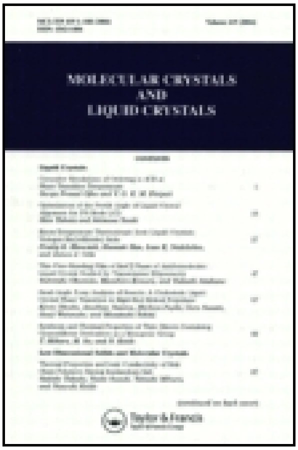

Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

The Role of Alignment Layers on the Induced Relaxation of Passively Multiplexed Antiferroelectric Liquid Crystal Displays

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Version of record first published: 31 Aug 2006

Mol. Cryst. Liq. Cryst., Vol. 433, pp. 207–216, 2005

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421400590955677

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We have investigated the static and dynamic electrooptical effects of adding an alignment layer derived from a chiral liquid crystal having SmC and N* phases to the standard polymer alignment layer in antiferroelectric liquid crystal cells. Our results show that the added layer reduces the relaxation time of the liquid crystal, the threshold voltage and the dynamic range required to generate a full greyscale. The electrooptical response of materials was tested using a 7 level waveform, and the relaxation was studied using a novel memory test.*

Keywords: alignment; antiferroelectric; AFLC; display; relaxation

INTRODUCTION

Antiferroelectric liquid crystals (AFLCs) have been attracting display manufacturers attention due to their analogue multiplexable greyscales, wide viewing angle and short response times. Several characterisation results have shown that usually, at room temperature, no more than 30 V are necessary for multiplexing with 55 μs selection

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slots [1] (i.e., the slot time required for multiplexing an SVGA display at 60 Hz video rate in double scan mode). Moreover, if the slot time (the width of the selection pulse, t_{slot}) is reduced to 36 μs (SXGA displays at video rate), saturation voltage usually increases less than 5 V. As a consequence, AFLCs are a promising alternative for passive matrix addressing of high resolution displays at video frequency.

However, pixel transmission in a display often depends on the pixel history, i.e., on the transmission of the pixel in the previous frame(s). This is a relatively common situation, linked to problems such as image sticking and ghosts [2]. Several addressing waveforms have been proposed to drive these materials in video applications, either based on saturation or relaxation schemes [3,4]. Saturation schemes are faster, while relaxation schemes produce better greyscales, but need a blanking strategy to achieve a good dark state in no more than 1 ms to suit with high resolution and video frequency applications.

In this work, modified alignment layers are introduced and compared to standard layers. The scope of the work is to achieve better anchoring characteristics of the alignment with moderate increasing of the anchoring strength. These specific conditions are required for video rate passive multiplexing, as outlined in the following section.

VIDEO RATE MULTIPLEXING AND MEMORY EFFECT

Multiplexed addressing is often precluded by a deficient relaxation of the material during the erasing step of the frame.

The seven level driving waveform (selection, bias, well and relaxation) used to address the display in this study, has been specifically developed to deal with AFLC materials requiring forced relaxation. It includes a well pulse to speed up the LC relaxation from the grey level of the previous frame [1]. Nevertheless, even with this driving scheme, we have found several antiferroelectric materials where the grey level achieved in one frame depends on the grey level in the previous one (we call this *memory effect*). The origin of memory effect in passively multiplexed AFLC displays is still under study. It is attributed to an incomplete or unfinished relaxation of the LC, although ionic adsorption onto the alignment layers may play an important role as well. It is worth mentioning that the presence of memory effect cannot be assessed by simple optical transmission measurements; indeed, it arises even in apparently relaxed pixels, i.e., pixels brought to dark state during the reset (blanking) time. As a matter of fact, a specific procedure to detect and quantify memory effect had to be developed.

We have identified several factors contributing to deficient relaxations and enhancing the memory effect:

- Intrinsically slow response time shown by some materials
- Non-optimised well voltage pulses
- Low anchoring strength of the alignment layer

The first factor is a characteristic parameter of the material, related to its rotational viscosity. If the pixel is switched by an external electric signal, the response time can be adjusted by increasing either the voltage amplitude or duration of the switching pulse. However, voltage cannot be arbitrarily increased for practical reasons – lack of suitable drivers and dielectric short circuits among others – while increasing the slot time reduces the multiplexing level or the frame rate. If the external voltage is removed, as in relaxation based addressing schemes, the pixel must reach the AFLC state upon relaxation on every frame. Besides the rotational viscosity issue, relaxation is an intrinsically slow process in AFLCs, typically 10–100 times longer than switching. Relaxation time of a given material can only be alleviated by increasing temperature [5,6]. In practice, forced relaxation rather than free relaxation is used (e.g., well pulses). Increasing anchoring strength also speeds up relaxation – but threshold voltage and dynamic range are increased as well. Both issues are commented below.

