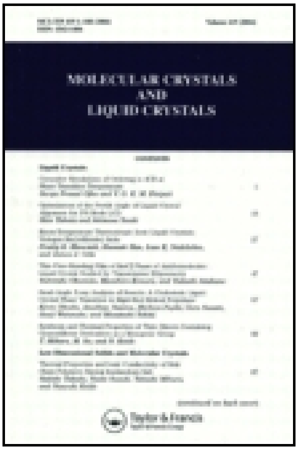

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EVALUATION OF ORTHOCONIC ANTIFERROELECTRIC MATERIALS FOR PHOTONIC APPLICATIONS

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The use of antiferroelectric liquid crystals (AFLCs) on practical applications is often precluded by their low contrast. Orthoconic AFLCs, in principle, may overcome this limitation, for they behave as isotropic plates at normal incidence. A number of orthoconic AFLC materials have been evaluated. Multiplexed seven-level driving schemes have been employed for dynamic analysis. The most relevant results include average static contrast ratio over 200:1 and dynamic contrast ratio over 130:1. On the other hand, hysteresis often shows slight voltage shifts when the cells are driven with low frequency AC signals. This feature impairs symmetry of the transmission maxima on the positive and negative lobes of the hysteresis curve. The effect is attributed to the extremely low pitch of actual orthoconic materials – usually below 1 μm. The distinctive properties of orthoconic materials make them suitable for photonic applications requiring moderate response time such as routing or beam steering applications.

Keywords: alignment; analogue grayscale; antiferroelectric liquid crystal; orthoconic

INTRODUCTION

Antiferroelectric liquid crystals (AFLCs) feature spontaneous gray levels upon multistability, wide viewing angle and low response time. The fast

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electrooptical response of surface stabilized AFLCs along with their intrinsic analogue grayscale may be of practical interest for a number of photonic applications requiring analogue variations of phase and/or polarization [1]. However, pretransitional effect (PE) produces light leakage when the cell is driven below threshold voltage, impairing contrast ratio [2].

Orthoconic AFLCs, i.e., antiferroelectric materials having 45° smectic cone half-angle, can avoid this problem [3,4]. The cone angle between the two opposite electrically induced ferroelectric states achieved upon switching is 90°. Moreover, the birefringence of the anticlinic relaxed AFLC at normal incidence cancels out by symmetry. As a consequence, the material behaves as optically isotropic at normal incidence, and the contrast of orthoconic AFLCs is just dependent on the polarizers' residual transmission.

Figure 1 shows two possible orientations of the AFLC cell [5]. Between crossed polarizers, the AFLC state at normal incidence is always dark, regardless its relative orientation with the polarizers. If polarizers are placed parallel and perpendicular to the smectic layers (Figure 1a), the switched ferroelectric states become linear retardation plates at 45° and −45° of the incident light polarization. Using a single polarizer rotated 45° (Figure 1b) the light impinging the cell does not modify its state of polarization (SOP).

