Liquid Crystal Device associated with Fringe-Field Driven Optically Compensated Splay

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Abstract

We have studied an optically compensated splay (OCS) mode driven by fringe electric field. The OCS configuration obtained by applying voltage to vertically aligned LCs shows a dark state when an optic axis of the OCS cell coincides with one of crossed polarizer axis. When the fringe electric field is applied, the LC director rotates in plane above whole electrode surface, giving rise to the high transmittance, the low operating voltage and wide viewing angle simultaneously.

1. Objectives and Background

Recently, the liquid crystal displays (LCDs) are in charge of an important role in human to machine interfaces. Therefore, the LCD must be expressing much data and also the customer's requirement increasing; wide viewing angle, fast response, high resolution and wide color reproducibility. These requirements of the customer's satisfy the many research going on. Furthermore, the application fields of the LCDs are greatly extended ranging from small size PDA to large size LC TV.

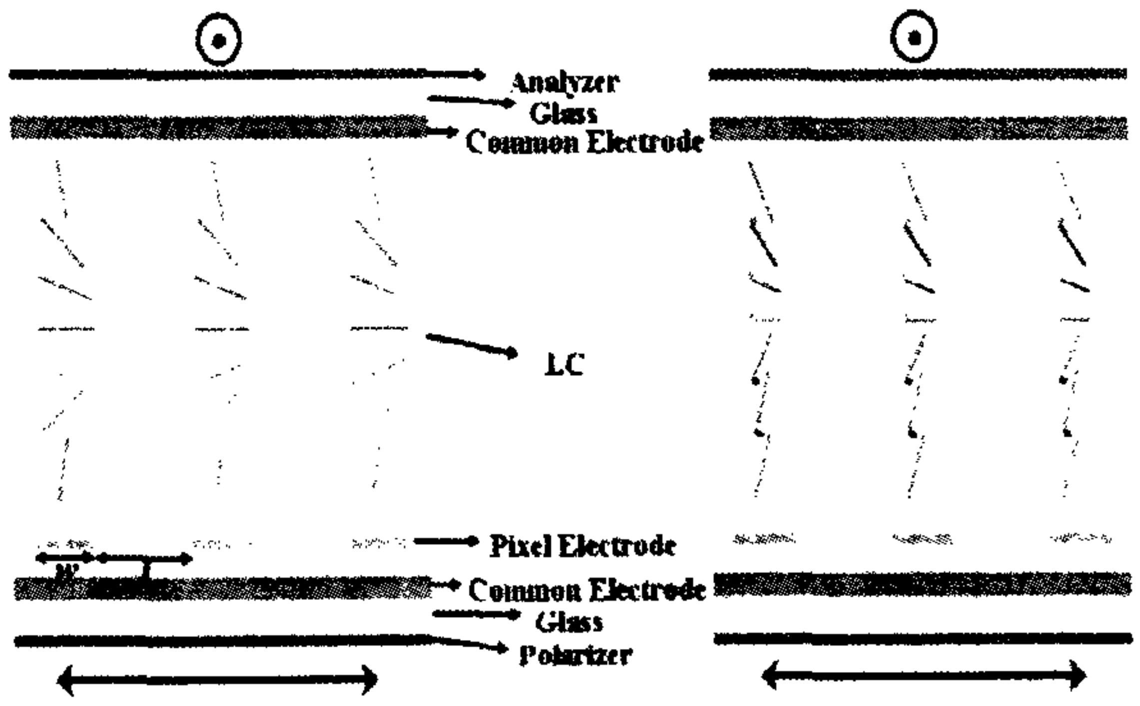
Nowadays, several new nematic liquid crystal display (LCD) modes to overcome narrow viewing angle and slow response time are introduced. Among them are film-compensated twisted nematic (TN) using discotic liquid crystals [1], in-plane switching (IPS) [2], multi-domain vertical alignment (MVA) [3], optically compensated bend (OCB) [4, 5], optically compensated splay (OCS) [6-10] and fringe-field switching (FFS) [11, 12]. Among them, the OCB mode exhibits the fastest response time less than 10 ms due to flow acceleration effects and bend transition and thus this device is one of strongest candidate for LC television application. In the OCB mode, the optical switching of a white and dark state is obtained in the bend state by controlling voltages and the device with the help of self-compensation structure and optical compensation films shows wide viewing angle. Furthermore, the OCS mode also shows fast response time and wide viewing angle. The OCS mode, when a high pulse voltage is applied to the cell, the LCs transits twisted bend state to splay state.

