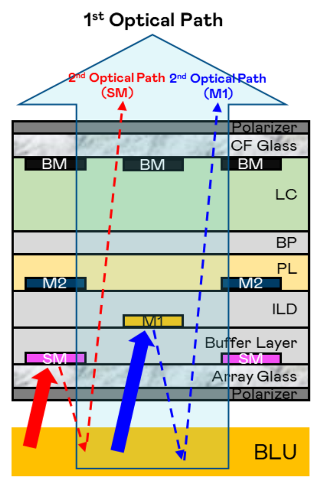


Figure 3 Schematic of optical paths of light from backlight unit (BLU) with LCD module including BLU, TFTs array, liquid crystal (LC) and color filter (CF)

In order to analyze how much new sub pixel brightness gain which is defined as total transmittance in new sub pixel design divides by total transmittance in normal sub pixel design of type Chip 1 contributing to transmittance (T%) of sub pixel level, we estimate it through simulation. When light passes through the cell from the BLU, it can be divided into two main paths. The first one is directly passing through the cell (1st), and its transmittance is defined as T_1. Transmittance T_1 for the 1st optical path is given by Equation (1).

$$T_1 = T_{TFT} \times LC\% \times T_{CF} \times AR\% \times T_{PI} \times T_{AOC} \quad (1)$$

Among them, T_{TFT} is the transmittance of the glass on the TFT side plus the stacked structure of each thin film layer, the alignment film, T_{CF} is the average transmittance of the RGB three-color color resistor, T_{PI} is the transmittance of the alignment film on the CF side, and T_{AOC} is the anti-static coating of the glass surface up the CF side. The penetration rates are simulated by TechWiz 3D simulation software for different designs of liquid crystal efficiency. The AR% is the percentage of the effective light-transmitting area in the entire sub pixel. The second path is for the light of BLU to be reflected by the lowermost metals (SM and M1) and then return to the BLU for light extraction. The efficiency of this kind of light recycle can be defined as E. When the metal used in SM is different, the efficiency of light recycle will be different, where Molybdenum (Mo) reflection with SM is defined as E_{Mo} and new-Alloy metal reflection is defined as $E_{new\text{-}Alloy}$, light recycling efficiency is given by Equation (2) and (3).

$$E_{Mo} = \text{BLU} \times (AR_{M1} \times R_{Mo} + AR_{SM} \times R_{Mo}) \times L \quad (2)$$

$$E_{new-Alloy} = \text{BLU} \times \left(AR_{M1} \times R_{Mo} + AR_{SM} \times R_{new-Alloy}\right) \times L \quad (3)$$

Among them, AR_{M1} and AR_{SM} are the area ratio of M1 and SM in the entire sub pixel design, R_{Mo} and $R_{new\text{-}Alloy}$ are the average metal reflectances of Mo and new-Alloy at visible light wavelengths. L is the non-polarization value starting from BLU, passing through the lower polarizer, and the loss of each layer of coating. The transmittance of light after one reflection from M1 or SM metal can be defined as T_2, and the transmittance of light after N reflections can be defined as T_{N+1}, T_{N+1} is given by Equation (4).

$$T_{N+1} = T_1 \times E^{N+1} \quad (4)$$

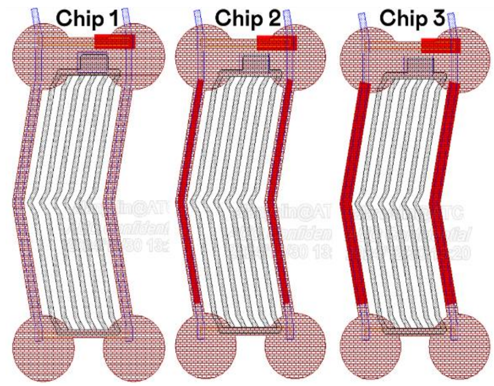
Finally, it can be known from the simulation results that using type Chip 1 as the standard design, when SMs with different area ratios are added under the data line, type Chip 2 and type Chip 3 can achieve brightness gains of 101.96% and 103.66%, respectively in Table 3.

