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A Fast Response Smectic LCD using Induced Polarization

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Abstract

In this paper, a general performance of the PSS-LCD or Polarization Shielded Smectic Liquid Crystal Display is discussed. This smectic base LCD does not use any spontaneous polarization, but uses induced polarization just sa me with current nematic base LCDs. Specific initial molecular alignment as well as specific cell design realizes ext remely fast optical response speed with native wide viewing angle. Moreover, this performance is provided by full compatible electronics for current conventional LCDs. A general performance of the PSS-LCD is introduced herein.

Keywords : LCD, smectic LC, PSS-LCD

1. Introduction

In the last two decades, more than dozens of new liquid crystal display modes have been proposed and investigated for their practical use as well as fundamental researches. Some of them are based on conventional nematic liquid crystal technologies, some utilize spontaneous polari-zation from specific smectic liquid crystal materials, and some use liquid crystal and polymer gel interaction. In addition to improving the liquid crystal drive mode, TFT base LCDs have shwon to have progressed significantly in terms of an advanced flat panel display. MVA mode LCDs [1], IPS mode LCDs [2], FFS mode LCDs [3] and OCB mode LCDs [4] are the results of these efforts. Their contrast ratio currently exceeds 600:1 with a faster optical response speed than ever; moreover, their viewing angle is now competing with that of emissive FPD.

On the other hand, the successes achieved has also brought about challenges to the LCD industry. In particular, both optical response speed and viewing angle have been realized under the some sacrifices both in characteristic properties of liquid crystal physics and volume manufacturing payload. In the last decade, along with the significant success of the new TFT-based types of LCD modes, several unique approaches have been of our acknowledges such as ferroelectric LCDs [5], antiferroelectric LCDs [6] those are attempting to have much faster optical response speed with native wider viewing angle. Unfortunately, these approaches have not yet shown great success from an industrial point of view.

From a practical application point of view, the origin of drive torque of the liquid crystal molecules can be said to be the most important in terms of its applicability. So far, most liquid crystal displays being used are based on induced polarization of the liquid crystal molecules. Due to this wide use of this type of LCD drive mode, most active backplanes such as amorphous silicon thin film transistors (TFTs), low temperature TFTs, high temperature TFTs, and monolithic silicon backplanes have been de-signed and used for this particular application.

In this paper, a new type of smectic LCD mode is introduced. This display mode is called Polarization Shielded Smectic LCDs or PSS-LCDs. The PSS-LCD is driven by a coupling between applied electric filed and induced polarization that is very common for most of above described LCDs.

Moreover, the PSS-LCD shows very fast optical response as well as native wide viewing angle due to its origin of induced polarization.

2. PSS-LCD

The PSS-LCD or Polarization Shielded Smectic Liquid Crystal Display uses a certain type of smectic liquid crystal molecules in conjunction with very strong azimuthal anchoring energy. Its driving torque is provided by a coupling between applied electric field and induced

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polarization from liquid crystals. In this sense, the PSS-LCD would be classified in conventional LCD drive mode in terms of its driving source. Although the PSS-LCD requires using a certain type of smectic liquid crystal materials, it does not use any spontaneous polarization at all. Due to the torque source, the PSS-LCD has exactly the same voltage–transmittance curve as that of most nematic base LCDs such as analog gray scale with a certain threshold property.

The important features characterized the PSS-LCD are as follows: (1) using specific type of smectic liquid crystal mixtures, (2) applying very strong azimuthal anchoring energy with weak polar energy, (3) driving the LCD using same electronics for conventional LCDs.

3. How the PSS-LCD Works?

3.1 Principle of the PSS-LCD

Fig. 1 illustrates a general description of the PSS-LCD. The smectic liquid crystal molecules have an initial molecular alignment along with set alignment direction in their n-directors. A pair of linear polarizers is set as cross Nicole position. Usually, the PSS-LCD is used as a normally black mode. Therefore, the initial molecular alignment quality is very important to obtain higher contrast ratio same with an IPS-LCD and an FFS-LCD.

The liquid crystal molecular movement is not like most of nematic base LCDs. The PSS liquid crystal molecules move along with cone surface shown in Fig. 1. The tilt direction of the molecule is decided by the direction of the applied electric field, but not by polarity of the applied field. Therefore, the PSS-LCD is fully compatible with current conventional drive scheme with nematic base LCDs. Every time the applied electric field changes its direction by frame inversion, line inversion, or dot inversion whatever, the PSS-LC molecules move along with the cone surface passing through the top of the cone. Thus, a typical light throughput behavior to the time base of the PSS-LCD is the same as that in Fig. 2. This automatic blanking function of the PSS-LCD is one of its unique properties. Typical optical response time of the PSS-LCD is 350 μs. However, the response time is very dependent on anchoring energy rather than PSS liquid crystal materials. In some cases, the PSS-LCDs show 100 μs of rise time and 50 μs of fall time under the standard drive condition.

