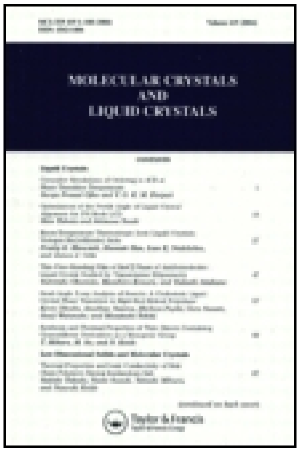

Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

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

Electro-Optic Effects in Smectic a Phase

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Version of record first published: 04 Oct 2006.

To cite this article: A. Jákli & A. Saupe (1992): Electro-Optic Effects in Smectic a Phase, Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals, 222:1, 101-109

To link to this article: http://dx.doi.org/10.1080/15421409208048685

Mol. Cryst. Liq. Cryst. 1992, Vol. 222, pp. 101–109
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Printed in the United States of America

ELECTRO-OPTIC EFFECTS IN SMECTIC A PHASE

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(Received October 6, 1991)

Abstract Smectic A films with a positive dielectric anisotropy can be switched to homeotropic textures by application of sufficiently high AC electric fields. They can relax to a light scattering state when the field is removed. The transition between the homeotropic and the light scattering focal conic texture is attractive for display applications, but Le Berre and Hareng found with 4-4'-cyano-octyl biphenyl (8CB), that the relaxation was slow and limited to a range of 3° C at the S_A-N phase transition. We found that the relaxation can be enhanced by suitable surface treatments. With conventional polyimide coatings the relaxation to the scattering state occurs through the entire S_A range (12°C). Observations on samples with differently treated polyimide coated surfaces indicate that the surface roughnes facilitates the relaxations. The relaxation time depends strongly on the temperature. It increases from 50ms near the N-S_A transition to 0.3 s at the S_A-solid crystal transition. In the range of 5 to 50μm, the contrast and the relaxation time are nearly independent of the sample thickness. The drive voltage is temperature and thickness dependent. For a 5μm film it was below 20V over the whole temperature range. Comparing a smectic A shutter with a typical PDLC device we found that the contrast ratio is smaller, but the non scattering state is completely haze free.

INTRODUCTION

Smectic A films can be switched from transparent to scattering state by various methods[1]. The initially homeotropically aligned, transparent S_A state can be locally heated into the nematic phase (for example by a laser beam), and cooling back a scattering focal conic texture develops[2]. Homeotropically aligned films can also be switched by electric fields. A scattering state can be induced[4] and erased in the films with high electric conductivities[3]. The frequency of the erase field is higher (in the range of 1kHz) than the cut-off frequency for electrohydrodynamic instabilities. The scattering state however is induced by an electrohydrodynamic instability due to the application of low frequency (typically less than 100Hz) electric fields. The thresholds for induce the scattering state in case of 20μm thick samples are larger than 100V and use of additional ionic dopants are usually required (the electric conductivity should be larger than 10^{-9} $1/\Omega$cm). This means that relatively large electric currents are flowing through the sample.

It was shown by Hareng et al[5-7], that the random focal conic texture of the S_A phase could be switched to homeotropic texture by strong AC electric fields. Close to the nematic phase (closer than 3°C) the homeotropic structure relaxed to the scattering state, but it was not fast and not complete.

The relaxation mechanism from homeotropic to scattering texture was studied later using SiO[9] and PVA[10] anchoring layers. It was found that the relaxation can happen in 1-2 sec if the preceding nematic state was twisted and the sample was less than 3°C far from the S_A-N phase transition.

In this paper we report that the relaxation from the quasi homeotropic to the scattering texture can be sufficiently complete and fairly quick over the whole S_A range. We used a polyimide coating for surface alignment.

EXPERIMENTAL

We studied the switching processes of cells containing a liquid crystal 4-4'-cyano octyl-biphenyl (8CB) made by the BDH. The phase sequence of 8CB is:

$$\begin{array}{ccccccc} K & \text{-----} & S_A & \text{-----} & N & \text{-----} & I \\ & 21^\circ C & & 32.5^\circ C & & 40.5^\circ C & \end{array}$$

It has a relatively large positive dielectric anisotropy $\epsilon_a=8.3$, and an average optical anisotropy[8] $\Delta n=0.14$.

