A Novel Phase Transition from a Vertical Alignment to Optically Compensated Splay

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Abstract

We have studied a novel vertical alignment liquid crystal cell. At initial state of a cell with rubbed parallel on top and bottom substrates, the vertically aligned LCs are twisted by 180°. However, after a critical voltage is applied to the cell, the configuration of the LC changes to optically compensated splay form, where the mid-director lies parallel to the substrate and thus the LC has two hybrid alignments around center.

1. Objectives and Background

Recently, the application fields of the liquid crystal displays (LCDs) are greatly extended ranging from small size PDA to large size LC TV. Therefore, the response time of the LCD becomes more important to generate moving pictures perfectly and thus development of a fast response LC mode is absolutely required.[1] The rising response time of the LCD depends on applied voltage, dynamic stability of the LC director, and the viscosity of the LC while the decaying time depends on the LC's elastic constants, cell gap and the viscosity of the LC. Among several LC modes, vertical alignment (VA) mode shows quite fast decaying time due to bend transition from a vertical alignment although the LC with negative dielectric anisotropy and high viscosity is used.[2] However, for a single domain of the VA mode, the viewing angle is narrow and in order to solve this, multi-domain VA (MVA) mode is proposed.[3-5] In MVA mode, there is possibility of collisions between the LCs when an applied voltage is applied, which may cause a slow response time in grey to grey transition. Another LC mode, optically compensated bend (OCB) shows fastest response time with a proper viewing angle although it is a single domain.[6-8] In the OCB mode, the rubbing on top and bottom substrates is performed in parallel directions and the configuration of the LC changes to bend after a critical voltage is applied. In other words, the mid-director is vertically aligned and around the mid-director the LCs are homogeneously aligned at surfaces of both substrates symmetrically. In this case, the black and white state is achieved by controlling the array of the LC around mid-director but to obtain a good dark state, an optical compensation film must be used. In this mode, the flow directions around the mid-director are the same when voltage-on and off, which accelerates response time, nevertheless several compensation layers must be used to exhibit a good dark state.

In this paper, we propose a new vertical alignment LC cell. In the device, the LCs are vertically aligned at initial state and after a critical voltage is applied, the LCs changes to splay state such that the mid-director lies parallel to the substrate and around it the LCs are vertically aligned at surfaces of both substrates symmetrically. Since the configuration of the LC has mirror symmetry around mid-director, we have named the device optically compensated splay (OCS) mode.[9] In this paper, we will discuss how this kind of configuration can be achieved by experiment and computer simulation.

2. Results

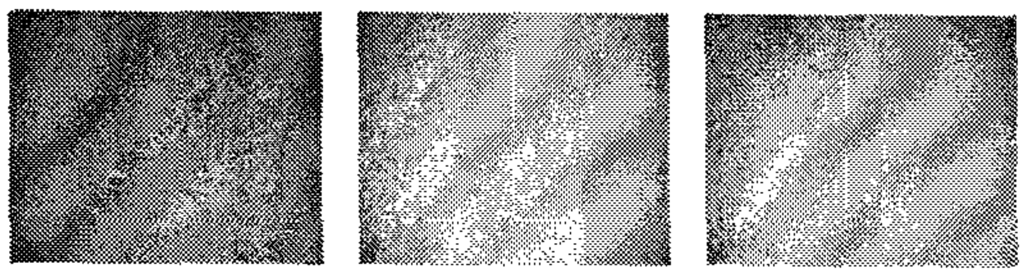
For cell fabrications, the vertical alignment layer is coated on ITO-coated glass substrate with thickness of 800Å. The rubbing was performed in parallel directions on both top and bottom substrates. The two substrates were assembled to give a cell gap of 4.8μm. And then the LC with dielectric anisotropy of -4 and birefringence of 0.077 was filled.

The 60Hz sine wave is applied to deform the LC and the cell was observed under optical microscope while changing the angle between the rubbing direction and the transmission axis of the crossed polarizer.

