A Four-Ways Viewing Angle Controllable Display using Specify Pixel Structure and Separated Rubbing Method

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ABSTRACT

We present a viewing angle controllable display capable of displaying in two viewing modes, i.e. wide view mode and four-ways privacy mode. Pixel is divided into two domains of perpendicular LC orientation direction with separated rubbing method. By controlling the LC phase retardation at off-axis, viewing angle switching realized.

1. INTRODUCTION

With the development of the liquid crystal display (LCD) technology, wide view angle technique has become more and more mature. People are paying much more attention on personal privacy as well as they are enjoying on the benefits of the wide view technology. On one hand, wide view angle mode is necessary on the case that the requirement of interesting things sharing on public occasion, on the other hand, privacy mode is required in these display functions such as mobile electronic devices such as the mobile phone, and notebook computer. In order to do that, viewing angle controllable (VAC) device is required which can switch wide viewing angle mode and privacy mode up to the user. To obtain viewing angle controllable, various methods have been proposed on recent years by adopting dual backlight systems or single panel technology with three-terminal electrodes, or using large optically anisotropic behaviors of twisted-nematic LCs [1-3]. All these methods disclosed privacy mode with two-ways, meaning only with horizontal privacy, or three ways privacy mode except that downward view. Information can still be observed because of wide viewing angle happened in vertical directions. In these situations, privacy function disappeared as user switch between landscape screen display and portrait screen display of device.

In this paper, we discuss a viewing angle switching fringe field switching (FFS) TFT- LCD that can solve the problem mentioned on above. Four ways privacy i.e. horizontal privacy and vertical privacy mode bring us benefits to change privacy view direction freely let alone switching between the landscape and the portrait. Phase retardation of liquid crystal (LC) at off axis in horizontal and vertical direction are investigated in this work, meanwhile, process flow of a new rubbing method for perpendicular LC orientation direction dominated in each domain of pixel is proposed. Optical characteristics are also calculated to confirm our new structure for viewing angle controlling between four ways privacy mode and wide viewing angle mode.

2. STRUCTURE and OPERATION PRINCIPLAE

The proposed viewing angle controllable (VAC) device consists of a color filter layer, a thin film transistor layer and a positive nematic liquid crystal layer sandwiched between them. Schematic diagram of the proposed VAC FFS LCD and orientation of LC molecules dominated in each domain are depicted in Figure 1. Bias electrode is setting on top plate, here named as CF bias electrode. There is an insulator using passivation layer between pixel electrode and common electrode on bottom substrate. The orientation of LC molecules in sub pixel-A and sub pixel-B is mutually perpendicular.

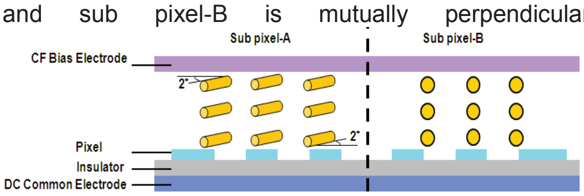


Fig. 1 Schematic diagram of the proposed VAC FFS LCD and orientation of LC molecules dominated in each domain

The "Separated rubbing" method is considered to be suitable for use to realize different alignment direction. The process flow of the "Separated rubbing" method is shown in figure 2. In this method, firstly, the entire photo resist (abbreviated PR) layer is coating on the pre-clean substrate, then exposed with a metal mask with holes whose shapes are the same as those of one kind of divided area likes sub pixel-A area or sub pixel-B area, followed by development. After the separated area is defined, polyimide is printed on the treated substrate, then pre-baked and post-baked. The entire alignment layer is treated by conventional rubbing process. One LC orientation direction of one of the divided domains completes after lifting the PR off. Next, repeating the above process to perform a second rubbing treatment in the perpendicular direction. With the exception of the separated rubbing process, the display is manufactured using the conventional LCD production process.

As shown in Figure.3, the pixel is made of two sub-pixels distinguish by distribution direction of slit electrode, they plays role of primary unit on bottom plate, and operated by the same transistors. The aperture ratio designed between sub pixel-A and sub pixel-B should be keep in balance to ensure the visual symmetry.