Table 1. A general comparison among PSS-LCD, SSFLCD and TN-LCD

	PSS-LCD	SSFLCD	TN-LCD
Liquid Crystals	Smectic C LCs	Ferroelectric LCs	Nematic LCs
Alignment	Homogeneous	Homogeneous	Twisted
Initial director alignment	Parallel to buffing direction	Tilted by a half cone angle from buffing direction	Parallel to buffing direction
Typical cell gap	1.8 μm	2 μm	4 μm
Spontaneous polarization	No	Yes	No
Driving torque	Induced polarization	Spontaneous polarization	Induced polarization
Permittivity change by drive	$\Delta\varepsilon$	2Ps	$\Delta\varepsilon$

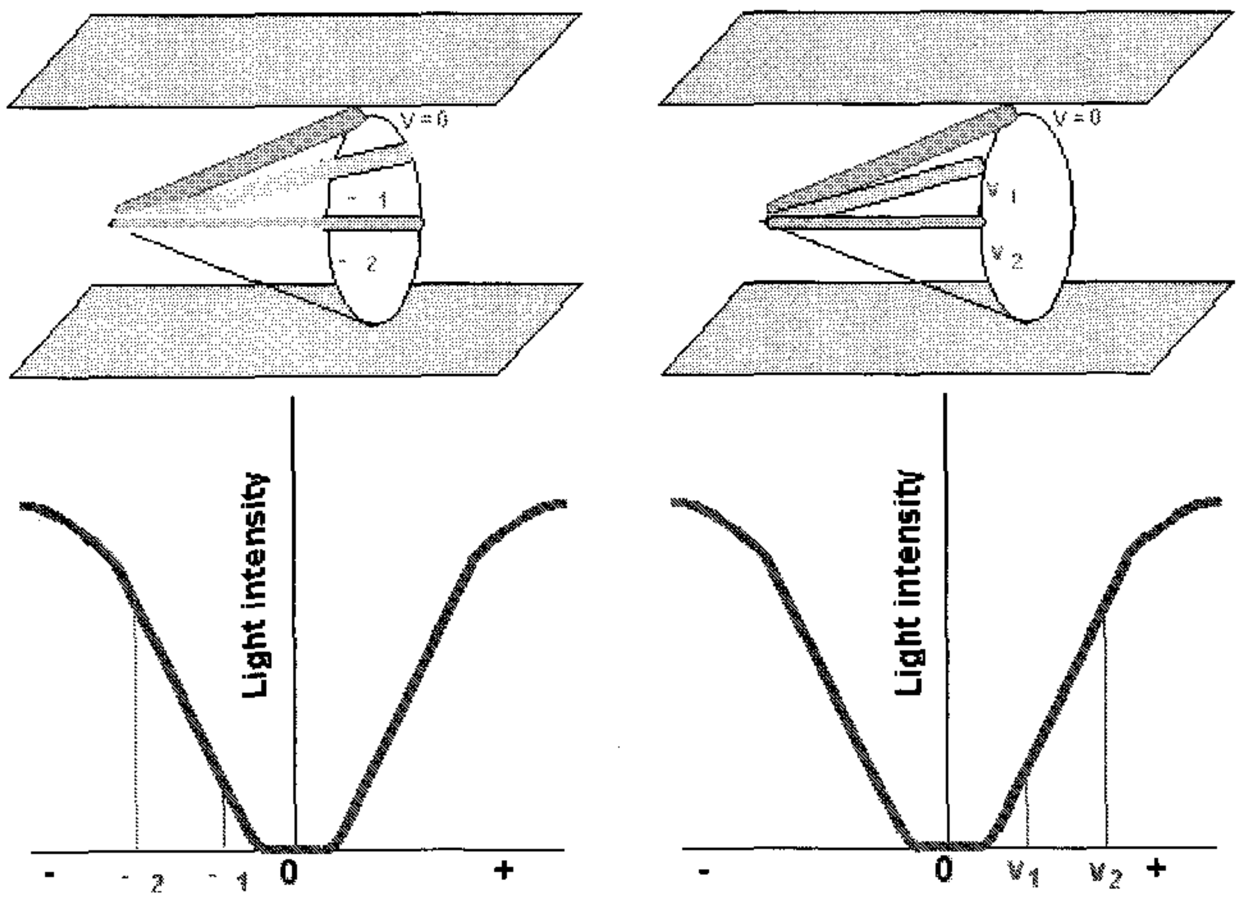


Fig. 1. Molecular switching behaviour of the PSS-LCD.