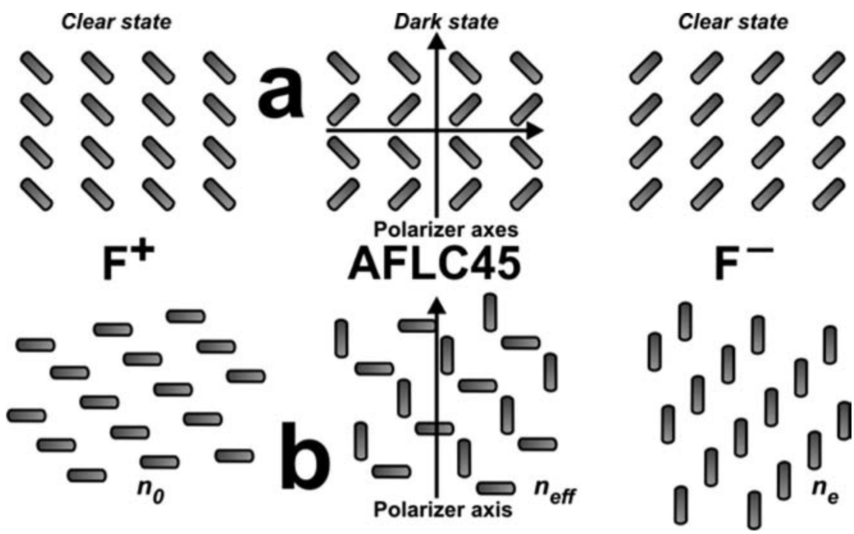

FIGURE 1 Two possible orientations of an orthoconic AFLC cell. a) Between crossed polarizers, giving two symmetric ferroelectric clear states (linear retarders) and a dark AFLC state. b) As a phase-only retarder, giving three states with different refractive indices without modifying the state of polarization.

Depending on the state, the refractive index of the cell is the ordinary n_o index (for one ferroelectric state), the extraordinary n_e index (for the other ferroelectric state) or an intermediate effective index n_{eff} (for the AFLC state). Thus the cell becomes a variable phase retarder with no SOP modifications.

A number of orthoconic materials have been tested and evaluated for possible applications. All of them are experimental mixtures showing smectic cone angles close to 90° within a certain temperature range.

EXPERIMENTAL

Orthoconic AFLC materials have been obtained as mixtures of several chiral and achiral compounds [6]. Surface stabilized samples were prepared by inducing homogeneous alignment in 1.5 μm cells. The alignment process was quite involved for several reasons [7]. As usual in AFLC mixtures, no nematic phase is present in the phase sequence of any orthoconic material tested in this work; this results in poor alignment if standard rubbed polyimides are used [8]. Surface conditioning was achieved with spin-coated Nylon-6; in most cases, additional polymers were tested as well: fluorinated nylons, nylons cross-linked with epoxies and copper acetate, and several special polyimides. A detailed study of these alignment materials in AFLC cells has been presented elsewhere [9]. Additionally, the pitch of all tested orthoconic materials is fairly short, below 1 μm. This is a common feature in current orthoconic AFLCs that makes it more difficult to achieve a correct alignment and induces unwanted asymmetry on the hysteresis curve of the electrooptical AFLC response.

Quasistatic electrooptical responses of every material were obtained applying a saturating triangular waveform of 1 Hz–or 0.1 Hz if the sample was not be able to achieve the intermediate AFLC relaxed state at the former frequency. Working temperature was 35°C. Orthoconic mixtures unable to relax at 0.1 Hz were rejected. The optical output at normal incidence was recorded using a Hamamatsu microphotomultiplier mounted on a polarizing microscope, and switching current was simultaneously acquired.

When appropriate, a further dynamic characterization was performed, employing a symmetric seven-level waveform for passive multiplexing. Details on symmetric driving of AFLC cells have been published elsewhere [10].

RESULTS AND DISCUSSION

Table 1 summarizes the most relevant quasistatic data of tested orthoconic materials. In every case, the results obtained with most appropriate

TABLE 1 Static electrooptic response of several orthoconic AFLC mixtures

Orthoconic AFLC material	Cone angle	Static Behavior				
		Contrast ratio	Threshold voltage	Saturation voltage	Grey level range	Hysteresis freq.
W-153	44°	69	14	17	3V	1 Hz
W-155	45°	72	14	16.5	2.5V	1 Hz
W-193	45°	73	16	20	4V	1 Hz
W-182A	45°	83	16.5	20	3.5V	1 Hz
W-182B	45°	87	16.5	20	3.5V	1 Hz
W-176	46°	37	13.5	15.5	2V	0.1 Hz
W-182	45°	136	15	17	2V	0.1 Hz
W-182A	45°	78	13	17	4V	0.1 Hz
W-182B	45°	87	13.5	16	2.5V	0.1 Hz
W-182C	45°	228	11	13	2V	0.1 Hz
W-183	45°	154	11	14	3V	0.1 Hz
W-190	45°	152	18	20	2V	0.1 Hz
W-193A	45°	168	13	15	2V	0.1 Hz
W-193B	45°	183	13.5	15.5	2V	0.1 Hz

aligning conditioning are shown. Material numbers correspond to mixtures having different components whereas series having the same number are different mixtures with the same components.

