Characterization protocol to evaluate chiral smectic liquid crystals for high-end display applications

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Abstract: A protocol based on systematic experimental measurements to characterize the electro-optic behavior of chiral smectic liquid-crystal (LC) materials with V/W-shaped responses is presented. An experimental smectic LC material has been checked by use of this protocol. It has been found that results derived from this procedure permit a reasonable evaluation of the electro-optic performance of these LC materials as well as their capability to be used in high-end display applications.

OCIS codes: (110.0180) Microscopy; (160.3710) Liquid crystals; (230.3720) Liquid crystal devices; (120.2040) Displays

References and links

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1. Introduction

The V-shaped electro-optic response was first reported in chiral smectic liquid-crystal (LC) displays in 1995 [1]. Since then, it has not been easy to do research on a model that explains the molecular arrangement and switching inside the cell.

In fact, the analog response has already been shown in other modes [2]. The V-shaped response, however, may be one of the most promising responses for display applications. There are several theoretical and experimental studies that justify that thresholdless electro-optic behavior from different points of view, and from these studies two switching models have appeared. The first one is based on the molecular arrangement coherence inside each smectic layer and the molecular tilting randomness in adjacent layers [3]. On the other hand, in the second model the arrangement coherence is maximum between layers, and molecules switch collectively. However, inside each layer the director-polarization couple exhibits a combined, elastic twisted-splayed deformation [4, 5].

The greatest interest in these devices is due to the capacity of analog gray-scale generation under an external electric field. V-shaped devices share typical features with chiral smectic LC devices, such as fast switching, excellent contrast ratio, and a very wide viewing angle. In addition, the driving of devices requires voltages only up to 5V, and so the devices are compatible with standard microelectronic voltages.

The most direct application might be in active matrices built over silicon wafers, i.e., LC on silicon (LCoS). However, the high price of the silicon wafers makes microdisplays, because of their small size, the most profitable applications. Particularly, they are used in nondirect-vision display applications, projection systems, and near-eye virtual image devices. At present, LCoS manufacturers employ analog such as Twisted Nematic (TN) and Electrically-controlled Birefringence (ECB) and digital like Ferroelectric LCs. Thus far, only prototypes of devices with V-shaped LCs have been proposed [6].

Our goal here is to show an experimental procedure that is able to evaluate electro-optic characteristics of V/W-shaped LC devices. Accordingly, several experiments have been carried out.

2. Experimental setup

A Nikon Eclipse E600 polarized microscope was used for electro-optic characterization of V-shaped response cells. Driving voltage waveforms were obtained with a Hewlett-Packard 33120A digital arbitrary waveform generator. A large-area photodiode was used to measure optical transmittance in samples placed between crossed polarizers. Results were acquired and displayed with a Tektronix TDS3052 digital oscilloscope. Sample microscopic photographs were made with a Cohu CCD camera.

Characterization experiments were applied to a set of cells filled with the same LC. In the present study, we used an antiferroelectric mixture supplied from the Military University of Warsaw (Poland). Test cells were manufactured by the Liquid Crystal Group of Polytechnic University of Madrid. In this study, results for a particular sample are reported. The device under study was a monopixel cell with an electrode area of 1 x 1 cm^2 and a thickness of 1.8 μm. Rubbed nylon was used as alignment material in both sides of the glass plates, and, finally, both were assembled in a parallel configuration. Experimental results were obtained at room temperature, ~25°C. During the experiments, temperature was kept to a constant value with an external temperature controller. Temperature changes of ±2°C may produce slight deviations in some parameters such as response time, optical loops, and so on.

3. Results and discussion

A complete set of systematic measurements have been carried out to evaluate potential applications of smectic LC materials as video-rate displays. A brief description of the experimental methods used, as well as the main results obtained, are shown in the following sections.

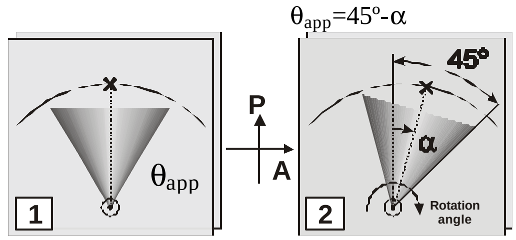

Fig. 1. Measurement of the apparent tilt angle.