First, we have observed the cell under optical microscopy when a voltage is not applied. The OCS cell under crossed polarizers shows a complete dark state irrespective of the angles between the polarizer and the rubbing direction as shown in Fig. 1, except some areas around spacer.

Fig. 1 Optical microphotograph of the OCS cell when a voltage is zero.

As an applied voltage increases, the transmittance starts to occur. Even at the angle that the rubbing direction coincides with polarizer, the transmittance appears. This indicates that the vertically aligned LC tilts down to the direction that is not coincident with the polarizer, that is, the LC tilts down in three dimensions not two dimensions. Fig. 2 shows the LC texture while changing the white state (applied voltage is 20V) of the cell. Here the angle indicates the value between the rubbing direction and the transmission axis of the crossed polarizer. The extinction of the transmittance does not occur, which means that the LC tilts down while twisting.



0° 45° 90°

Fig. 2 Optical microphotograph of the OCS cell with applied voltage of 20V while rotating the cell with respect to the crossed polarizer.

From experimental results, we can predict that the LCs are twisted by 180° at initial state and with bias voltage, the LC tilts down while twisting by 180°, as shown in Fig. 3, Fig. 4 shows a simulated result of the transmittance while changing the angle between the rubbing direction and the polarizer axis. As indicated, the light transmittance oscillates without extinction at any angle, which is coincident with experimental results.

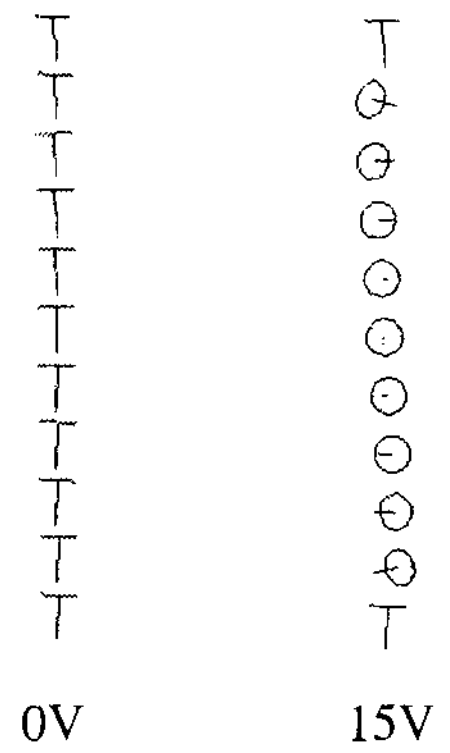


Fig. 3 Simulated results describing how the LC deforms as increasing voltage.

