Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl19

Polymer Network Volume Stabilized Ferroelectric Liquid Crystal Displays

J. Pirš [a] , R. Blinc [a] , B. Marin [a] , S. Pirs [a] & J. W. Doane [b]

[a] J. Stefan Institute, University of Ljubljana, 61000, Ljubljana, Slovenia

[b] Liquid Crystal Institute, Kent, Ohio, USA

Version of record first published: 23 Sep 2006.

To cite this article: J. Pirš , R. Blinc , B. Marin , S. Pirs & J. W. Doane (1995): Polymer Network Volume Stabilized Ferroelectric Liquid Crystal Displays, Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals, 264:1, 155-163

To link to this article: http://dx.doi.org/10.1080/10587259508037309

Mol. Cryst. Liq. Cryst., 1995, Vol. 264, pp. 155–163
Reprints available directly from the publisher
Photocopying permitted by license only

Polymer Network Volume Stabilized Ferroelectric Liquid Crystal Displays

J. PIRŠ, R. BLINC, B. MARIN, S. PIRŠ
J. Stefan Institute, University of Ljubljana, 61000 Ljubljana, Slovenia

and

J. W. DOANE
Liquid Crystal Institute, Kent, Ohio, USA

(Received October 18, 1993; in final form July 6, 1994)

A ferroelectric liquid crystal (FLC) cell for flat panel displays with volume stabilized bistable states is described. Volume stabilization is achieved by the FLC/polymer gel dispersion which is prepared by polymerizing a FLC/polymer precursor solution in a suitably aligned FLC display cell. The volume stabilized LC cell gives mechanical stability to FLC displays with internal memory and provides for high contrast shuttering while keeping all other excellent properties of the surface stabilized FLC displays (SSFLCD).

INTRODUCTION

Since 1980 when N. Clark and S. T. Lagerwall[1,2] introduced the surface stabilized ferroelectric LC cell (SSFLC), a number of improvements[3–5] of this technology has been made to the point, where commercial flat-panel displays are being marketed by Cannon. The principal advantages this device brings are significantly faster switching rates and more important a memory effect due to which electronic driving schemes are greatly simplified. All requirements are met by a passive matrix rather than with the active one, which is required for twisted nematic TN nematic liquid crystal cells, where high resolution and contrast is required.

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.[6–8] This structure critically depends on mechanical stresses causing local flow which results in an irreversible breaking of the smectic planes. A relatively complicated solution to this problem has been recently given by Cannon using a sophisticated mechanical solution based on elastic suspension of the SSFLC display.

Here we propose a solution to the problem of the mechanical strain instability in the SSFLC cell by the addition of polymers to stabilize the cell geometry as well as to volume stabilize the FLC molecular ordering.

The concept of "volume stabilization" of the molecular ordering in the FLC is based on the polymerization of a small amount of polymer precursor added to the FLC - the technique that has been relatively recently worked out in details by Hikmet and coworkers for nematic liquid crystals,[9-11] while the first essay to study the nature of smectic B liquid crystals in the presence of polymers has been done by P. Mariani *et al.*[12] The amount of the added polymer precursor is small enough so, that it does not significantly affect molecular ordering or alignment of the FLC material. The polymerization of the polymer precursor 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, hinders the mechanical flow of the LC under mechanical stress. The volume stabilization of the cell can be achieved with a relatively small concentration of the added polymer precursor (≈ 0.5–3%).

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 $\approx 3\,\mu m$ spacers, sealed with UV curable epoxy sealant and vacuum filled with E. Merck ZLI 4237–100 FLC mixture with 0.5–3% addition of acrylate Desolite 950-044. The cells were filled at an elevated temperature $\approx > 95°C$ (-isotropic phase) then slowly cooled through nematic and SmA phase into the SmC* phase. As the FLC ZLI 4237–100 experiences a pitch of $10\,\mu m$ in the SmC* phase, the cell thickness was sufficiently small in order to unwind the helical SmC* structure.[13] 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 (≈ 3 Hz) electric field pulses, a well known electric field induced stripe texture was obtained (Figure 1) in pure as well as in polymer doped samples. The competing effects of the molecular tilt on the nylon orienting layer, chevron structure, interactions with polymer additives and the electric field induced stripe texture resulted in a very small angle α (few degrees) between the molecular layer orientation in the consecutive stripes (see Figure 1) 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 ($\geq 40°$) was obtained (see Figure 5).

