Recent Trends on Wide-Viewing-Angle LC Modes and New Trials on CNT-LC System

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Abstract

Recently, competition between LC modes for LC TVs becomes high. In this paper, status of each mode is briefly reviewed with commenting on its electro-optic characteristics and possible application fields. Further, to understand effects of carbon nanotubes (CNTs) dispersed in nematic liquid crystal on electro-optic characteristic and orientation of the LC, CNT-doped NLC cells are made and evaluated. The hysterisis studies of voltage-dependent capacitance show that the amount of residual dc is greatly reduced due to ion trapping by CNTS.

1. Introduction

In an early 1990s, TFT-LCDs using the twisted nematic (TN) mode that exhibits a high transmittance, wide cell process margin, and enough image quality for notebook displays were dominant. With production technology improvement, the production of large-size TFT-LCDs over 15” became possible so that TFT-LCD started replacing CRT monitors since about 1996. As the size of TFT-LCD increases over 18”, people realize that the image quality of the TN mode is not enough.[1]

Many trials to improve the image quality of the TN mode have been challenged. First, many types of multi-domain TN was tested but never made commercialization.[2] In 1995, TFT-LCD adopting the in-plane switching (IPS) mode was proposed by Hitachi co. and since then, several companies were utilizing this due to its intrinsic wide-viewing-angle characteristics.[3] In 1996, optical compensation called wide-view (WV) film which improves a dark state of the TN mode greatly has been developed by Fuji co.[4] and owing to easiness for its application to conventional TN mode, it has been widely used up to 15”. However, due to cost issue rather than image quality recently, this is being adopted to even 19” TFT-LCD monitors. In 1997, multi-domain vertical alignment (MVA) mode was suggested by Fujitsu co. and at the moment, several companies are adopting this for large-size LC TVs.[5] In 1998, the fringe-field switching (FFS) mode which overcomes intrinsic problems of the IPS mode was developed by Hyundai Display Technology (now called BOE-Hydis).[6,7] At an early stage, the FFS mode using a LC with negative dielectric anisotropy ($\Delta\varepsilon$) was commercialized to position and pressure sensitive displays with 15”. Since then, the device using a LC with positive dielectric anisotropy has been commercialized to LCD monitors and tablet PC displays, being a major LC mode in this field. Perhaps, this is the first LC mode which was commercialized using both types of the LCs. Recently, Hitachi co. developed 32” LC TV using the FFS mode[8], which stimulates IPS groups to rethink the future technology. In 1998, SEC co. developed a new type of VA mode called the patterned VA (PVA) and nowadays, it has been adopted in all SEC’s large size LC TVs.[9]

Ever since the new LC modes were introduced, each company works hard to improve its own demerits and finally, they continue evolution, competing with emissive PDP in large-size TV fields. Until last year, it seemed that surviving LC modes in large-size LC TV can be classified into two groups such as a homogenous alignment (HA) group: IPS & FFS, and a VA group: MVA & PVA. However, another LC mode that has splay alignment initially (called pi-cell[10] or optically compensated-bend (OCB)[11] which shows the fastest response intrinsically among all nematic LC modes, which was first proposed by Bos in 1983) was commercialized in LC TVs last year by the TMD co.[12]. In fact, the mode had its high potential as one of excellent LC modes, but it was not commercialized before, due to some complexes such as transition voltage/time control and film compensation. According to the report of the TMD co., the LC TV using the OCB mode exhibited both fast response time of 4ms and wide-viewing angle.

Consequently, we expect three LC groups such as HA, VA and Splay to compete each other and the one may be merged into the other inside group in the future. In this presentation, we would like to point out their merit and demerit briefly with their recent achievements, and discuss the future.

In addition to use pure nematic LC in TFT-LCDs, recently there are new trials that try to improve electro-optic characteristics of the LC devices by employment of particles such as anisotropic solid CNT and particles like C60.[13-17] Our observations indicate that the CNT-doped TN and IPS cells reduces a residual dc greatly and further, at a very high voltage the CNTs start vibrating with translational motion, distorting the LC orientation.