3.1. Apparent tilt angle

The apparent tilt angle is defined as the angle formed between the smectic layer normal and the projection of the averaged molecular axis onto the glass surface. Under the assumption that the averaged molecular axes rotate around the smectic cone during switching [4], the value of the apparent tilt angle provides qualitative information about the optical response. That is, higher apparent tilt angle leads to higher transmittance and therefore higher brightness.

The apparent tilt angle was checked on test cells filled with the LC material. Its maximum value was measured by applying 1 Hz triangular waveform at saturation voltage and with the cell placed between crossed polarizers (P and A). Figure 1 shows a view of a LC cell from the glass plane.

The geometrical configuration of the switching molecule is plotted as a cone whose vertex points south. Numbers 1 and 2 represent the two positions of the cell that are used for measuring the apparent tilt angle. In 1 the polarizer is parallel to the smectic layer normal. In 2 the cell is rotated at angle α until the transmittance reaches the maximum value. So the apparent tilt angle is obtained as $45º-\alpha$. The average apparent tilt angles varied from 28º to 30º in the cells characterized with the LC material.

3.2. Low-frequency optical response

The response to low-frequency triangular signals shows a threshold-free feature in these kinds of cells. The transmission profile ideally corresponds to a V, but it can deviate to a W because of factors such as waveform frequency, temperature, or alignment layer conditions [7].

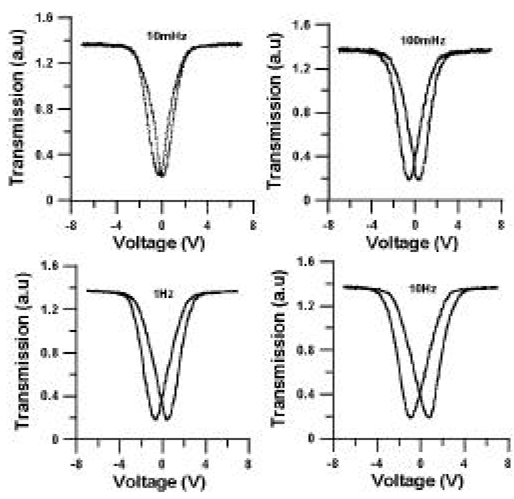

Fig. 2. Optical transmission for different frequencies of the triangular waveform applied to the LC cell.

In this study, frequency dependence in profile transmission was measured. Triangular signal frequency was changed from 10 mHz to 10 Hz. Test cell results are plotted in Fig. 2. The optical responses show a W-shaped profile that widens as frequency increases. Transmission at 10 mHz suggests that a V-shaped response can be obtained at lower frequencies.

3.3. Response time

A simple waveform, consisting of a selection pulse and a reset time as shown in Fig. 3(a), was used to drive the samples and check the response time. Alternative positive and negative pulses were used for dc compensation. Rise and fall times were measured as the difference between times in which transmission reaches 10% and 90% of this final value. Figure 3(b) shows the results for the cell that was studied. This cell presents a high rise time (520 μs) in contrast with the results obtained in other samples with similar characteristics, whereas the fall time (780 μs) is of the same order of magnitude. This slow fall time forces the inclusion of a well pulse to speed up the optical relaxation.

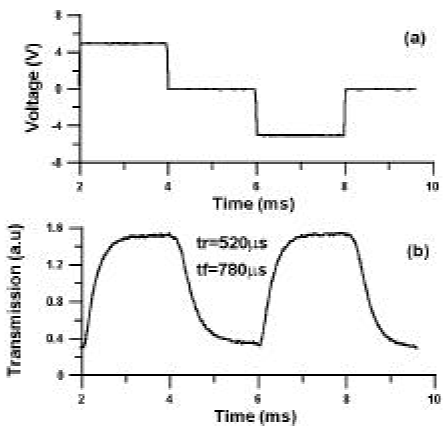

Fig. 3. (a) Voltage waveform and (b) optical transmission of the LC device in the time domain.