As the FLC/polymer precursor solution was filled in the FLC display cell at an elevated temperature (-in the isotropic phase of the FLC component), it had to be cooled down into the ferroelectric SmC* phase. The cooling of the FLC/polymer precursor dispersion and especially the structural changes due to phase transitions

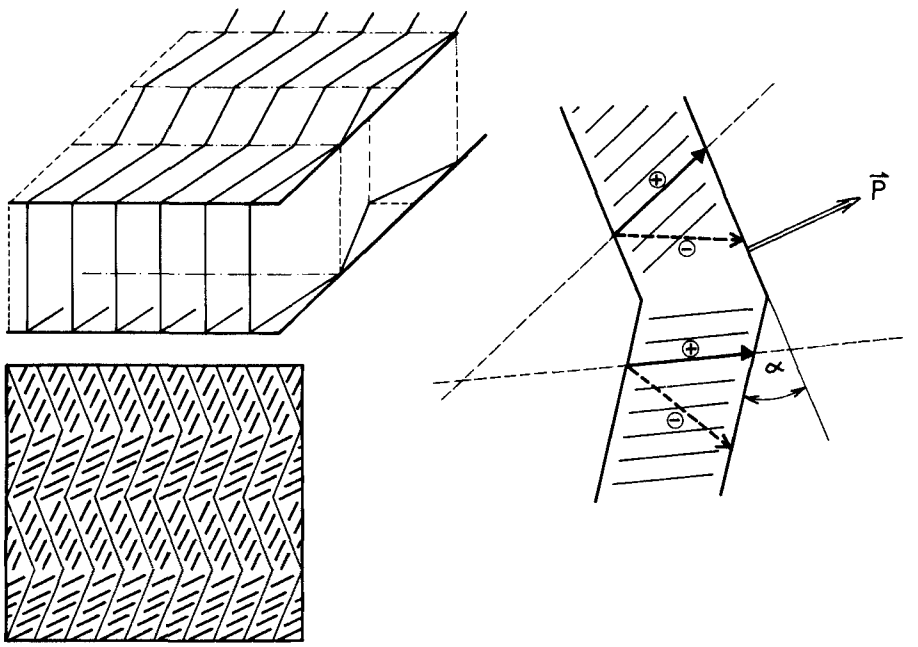

FIGURE 1 Schematic presentation of the electric field induced stripe texture in the thin layer of the polymer doped FLC.

reduced the solubility of the polymer precursor 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 ($\leqslant 1\,\mu m$). However, some of these droplets grew as large as $\approx 3\,\mu m$. These "giant" microdroplets linked both boundary glass plates of the LCD cell together and after UV light initiated polymerization acted at the same time as sealants and spacers. The occurrence of additional polymer seals in the volume stabilized cells over the entire display area prevented the geometry changes and reduced the possibility of molecular flow.

When the FLC/polymer precursor solution was cooled down in the ordered liquid crystalline phase, the UV light initiated polymerization of the polymer precursor was induced using the 150 W UV light source (360 nm) for few minutes. The applied UV light caused the polymerization of the polymer precursor microdroplets as well as the phase separation of the rest of the polymer precursor molecules, that were until that time still "dissolved" in the FLC material. During polymerization in the ordered FLC medium, the polymer molecules formed a well ordered polymer network that reflected the molecular ordering (see Figure 2). The chevron defect walls between the consecutive stripes (see Fig. 1), 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 Figures 2, 3) 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.

