

FERROELECTRIC LIQUID CRYSTAL-POLYMER GEL DISPLAYS

J.Pirš, B.Marin, S.Pirš

Keywords: television displays, television projectors, LCD displays, ferroelectric liquid crystals, FLC molecules, electrooptical properties, memory properties, molecular ordering, ordering stabilization, mechanical stability, novel technology, gel solution, gel monomer, polymerizing, switching times, short times

Abstract: Complex molecular ordering in ferroelectric liquid crystals (FLC), unlike in simple, standard nematic liquid crystals, enables the manufacturing of liquid crystal displays (LCD) with inherent memory properties and standard TV compatible electrooptic switching speeds. However under the present state of the art FLC displays are unstable against mechanical shock and therefore still unreliable. This paper presents a novel technological solution that enables the stabilization of the FLC molecular ordering through entire volume of the FLC cell. Volume stabilization is achieved by the LC/polymer gel dispersion which is prepared by polymerizing a gel monomer solution in suitably aligned ferroelectric display cell. The volume stabilized LC cell gives mechanical stability to FLC displays with internal memory and provides for high contrast, high speed shuttering.

Prikazovalnik na osnovi feroelektričnih tekočih kristalov in polimernih gelov

Ključne besede: zasloni televizijski, projektorji televizijski, LCD zasloni, FLC kristali tekoči feroelektrični, FLC molekule, lastnosti elektrooptične, lastnosti pomnilniške, urejenost molekularna, stabilizacija urejenosti, stabilnost mehanska, tehnologije nove, raztopina želatine, želatina monomerna, polimerizacija, časi preklopni, časi kratki

Povzetek: Za razliko od standardnih nematskih tekočih kristalov omogoča kompleksnejša urejenost molekul feroelektričnih tekočih kristalov (FLC) izdelava tekočeh kristalnih prikazovalnikov (LCD) s spominskimi lastnostmi in hitrostjo preklopnih časov, ki je kompatibilna s standardnimi TV signali. Na žalost standardni FLC prikazalniki še niso mehansko dovolj stabilni in zato niso primerni za praktično uporabo. Članek podaja novo tehnološko rešitev, ki omogoča stabilizacijo urejenosti molekul FLC po vsej prostornini FLC celice. Volumsko stabilizacijo urejenosti molekul zagotavlja v kristal vgrajena urejena polimerna mreža, ki nastane pri feroelektričnem tekočem kristalu. Vakuumska stabilizacija zagotavlja mehansko stabilnost FLC prikazovalnikov hkrati pa ohranja spominske lastnosti ter hitre preklopne čase.

Introduction

Since 1980 when N.Clark and S.T.Lagerwall^{1,2} introduced the surface stabilized ferroelectric LC cell (SSFLC), a number of improvements^{3,4,5} of this technology has been made, to the point, where commercial flat-panel displays are being announced. The principal advantage this device brings is a significantly faster switching rate and even more important, a memory effect which makes it possible to use greatly simplified electronic driving schemes. All requirements are met by a passive matrix rather than by an active one, which is required for twisted nematic (TN) liquid crystal cells.

The basic operating principles of the FLC displays are demonstrated in figures 1 and 2⁽¹⁴⁾. Unlike in standard nematic liquid crystals (NLC), the FLC molecules are not just oriented parallel, but they tend to form monomolecular layers within which the FLC molecules are parallel and tilted for an angle Θ from the layer plane normal. Since FLC molecules don't have a center of symmetry (chiral molecules), such molecular orientation allows for

the appearance of the net spontaneous electric polarization.

During the display manufacturing process the FLC is placed between two glass walls with transparent electrodes covered with adequate orienting layers (typical display configuration!). The FLC is then cooled down through various phase transitions from the isotropic, through nematic, smectic SmA into the ferroelectric smectic SmC^{*} phase. The FLC molecules orient themselves in layers perpendicular to the glass surfaces and to the direction of the orienting layers. If the thickness of the display glass cell is small enough (1-3 μm), the FLC molecules due to their tilted orientation in the SmC^{*} layers can assume only two orientations: $+\Theta$ or $-\Theta$ with respect to the smectic layer normal (see fig. 1).

