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Evaluating and improving color washout of vertical aligned liquid crystal display

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ABSTRACT

We demonstrated an optimized 8-domain vertical aligned (VA) liquid crystal display (LCD) by minimizing its color washout. The index G is adopted to analyze the degree of color washout through simulation. By using linearly and circularly polarized incident light, the optimized regime of the area and applied voltage ratios of sub-pixels is obtained. In the experiments with the circularly polarized light, the images are sensuously improved in a coupled capacity type LCD by applying the simulated applied voltage ratio of two sub-pixels.

1. Introduction

While large-screen liquid crystal display (LCD) becomes main stream of TV markets, consumers demand high quality of color image not only at normal direction but also at the oblique directions. Vertical alignment (VA) LC mode technology is wildly used in TV design owing to the advantage of high contrast ratio. To eliminate the unsymmetrical viewing character, multi-domain VA (MVA) LC mode technology has been proposed [1], in which one pixel is divided into 4 domains with 4 different pre-determined directions depicted in Fig. 1a. These multiple domains can be obtained by introducing protrusions on both substrates [2], patterned electrodes which induce fringe fields of 4 directions (Patterned Vertical Alignment, PVA) [3], etc. The MVA LCD has high contrast ratio and is symmetric with no gray level inversion. However, it still shows noticeable color washout phenomena in the oblique viewing directions [4]. To further improve the performance of 4-domain VA mode, an 8-domain VA LC mode was proposed [5–9]. One pixel is further divided into two sub-pixels A and B, which is illustrated in Fig. 1b. The tilt angles of LC directors in the sub-pixel A and B are designed to be different in order to fine tune the image quality. And this can be achieved by applying different voltages to the sub-pixels through different common electrode voltages [7], two transistors (TT-type) [8] or a coupled capacity (CC-type) between them. The latter design is especially simple to be adapted in the manufacture, and the LCDs can be maintained in the low cost. Additional Refresh Technology (ART) and Innolux multi-domain vertically alignment (iMVA) [9] of 8-domain CC-type MVA LC mode, were proposed to improve image sticking occurred in the CC-type design. However, the color washout phenomena in these 8-domain VA LC mode still needs to be analyzed.

Color washout is a phrase to describe the displayed images with fading colors, which is due to losing color gradient, or sometimes color shift. It usually happens when we view a display at the oblique directions and compared the pictures with that at the normal direction. It results from the different voltage–transmittance (V–T) curves of normal viewing angle (on-axis) and oblique viewing angle (off-axis). Therefore, these deviations have positive relationship with color shift and color washout.

When a display is designed, the V–T curve of normal incident is used to determine the applied voltage of each gray level. The gray level versus transmittance curve is called the gamma curve. Since the V–T curve of on-axis is different from that of off-axis; the gamma curves of different oblique viewing angle can be various. Fig. 2 shows the typical gamma curves of VA mode LCD at various oblique viewing angles. Since the deviation varied in many shapes, it is important to have an index to render the overall color washout of the images. And from this index, one can analyze the factors which influence the images in order to optimize the color quality of LCD.

Several indexes [9–13] which wish to reveal the discrepancy of on and off axis images have been proposed. P value, [10,11] is defined by the transmittance ratio of off-axis to that of on-axis at 96th gray level. It is very easy to obtain but cannot manifest the whole deviation of two gamma curves. The area between two