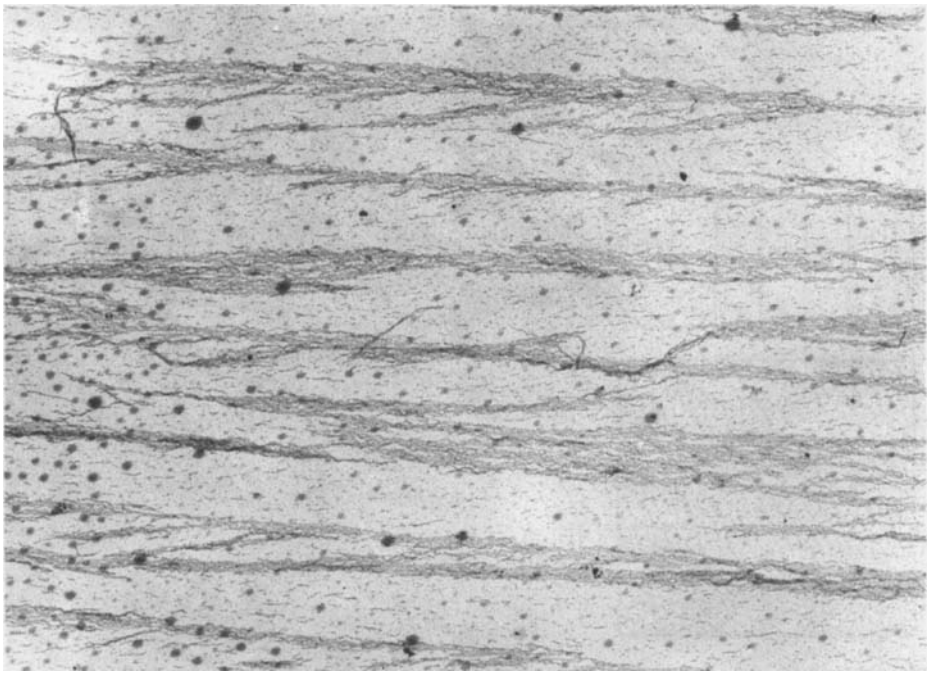

FIGURE 2 TEM micrograph of the ordered polymer texture formed during UV activated polymerization process in the polymer/FLC gel containing 2% of the polymer Desolite D044 (magnification 2400-1 cm ≈ 2 μm).

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 polymer precursor in the nematic phase.

The ordered polymer network texture was reasonably well confirmed by electron microscopy of the boundary surfaces of the disassembled VSFLCD cells, where FLC was flushed away by acetone in the "acetone vapor degreaser". Figures 2 and 3 show TEM micrographs of the polymer network in an FLC/polymer gel containing 98% of ZLI 4237–100 and 2% of Desolite 950-044 acrylate.

The TEM micrograph, clearly show the ordered polymer texture formed along the defects walls between the stripes and the small polymer microdroplets that "condensed" on the cell walls during the cool-down process. The "giant microdroplets" can be seen (Figure 4) under the polarizing microscope. TEM micrograph as well as the polarizing microscope analysis give only a qualitative picture of the polymer network, since the ordered polymer texture is very fragile and could be easily partly flushed away during the sample preparation.

The built-in ordered polymer texture significantly improved the stability of the FLC molecular order against the mechanical stress. If for example the test cells ($\approx 1\,cm^2$)

