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Viewing Angle Switching in In-Plane Switching Liquid Crystal Display

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We demonstrated a novel viewing angle controllable display device in in-plane switching (IPS) mode with single panel. In the device, single pixel is separated into two regions, named as main pixel for displaying images and sub pixel for viewing angle control. Initially, the liquid crystal (LC) in sub pixel is homogenously aligned on substrate. For wide viewing angle mode, the LC switches in plane in the main pixel and for narrow viewing angle mode the LC switches the level of tilt angle without rotating by applying fringe electric fieldge. The proposed device is facilitated with simple manufacturing process and good viewing angle control with single panel.

Keywords In-plane switching mode; narrow viewing angle mode; viewing angle controllable display device; wide viewing angle mode

1. Introduction

In general, the wide viewing angle characteristic was the most important issue for liquid crystal display (LCD) to realize large-sized LC television. Owing to several wide viewing angle technologies such as multi-domain vertical alignment (VA) [1,2], in-plane switching (IPS) [3–5] and fringe-field switching (FFS) [6–9], great improvements in performance have been made. On the other hands, with an explosive increase in the wide use of various portable display devices suhc as mobile phones, notebook, personal digital assistants (PDAs) and tablet PCs, privacy protection of individual information has recently become an important factor for displays, too. To overcome these issues, numerous studies have been proposed regarding with narrow viewing angle characteristic to control the viewing angle for private use and

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several techniques has been adopted to develop the viewing angle controllable liquid crystal display devices.

Among these techniques, in the first method, the viewing angle controllable display has been proposed by adopting additional panel [10–12] and backlight unit [13]. In this case the additional liquid crystal panel was used outside the main panel in such a way that the main images were displayed by main panel and the additional panel was used to control the viewing angle. However, increased panel thickness and high manufacturing cost due to complicated process make it inconvenient to adopt this method. The other way is associated with dual backlight systems but was not perfectly operated with narrow viewing angle characteristic due to incomplete luminance and still has higher cost with increased panel thickness. In the second method, use of the portable viewing angle controllable film having a so called micro louver line was suggested [14]. However, for controlling the viewing angle, to carry the film all the time was the main drawback and make imperfect to this approach also. The third method uses pixel division [15–19] in which one pixel is divided to main image pixel and sub pixel for viewing angle control. This method has an additional process to generate extra electrode at upper substrate of sub pixel which results in relatively higher cost LCD.

In this paper, to overcome these problems, we proposed viewing angle switchable LCD associated with IPS mode by using single panel. To add narrow viewing angle characteristic in IPS mode with wide viewing angle characteristic, we used pixel division technology. For minimum additional process to this device, the electrodes were generated at a bottom substrate only and projected a good viewing angle control single panel LCD with relatively simple fabrication process.

2. Device Structure and Its Switching Principle

As in the IPS device the uniaxial medium exists under crossed polarizer and the normalized transmittance (T) is given by

$$\mathrm{T} = sin^2 2\psi(V) sin^2(\pi d \Delta n_{eff}(V, \theta, \varphi)/\lambda) \tag{1}$$

where ψ is an voltage-dependent angle between the input polarizer and LC director, d is a cell gap, Δn_{eff} is the voltage- and viewing-angle-dependent effective birefringence of the liquid crystal medium, whereas θ, φ and λ are the polar angle, azimuthal angle and wavelength of incident light, respectively.

According to the equation (1), the IPS mode has maximum transmittance when ψ is 45°, Δn_{eff} is $\lambda/2$, respectively. In general, for the LCDs to exhibit wide viewing angle, as a minimum two important requirements must be satisfied. One is a good dark state at viewing directions as well as in normal directions and the other is good uniformity of grey and white states along with viewing directions. In case of the dark state in IPS mode, the LC is homogenously aligned and the effective retardation is almost zero at normal direction and not large in oblique viewing directions, resulting in a good dark state and the LC rotates in plane in on state, resulting in good unifomity of all grey levels. As a result, the IPS mode shows wide viewing angle characteristics.