In this paper, we propose a new vertical alignment LC device driven by fringe electric field as F-OCS. In the device, the LC is vertically aligned at initial state and after a critical voltage is applied, the LC transits to splay state such that the mid-director lies parallel to the substrate and around it. And then we have applied fringe electric for rotating LC director like in the FFS mode. Electro-optic characteristic of the new device is discussed by computer simulation and experiment.

2. Results

2.1. Simulation

To perform the simulation, the LC with physical properties such as $\Delta\varepsilon=-4.0$, $K_{11}=13.5$pN, $K_{22}=6.5$pN, $K_{33}=15.1$pN is used. The surface



(a) (b)

Fig. 1 The cell configuration of LC molecules as a function of the voltage applied for a parallel rubbed vertically aligned cell: (a) splay state at absence of electric field, (b) rotated state applied voltage.

pretilt angle is 88° and rubbing angle is 12° with respect to horizontal field component. For optical calculations, 2×2 extended Jones matrix is applied for an incident light 550nm.

Figure 1 shows the LC configuration and transmittance depending on the voltage-on and off. On a bottom substrate, pixel and common electrodes exist and on a top substrate, another common electrode exists such that the vertical and fringe-electric field is generated. At initial state of the cell, the LC has a hybrid orientation around a mid-director. When a voltage is applied the cell, the LC molecules are mainly twisted due to strong fringe-electric field, causing the transmittance.

Using the cell with OCS configuration, an electro-optic LC device can be made. We have calculated maximum transmittance (T_{max}) and operating voltage (V_{op}) while changing the cell retardation values ($d\Delta n$) from 0.3 μm to 0.60 μm. For the retardation value-dependent T_{max}, the optimal $d\Delta n$ appeared at 0.48 μm. And for the $d\Delta n$–dependent V_{op}, the V_{op} decreases with increasing the $d\Delta n$. This indicates that the higher cell retardation value, the effective $\lambda/2$ is achieved at a lower voltage but the value larger than 0.48 μm becomes over-retarded to reduce the transmittance. Therefore, if we consider the optimal $d\Delta n$ in both the T_{max} and V_{op} aspects, the optimal condition can be chosen as $d\Delta n$ = 0.48 of the cell with the high transmittance of 89.3% and the low operating voltage of 4.2V, as shown in Fig. 2. Figure 3 shows calculated voltage-dependent transmittance curve, when the $d\Delta n$ is 0.48 μm. On this occasion, the transmittance is similar to the conventional FFS mode. But the operating voltage is reduced from 5.1V of the FFS to 4.2V of the F-OCS, as shown in Fig. 3. In succession, we calculated luminance uniformity when the transmittance is 100%, for an incident light D65, as shown in Fig. 4. Here, T_{70}, T_{50} and T_{30} indicated relative transmittance of 70%, 50% and 30% of the maximum intensity at normal direction, respectively. The luminance uniformity is excellent even in the white state, that is, the relative transmittance of 70% exists over 60° of the polar angle for all directions. In order to confirm the simulation results, we fabricated a test cell.