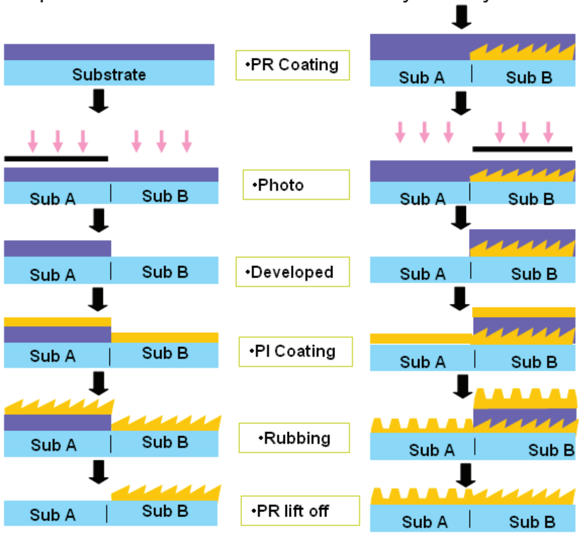


Fig. 2 Separated rubbing process flow of the proposed VAC FFS LCD

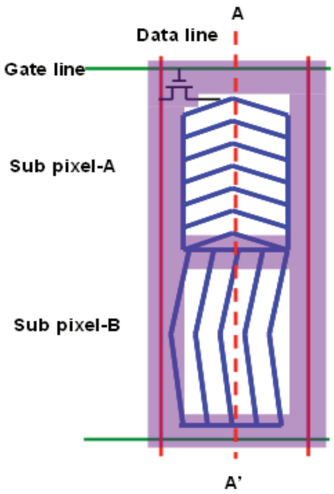


Fig.3 Pixel designed of the VAC FFS LCD

The optical transmittance of a homogeneously aligned nematic LC layer between crossed polarizer can be given as

$$T = \sin^2(2\varphi)\sin^2\left(\frac{\Gamma}{2}\right) \qquad (1)$$

Where φ is the LC director angle with the transmission axis of the bottom polarizer as the reference and Γ is the in-plane phase retardation, and the effective retardation in oblique direction of the LC layer in the proposed display mode can be expressed as followed [4]

$$\Gamma_{LC} = \frac{2\pi d}{\lambda}\left[ne\left(1-\frac{\sin^2\theta\sin^2\phi}{n^2{}_e}-\frac{\sin^2\theta\cos^2\phi}{n^2{}_o}\right)^{1/2}-n_o\left(1-\frac{\sin^2\theta}{n^2{}_o}\right)^{1/2}\right] \qquad (2)$$

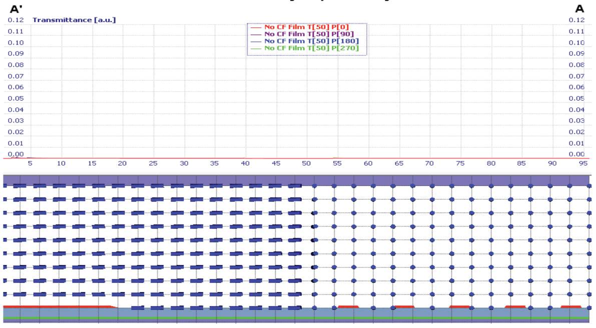
Here, Γ_{LC}, θ , ϕ and d represents the phase retardation of the LC layer at the oblique incidence, the polar angle of the incident light in the LC layer, the azimuth angle of the incident angle and the thickness of the LC layer, respectively. According to the equation (1), it should be required that Γ is π and the rotating angle of the LC φ is 45° to achieve a fully white state, while φ should be zero to achieve a dark state in the normal direction. Based on equation (2), the effective retardation is proportional to sin2θ. The retardation of the LC layer becomes never zero and is changed as functions of the misalignment between LC layer and the polarizer in the oblique direction. Consequently, the analyzer cannot completely absorb the elliptically polarized light leading to light leakage off-axis. To obtain a wide viewing angle just like FFS mode, Γ_{LC} should be close to zero to achieve a good dark state at the off-normal axis. As for privacy mode, we can control the light leakage at off axis by changing the tilt angle because of Γ_{LC} have some value in oblique view, this light leakage in the dark state deteriorates the CR in oblique direction and thereby realized narrow viewing angle display.