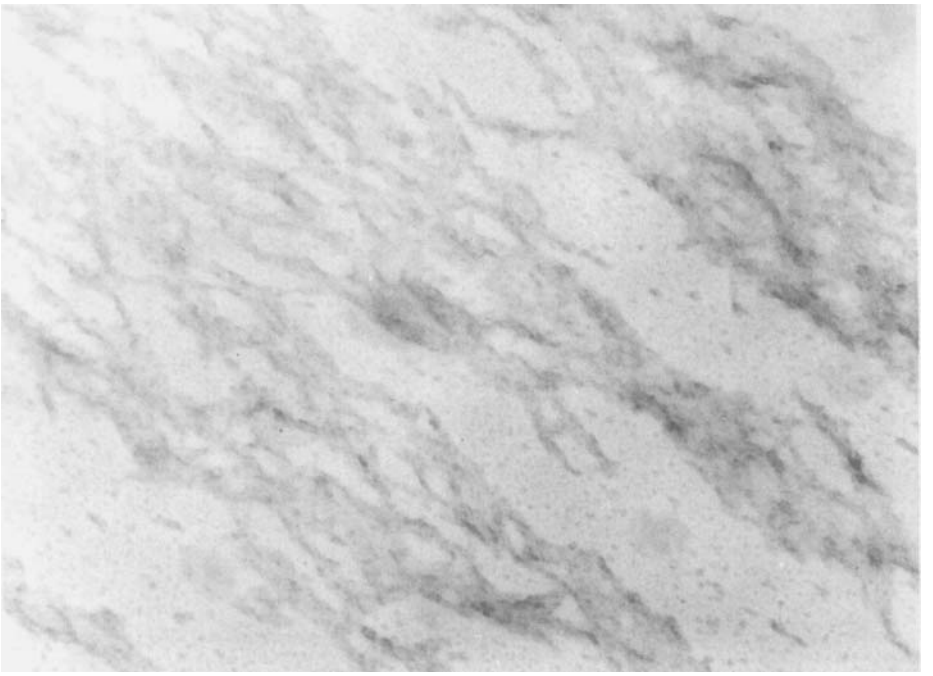

FIGURE 3 TEM micrograph of the detail of the polymer texture on Figure 2 (magnification 40000-1 cm ≈ 0.12 μm).

made in the conventional SSFLC technology were squeezed in their centers by a periodic force ≈ 1 N and a frequency 10 Hz, a large number of chevron defect walls appeared already after few minutes. The existence of these defects noticeably affected the appearance of the displays. Applying the same mechanical stress to the volume stabilized FLC cells didn't cause any change in their outside appearance or contrast. The same was also true if the force was increased to 2 N and the time of the mechanical stress extended to several hours while the frequency was varied from few Hz to several KHz.

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. The electrooptic response measurements of the VSFLC display cells were made between crossed polarizers. They were oriented so, that the polarizer axis was pointing along the symmetry axis between the orientations of the molecules in two parallel stripes (see Figure 1) and the analyzer was orthogonal to it.

In order to be able to observe also the "local" molecular order dynamics, the measuring set-up shown on the Figure 5 was used. The experiment was performed under the polarizing microscope (Leitz Metalloplan) modified so, that a single mode He–Ne laser was used instead of the standard white light source. The laser light was focused in the FLC layer plane so that the entire light was passing through the circle