2. HA Groups: IPS vs. FFS

Figure 1 shows a schematic cell structure of the IPS and FFS mode. Although both devices have a homogenous alignment at am initial state, the rotation angle of the LC director in a white state is quite different each other, such that in the IPS mode the mid-LC layer twists most while in the FFS mode, the twisted angle of the LC director oscillates along electrode direction and at all electrode positions the most twisted LC layer exists below mid-layer. Further, the light modulation occurs by only birefringence effect in the IPS mode while in the FFS mode it does occur by mixed concepts of birefringence and polarization rotation effect. The difference comes from electric field shape, that is, in-plane field (E_y) in the IPS and fringe-field (E_y & E_z) in the FFS mode. This differentiate both modes each other in all electro-optic characteristics such as transmittance, color characteristic, cell-gap (d) dependent operating voltage (V_{op}), optimal cell retardation value, pressure resistant characteristic, and cell gap margin.

Hereafter, origins of difference between two modes are briefly reviewed.

-Transmittance

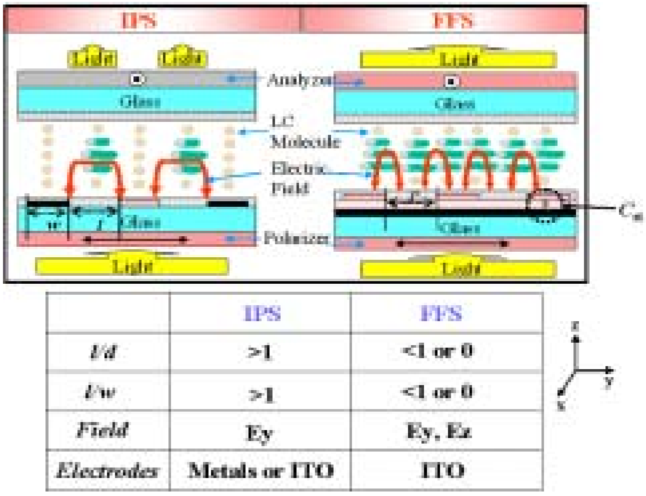
In the IPS mode, the light efficiency is very high between electrodes, while it is very low above electrodes since the in-plane field does not exist in those areas. Consequently, the more the number of electrodes, the less the transmittance is. However, in the FFS mode, the electrode width is minimized and instead of in-plane field, fringe-field which has strong horizontal component near edges of electrodes is utilized. Consequently, the strong rotation of the LC about 70^o near edge of electrodes by dielectric torque exerts elastic torque on the LC at the center of electrode, resulting in enough twist angles even at those areas. As a result, the LCs twist properly along whole electrode area, giving rise to high transmittance. Further, a rubbing direction in the IPS mode is in a vertical direction while it is in a horizontal one in the FFS mode. This causes a big difference in an aperture ratio of TFT-LCD since the light leakage between pixel and data line can be blocked automatically in the FFS mode.[18]

-Color Characteristic

To achieve a high contrast ratio with wide margin, O-mode is favorable for both modes.[19] However, E-mode shows less color shift than in the O-mode and this difference is smaller in the FFS mode than in the IPS mode, since in the FFS mode, the oscillating LC directors along electrodes do show self-compensation effect.[20]

-Cell-gap dependent V_{op}

In the IPS mode, the V_{op} is inversely proportional to the d, that is, more electrical energy is required to cause a twist deformation of the LC when a cell gap is lowered. This is similar to that in the FFS mode when using the LC with negative $\Delta\varepsilon$ (-LC) where the twist deformation mainly occurs. However, in the FFS mode using a LC with positive $\Delta\varepsilon$ (+LC), the tilt as well as twist deformation does occur with increasing voltage. So, when a cell gap is lowered, a field strength exerting on the LC becomes stronger than that in a high cell gap so that with increasing voltage, a high tilt angle is generated, which reduces effective cell retardation value, causing transmittance decrease. This principle allows the FFS mode to have low V_{op} even in low cell gap.[21]



	IPS	FFS
l/d	>1	<1 or 0
l/w	>1	<1 or 0
Field	Ey	Ey, Ez
Electrodes	Metals or ITO	ITO

Figure 1. Comparison of the cell structures and their light efficiency between IPS and FFS mode.