On the other hand, for the LCDs to exhibit narrow viewing angle, light leakage or imgaes utilizing the ligh lekage should be taken place in oblique viewing direction without any light lekage at normal direction, that is, $d\Delta n_{\mathrm{eff}}$ should be zero at normal direction but should be close to $\lambda/2$ in viewing directions. In the IPS mode, we can control the LC directors in viewing angle region according to patternd electrode. On the application of vertical electric field the LCs almost tilt upward so that the light leakage is strong in viewing angle controled region to control the viewing angle. Thus the effective retardation is large enough in oblique viewing direction for narrow viewing angle characteristics. However, this case needs additional electrode on top substrate.

Figure 1 shows a proposed pixel structure of viewing angle controllable LCD with an IPS mode. The device uses different pixel pattern in main pixel and sub pixel. In the device, the pixel and common electrodes exist only on the bottom substrate. The single pixel is divided in two regions as main and sub pixels for displaying the image and controlling viewing angle, respectively. The electrode structures of main pixel have normal IPS however the electrode structure of viewing angle control region is patterned in parallel with gate line. The rubbing direction of the LC coinciding with one of the polarizer axis of two crossed polarizers is in vertical direction for both main and sub pixels. In the way, the in-plane field direction makes some angle with the LC direction in main pixel, however, it is coincident with the LC director in the sub pixel.

Figure 2 shows cross-sectional view of the viewing angle controllable LCD with LC profile under the application of an operating voltage to the main pixel and sub pixel. As indicated, the homogenously aligned LC director rotates in plane in main pixel since the in-plane field direction makes some angle with LC director (see Figure 2(a)), however, the LC is not rotated at all but only tilted up to the substrate

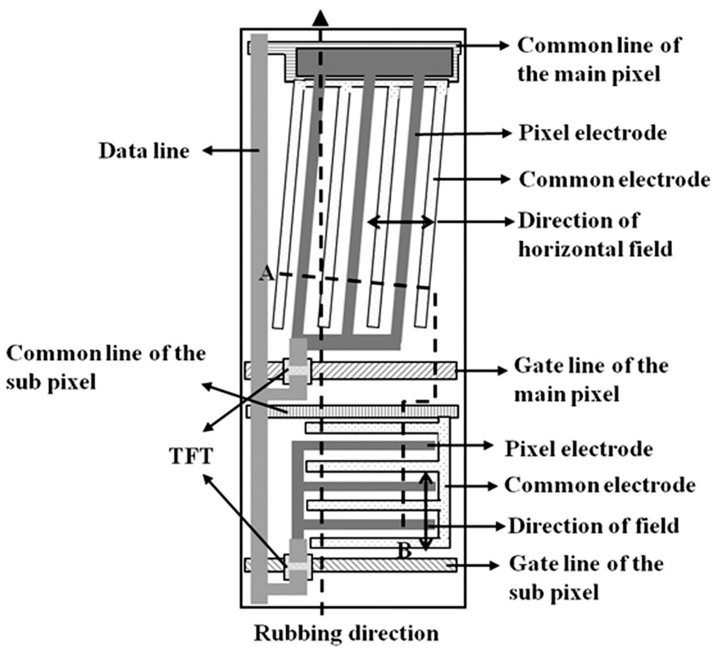

Figure 1. Schematic pixel structure of proposed viewing angle controllable LCD using IPS mode.

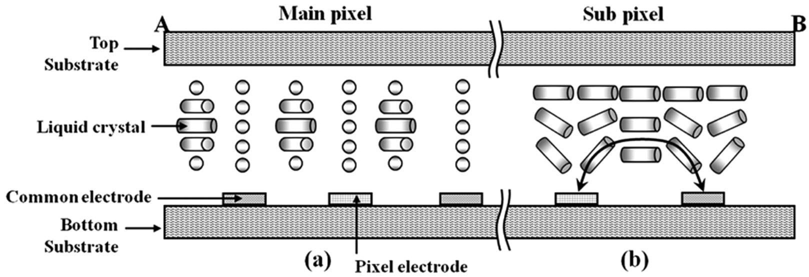

Figure 2. Cross sectional view of the viewing angle controllable LCD with LC profile in presence of an applied voltage in (a) main and (b) sub pixels.