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0141-9382/

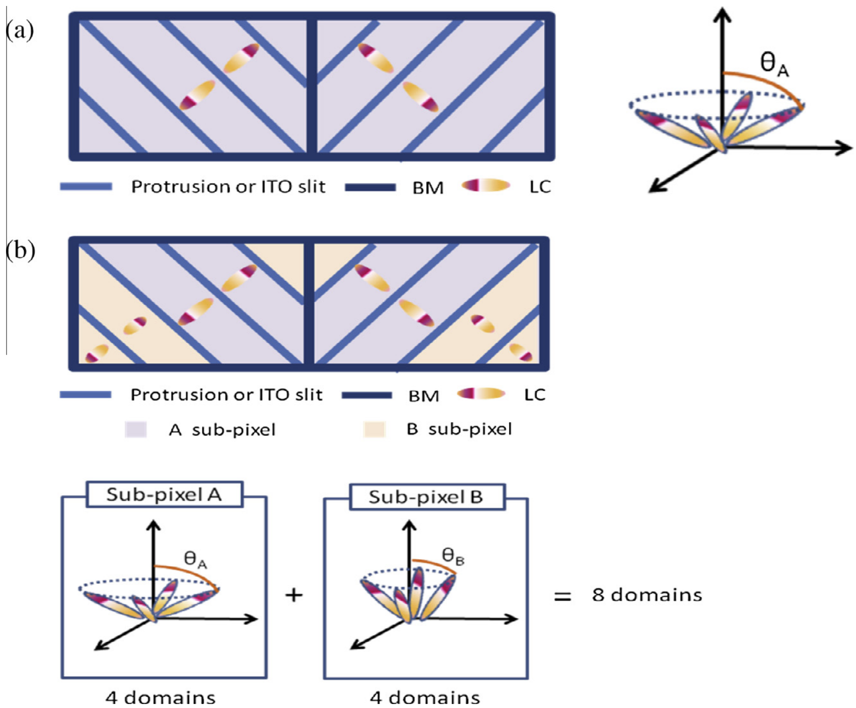


Fig. 1. The sketches of pixel and LC molecules in (a) 4-domains (b) 8-domains VA LC modes.

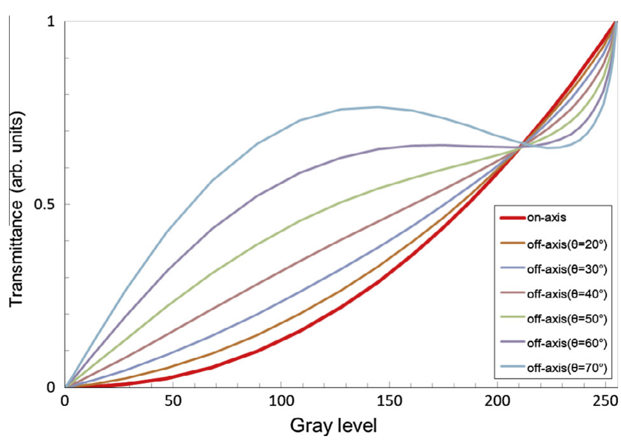
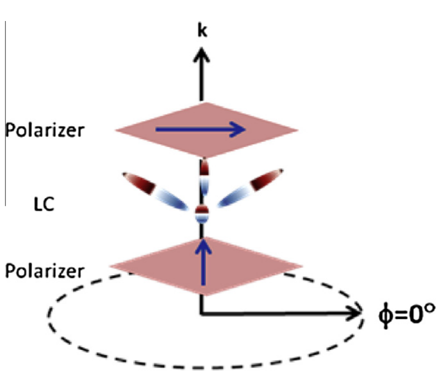


Fig. 2. The typical gamma curves of normal and oblique viewing directions.



	d(μm)
Polarizer	20
TAC	20
Glass	700
LC	3.5
Glass	700
X-plane	7.8
TAC	20
Polarizer	20

Fig. 3. The LCD structure designed for the use of linearly polarized incident light and corresponding parameters in the simulation.

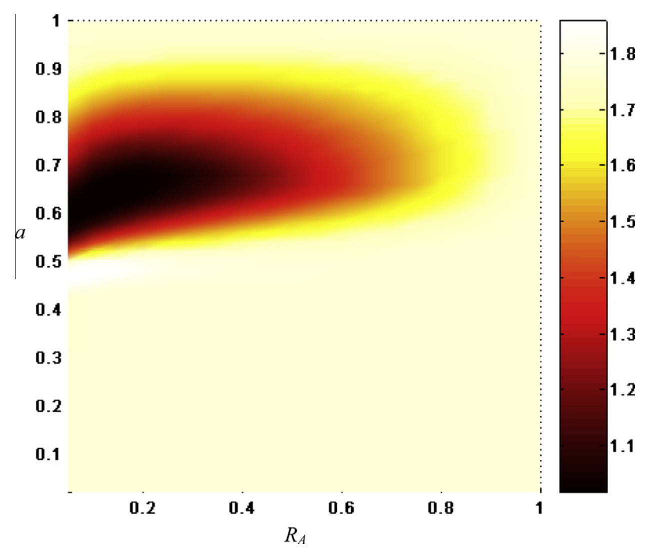


Fig. 4. The index G of various a and R_A at the worst oblique angle ($\theta = 60°$, $\phi = 45°$) for the linearly polarized incident light.

gamma curves is another solution; however it fails to reveal the curvature information. For example: with the same value of areas, a flatter gamma curve renders less gradient brightness in some gray levels and the color washout is more severe.

As the image quality becomes better, these two methods are insufficient. To include the gradient of transmittance in the gamma curve, an off-axis image distortion index D was proposed [12]. It is defined by averaging the percentages of brightness gradient differences between every on and off-axis gray level. In this paper we adopted the index G [13] to render the color washout phenomenon, which can be calculated from the transmittance curves of various viewing angles. The optimized area and applied voltage ratios