The electrical polarization (P) corresponding to these two allowed molecular orientations is perpendicular to the display cell walls and can either point "UP" ($+\Theta$) or "DOWN" ($-\Theta$). Both orientations are equivalent as far as energy is concerned and therefore bistable (memory!!),

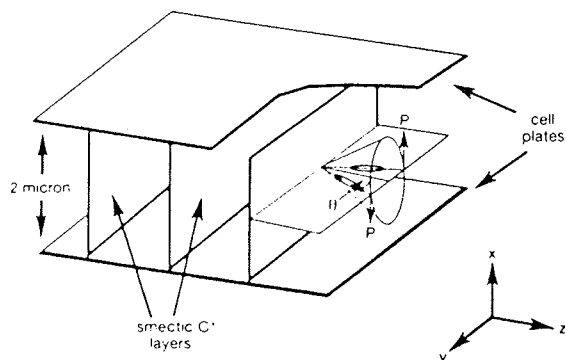


Fig. 1: Schematic presentation of the smectic FLC molecular layers and molecular orientation in the "Surface stabilized FLC displays"

but can be switched from one to another by means of the pulses of electric field.

These two allowed molecular orientations can be optically distinguished by means of the crossed polarizers, where the polarizing axis of one polarizer is parallel to one of the allowed molecular orientations ($+\Theta$ or $-\Theta$) - see fig 2. If the FLC molecular tilt angle is 22.5° and if the display cell thickness is chosen so that the FLC layer acts as a half-wave plate, such a sandwich of FLC display cell between crossed polarizers acts as electrically switchable optical light shutter with internal memory.

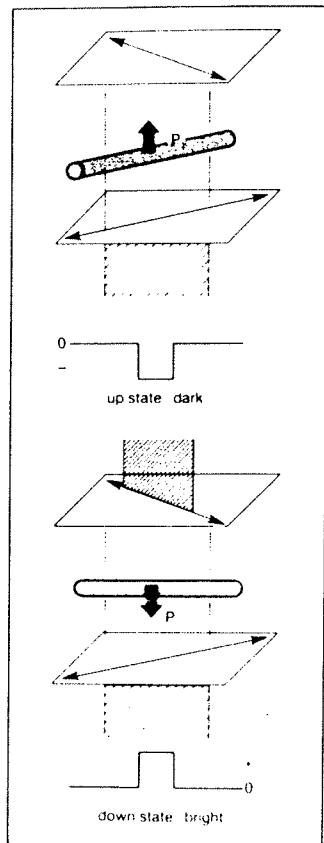


Fig. 2: Operating principle of the FLC display

A major drawback of the present state of art of the above described surface stabilized ferroelectric liquid crystal (SSFLC) displays is, that they are unstable against mechanical shock. The origin of this problem is the shrinking of smectic layers at the SmA to SmC^* phase transition due to the molecular tilt in the ferroelectric SmC^* phase. In order to avoid a dilation in the confined geometry of the cell, a well known chevron structure appears^{9,10,11}. This structure critically depends on mechanical stresses causing local flow which results in an irreversible breaking of the smectic planes.

Here we propose a solution to the problem of the instability in the SSFLC cell by the addition of gel polymers to stabilize the cell geometry as well as to volume stabilize the FLC order.

The concept of "volume stabilization" of the molecular ordering in FLC is based on the polymerization of a small amount of gel monomer added to the FLC. The amount of the added monomer is small enough so, that it does not significantly affect molecular ordering or alignment of the FLC material. The polymerization of the monomer is "initiated" when the molecules of the FLC acquire the desired orientation determined by the boundary conditions and/or interactions with orienting magnetic/electric field. Under these conditions they polymerize in a highly anisotropic texture. Such a polymer forms a network through the entire LC and volume stabilizes the LC cell geometry as well as the microscopic ferroelectric ordering of the LC molecules. It is also important, that the polymer network formed in the LC, hinder the mechanical flow of the LC under mechanical stress. Volume stabilization of the cell can be achieved with a relatively small concentration of the monomer additives $\approx 0.5\text{-}3\%$.

Experimental

The sample "volume stabilized" FLC (VSFLC) display cells were made in almost the same way as the conventional surface stabilized ferroelectric liquid crystal (SSFLC) displays (- ITO covered flat glass plates with rubbed nylon orienting layer separated by $\approx 3 \mu\text{m}$ spacers, sealed with UV curable epoxy sealant and vacuum filled with E.Merck ZLI 4237-100 FLC mixture and 0.5-3% addition of acrylate Desolite DO44 of DSM Resins International). The cells were filled at an elevated temperature $\approx >95^\circ\text{C}$ (- isotropic phase) then slowly cooled through nematic and SmA phase into the SmC^* phase. As the FLC ZLI 4237-100 experiences a pitch of $10 \mu\text{m}$ in the SmC^* phase, the cell thickness was sufficiently small in order to unwind the helical SmC^* structure¹³. Together with the homogeneous boundary conditions caused by rubbed nylon, this resulted in a homogeneous chevron SSFLC molecular ordering. Using strong (80 V), slowly alternating (3Hz) electric field pulses a well known stripe texture was obtained (fig3). The competing effects of the molecular tilt on the nylon orienting layer, chevron structure and the electric field induced stripe texture resulted in a very small angle (few degrees)