-Cell Retardation Value

In the IPS mode, the optimal cell retardation is slightly higher than $\lambda/2$, however, in the FFS mode using the +LC, it is much higher than $\lambda/2$ due to mixed concepts of the TN and IPS mode.[22]

-Pressure Resistant Characteristic

In general, the LC modes with HA show better dynamic stability than those with VA and splay when an external pressure is applied to the panel. Especially, the FFS mode in which the LC are anchored tightly by strong field shows a best performance.[23]

-Cell Gap Margin

Cell gap margin is also important factor to be considered in manufacturing. According to our study, the FFS mode with +LC shows better process margin than those in the IPS mode.

-Overall Review

As discussed above, the FFS mode has many advantages over the IPS mode although the number of array masks is one more than in the low transmittance IPS mode. Especially, the FFS mode shows high transmittance and wide-viewing-angle simultaneously with low operating

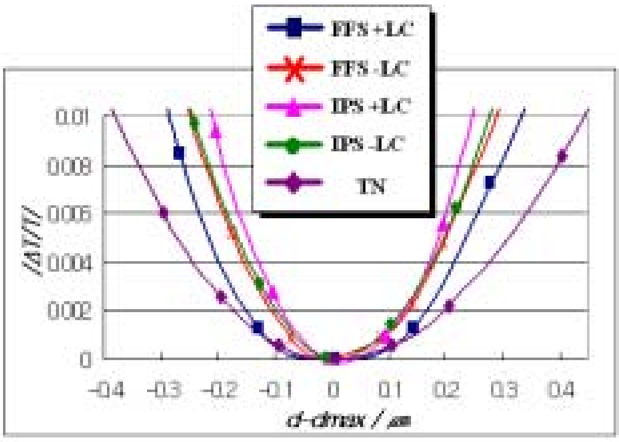


Figure 2. Cell gap margin of several LC modes.

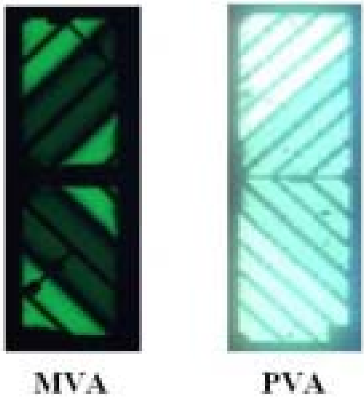


Figure 3. One pixel structure of the MVA & PVA modes with 8-domain.

voltage. Owing to this, this device can even be applied to a portable display of which low power consumption is highly required, and may replace the conventional TN mode in most high-end products for tablet PC and notebooks. For LC TVs, both IPS and FFS modes run in parallel at present, but in the future, the merge may be made (Hitachi also claims that the FFS (IPS-Pro) panel is the best solution for LC TV applications), overcoming their drawbacks such as color shift in a dark state, process sensitivity, and slow response time.

3. VA Groups: PVA vs. MVA

VA modes have one big advantage compared to the HA modes such that a rubbing process is not required. However, compensation films to suppress a light leakage at a dark state are absolutely required and further, how to tilt down the LCs in four directions is a key technology. The MVA utilizes a protrusion and fringe-electric field by patterned ITO to bias the LCs while the PVA utilizes only fringe-field patterned by top and bottom ITOs. Both devices have an intrinsic sensitivity in misalignment of top and bottom substrates and further, the wavelength dispersion of effective cell retardation value strongly depends on viewing direction. To overcome this, Fujitsu[24] and SEC[25] developed new pixels such that the degree of tilt angle as well as tilt direction varies in one pixel, imitating 8-domain VA, as shown in Fig. 3. This approach greatly reduces a color shift existed in the VA modes. Further, in the PVA mode, the LC has a perfect vertical alignment at an initial state (which is an origin showing a high contrast ratio at a normal direction) so that when overshooting voltage is applied, the LC gets lost where to go instantaneously. Smartly, SEC developed a new method called DCC II and achieved a fast response time less than 8ms for all gray to gray transitions. Nevertheless, the VA modes still need to be improved in transmittance, operation voltage, process margin, and response time. Both modes may run in parallel in LC TVs competing with the HA modes, but have difficulties to be applied to notebook displays.