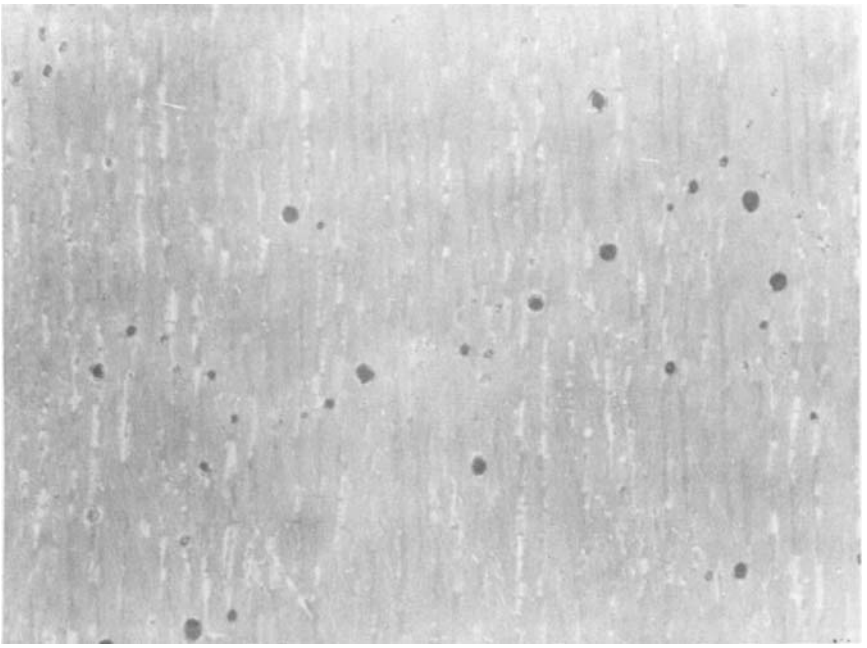

FIGURE 4 Polarizing microscope picture of the stripe texture in the FLC showing "giant microdroplets" (dark dots) as well as the regular microdroplets (1 cm ≈ 15 μm).

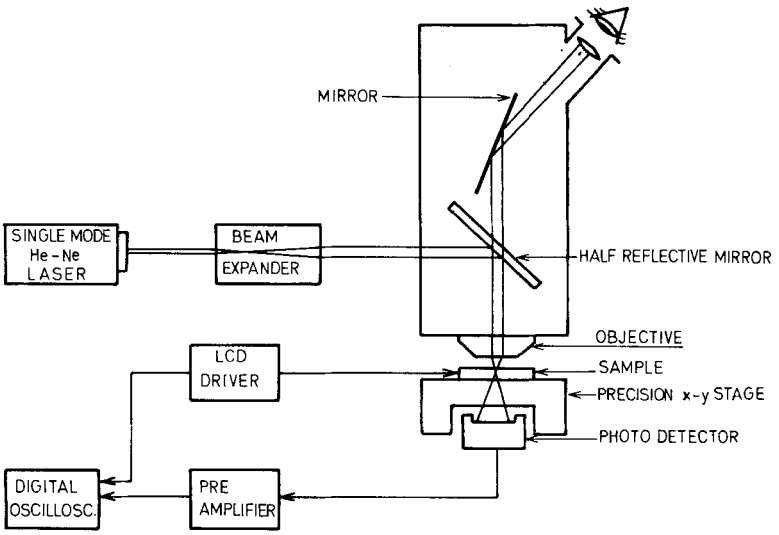

FIGURE 5 Block diagram of the local order parameter dynamics measurement.

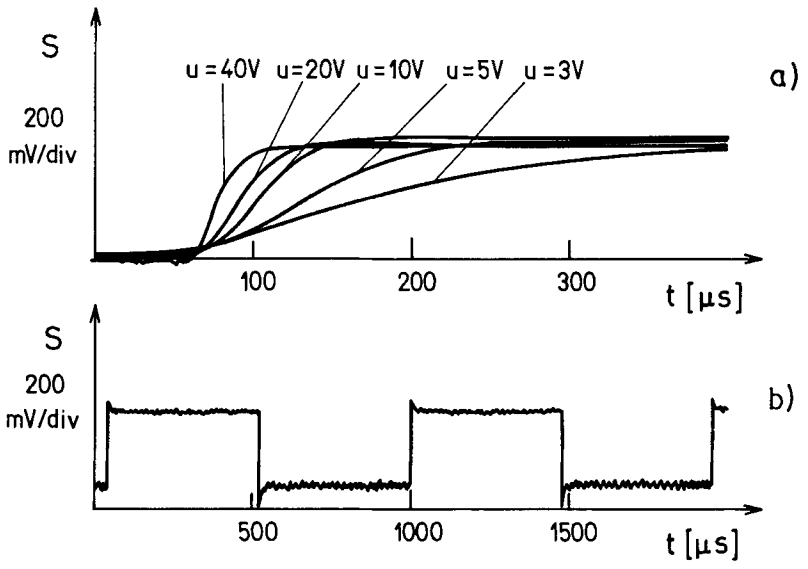

FIGURE 6 Time dependence of the optical switching of the VSFLC display cell showing the dependence of the switching speed on the amplitude of the electric driving pulse (a) as well as excellent bistability of both optical states (b).

with the diameter $\leq 2\,\mu m$. The transmitted light was measured by a photodiode located under the precision xy translation stage allowing for the precise positioning of the sample.