The design of well pulses is a part of the addressing waveform design. This can be tailored to adapt the voltage levels and timing to a specific display. However, it has been found that no optimum well pulse exist for all different grey levels of the pixels. Indeed, slight modifications of any given well pulse improve the forced relaxation fall time depending on the initial transmission level. Nevertheless, this procedure is not compatible with multiplexing itself, since the drivers provide the same voltage level for every frame.

The aligning process in AFLCs is more involved than in nematics. Standard polyimides usually do not align properly these materials. The issue arises from the lack of nematic phase in the phase sequence of AFLCs (to the best of our knowledge, no AFLC mixture featuring nematic phase has been reported yet). As a consequence, alignment is achieved with special polyimides or polyamides like Nylon, whose alignment properties are less satisfactory. Anchoring strength can be chosen upon manufacturing, by modifying the thickness, composition, and curing time and temperature of the alignment layer. However, increasing the anchoring strength increases the threshold voltage, the dynamic range of the greyscale, and the saturation voltage. In practice, one should seek to increase the alignment layer anchoring as long as the driving voltage levels remain within reasonable values. Unfortunately, this is often not possible; indeed, saturation voltage frequently reaches the 40 V_p practical limit imposed by the addressing electronics [7]. Furthermore, increasing anchoring strength results in dynamic data ranges exceeding the range that can be achieved using conventional electronics (approximately 5–6 V) [8]. This implies the need of custom electronics for the column drivers, making the display less interesting for practical applications.

Since the relaxation process is closely related to the alignment layer composition and anchoring strength, experiments have been carried out to test the dynamic behaviour of AFLC materials using modified alignment layers.

Although no AFLC mixtures showing nematic phase are known, a number of ferroelectric liquid crystals (FLC) do show nematic phase upon their phase sequence. In this work, an attempt to mimic the missing nematic phase of the AFLC materials has been done by applying a solution of an FLC material having nematic phase to the alignment surfaces.

EXPERIMENTAL

Sets of surface stabilised AFLC samples were prepared with parallel homogeneous alignment in 1.5 μm thick cells using a commercial polyamide (nylon 6). Three different AFLC mixtures were used to fill test cells: the commercial CS-4001 (Chisso Petrochemical Corp.) and two experimental mixtures W-185 and W-199A. Their main characteristics are listed in Table 1. After curing and rubbing the nylon surfaces, a solution of C8H17OPhPhOCOPhOC*H(CH3)C6H13 (Cr 78.4 SmC* 93 N 120 Iso) in ethanol was spun over both coated glass plates in half

TABLE 1 Electro Optical Response for Cells with and without an Added LC Alignment Layer

Material	Tilt (°)	Sat. (V)	Bias (V)	*DR* (V) 10–90%	t_{rise} (μs)	t_{fall} (μs)	CR 0.1 Hz	CR 60 Hz
W-185	24	24	3.0	6.0	18	212	52	37
W-185 + LC layer	24	22	3.1	5.0	18	140	34	31
CS-4001 (t_{slot} = 36 μs)	26	33	8.5	4.4	26	170	40	23
CS-4001 + LC layer (t_{slot} = 36 μs)	26	34	9.9	3.5	26	157	34	25
CS-4001	26	29	8.5	2.1	40	232	40	20
CS-4001 + LC layer	26	29	9.9	1.6	39	172	34	22
W-199A	27	29	8.4	5.1	38	212	63	28
W-199A + LC layer	27	31	8.7	5.7	38	128	82	32

of the cells before assembly (Fig. 1). The remaining cells were manufactured following the standard protocol for comparison.

The cells were characterised with the above mentioned 7-level waveform (Table 1) using a pulse duration, t_{slot}, of 55 μs for all the materials and in addition a $t_{slot} = 36$ μs to one of them in order to confirm the tendency of the results. The results are depicted in Figure 2.

We have designed a procedure to test the memory effect. This "memory test" consists of one 7-level saturating frame followed by 10 low transmission frames. Unlike the usual addressing schemes, all the frames have the same voltage polarity, and are followed by an identical set of frames with opposite polarity for DC compensation. The voltage levels required for the cells to reach the saturated and the dark states in these multiplexing regimes were determined in advance as a part of the electrooptical characterization protocol. In order to compare the memory tests of CS-4001 and W-199A with and without LC layer, different data voltages covering the full dynamic range were applied to the cells.