A conventional polyimide coating was applied to the electrodes by spin coating. Samples with differently rubbed surfaces and unrubbed surfaces were made and electrooptic properties were measured. The cells were thermostated and illuminated by white light. The rise and decay times together with the direct transmitted light intensities were measured by a photo diode. The temperature and applied field dependencies were measured in four 20μm thick samples with different surface treatments: unidirectional rubbing parallel and perpendicular to each other on the two surfaces (sample A and B respectively); successive rubbing in perpendicular direction on both surfaces (sample C); and no rubbing (sample D). In addition we studied the effect of sample thickness by making a wedge shape sample (5μm<d<50μm, sample E) with boundary layers rubbed in one direction and parallel to each other on the different plates. The textures were optically studied using polarising microscope.

In sample A fairly homogeneous planar alignment was observed. In case of sample B and C the achieved alignments were still planar, but not homogeneous. Focal conics with the typical size of 200μm were present. Without a preferred direction, sample D showed a planar focal conic texture with typical domain sizes of 50μm. As the domain sizes were much larger than the visible light wavelength all the samples (no matter which type of rubbing was used) were initially transparent . Under application of AC electric field the following domains were observed.

(i) The textures did not change until $U<U_1$.

(ii) At $U=U_1$ a new texture developed. It started at the edges of mono domains and propagated parallel to the smectic layers (see Fig.1a,b). This propagation was not reported by Hareng et al.[6], who studied the layer reorientation on focal conic textures. We found that the threshold voltage U_1 depends linearly on the sample thickness (threshold electric field), and it increases considerably with the decrease of the temperature. For example in case of 20μm samples $U_1 \sim 10$V at T=32°C and about 50V at T=22°C. U_1 however does not depend on buffing. The temperature and sample thickness dependence of U_1 agrees well with the observations of Hareng et al[5]. Also in agreement to their findings we found that there is no frequency dependence in the range from 20Hz up to 10kHz. We note here, that an electrohydrodynamic instability was observed at frequencies about 3Hz.

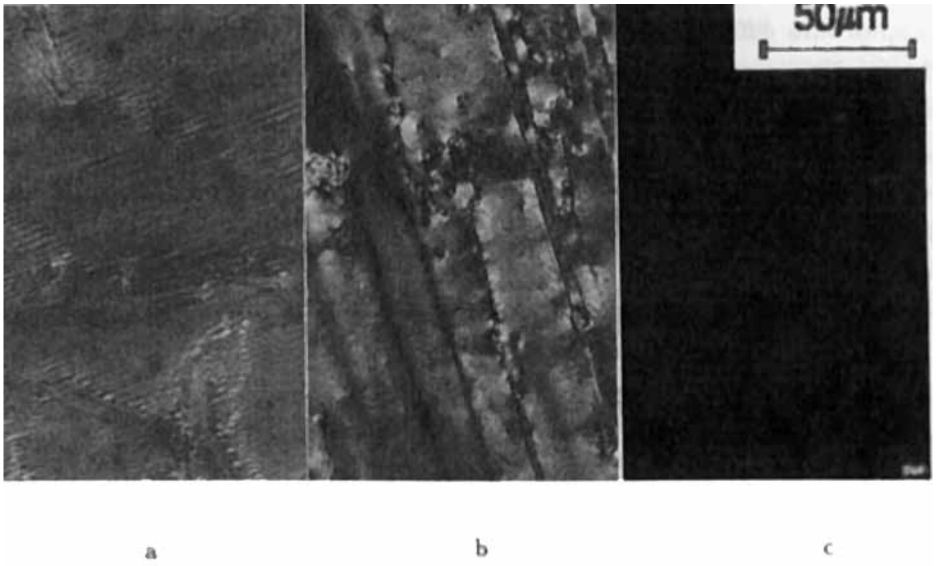

FIGURE 1. Texture variation by the application of alternating fields. Polyimide coated surfaces. Buffed unidirectionally, aligned parallel. The sample thickness d=20μm. (T=32°C) a.) U=15V; b.) U=17V; c.) U=20V (f=1kHz)

(iii) With increasing voltages the texture became gradually darker between crossed polarizers and finally above $U_2 \sim U_1+15V$ it was almost completely black (see Fig.1c). This observation shows that the layers are parallel to the plates.