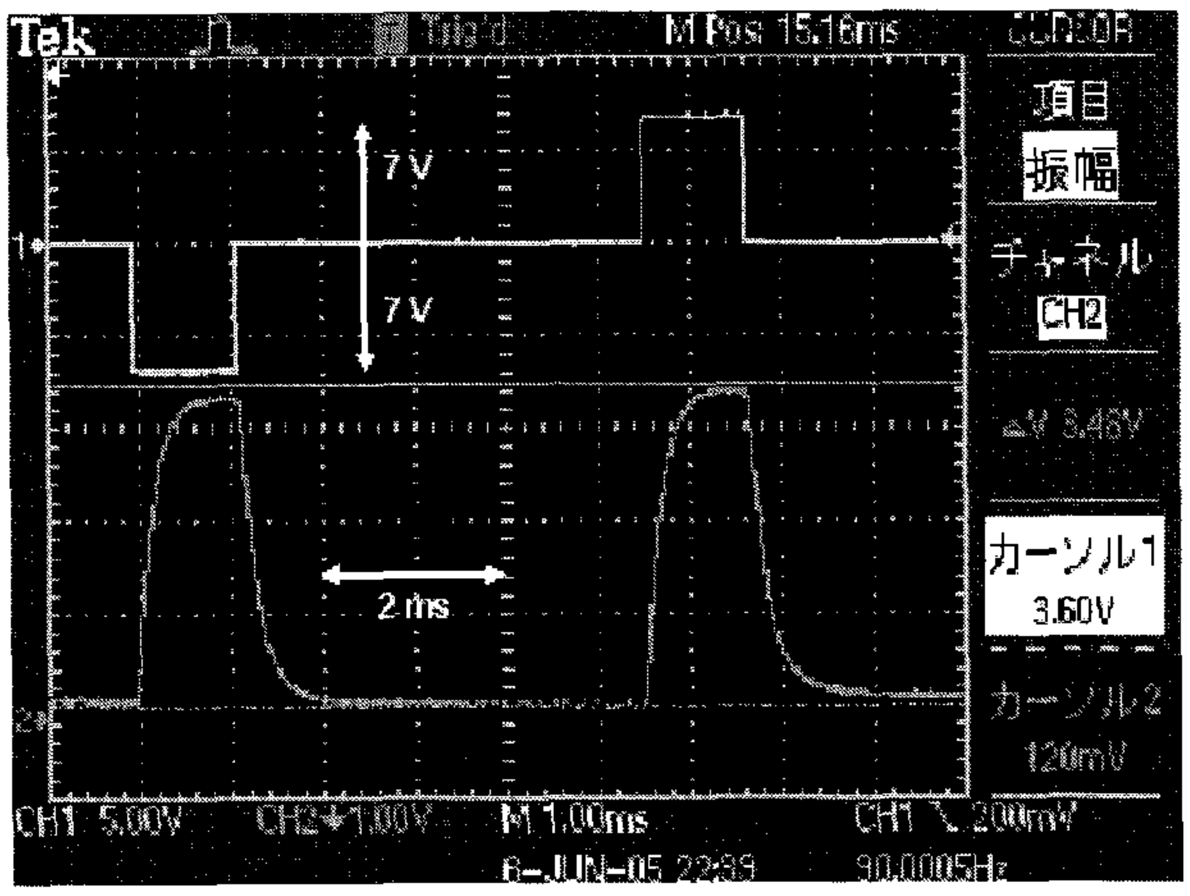


Fig. 2. A typical light throughput profile of the PSS-LCD.

The native wide viewing angle has been provided by the PSS-LCD's molecular switching configuration as well as its extremely fast optical switching. As illustrated in Fig. 1, the PSS-LCD's molecular switching configuration is similar for both IPS-LCDs and FFS-LCDs in terms of in-plane switching. Moreover, the extremely fast optical switching of the PSS-LCD realizes the time domain averaging in the birefringence. Unlike conventional LCDs, the PSS-LCD decides its birefringence dynamically with a time range of frame inversion, line inversion or dot inversion. This dynamic birefringence mode makes time domain averaging in birefringence. In addition, owing to an extremely fast optical switching speed of the PSS-LCD, the PSS-LCD provides very wide viewing angle without birefringence averaging in space domain, which sacrifices aperture ratio in most cases.

3.2 The initial molecular alignment

One of the unique properties of the PSS-LCD in its initial molecular alignment is its n-director molecular alignment. The PSS-LCD requires using a certain category of smectic liquid crystal molecules. The usable smectic liquid crystal molecules must have its n-director tilted from the smectic layer normal as a bulk. Using this type of asymmetrical smectic liquid crystal molecules, the PSS-LCD forces the n-directors normal to the smectic layer as the initial molecular alignment as illustrated in Figs. 3 (a) and (b).

This n-director normal to the smectic layer is provided by strong azimuthal anchoring as well as careful cell design balanced in mechanical influence from perimeter seal materials. Due to the conceptional existence of the smectic layer structure, the display performance of the PSS-LCD is decided by the specific balance among liquid crystal materials, alignment materials and perimeter seal materials. The strong azimuthal anchoring as well as the induced polarization torque creates clear threshold voltage in the PSS-LCD. This threshold property is the one that clearly distinguishes smectic LCD using spontaneous polarization such as ferroelectric LCDs from anti-ferroelectric LCDs.

The threshold is confirmed both by the PSS-LCD's voltage-transmittance (V-T) curve and optical response to a slow frequency triangular waveform voltage as illustrated in Fig. 4 and Fig. 5, respectively. The observed threshold voltage shown in Fig. 4 is relatively small. In the PSS-LCD, the threshold voltage is governed both by the PSS liquid