The frame rate was set to 60 Hz. A material is considered to pass the test if it reaches the required transmission in less than five frames,

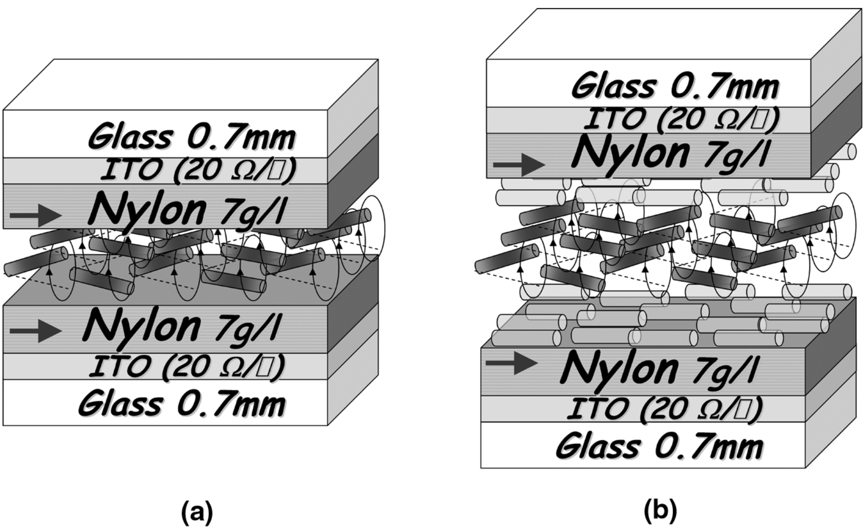

FIGURE 1 Distribution of alignment layers in test cells for characterisation studies: a) Rubbed Nylon 6 in parallel 1.5 μm thickness test cells; b) The same with an LC liquid crystal layer spun over Nylon, with the aim of improving the anchoring.