Table 3 The simulation results of total transmittance in different sub pixel design in liquid crystal display, type Chip 1 or 2 or 3, then to get brightness gains which is defined as total transmittance in pixel design/ total transmittance in pixel design of Chip1, total transmittances ratio value

		Chip 1	Chip 2	Chip 3
Transmittance of the 1st Optical Path	T_1	**6.01%**	**6.01%**	**6.01%**
Transmittance of AOC	T_{AOC}	9x%	9x%	9x%
Transmittance of Polyimide	T_{PI}	9x%	9x%	9x%
Aperture Ratio of CF Substrate	$AR\%$	7x%	7x%	7x%
Transmittance of CF Substrate	T_{CF}	3x%	3x%	3x%
LC Efficiency	$LC\%$	3x%	3x%	3x%
Transmittance of TFT Substrate	T_{TFT}	9x%	9x%	9x%
Light Recycling Efficiency	E	**1.14%**	**3.02%**	**4.60%**
Optical Path Loss	L	40.00%	40.00%	40.00%
Area Ratio of M1	AR_{M1}	1.63%	1.63%	1.63%
Area Ratio of SM	AR_{SM}	2.22%	7.44%	11.86%
Reflectance of Molybdenum	R_{Mo}	53.70%	53.70%	53.70%
Reflectance of Aluminum-alloy	$R_{Al\text{-}alloy}$	89.62%	89.62%	89.62%
Initial BLU Brightness	BLU	100%	100%	100%
Total Transmittance	T	**6.07%**	**6.19%**	**6.30%**
1st Optical Path	T_1	6.01%	6.01%	6.01%
2nd Optical Path	$T_2=T_1*E$	0.07%	0.18%	0.28%
3rd Optical Path	$T_3=T_1*E^2$	0.00%	0.01%	0.01%
4th Optical Path	$T_4=T_1*E^3$	0.00%	0.00%	0.00%
Brightness Gain		**100%**	**101.96%**	**103.66%**

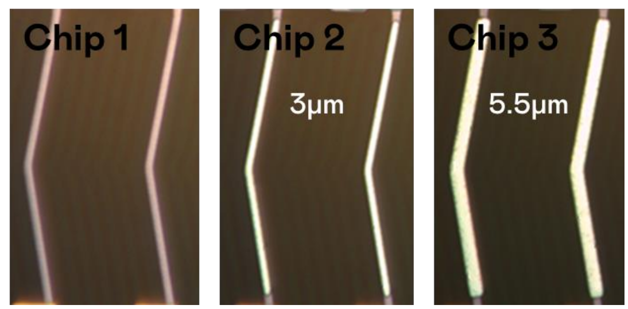
2-3 Sub pixel design with light-shield metal

In order to increase the reflection area causing light transmittance rising of overall display as much as possible without affecting the aperture ratio of pixel design, the new type light-shied metal (SM) width added to 3um and 5.5um under the data lines of LCD. The proportions of SM area with entire sub pixel area in types (Chip1, 2, 3) are 2.22%, 7.44% and 11.86% respectively shown in Figure 4(a), Figure 4(b), Figure 4(c). Figure 5 shows that light-shield metal widths along data line under optical microscope check and the measured values are close to parameters of simulation.



(a) (b) (c)

Figure 4 Designs of different SM area embed in sub pixel as light switch unit of liquid crystal display **(a).**Normal pixel design (type Chip 1) with SM under poly-Si of active layer **(b)**.Pixel design of type Chip 2 with 3 μm wide of narrow SM under the data line of light switch unit expect protective layer of poly-Si **(c)**.Pixel design of type Chip 3 similar to type Chip 2 with 5.5 μm SM no larger than black resin (BM) width



(a) (b) (c)

Figure 5 SM width under data line images by optical microscope **(a).**Type Chip 1 without new-Alloy metal **(b).**Type Chip 2 with 3 μm width of new-Alloy metal **(c).**Type Chip 3 with 5.5 μm width of new-Alloy metal

2-4 Reflectivity from TFT side

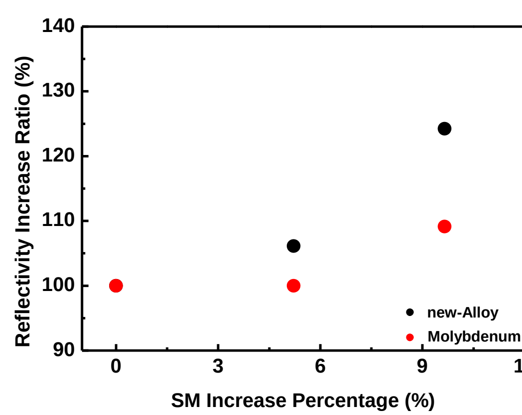


Figure 6 Relationship between reflectivity increase ratio and light-shield metal (SM) increase percentage