between the molecular layer orientation in the consecutive stripes (see fig 3) allowing for high contrast ≈ 20 in the transmissive mode. Due to a "bookshelf structure" in the stripe texture a very good bistability as well as very high angle between both optical states ($\geq 40^\circ$) was obtained.

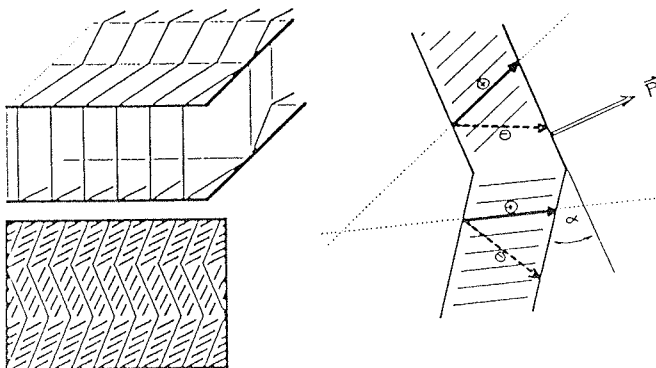


Fig. 3: Schematic presentation of the electric field induced stripe texture in thin layer of FLC

As the FLC/monomer dispersion was filled in the FLC display cell at an elevated temperature (-in the isotropic phase of FLC component), it had to be cooled down into the ferroelectric SmC' phase.

The cooling of the FLC/monomer dispersion and especially the structural changes due to phase transitions reduced the solubility of the monomer in the FLC so, that it partially phase separated in the form of microdroplets. Most of these microdroplets formed predominantly on the cell walls were very small ($\leq 1 \mu\text{m}$), however some of these droplets grew as large as $\approx 10 \mu\text{m}$. These "giant" microdroplets linked both boundary glass plates of the LCD cell and after polymerization acted at the same time as sealant and spacers. This polymer droplet formation efficiently stabilized the "geometry" of the LC cell.

When the FLC/monomer dispersion was cooled down in the ordered liquid crystalline phase, the photopolymerization of the monomer was induced using the 150 W UV light source (360 nm) for few minutes. The applied UV light caused the polymerization of the monomer microdroplets as well as the phase separation of the rest of the monomer molecules, that were until that time still "dissolved" in the FLC material. These monomer molecules polymerizing in the ordered FLC medium, formed a well ordered polymer network that reflected the molecular ordering (see fig.4). The chevron defect walls between the consecutive stripes (see fig. 3) acting as polymerization centers induced the polymer phase separation during the UV polymerization process. So the oriented polymer network was formed predominantly along the chevron defect walls (see fig 4) efficiently stabilizing the stripe texture orientation of the FLC. This structure remained preserved even when the FLC was heated above the isotropic phase transition and then cooled back into the ferroelectric SmC' phase.

The best results were obtained when the polymerization was induced in the ferroelectric SmC' phase, however the ordered polymer texture was formed in the SmA and in the nematic phase as well. The results were not significantly different, except that the amount of polymer microdroplets was much smaller/negligible in the nematic phase due to significantly higher solubility of the monomer in the nematic phase.

The ordered phase separated polymer network structure in the ordered FLC layer was reasonably well confirmed by the electron microscopy. Figures 4 and 5 show TEM micrographs of the polymer network in an FLC/polymer gel containing 98% of ZLI 4237-100 and 2% of Desolite D 044 acrylate.