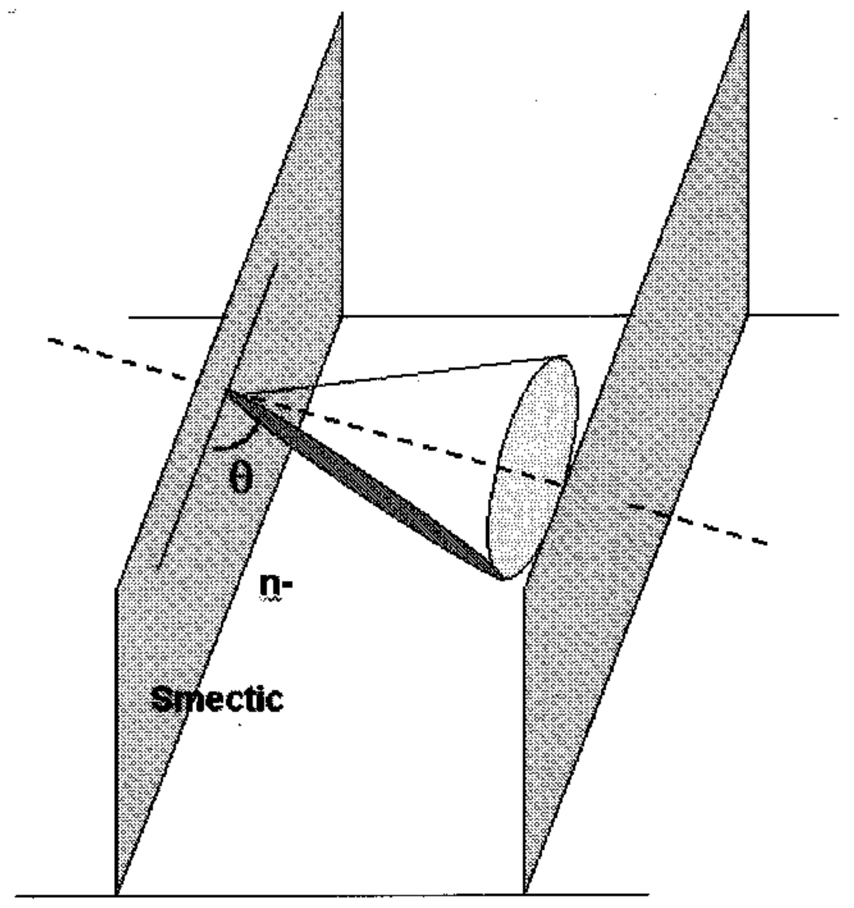


Fig. 3 (a). A smectic liquid crystal whose n-director has a tilt normal to the smectic layer as a bulk is used for the PSS-LCD.

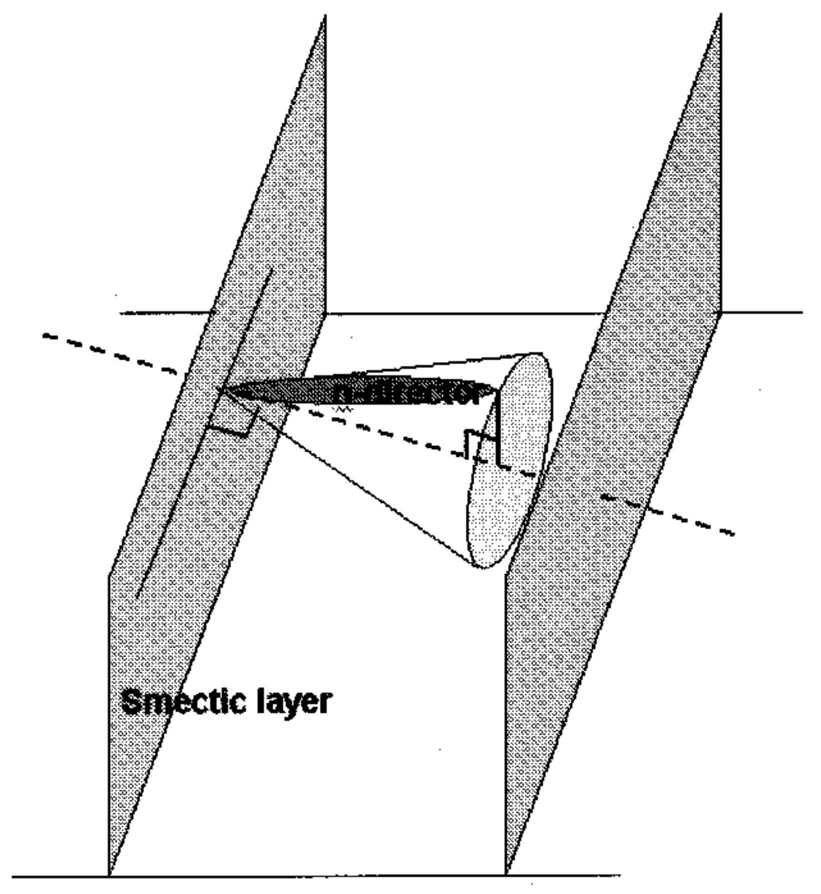


Fig. 3 (b). The smectic liquid crystal whose n-director has a tilt normal to the smectic layer is initially aligned normal to the smectic layer by strong azimuthal anchoring and specific balance between the bulk alignment and mechanical matching from the perimeter seal.