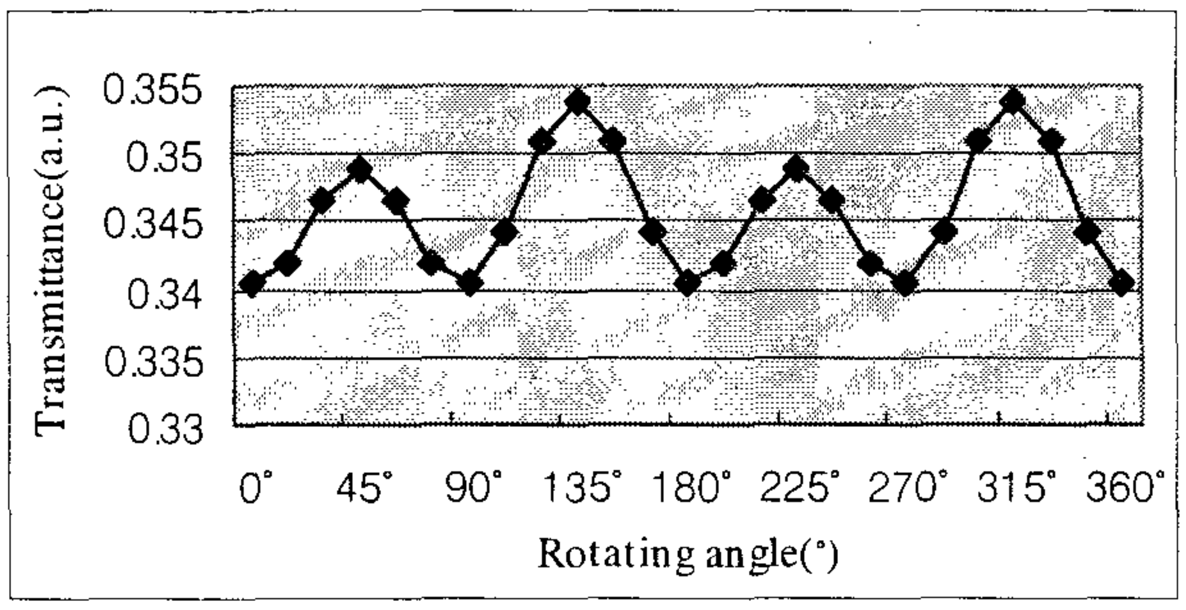


Fig. 4 Calculated transmittance as a function of the angle between the rubbing direction and the polarizer axis.

Unlike this behavior, an interesting phenomenon occurs when a critical voltage is applied to the cell. When the applied voltage is about 50V, new domains associated with a different deformation of the LC from surrounded areas are created as shown in Fig. 5(a). Here the rubbing axis is coincident with one of the crossed polarizer axes. The new domains become large when decreasing the bias voltage and finally cover all area as shown in Fig. 5(c). In order to confirm the LC director profile of the new domain, we have observed the LC cell while rotating it. Surprisingly, the dark area which appeared when the rubbing axis coincides with the polarizer axis becomes bright as the rubbing axis deviates from the polarizer axis. Further, when the angle is 45°, the cell shows the brightest state, as shown in Fig. 5(d). This state remains until lowering voltage down to 3V.

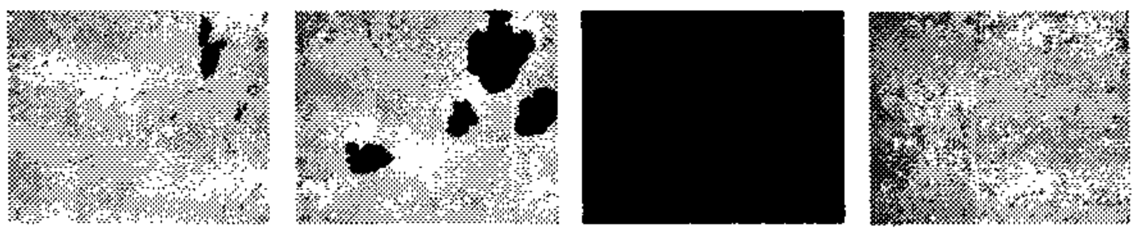

(a) (b) (c) (d)

Fig. 5 Optical microphotograph showing (a) a creation of the new domains with bias voltage of 50V, (b) extension of the domain when decreasing the voltage, (c) a dark state in a whole area, and (d) a bright state when the rubbing axis makes 45° with the of the polarizer axis.

Above results clearly indicates that the deformation of the LC occurs in two dimensions, that is, the polarization of a linearly polarized light pass through the cell remains the same such that the light is blocked by an analyzer. In addition, when we observe the LC cell of Fig. 5(d) in horizontal oblique direction, the transmittance at left and right oblique directions is the same. This informs that the LC has symmetric configuration around the mid-director, which is in splay state with a mid-director lying parallel to the substrate, not a lying down in one direction with some tilt angle.

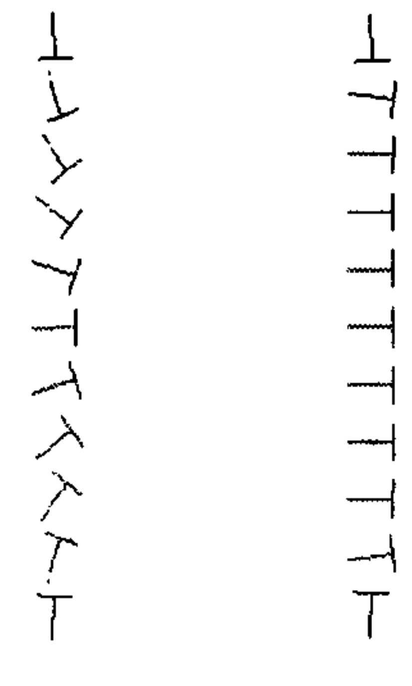

(a) (b)

Figure 6 OSimulated configuration of the LCs in the OCS cell when an applied voltage is (a) 0V and (b) 15V.