4. Splay

The OCB mode was always attractive to LC device researchers but believed to have difficulties in commercialization. However, TMD co. made breakthrough to solve several problems. In addition, owing to fast response time (MPRT ~8ms); they insert black data, imitating impulse type display. However, the device has a relatively low contrast ratio at normal direction and in addition; the wavelength dispersion of effective retardation in viewing direction seems inevitable.

5. New Trials on CNT-LC System

To breakthrough the limitability of the viscous nematic LC, we have evaluated the feasibility that the anisotropic solid CNT may help electro-optic characteristics of the LCDs. We fabricated CNT-doped TN and IPS cells with a very low concentration of the CNT ~ 10^{-4} wt%. Here, the superfluorinated LC mixture from Merck Co. ($\Delta\varepsilon = +7.4$, $\Delta n = 0.088$ at $\lambda = 589$ nm) with CNT-doped, was filled at room temperature by the capillary action. The residual dc is measured through voltage-dependent capacitance (V-C) hysterisis curves for the TN cell, as shown in Fig. 4. Amplitudes of the residual dc at positive and negative cycles, which are defined as the voltage difference between rise and fall at half of the maximum capacitance, were 0.248 V and 0.252 V in the pure LC cell, respectively, while they were 0.005 V and 0.004 V in the MWNT-doped cell. Even in the pure IPS cell, they were 1.221 V and 1.164 V, respectively while in the SWNT-doped cell, they were 0.631 V and 0.641 V. Now, a question arises why the existence of CNTs dispersed in nematic LC medium reduces the residual dc. We presume that in the pure LC cell, the atom size of ions must be trapped at an interface between LC and alignment layer during applied dc voltage, while in the SWNT-doped cell, the CNTs attract small ions

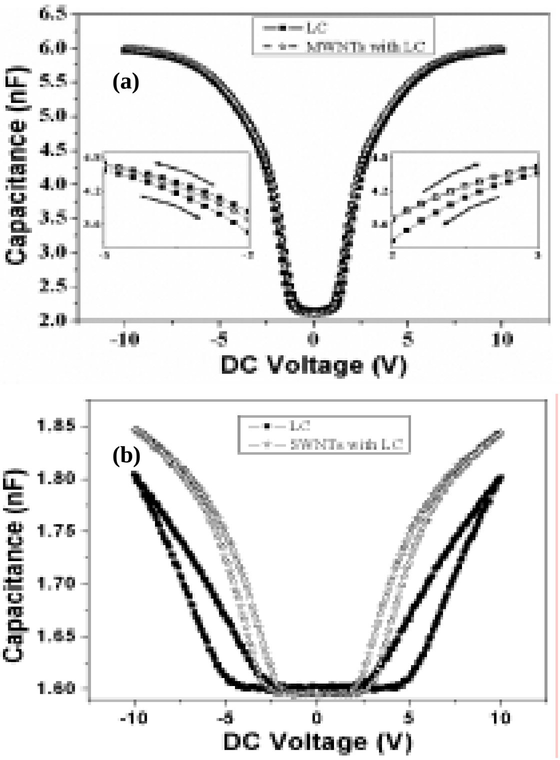


Figure 4. Measured voltage-dependent capacitance hysteresis curves for (a) pure LC and MWNT-doped TN cell and (b) pure LC and SWNT-doped IPS cell.

due to the existence of dipole field so that less ions are trapped at the interface.

6. Summary

About a year ago, the IPS, MVA, and PVA modes commercialized for LC TVs but nowadays, two more LC modes such as FFS and OCB joined the group. The LC modes which can be classified into three groups: HA, VA, and Splay, compete each other inside and inter groups. However, to be more competitive, each mode should take advantages of the other mode inside group, competing with other groups. In the future, each HA and VA group may be joined into one mode competing each other, but still it is exciting to see how the splay mode survives. Further, it is worthwhile to study the LC cell with nanoparticles to overcome a limitation that pure nematic LC has.

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