The static gray level range, i.e., the voltage difference between threshold and saturation voltages, varied between 2–4 V in all cases. Best contrast ratios were obtained with some mixtures of W-182 and W-193 series. Although achieved contrast was significantly higher than those usually found in regular AFLCs, the electrooptical response often became asymmetric.

Figure 2 shows several examples of electrooptical responses of orthoconic AFLCs. The samples were oriented between crossed polarizers so that a symmetric response between hysteresis lobes was obtained upon saturation. When voltage was reduced to generate intermediate gray levels, many materials gave markedly asymmetric responses. Previous work on asymmetric AFLC cells [11] suggested that shifts of hysteresis curves could be attributed to pile-up of charges on one electrode. Measurements of switching currents were performed to ascertain whether the observed asymmetric grayscales could be due to the presence of charges.

Figure 3 shows an example of current registered while applying a saturating AC triangular wave. Beside the switching peaks and the capacitor response, the current density was below 1 $\mu A/cm^2$, suggesting a relatively concentration of ions. The asymmetry in the grayscale is thus

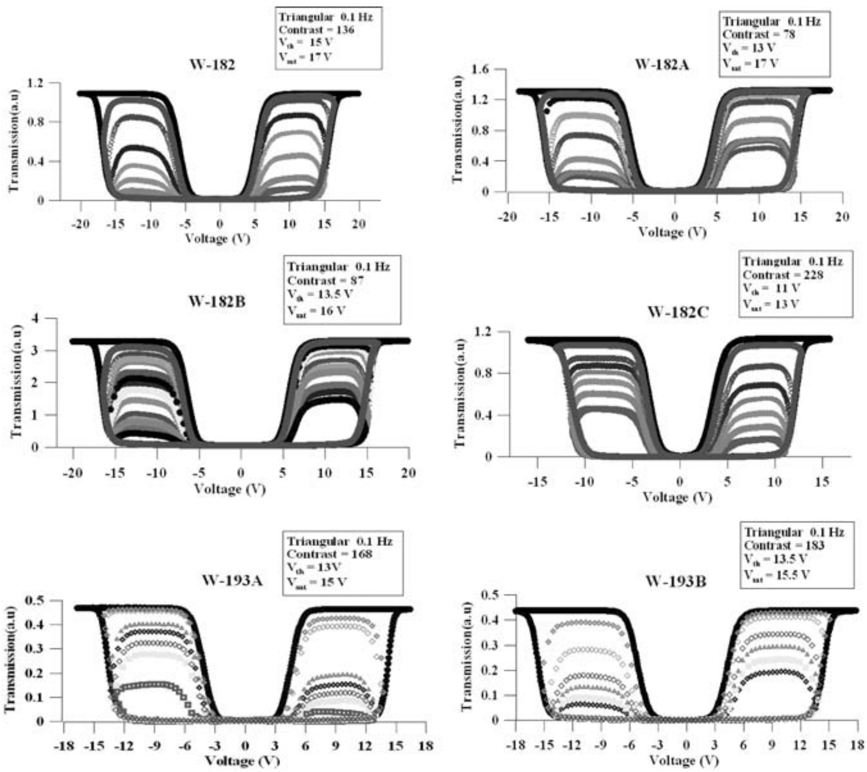

FIGURE 2 Electrooptical response of several orthoconic materials to 0.1 Hz triangular AC signals with different amplitudes within the materials' gray level ranges.

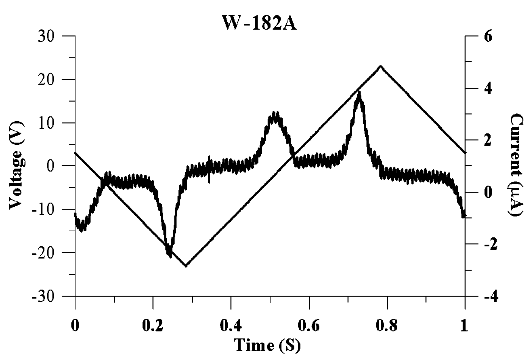

FIGURE 3 Current across the cell while applying a triangular wave.

attributed to the short pitch exhibited by the mixtures (< 1 μm). Longer pitch would be required to improve the applicability of these materials. Anyhow, any of these materials could be used in photonic or display applications as is, employing asymmetric monopolar addressing schemes [12]. In this mode, only one lobe is responsible for transmission, while a negative section is included in the waveform merely as DC compensation.