(iv) Decreasing the electric field gradually, we observed that below U_2 the texture became brighter, then bright spots (with typical size of about 5μm) appeared. Most of them formed strings. The preferred direction of these strings was parallel to the rubbing direction. The typically observed texture with the strings is represented in Fig.2a. The specific distribution of the strings reproduced when the process repeated.

(v) The number of scattering centers increased with decreasing voltages and at U=0 they covered the whole area. A typical texture for U=0 is seen in Fig.2b. The domain size is typically 2-5μm. The domains are usually non regular, and the distinct crosses can no more be seen. When turning the field off directly, a similar scattering texture, but with smaller domains forms quickly. This is true for the whole S_A temperature interval.

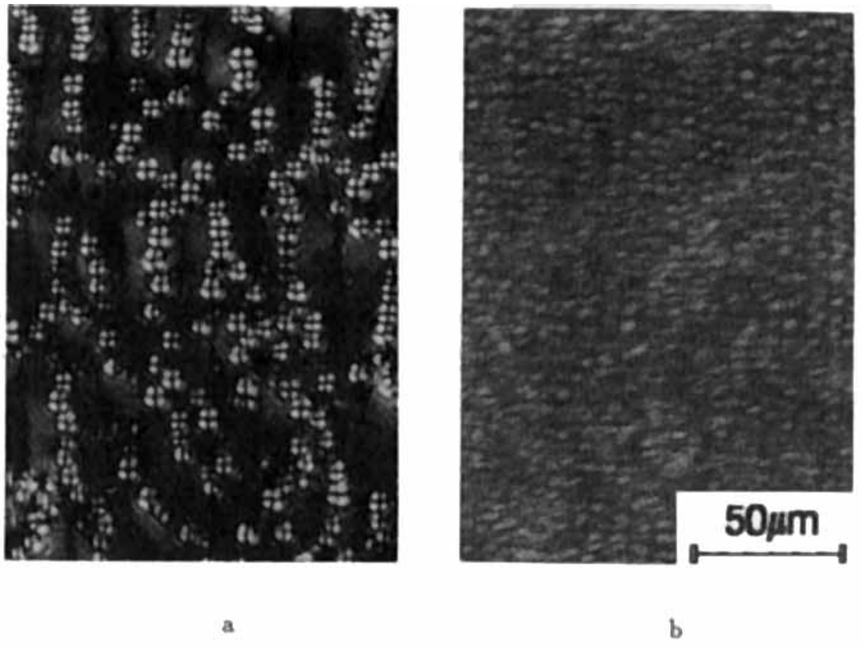

Figure 2. Texture changes reducing the voltages from $U>U_2$. ($d=20\mu m$, $T=32°C$) a.) $U=12.5V$ ($f=1kHz$); b.) $U=0V$

Above U_2 the film is transparent, while at $U=0$ it is opaque. So the film that initially was transparent at $U=0$ is now scattering. The appearance of the scattering film is similar to a polymer dispersed liquid crystal. The film can be switched between opaque and transparent states.

In the following we describes how the film changes starting from a scattering ground state.

The voltage dependence of the transmitted light intensity shows a threshold U_{th}. Only above the threshold the transmitted intensity start to increase. We can also define a value U_{sat}, where the transmitted intensity saturates. U_{th} and U_{sat} are proportional to the sample thickness (therefore the corresponding fields E_{th} and E_{sat} are independent of the sample thickness), furthermore $U_{th} \sim U_1$ and $U_{sat} \sim U_2$.