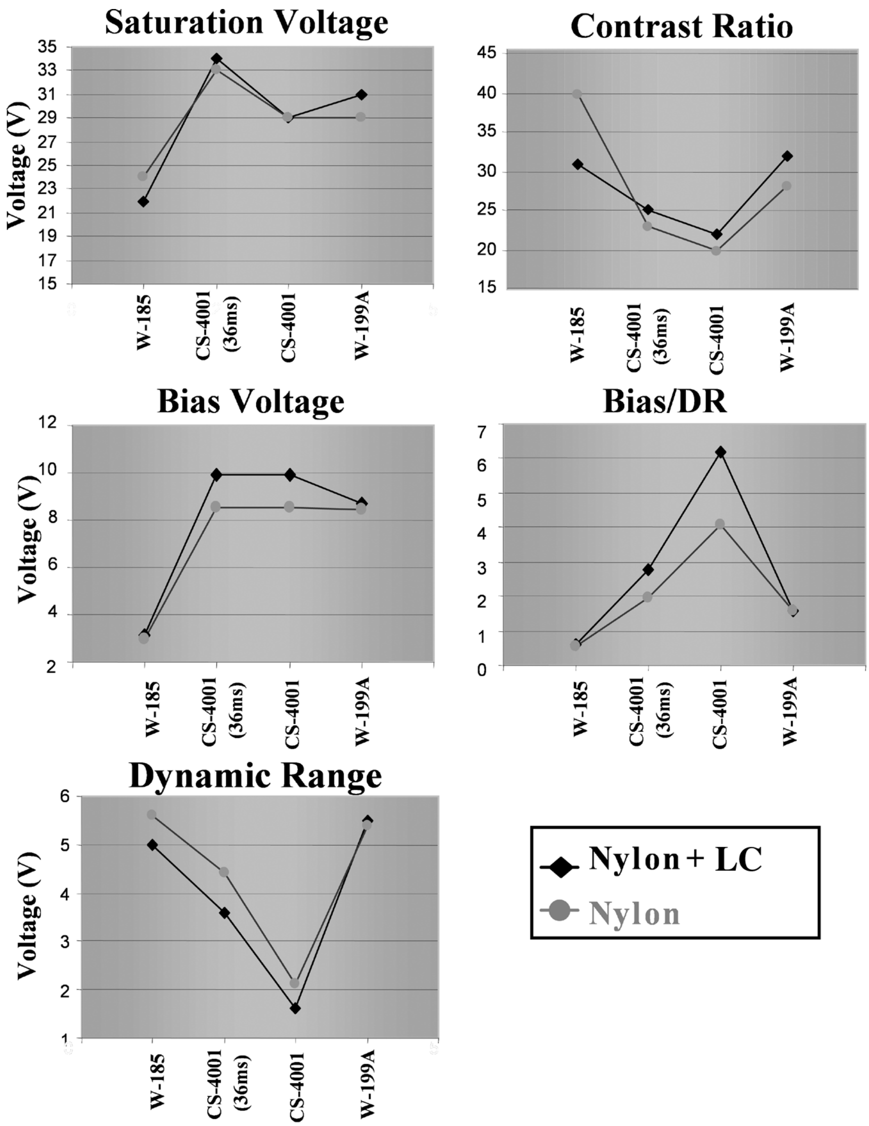

FIGURE 2 Comparison between main electrooptical characteristics for CS-4001, W-185 and W-199A, in test cells with and without added LC layer over the nylon alignment. CS-4001 results are shown both for 36 and 55 μs. In all cases, bias remains the same or higher while DR decreases so that the ratio Bias/DR improves.

since eye persistence integrates the transmission variation, smoothing the transition.

The angular performance of the display cells with and without the added LC layer was assessed using luminance analysis using ELDIM EZContrast equipment.

RESULTS AND DISCUSSION

Electrooptical Characteristics

The electrooptical characteristics – saturation voltage, *Sat*, bias voltage, dynamic range, *DR*, rise and fall time, t_{rise} and t_{fall}, and quasistatic (0.1 Hz) and dynamic (60 Hz) contrast ratio, (*CR*) of the cells – without and with the added LC layers are shown in Table 1. Unless otherwise stated, a 55 μs slot is used.

The dynamic range for all the materials falls within 2 and 6 V for $t_{slot} = 55\,\mu s$. For this time slot, CS-4001 and W-199A have similar values of saturation and bias voltages, but since the bias/DR ratio of CS-4001 is higher, it is better suited for video applications in spite of a lower contrast. The dynamic contrast ratio of W-185 is the best, but it has higher dynamic range and lower bias/DR than the two other materials.

The most noticeable change has been observed in CS-4001. In this material the bias increased about 1.5 V while the DR decreased by 0.5 V and 1.0 V for pulse widths of 55 μs and 36 μs respectively, improving the ratio bias/DR by at least 50%.

Memory Testing

The memory tests of the materials are presented in Figure 3. In all three experiments the number of frames required to obtain the dark state after the saturating frame at 60 Hz is reduced in cells containing the LC layer.

In the case of W-185, the dark state is achieved neither with nor without an LC alignment layer at 60 Hz. However, it is obvious from Figure 3b that the relaxation is considerably faster with the applied LC.

Using full data voltage of 10 V, CS-4001 show a reduction in the number of frames required to reach the dark state from four to two frames. The cells with W-199A show slower relaxation than those filled with CS-4001; yet the presence of the added LC layer improves the response as well. For example, when 9 V data voltage is applied to the cells, the material achieves the dark state in four frames. With LC layer while it needs nine to relax if the LC is not used. Even in