Dynamic grayscales can be generated with orthoconic AFLCs using a seven-level waveform similar to that employed in passive multiplexing of regular AFLCs. Figure 4 shows the driving waveform (top), the electrooptic response (middle) and the dynamic grayscale (bottom) obtained with one material. The dynamic contrast is remarkably high compared to the usual figures obtained with regular AFLCs. The asymmetry detected in the hysteresis cycle is still present here; indeed, the positive and the negative lobes give two different grayscales as seen in the figure. The relaxation transition F → AF is significantly slower than usual. Even the forced relaxation induced by the waveform showed fall times close to 1 ms. In these circumstances, high rate multiplexing (e.g., video rate) is unfeasible, since

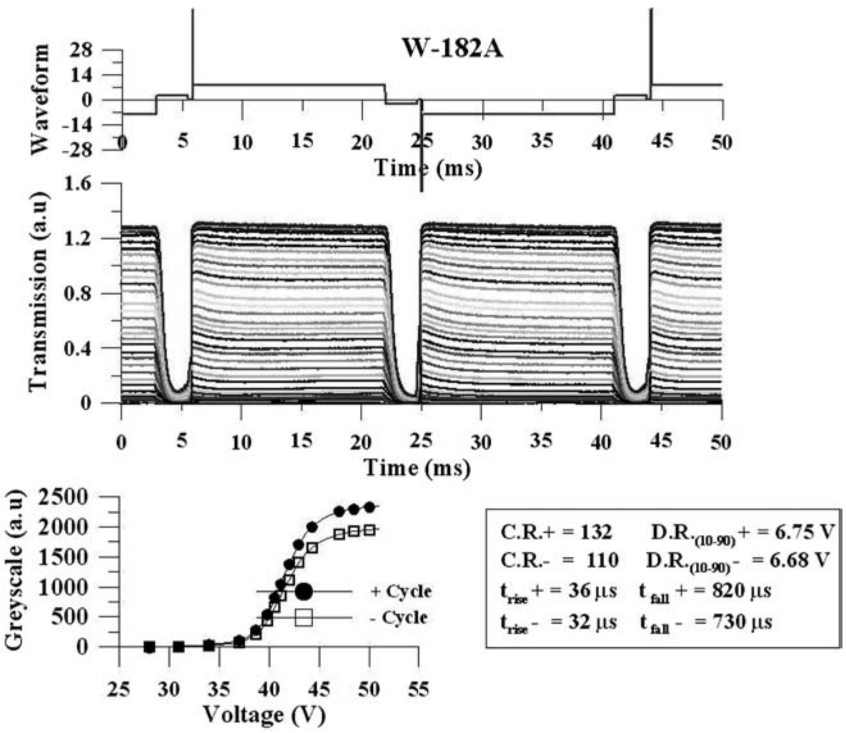

FIGURE 4 Current across the cell while applying a triangular wave.

pixels cannot be completely blanked between consecutive frames. Consequently a memory effect arises, by which the transmission of a pixel in a given frame depends on its transmission in the previous frame. This unwanted effect can obviously be avoided by reducing the frame rate and/or the multiplexing rate (i.e., increasing the slot time). In this way, a fully relaxed AFLC state can be achieved erasing the pixel history.

CONCLUSIONS

Orthoconic AFLCs behave as regular AFLCs in manufacturing and driving. However, their alignment is more difficult, often requiring the use of specific alignment conditionings. The gray scales developed in the hysteresis lobes show asymmetry that can be attributed to the reduced pitch of all tested materials. Dynamic response is usually slower than the response shown by regular AFLCs in the same conditions. However, contrast ratios are significantly higher, both in static and in dynamic mode.

Photonic applications of orthoconic AFLCs should take advantage of their unique features, albeit necessarily restricted to those not requiring high speed or high resolution. A new generation of orthoconics with longer pitch and faster response would certainly boost the application areas of these materials.

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