E_{th} and E_{sat} depend strongly on temperature. For example at $T=32°C$

$E_{th} \approx 0.6V/\mu m$ and $E_{sat} \approx 1.1V/\mu m$, while at T=23°C $E_{th} \approx 2.5V/\mu m$ and $E_{sat} \approx 3.2V/\mu m$. These values depend slightly (± 10%) on the surface treatment. They are the smallest for parallel rubbing (sample A), and the largest for non rubbed surfaces (sample D).

The contrast ratio between on and off states is about 7. (It was determined by illuminating the sample with a laser beam, and the transmitted intensity was measured by a photodiode with a sensitive area equal to the area of the non scattered laser beam.) The contrast is nearly independent of the sample thickness and the rubbing conditions.

The relaxation time is practically the same in samples with rubbed surfaces (A,B and C), and roughly twice as large in the sample D. The relaxations are slower at the lower temperatures (300ms) while close to the S_A -N phase transition they are about 50ms (see Fig.3).

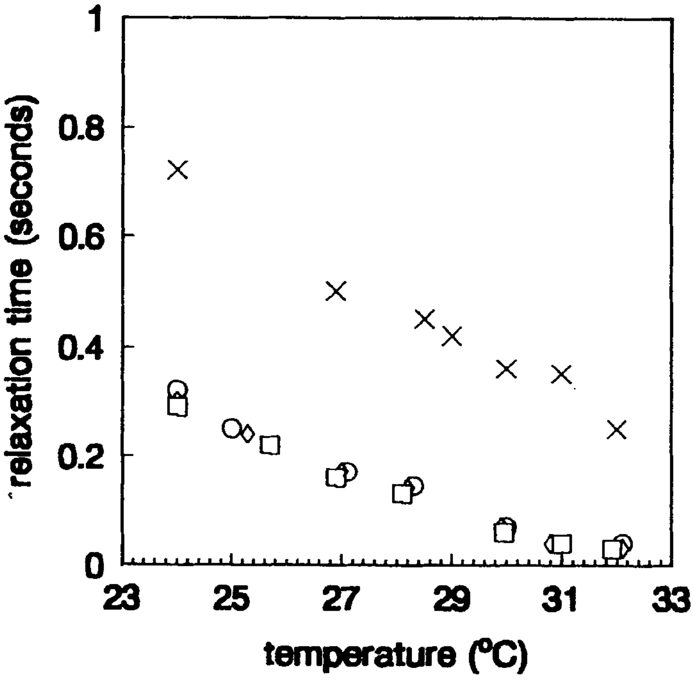

Figure 3. Temperature dependence of the relaxation times for different surface treatments (o: rubbed surfaces parallel, : rubbed surfaces perpendicular, : surfaces with crossed rubbing, x: no rubbing).

The relaxation time does not depend on the on-state voltage, while the rise time (time period during the homeotropic texture develops from the scattering state) decreases strongly with increasing electric fields (see Fig.4).

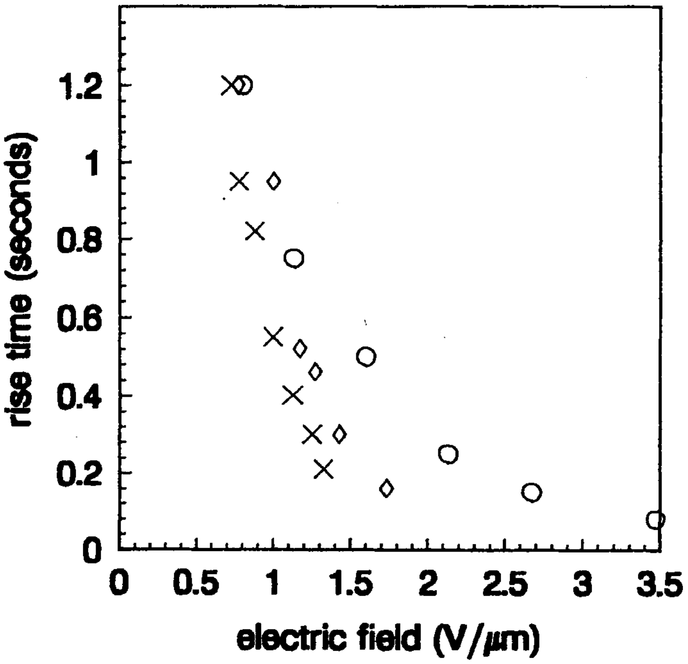

Figure 4. Applied electric field dependence of the rise time for different sample thicknesses. (T=30°C; parallel rubbing)