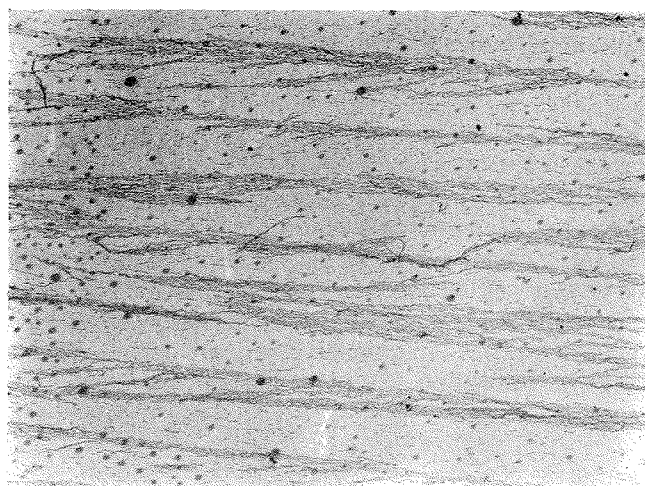


Fig. 4: TEM micrograph of the ordered polymer texture formed during UV activated polymerization process in the 2% FLC/polymer gel (magnification 2400)

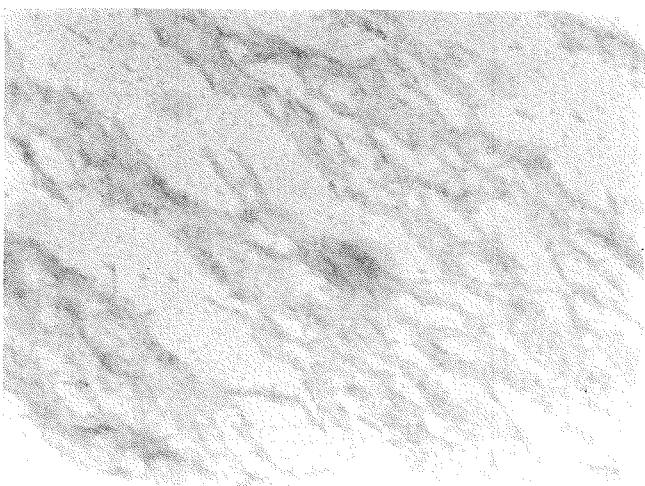


Fig. 5: TEM micrograph of the detail of the polymer texture on Fig.4 (magnification 40000)

The TEM micrograph clearly shows the ordered polymer texture and the small polymer microdroplets that "condensed" on the cell walls during the cooling down process. The "giant microdroplets" can be seen (Figure 6) under polarizing microscope. TEM micrograph as well as polarizing microscope analysis give only a qualitative

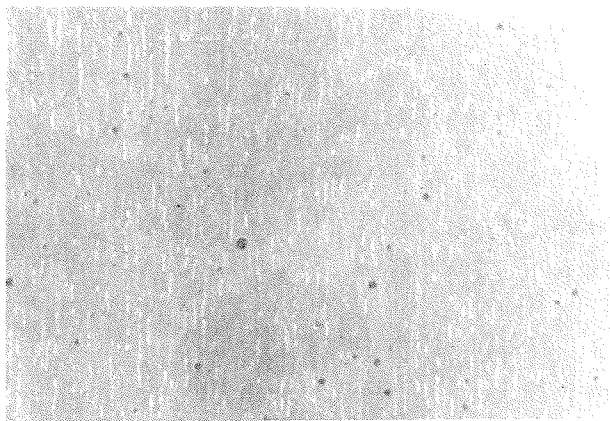


Fig. 6: Polarizing microscope picture of the stripe texture in FLC showing "giant microdroplets" (dark dots) as well as the regular microdroplets

picture of the polymer network since the ordered polymer texture is very fragile and could be easily partly flushed away during the sample preparation.

As long as the polymer concentration was kept low ($\leq 4\%$), the ordered polymer network in the FLC/polymer gel oriented layer did not appreciably affect the FLC molecular order. Therefore the electrooptical properties of these composite ferroelectric materials remained almost identical to the properties of the pure FLC materials. These properties were measured using crossed polarizers in the same configuration as with standard FLC displays (see fig. 2). A $3\text{ }\mu\text{m}$ thick oriented FLC/polymer gel layer was oriented so that one of the polarizing axis was oriented along the "symmetry" axis between the orientations of the molecules in two parallel stripes (see Fig.3).