Figure 6 shows the reflected light recycling efficiency of two different metals depends on the reflectivity. The amount of light that can be recycled under different SM area ratios is directly related to the reflectivity. This can be normalized by measuring the reflectivity on the TFT side. It can be clearly analyzed that the new-Alloy is more efficient at recycling light than the normally used metal, Molybdenum, and that the amount of light reflected back into the BLU by both metals is positively correlated with the increase in SM area. When more recycled light is reflected back to the BLU, it means that the BLU light utilization rate increases, which means that under the same power drive, a higher BLU brightness can be obtained, thereby increasing the overall transmittance of a display.

2.5 Panel Transmittance

The actual panel transmittance is obtained by measuring the BLU brightness by goniophotometers (DMS 903) and the Panel brightness by luminance meter (Konica Minolta CA-410), and then dividing the Panel brightness by the BLU brightness. When the SM area of Molybdenum or new-Alloys increases, the actual panel transmittance T% increases. The actual panel brightness gain is measured based on the transmittance standard of the new-Alloy panel designed by type Chip 1. The gain value can be obtained by dividing the transmittance of type Chip 2 or type Chip 3 by type Chip 1. The gain values are 101.86% and 103.31% respectively shown in Figure 7. This values and the simulation results, the gain values provided in Table 2, 101.96%, 103.66%, consistent. This result can further prove that without losing the aperture ratio and without increasing the cost, the newly added SM area can be used as the BLU reflective layer so that the BLU light brightness can be reused and the total power consumption can be reduced from 5.8W reduced to 5.6W, saving 3.4% of energy consumption by maintaining the same panel brightness of standard type.

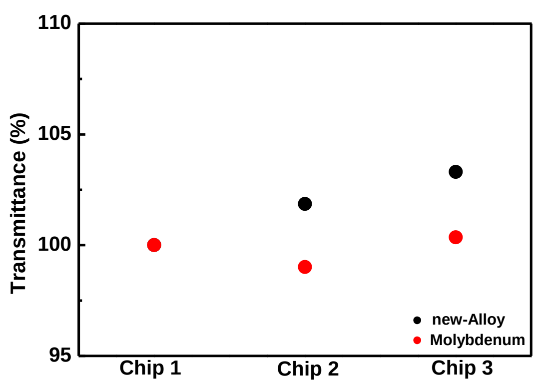


Figure 7 Panel transmittance of different SM design embed in sub pixel under Molybdenum and new-Alloy metal materials

Figure 8 shows the sub pixel images and color screens with type Chip 1 and Chip 3 designs, it can be observed that when the SM covering area becomes larger, there is a slight increase in the brightness of the sub pixel, indicating that the enlarged SM area can indeed increase T%. When observing the overall picture, the picture still remains sharp, and the contrast will not be affected by the addition of metal area under the data line, and it still remains at 1800:1.

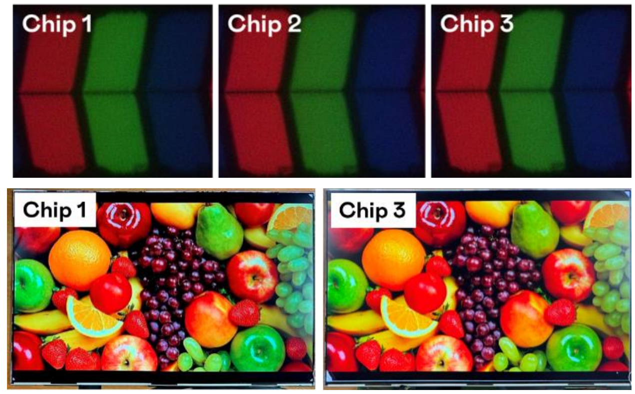


Figure 8 16-inch WQXGA LCDs with new sub pixel design of new-Alloy SM and sub pixel images by optical microscope

3. SUMMARY

A LTPS 16-inch WQXGA LCD with high reflectivity light-shield metal embed in new sub pixel design and fast response time AFFS (Advanced Fringe Field Switching) has been developed, which has panel brightness gain value 103.31% and 5.6W of total power compared with 5.8W of normal panel design, saving 3.4% of energy consumption by maintaining the same brightness. Those technologies of the panel achieves a 1800 contrast ratio, 500nits brightness, multiplexer circuit of LTPS TFTs and brightness gain value 103.31% for green low-power display application.

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