Fig. 6 describes a configuration of the created domain by a computer simulation. As can be seen, the LC has optically compensated splay structure without twisting. Since the LC with negative dielectric anisotropy is used, the LCs will tilt down parallel to the substrate as shown in Fig. 6. The new device has a self-compensation structure, which can give rise to wide viewing angle with only a single domain. Further, we can achieve a bright and dark state using the deformation described above and optical compensation films.

Finally, we have performed a calculation to see which configuration is in the stable state by calculating the Gibbs free energy as a function of applied voltage. At voltages lower than 3V, the twist state is more stable than the splay state. However, with further increasing voltage larger than 3V, the splay state becomes more stable than the twist state although the difference in energy is quite small. From the results, we can understand that coexistence of two states is possible at certain voltages.

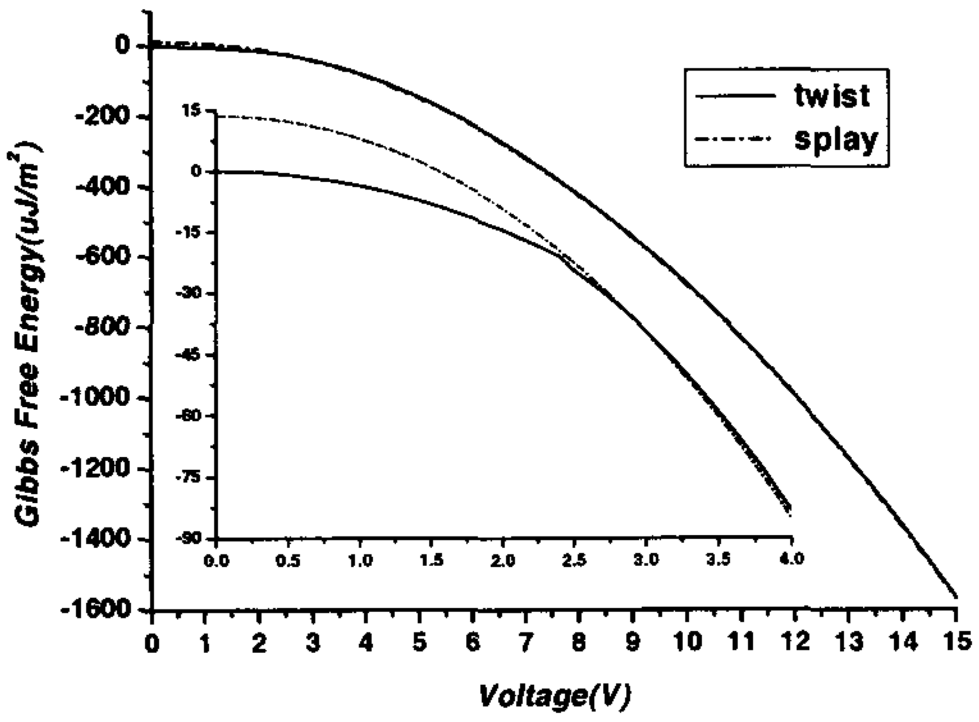


Fig. 7 Gibbs free energy as a function of voltage for the twist and splay state.

3. Summary

For the first time, we have developed a new LC cell associated with a transition from a vertical alignment to optically compensated splay structure. With new device, we can achieve a bright and dark state using the deformation described above and optical compensation films. Further, the new device has a self-compensation structure, which can give rise to wide viewing angle with only a single domain and considered to show a fast response time since the flow directions caused by the deformation of the LCs are the same around the mid-director, like in the OCB mode.

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5. References

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