alng the oblique field direction (see Fig. 2(b)). The level of tilt angle can be controlled by optimizing electrode structure and applied voltage such that the light leakage in viewing directions can be maximized. Using this light leakage of sub pixel, the characters or images can be controlled in oblique directions. As a result, the device can be switched from wide viewing angle mode narrow viewing angle mode by controlling an applied voltage to the sub-pixel.

3. Simulation Condition

In order to obtain one panel viewing angle controllable display in IPS mode, a computer simulation was performed by using the commercially available software LCD master (Shintech, Japan), optical calculation is based on 2×2 extended Jones matrix [20]. For the simulation, the cell retardation at normal direction was taken 0.32 μm with a cell gap of 4 μm. The surface tilt angle of the LC was 2° and the in-plane field direction makes an angle of 80° with respect to the LC director in the main field and 0° in sub pixel. The transmittance of single and parallel polarizers was assumed to be 41%, and 35%, respectively. In order to determine the optimal conditions of the suggested device, the electrode width (W) and distance (L), in main pixel were 5 μm, and 10 μm, respectively. However, in sub pixel the pixel electrode width was 4 μm with a variation from 2 μm to 8 μm in distance between them.

4. Simulation Results

Figure 3 shows calculated light leakage along horizontal direction as a function of polar angle with different electrode conditions at an applied voltage of 10 V in sub pixel. The simulated calculation was performed for narrow viewing angle mode. In order to optimize electrode condition, the L between two slit electrodes is varied from 2 μm to 8 μm with a fixed W of 4 μm. It can be seen from figure 3, that the light leakage increases with decreasing distance between two slit electrodes in the oblique direction while upholding an excellent dark state in normal direction because the tilt angle of LC can be controlled by the intensity of oblique electric field. Among these different electrode conditions, the biggest degree of light leakage is occurred at a condition in which L is 2 μm. It is also clear from the results that this value is twofold to the degree of light leakage in oblique viewing direction when L is 10 μm and a sufficient amount to realize narrow viewing angle.

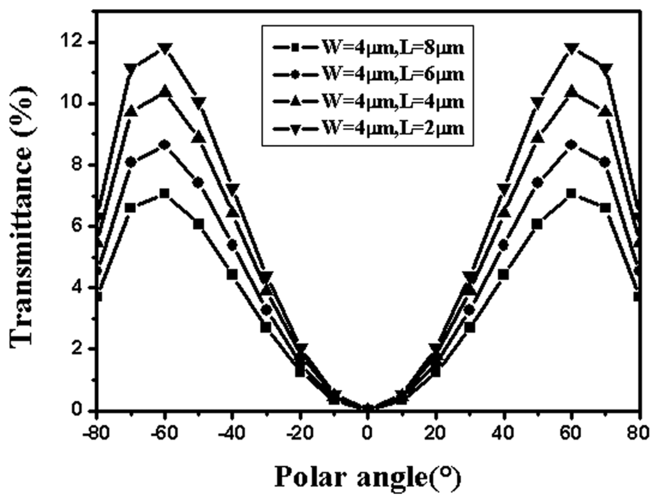

Figure 3. Calculated light leakage along horizontal direction as a function of polar angle with different electrode conditions under the action of an applied fixed voltage of 10 V.

Figure 4 shows calculated light leakage along horizontal direction at wide and narrow viewing angle modes. As shown in Figure 4, in case of narrow viewing angle mode, about 12% of light leakage is occurred in the polar angle ±60° at an applied voltage of 10 V in sub pixel. In contrast, light leakage of wide viewing angle mode is not occurred at all in the entire region of polar angle in absence of applied voltage in sub pixel. As a result, viewing angles in horizontal direction can be switchable by optimization of pixel structure.