The results show high contrast and excellent bistability as well as high switching rates. For the driving electric pulses with amplitudes 30 V and duration times 30 μs the switching times were well below 100 μs which is completely compatible with the standard TV requirements (see Figure 6). The measurements of the dependence of the electrooptic response (transmitted light-S versus time-t) show, that there exists a minimum driving voltage necessary for the electrooptic switching.

Plotting the inverse of the minimum duration time of the electric pulse necessary to cause the transition from one bistable optic state to another versus the electric pulse amplitude, a linear dependence (see Figure 7) is obtained:

$$1/t_p \propto (U - U_{th}),$$

where t_p = electric pulse duration (ms) U = electric pulse amplitude (V) U_{th} = threshold voltage (V). If this threshold voltage (≈ 2.5 V) is subtracted from the drive voltage, the calculated "electric response" (pulse amplitude multiplied by minimum duration time required for switching from one optically stable state to the other) becomes independent of the applied voltage ($\approx 3.3 \times 10^{-3}$ Vs). This threshold voltage can be attributed to the surface interactions with polymer orienting layers as well as with the built-in oriented polymer network.

This assumption is well confirmed by the measurements of the "local" dynamics in the boundary area (Figure 8a) between the consecutive stripes (—filled with polymer

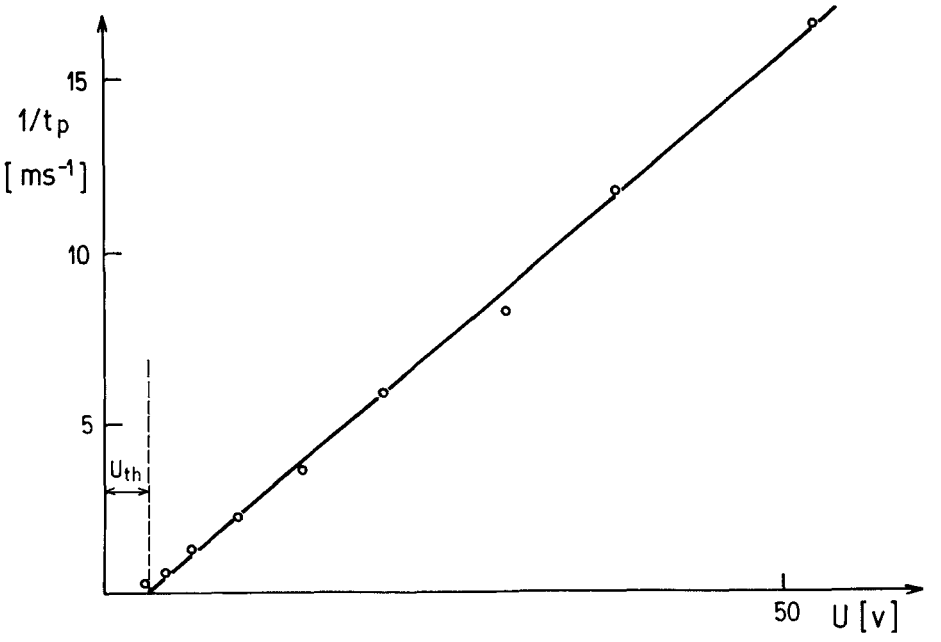

FIGURE 7 Electric driving voltage dependence of the inverse of the minimum electric driving pulse duration time t_p necessary to cause the transition from one bistable optic state to the other.