According to equation (1) and (2), in order to obtain fully bright state, strong fringe electric potential is necessary between pixel and common electrode on array to lead to the LC molecular Φ tends to be 45 degree, and weakening the potential between bias electrode on top plate and bottom plate. At this time, the potential of bias electrode is the same as the DC common electrode.

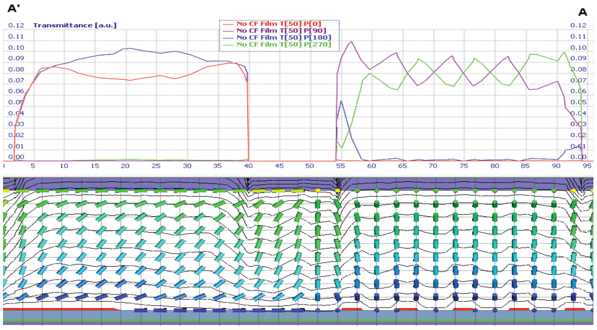
3. RESULTS and DISCUSSION

Optical analysis for the proposed configuration is carried out here to confirm the viewing angle controllable function of our proposed LCD. The retardation for the VAC cell is 0.335μm with d = 3.3μm and a surface tilt angle of 2° both of the ceiling and floor side. The dielectric anisotropy of the LC is 9.5 with elastic constants k11 = 11.5 pN, k22 = 5.75 pN and k33 = 13.8 pN. The thickness of the pixel electrode and DC common electrode are 0.06μm, and the width of the pixel electrode and the distance between them are 2.5μm and 5.5μm, respectively.

From the cross section view of the proposed VAC cell with the LC direction along A-A' see in figure 4(a), it confirms that when no potential difference between CF bias electrode and DC common electrode, lower tilt angle of LC in both of the divided areas, little light leakage at all directions. In this case, wide viewing angle (WVA) mode obtained. With enlarging the bias voltage on bias electrode, strong vertical potential generates to enlarge the tilt angle of LCs, phase retardation obtained in oblique directions to occur serious light leakage in four ways directions, as shown in figure 4(b).From figure 4(b), we analysis the light leakage of the polar angle of 50degree varied from different azimuthal angle. Serious light leakage at dark state performs in entire vertical direction in sub pixel-A rather than horizontal direction, on the contrary, light leakage seems much more higher in azimuthal view of left side and right side than the vertical direction. Compared figure 4(a) and figure 4(b), with higher vertical electric filed causing by the bias electrode, we find that the largest light leakage always tends to happen at the direction perpendicular to the rubbing direction, the LC initial orientation direction as well. It is supposed that the LC molecular will be keep the initial alignment direction affected by the molecular anchored by alignment layer even with strong vertical electric field. Combining entire the light leakage of horizontal direction and vertical direction, four ways privacy mode realized.



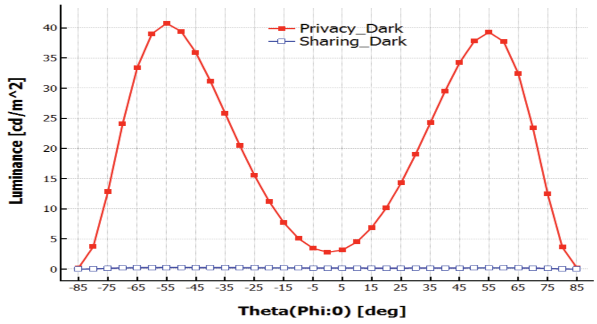
(a)WVA mode



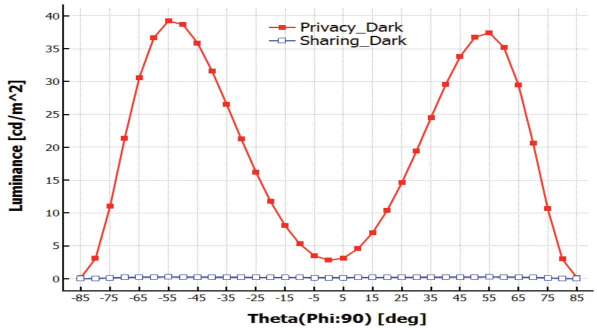
(b)NVA mode

Fig. 4 The cross section view of the proposed VAC cell with the LC direction along AA' at the black state (a) WVA mode (b) Four -ways privacy mode