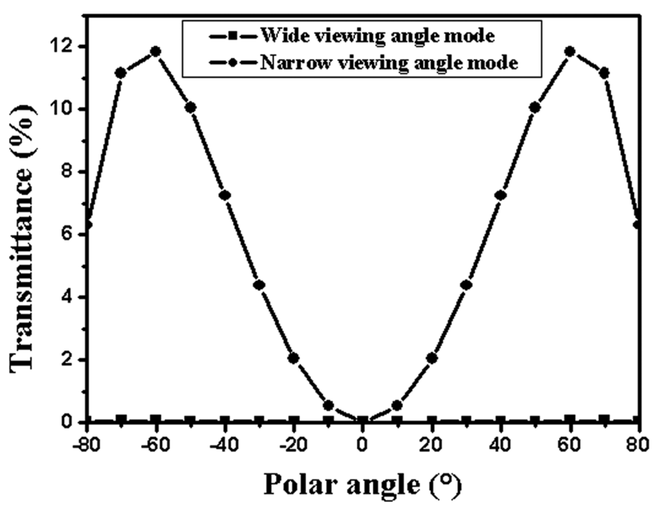

Figure 4. Calculated light leakage along horizontal direction as a function of polar angle in, wide at an applied voltage of 10 V and narrow viewing angle modes in absence of applied voltage.

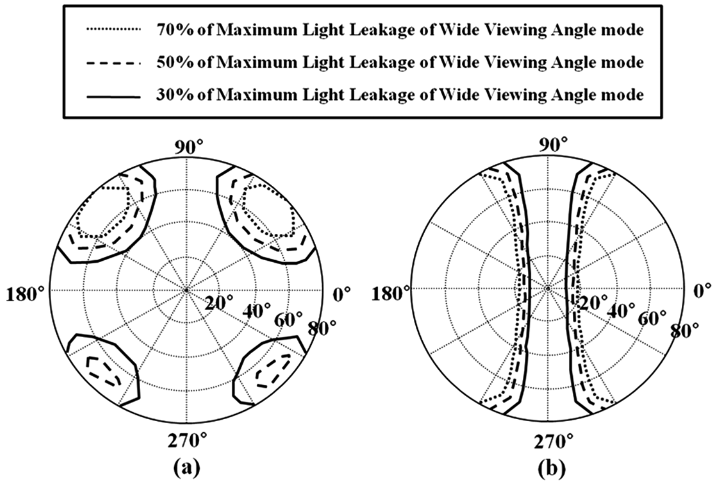

Figure 5. Calculated iso-luminance curves of dark state in (a) wide and (b) narrow viewing angle modes.

Figure 5 shows iso-luminance curves of the device at dark state in wide and narrow viewing angle modes at 550 nm. 70%, 50%, 30% of maximum light leakage of wide viewing angle mode is plotted. As shown in figure 5 (a), 70% of maximum light leakage is observed in the region concerning over 60° of polar angle in oblique diagonal direction whereas the light leakage of the wide viewing angle mode is not occurred in left and right direction. On the other hand, as shown in Figure 5(b) in narrow viewing angle modes, the region containing transmittance exceeding over 70% of the maximal light leakage at off normal direction, exists within 20° in both left and right direction. The maximum light leakage in narrow viewing angle mode was found 11.83%, six times larger than 2.13% observed in wide viewing angle mode which is fairly an adequate amount to be noticeable easily in oblique viewing direction.

5. Conclusions and Perspectives

In summary, we proposed here a new viewing angle controllable structure of IPS-LCD with single panel, in which one pixel is in possession of main image pixel and viewing angle control pixel. For wide viewing angle characteristic the LC rotates in plane in main pixel whereas for narrow viewing angle characteristic the LC rotation does not occur at all, instead the LC can be controlled merely by tilt upward with applied voltage in sub pixel. The device has single panel and operated by electrodes existing only at a bottom substrate, which allows manufacturing cost to be low. Thus viewing angle controllable display in IPS mode can be applied and commercialized for portable displays that require efficiently viewing angle control.

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