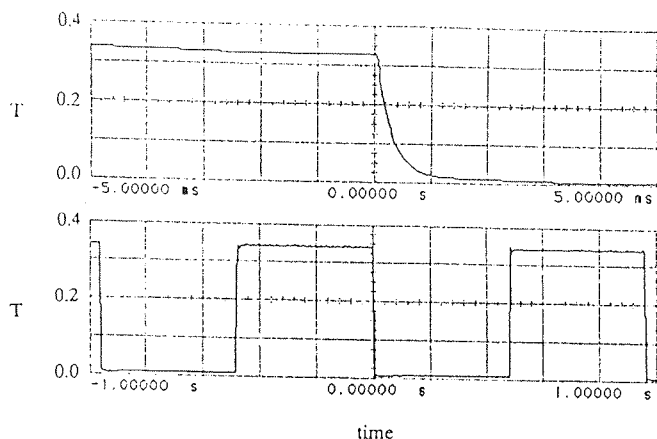


Fig. 7: Time dependence of the transmission T of the volume stabilized FLC display showing fast switching (upper oscilloscope trace) as well as excellent bistability of both optical states (lower oscilloscope trace).

The results show high contrast, excellent bistability ($\approx 100\%$), as well as high switching rates ($\leq 300\text{ }\mu\text{s}$) and high optical contrasts (see Fig.7).

Conclusion

The FLC/polymer gel displays maintain the electrooptic properties of the standard SSFLC cell but with substantially improved stability against mechanical stress. Due to extremely fast switching times (-compatible to the standard TV signals!) and inherent memory effects the electronic driving circuitry can be significantly reduced and simplified compared to the standard active matrix nematic liquid crystal displays, that presently offer the only acceptable solution for the flat, low power, high definition TV screen. Since these displays do not require the sophisticated active matrix driving, the density of information can be substantially improved (thin film active elements on each pixel take a lot of space!), which is especially important for large screen high information content projection devices.

REFERENCES

1. Surface-stabilized Ferroelectric Liquid Crystal Electro-optics: New Multistate Structures And Devices, Noel A.Clark and Sven T.Lagerwall, *Ferroelectrics* 59, 25-67, (1984).
2. Solid and Liquid Crystalline Ferroelectrics and Anti-ferroelectrics, R.Blinc, *Condensed Matter News*. 1, 17, (1991).
3. A Method for Director Alignment of SMC* Devices, Philip J.Bos and K.Rickey Koehler-Beran, *Ferroelectrics*, 85, 15-24, (1988).
4. Alignment of Ferroelectric Liquid Crystals on Commercially Available Polyimides, Bernt O.Myrvold, *Ferroelectrics* 85, 25- 30, (1988).
5. AC Electric Field Induced Helix Unwinding in Planar Texture of a Ferroelectric Liquid Crystal, Z.H.Wang, Z.M.Sun, and D.Feng, *Liquid Crystals* 9, 863-871, (1991).
6. Electrically Induced Light Scattering from Anisotropic Gels, R.A.M.Hikmet, *J.Appl.Phys* 68, 4406 (1990).
7. Anisotropic Gels and Plasticized Networks Formed by Liquid Crystal Molecules, R.A.M.Hikmet, *Liquid Crystals* 9, 405-416 (1991).
8. Gel Layers for Inducing Adjustable Pretilt Angles in Liquid Crystal Systems, R.A.M.Hikmet and C.de Witz, *J.Appl.Phys.* 70, 1265 (1991).
9. Smectic-c "chevron", A Planar Liquid-crystal Defect: Implications for the Surface-stabilized Ferroelectric Liquid Crystal Geometry, N.A.Clark and T.P.Rieker, *Physical Rev.A* 37, 1053 (1988).
10. The Field Induced Stripe Texture in Surface Stabilized Ferroelectric Liquid Crystal Cells, Ren Fan Shao, Paula C.Willis, and Noel A.Clark, *Ferroelectrics* 121, 127-136 (1991).
11. Description of Field-induced Director Patterns in Surface-stabilized Ferroelectric Liquid Crystal Structures in Terms of Smectic Layer Bending, W.J.A.M.Hartman, G.Vertogen, C.J.Gerritsma, H.A.V.Sprang, and A.G.H.Verhulst, *Europhys.Lett.* 10 657-661 (1989).
12. A New Type of Layer Structure Defects in Chiral Smectics, J.Pavel and M.Glogarova, *Liquid Crystals* 9, 87-93 (1991).

13. Handbook of Liquid Crystals, H.Kelker, R.Hatz; Verlag Chemie GmbH, 1980

14. Liquid Crystal Displays with High Information Content, B.S.Scheuble, SID SYmposium, Annaheim, USA 1988

dr. Janez Pirš, dipl.ing.
mgr. Bojan Marin, dipl.ing.
Silva Pirš ing

Inštitut Jožef Stefan
Ljubljana, Jamova 39, Slovenija

Prispelo: 27.1.93

Sprejeto: 25.2.93