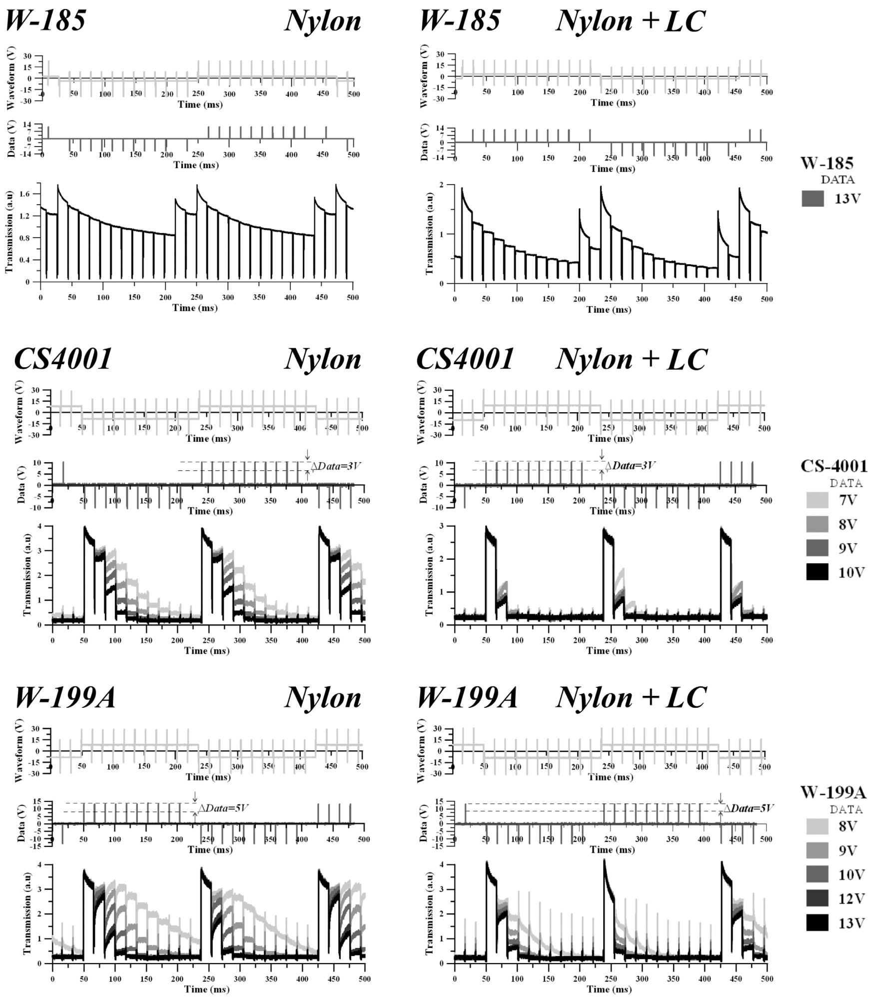

FIGURE 3 Memory test of W-185 (a and b), CS4001 (c and d) and W-199A (e and f) with and without LC layer over the nylon. The evolution of transmission, in arbitrary units, from saturation to dark state is faster when the LC layer is used. In the case of W-185, a full saturation and a zero frame added to the standard memory test shall be disregarded for this purpose.

cases the memory test is not fulfilled, like in the 13 V running, it is apparent that the LC considerably reduces the transmission of the first dark frame, demonstrating that the relaxation process has been sped up.

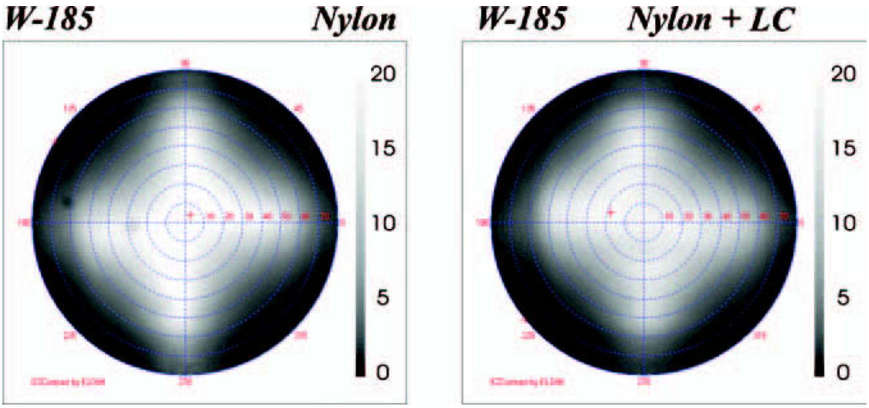

FIGURE 4 Dynamic isocontrast for W-185 mixture: a) Single nylon as alignment layer, b) Nylon + LC layer. This material contrast remains largely constant within the 80° viewing angle. For the nylon and LC combination the overall contrast slightly decreases.

It is worth noticing that in spite of the lower saturation voltage of W-185, it was not possible to relax the material even with a well pulse with a magnitude of 13 V, while CS-4001, with a higher saturation voltage, could be relaxed by applying a 9 V well pulse. This discrepancy points out that dynamic response, far for equilibrium, cannot be directly derived from comparison of quasistatic electrooptic responses. The V·t area of the pulse required for forced relaxation in CS-4001 is significantly lower than that of W-185, making the first material more suitable for video rate applications.

The Angular Dependency of the Contrast

The dynamic contrast at different viewing angles was determined, to assess whether the LC alignment layer would produce changes in the angular variation of contrast. The result for W-185 is shown in Figure 4, and illustrates that within the error of measurements the dynamic contrast remains largely unaffected by the LC.

CONCLUSION

When a solution of an FLC having nematic phase within its sequence is spun on substrates with rubbed nylon 6 layer, the number of zero frames required to achieve relaxation after a saturating frame is reduced in the tested AFLC mixtures. This feature is important for video-rate passive multiplexing, since an excessive number of frames leads to image persistence and smearing.

Furthermore, the LC layer also decreased the dynamic range. Increasing the bias/DR-ratio reduces crosstalking in high resolution multiplexed displays, since data sent to one selected pixel will affect pixels that are not selected, but located in the same data column.

Decreasing DR also makes the liquid crystal display more compatible with CMOS technology which is customarily used in the drivers of this kind of displays. CMOS technology is limited by an upper voltage of 5-6 V. In the case of CS4001 the application of the LC alignment layer, meant that this material could employ off-the-shelf electronics for the column drivers.

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