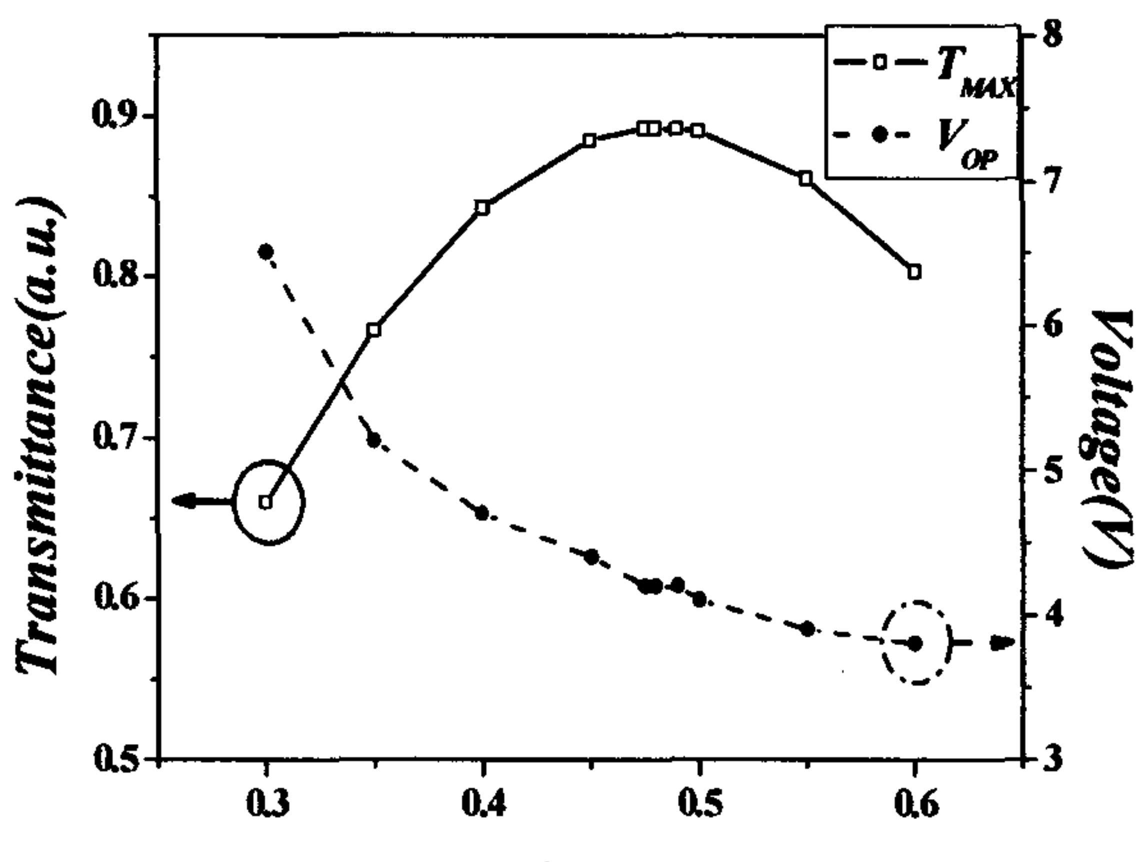


Fig. 2 Maximum transmittance & operating voltage as a function of retardation values.

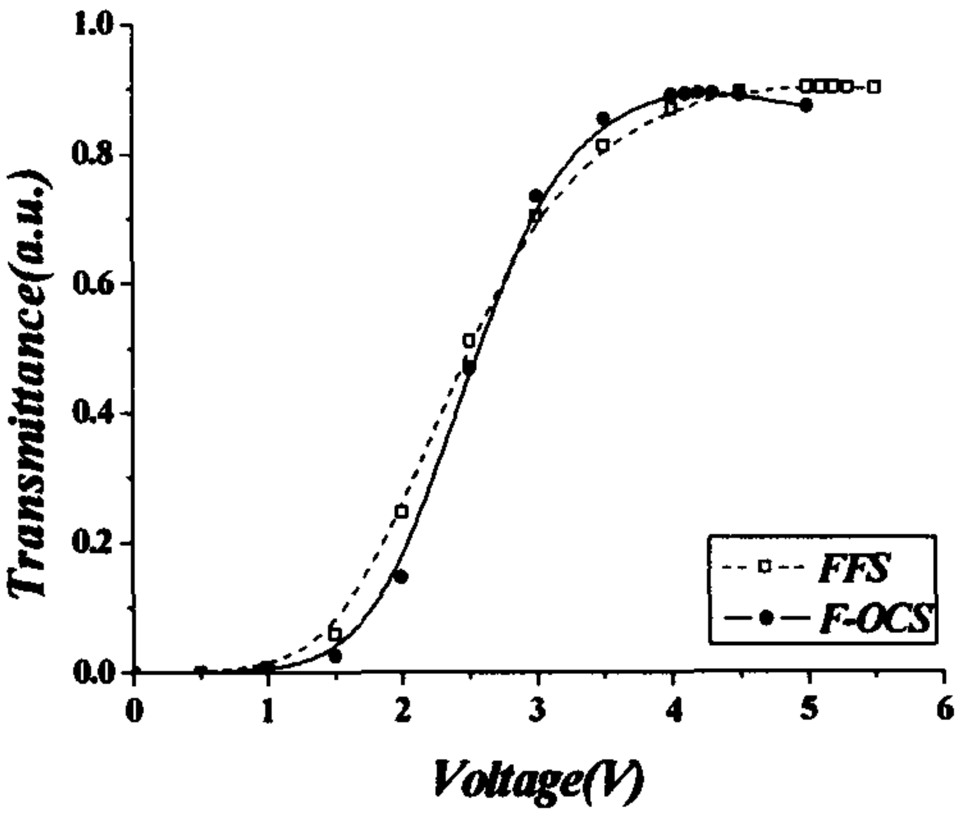


Fig. 3 Voltage-dependent transmittance curve of the FFS and F-OCS.