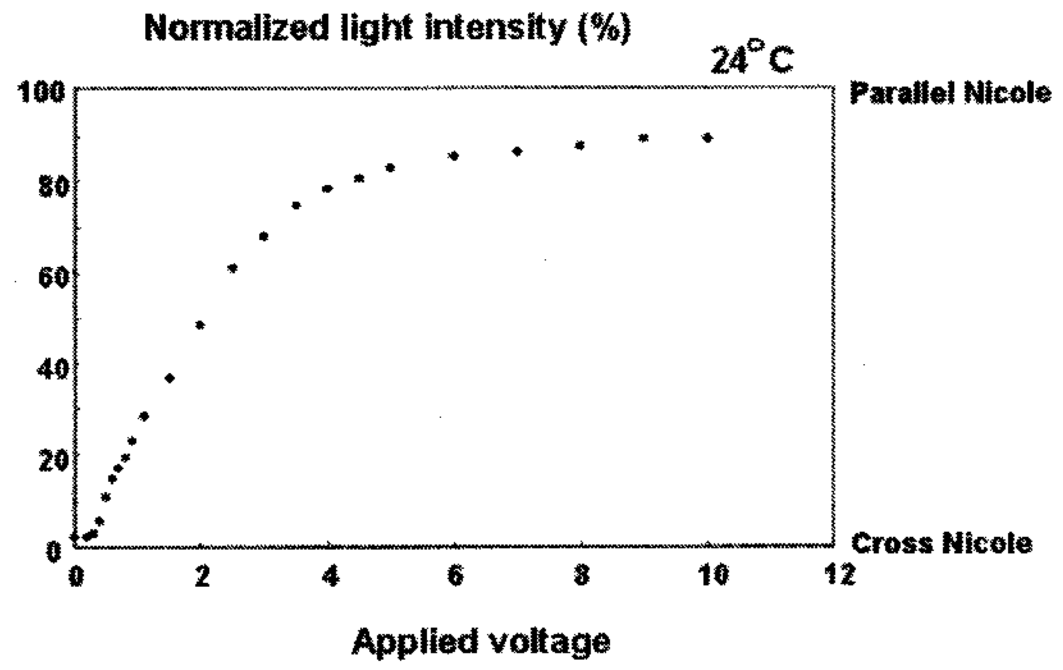


Fig. 4. An example of the V-T curve of the PSS-LCD. The PSS-LCD shows threshold voltage to the applied voltage. The threshold voltage is primary governed by the specific balance between the PSS LC material and azimuthal anchoring energy.

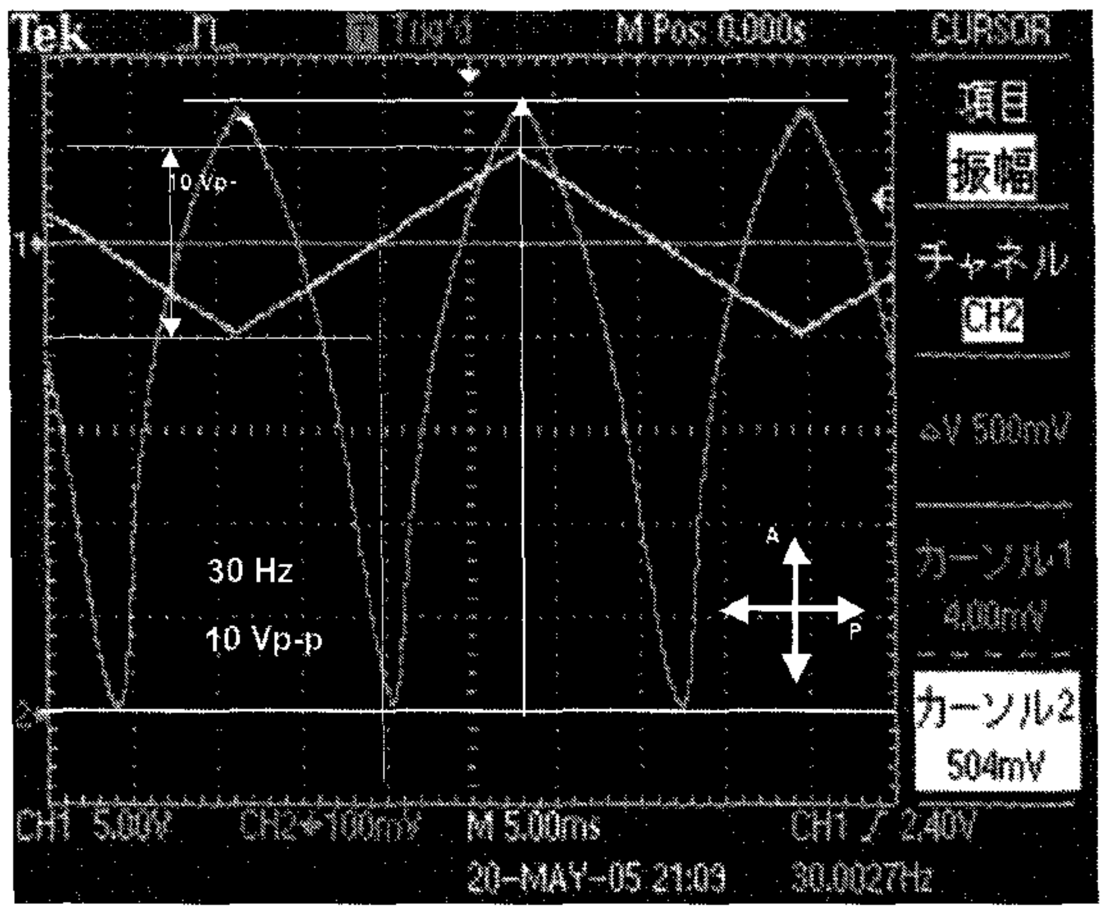


Fig. 5. The PSS-LCD responds to the applied electric field and not to the polarity of the applied voltage. The optical response to the applied electric field is exactly the same as that of most of nematic base LCDs.

crystal material and strength of the azimuthal anchoring energy. The induced polarization has some influence on the threshold voltage, however, its influence is not the primary one unlike most of nematic base LCDs using induced polarization. In other words, the fast optical response of the PSS-LCD is provided by the induced polarization originated by quadra pole momentum and consequent molecular movement orbit along with the edge of the cone as illustrated in Fig. 1. Due to its origin of the induced polarization, the PSS-LC molecules differentiates upward and downward applied electric field, resulting in flip-type of movement on the surface of the cone as shown in Fig. 1.

3.3 Overview of the feature

The major approach of the PSS-LCD in terms of securing the high display performance is its elimination of any hysteresis in the V-T curve. Other approaches include minimizing the pixel capacitance to fit any types of TFTs or drive backplanes. No need to say that these approaches should also provide extremely fast optical switching speed, nativly wide viewing angle and it does not require any new development of electronics.