Luminance difference of the proposed VAC structure is also calculated, as shown in figure 5. In the WVA mode, luminance remains to be very low in each direction at dark state, resulting in a wide view cone of a contrast ratio over 1000 (see in figure 6 (a)). When it switching to four ways privacy mode, it seems that the luminance remains low at the front view, but it raise up to 40 cd/cm2 at polar angle of about 50 degree, the highest light leakage happen at about polar angle of 50degree no matter viewed from any azimuthal view angle in privacy mode. A perfect four ways privacy mode with the contrast equals to even 2 at polar angle of 40 degree all directions (shown in fig6 (b)). Light leakage seems to be much more serious in NVA mode than WVA mode in oblique direction.



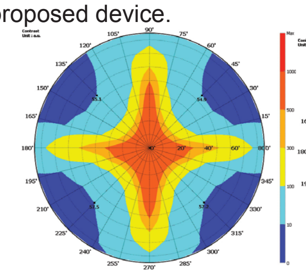
(a) Horizontal direction



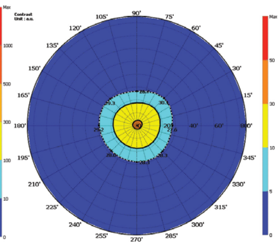
(b) Vertical direction

Fig. 5 Luminance difference of the proposed VAC Structure at dark state

Image quality simulation in terms of viewing angle direction of our proposed structure is shown in figure 7. In wide viewing mode, the main display image can be well perceived in all angles due to its operation mechanism as traditional FFS mode. On the other hand, in privacy mode, main image clearly observed in normal direction, and was perfect blocked in the horizontal direction as well as vertical direction when the viewing direction was larger than 50° of the polar angle in all directions due to a low CR. It demonstrates the outstanding effect of viewing angle controllable of the proposed device.



(a)WVA mode



(b) NVA mode

Fig. 6 Iso-contrast curves at an incident wavelength of 380–780 nm

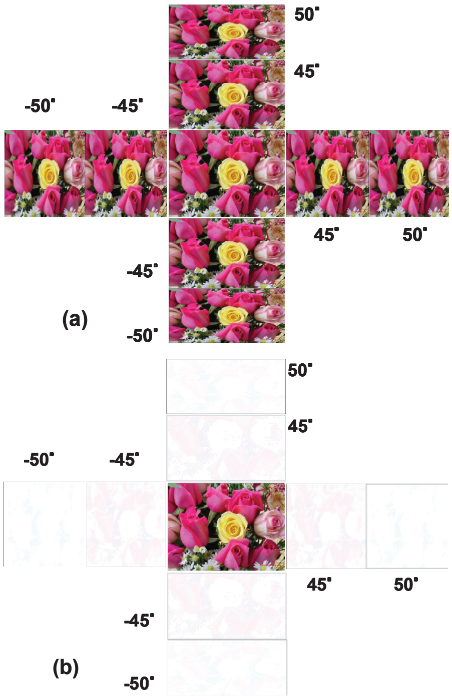


Fig.7 Picture performance simulation of the proposed structure (a) WVA mode and (b) Privacy mode.

4. CONCLUSION

In conclusion, this paper proposed a single panel FFS LCD Device with a specified pixel and novel separated rubbing method, through by modulating the bias signal to realize the viewing angle control function. And the narrow viewing angle mode not only shows a horizontal direction privacy but also an entire vertical direction privacy. These characteristics make users who need private protection to switch the panel display directions ether landscape display or portrait display screen without any worried. The VAC device has the advantage to switch WVA mode and four ways privacy mode freely without any extra components. We believe our studies will has influence on further researches on private protective LCD in the competitive personal display market. We expect that this distinct viewing angle difference between the two modes will open up further intriguing opportunities for applications of liquid crystal displays.

5. REFERENCES

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