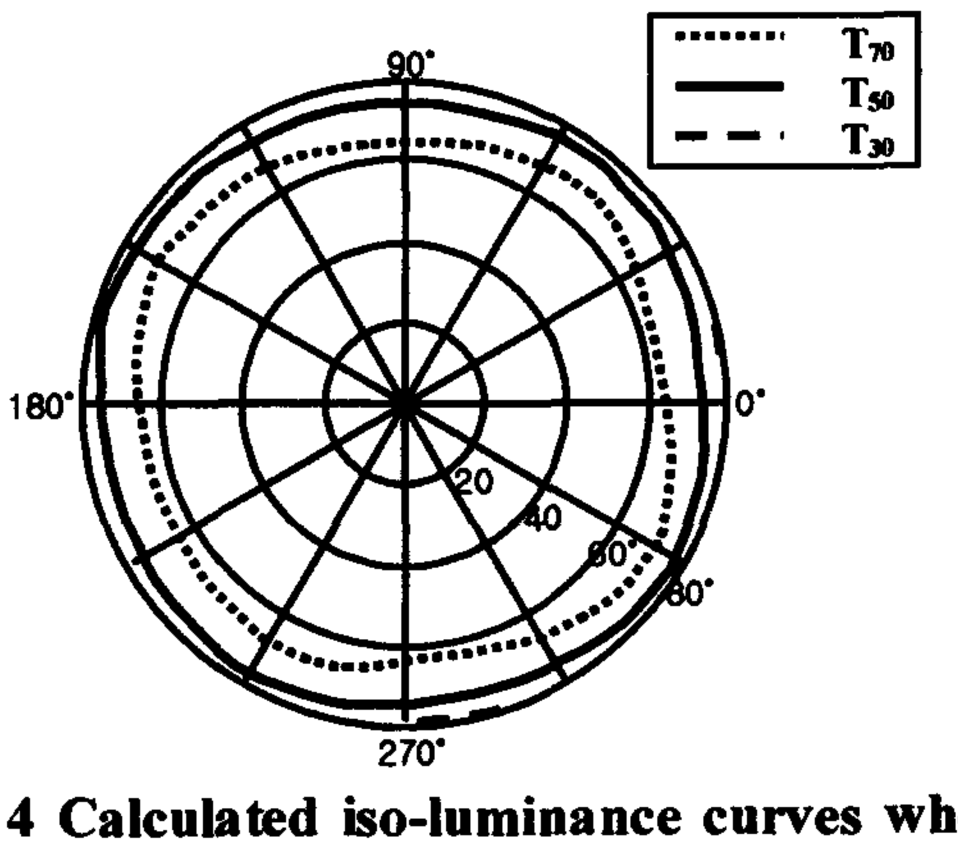


Fig. 4 Calculated iso-luminance curves when the transmittance at normal direction is 100%

2.2. Experiment

For cell fabrications, the vertical alignment layer is coated on top ITO-coated glass substrate and bottom FFS substrate with thickness of 1000Å. The rubbing was performed in parallel directions on both top and bottom substrates with 12° to horizontal electric component. The two substrates were assembled to give a cell gap of 4.5 ㎛. And then the LC with dielectric anisotropy of -4.7 and birefringence of 0.11 was filled into the cell at room temperature.

(a) (b)

Fig. 5 Optical microscopic image of the texture (a) when the whole area becomes splay transition, (b) the cell appears to be white by fringe field switching.

First of all, a high pulse voltage is applied to generate the OCS domains and then the voltage is lowered for the OCS orientation to be extended into the whole area. Here, the top and all bottom electrodes plays role of pixel and common electrodes, respectively to generate only a vertical electric field. When the rubbing direction of the cell is coincident with one of the crossed polarizer axes, the cell shows a complete dark state since the phase retardation is not generated at normal direction, as shown in Fig. 5(a), except some areas around spacer. As an applied voltage increases, which generates fringe-electric field, the cell gives rise to uniform transmittance as shown in Fig. 5(b). This indicates that the LC director with negative dielectric anisotropy rotates according to fringe electric field with perpendicular and horizontal component. Further, the transmittance was high in all electrode positions. These results were in good agreements with the calculated results.

3. Summary

In summary, we have found vertically aligned cell associated with a transition from an optically compensated splay state to twisted optically compensated state by fringe electric field. The novel device fringe-field driven shows electro-optic characteristics with the excellent luminance uniformity, the high transmittance and low operating voltage.

4. Acknowledgements

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5. References

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