The hysteresis free performance in the V-T curve is established by the induced polarization of the smectic liquid crystal molecules. The minimum pixel capacitance is realized by using specific induced polarization of the PSS-LCD. Although the measured anisotropy of dielectric constant of the PSS-LC materials is very small, for example $\Delta\varepsilon$ of 1.5 or 2.0, the PSS-LCD realizes extremely fast optical

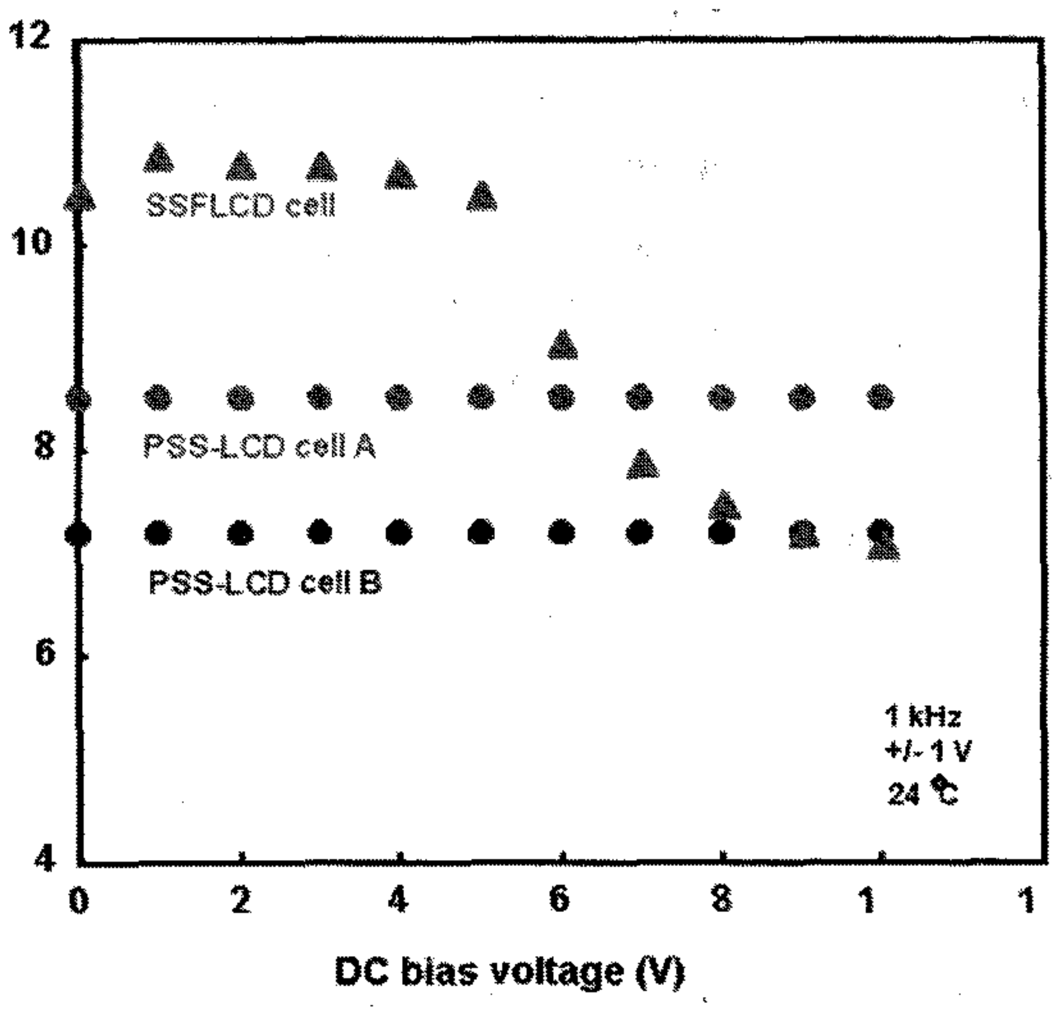
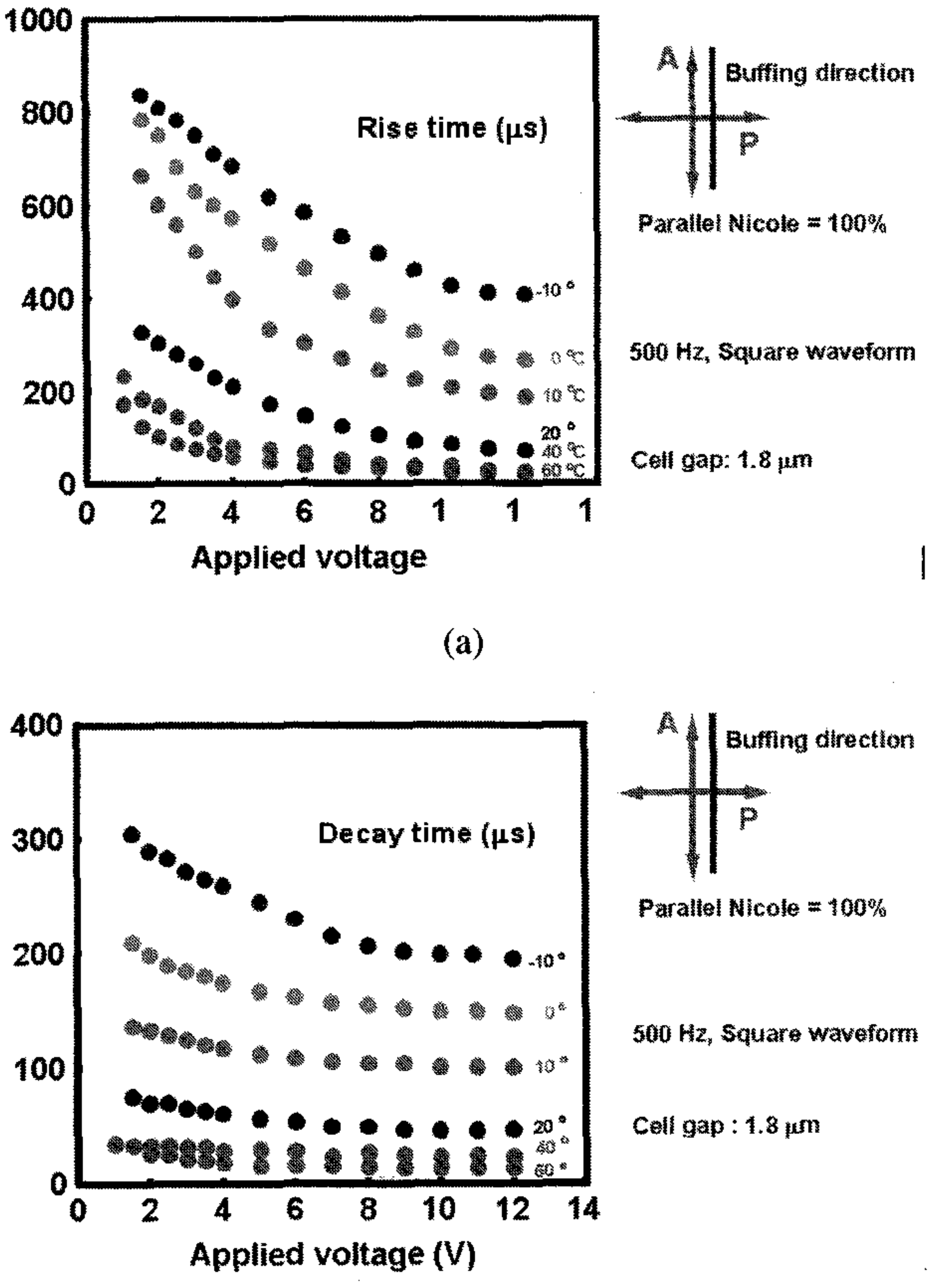