The rise time increases as the temperature decreases. At T=32°C and at E=2.7V/μm it is as low as 20ms, while at T=22°C and at the same field it is almost 1s (at this temperature E was only slightly larger than E_{sat}).

Regarding the sample thickness dependencies of the switching times we observed that the relaxation time is independent of the sample thickness, while for a given field the rise time is smaller if the sample thickness is larger (see Fig.4).

DISCUSSION

The main interest of this paper is the observation that the relaxation from a field induced homeotropic texture to a strongly scattering texture can be controlled by surface treatment. Earlier works on the same material with similar sample thicknesses but with different surface alignments showed relaxations only close to the N-S_A phase transition (3°C range), and with relaxation times in the order of seconds[6,9].

We obtained relaxation over the whole smectic range with relaxation times from 50 to 300 ms. It shows that the surface anchoring plays an important role in such relaxations. We studied the relaxation processes for differently treated polyimide surfaces. We found that the homeotropic state was not perfectly uniform even when $U \gg U_{sat}$. The first focal conic domains that formed when the voltage was reduced tended to appear always at the same places (the pattern of string of bright spots reproduced in the repeated switching cycles, see Fig.2a). Finally, we observed that the decay times were larger when the surfaces were not rubbed and therefore were presumably smoother (see Fig.3).

From these observations we conclude that the roughness of the surface facilitates relaxation. It is likely, that during the rubbing grooves created, which made the surface rough. Releasing the voltage these local inhomogeneities facilitate the nucleation of the focal conics which can be identified by the bright circles. Based on these results we conclude, that fast and complete relaxation to a scattering texture can be achieved with rough surfaces.

The SiO and PVA treated surfaces gave slower and less complete relaxation than the polyimide treatment. Probably the polyimide gives a stronger anchoring, and does not allow perpendicular surface alignment. Therefore with polyimide an elastic torque is present even at lower temperatures which drives the layers into a focal-conic configuration.

We observed that in the range of 5-50μm the contrast is nearly independent of the sample thickness. The scattering texture is necesserily limited to a surface layer and in the middle of the sample the smectic layers stay homeotropic (see Fig.5). This means that the driving voltages can be decreased by deceasing the sample thickness. It also means that the contrast cannot be increased by using thicker samples.

Although the obtained contrasts are relatively poor, there are several possibilities to increase them. First of all, it is possible to find materials with larger birefringence, which would increase the contrast. It is also possible to use dyes to enhance contrast.

In summary, we demonstrate the possibility of making a S_A electrooptic device with planar boundary condition and with fairly good relaxation times.

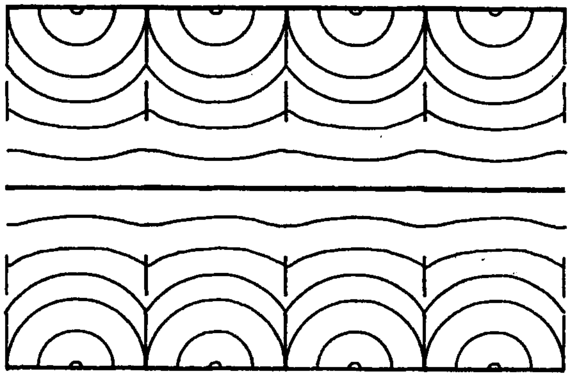

Figure 5. Schematics of the layer structure of the light scattering state.

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ACKNOWLEDGEMNT

We thank Mr. Pat Dunn for making the polyimide coating.

The research was supported in part by DARPA/ONR under Contract N00014-86-K-0766 and the National Science Foundation (ALCOM).