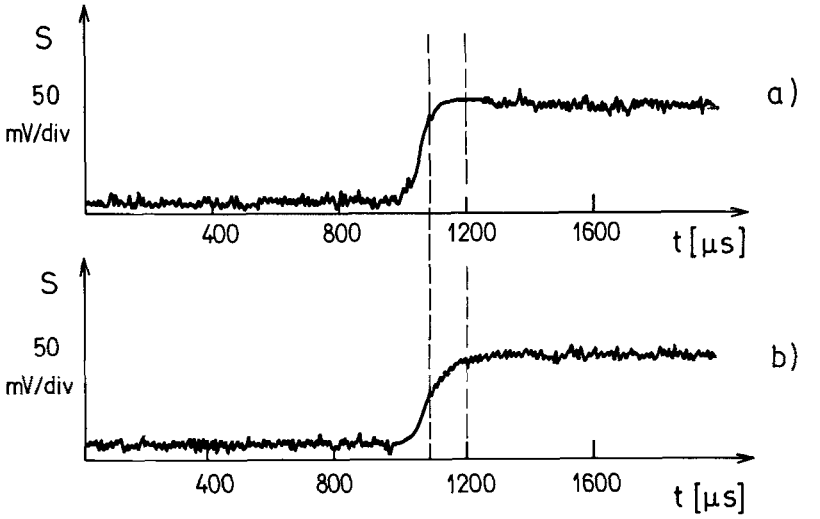

FIGURE 8 The effect of the polymer network on the dynamics of the electrooptical response.

network) and in the center of the stripe (Figure 8b) where polymer network concentration is lower. The measurements of the dynamics of the electrooptic response (transmitted light-S versus time-t) on 60 μs long electric pulse with the amplitude 40 V show noticeably different results. The switching time in the polymer rich boundary between

two consecutive stripes ($\approx 100\,\mu s$) seems to be almost two times shorter than the switching time in the center of the stripe. Therefore it is obvious, that the oriented polymer network affects the dynamics of the VSFLC displays.

CONCLUSION

The VSFLC display cell maintains the electrooptic properties equivalent to the standard SSFLC cell but with substantially improved stability against mechanical stress.

Acknowledgement

The authors would like to thank V. Marinkovič for TEM sample analysis, I. Kvasič for mechanical stress measurements and I. Muševič for helpful discussions.

References

1. Noel A. Clark and Sven T. Lagerwall, *Ferroelectrics*, **59**, 25–67 (1984)
2. M. A. Handschy and N. A. Clark, *Ferroelectrics*, **59**, 69 (1984).
3. Philip J. Bos and K. Rickey Koehler-Beran, *Ferroelectrics*, **85**, 15–24 (1988).
4. Berndt O. Myrvold, *Ferroelectrics*, **85**, 25–30 (1988).
5. Z. H. Wang, Z. M. Sun, and D. Feng, *Liquid Crystals* **9**, 863–871 (1991).
6. Noel A. Clark and T. P. Rieker, *Physical Rev.* A **37**, 1053 (1988).
7. Ren Fan Shao, Paula C. Willis and Noel A. Clark, *Ferroelectrics*, **121**, 127–136 (1991).
8. J. Pavel and M. Glogarova, *Liquid Crystals* **9**, 87–93 (1991).
9. R. A. M. Hikmet, *J. Appl. Phys.*, **68**, 4406 (1990).
10. R. A. M. Hikmet, *Liquid Crystals*, **9**, 405–416 (1991).
11. R. A. M. Hikmet and C. de Witz, *J. Appl. Phys.*, **70**, 1265 (1991).
12. P. Mariani, B. Samori, A. S. Angeloni and P. Ferruti, *Liquid Crystals*, vol 1, **4**, 327–336 (1986).
13. J. Pirš, R. Blinc, B. Marin, S. Pirš, I. Muševic, S. Žumer and J. W. Doane, 14 ILCC Meeting, Pisa (1992).