Fig. 6. Dielectric change before and after the optical switching. Comparison between the SSFLCD and the PSS-LCDs.



(a)

(b)

Fig. 7. Examples of the optical switching times depending on applied voltage and ambient temperature. (a) shows rise time and (b) shows decay time. Inter gray optical response times are presented by each applied voltage. One of the specific performances of the PSS-LCD is its very small influence on the optical switching time by applied voltage.

response due to its specific molecular movement along with a cone surface. The small distance of the PSS-LC molecules' travel in the panel to create large enough birefringence to provide two major benefits in terms of TFT-LCD performance. One is extremely fast optical response speed such as 300 μs with a typical driving condition. The other is very small change in pixel capacitance. These two major accomplishments by the PSS-LCD enable any conventional types of TFTs drive with some certain significant tolerance. Fig. 6 shows an example of the small capacitance change before and after the optical switching of the PSS-LCD pixel.

3.4 Overview in the E-O performance

Fig. 7 presents a typical optical response of the PSS-LCD. As discussed above, one of the unique characteristic properties of the PSS-LCD is its much faster response to the decay process than that in the rise process. Moreover, the temperature dependence of the response time is very small in decay process. The rise process displays some temperature dependence similar to most nematic base LCDs; the decay process is almost independent from ambient temperature and drive voltage.

This unique performance is made possible by its unique initial molecular alignment. The PSS-LC molecules align tilted from the smectic layer normal as a bulk, or in nature. These molecules are forced to align the layer normal. Therefore, all of the PSS-LC molecules have a great tendency to flip back to the tilted layer normal. This energy is suppressed by the strong azimuthal anchoring energy. Just like a spring coil, an elongated spring coil backs to the original length immediately after the power is removed. This recovery time in a spring coil is almost independent from the elongated power. This extremely fast decay performance fits for use the PSS-LCD in a field sequential color system.

The PSS-LCD's specific molecular movement also allows extremely fast inter-gray scale response as shown in Fig. 7. Although the driving torque is provided by the coupling between the applied electric field and dielectric anisotropy of the PSS-LC materials, the PSS-LC molecular movement is along with cone surface illustrated in Fig. 1, hence making substantially large enough voltage change in the intergray scale driving. The smaller capacitance of the PSS-LCD allows this "dynamic" dielectric driving method to be effective.

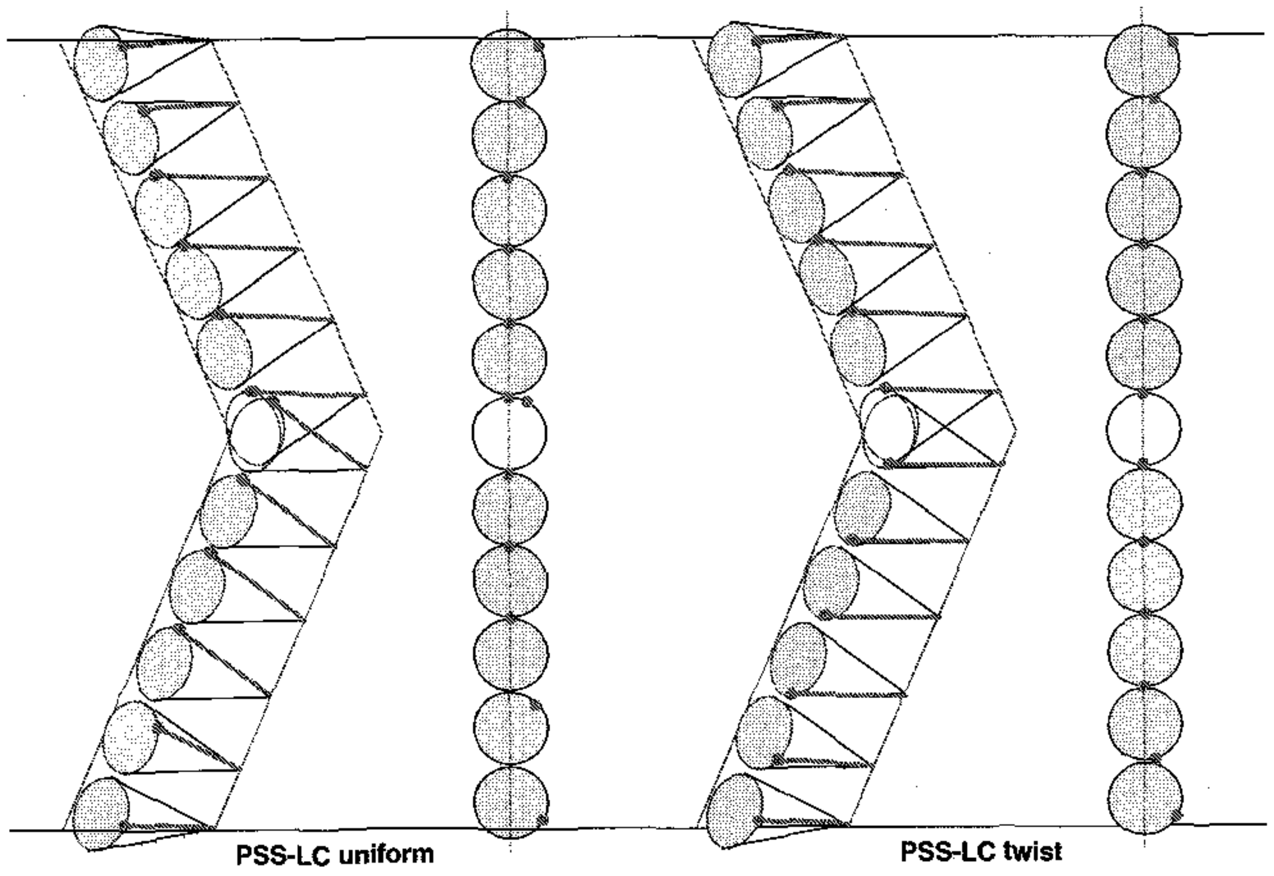


Fig. 8. A typical c-director configuration in the PSS-LCD. Left side shows uniform configuration, right side shows twisted configuration. The ideal c-director configuration is a uniform one.

4. Specific Design for the PSS-LCD

Unlike conventional nematic LCDs, the PSS-LCD has a conceptional smectic layer structure. This layer structure has requirements in terms of its cell design. Perimeter seal is one of the most required materials for the design of the PSS-LCD, in particular, from a volume manufacturing point of view.

The strong azimuthal anchoring energy mostly provided by surface anchoring layer needs to have a specific balance to keep c-director of the PSS-LC molecules uniform as shown in left part of Fig. 8. If the specific balance between the surface anchoring and mechanical stress caused by mechanical performance of the perimeter seal does not match in a satisfactory manner, the c-director of the PSS-LC molecules may have some twist, resulting in degradation of the display performance as illustrated in the right side of Fig. 8. Therefore, in the design of the PSS-LCD, perimeter seal design is a key factor to consider.

5. Summary of the Features

The PSS-LCD was fully inherited from major current nematic-based TFT-LCDs in its electrical drive portion.

The V-T curve of the PSS-LCD is the same as that of TN-LCDs. Therefore, the commercially available drive LSI and controllers can be used to drive the PSS-LCDs as they are. The extremely fast optical response speed without increase in capacitance would offer more advantages in driver LSIs.

On the other hand, the molecular movement is somewhat similar with an SSFLCD. The largest difference in the molecular movement between the SSFLCD and the PSS-LCD is their molecular tilt configuration. Due to spontaneous polarization, the stable tilt angle of the SSFLC is decided by the strength of the polarization. The strength of the polarization is a function of ambient temperature.

Therefore, the initial molecular alignment of the SSFLCD is dependent on ambient temperature. Unlike this situation, the extinction angle of the PSS-LCD is decided by the initial molecular alignment pre-set by molecular alignment direction. The extinction angle of the PSS-LCD is independent from ambient temperature. Moreover, due to the induced polarization nature, the PSS-LC molecules keep their specific tilt angle on the cone surface solely by the coupling between the applied electric field and the induced dielectric anisotropy of the liquid crystals.

The PSS-LCD is proposed taking into consideration the practical requirement of the actual circumstances in the relevant industry. Full compatibility of currently established electronics for LCDs allows potentially wide flexible use of the PSS-LCDs. Moreover, most of the LC panel manufacturing processes are compatible with current dominant LCD mfgs. In fact, some of the mfg process is simpler than those of current one, in particular, it is free from pixel division for wide viewing angle.

6. Conclusion

The PSS-LCD was proposed taking into consideration the practical requirement of the actual circumstances of the relevant industry. Full compatibility of the currently established electronics for LCDs allows potentially wide flexible use of the PSS-LCDs. In fact, most LC panel manufacturing processes are compatible with current dominant LCD mfgs. Some mfg processes are simpler than those of the existing one, in particular, the fact that it is free from pixel division for wide viewing angle.

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