Response time of smectic LCs is determined by the material viscosity. The viscosity defines the joining degree of particles in the mass of LC. When the temperature increases, the viscosity diminishes; therefore, both rise and fall times are lower. In a projection system, the display may withstand a temperature of approximately 45–55°C. Experimental materials employed in the study did not show limitations in this operation temperature range.

3.4. Microscopic observation

A driving signal similar to the previous one was used to get intermediate levels of transmission. The waveform consisted of 16 different levels of data, as shown in Fig. 4(a). Reset and data times were at 250 ms to achieve more stability in the gray levels. Optical transmission that was measured for this driving waveform [see Fig. 4(b)] shows 11 different intermediate transmission levels. Some consecutive cycles with voltage higher than 3V were applied to guarantee the saturation of the optical transmission. Optical saturation delimits the operation dynamic range in a real device.

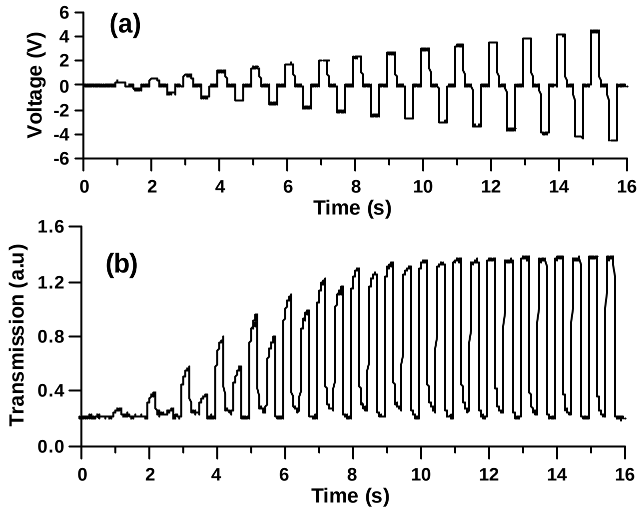

Fig. 4. (a) Driving waveform and (b) the gray scale obtained in the time domain.

Alignment protocol during the manufacturing processes is a key issue. Unlike ferroelectric LCs, which are very hard to align with rubbed polymers, V-shaped devices with homogeneous texture have been reported using traditional techniques of alignment based in rubbed polymer layers.

Next, microscopic observations of a cell with rubbed nylon as the alignment layer in both glasses are shown. A 10x magnification was used, and photographs were captured with a CCD camera. Figure 5 shows 11 distinct gray levels for increasing data voltages. Particular voltages applied in each case are also displayed.

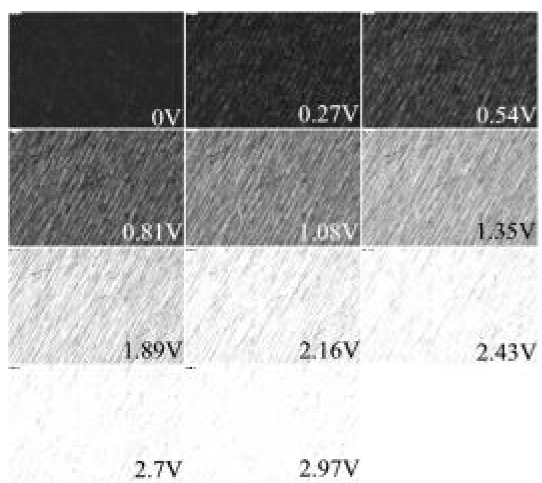

Fig. 5. Microscopic photographs of a generated gray scale.

3.5. Analog gray-scale generation

Analog gray-scale generation is an intrinsic feature in V-shaped materials. Some schemes to drive the materials at video-rate frequency devices have been developed [8]. In spite of the free-hysteresis, electro-optic response LCs that are under consideration share the problem of memory with the antiferroelectric LCs. That is, one transmission level depends on the previous one.

Some experiments were carried out to obtain analog gray scales and study the memory dependence of the optical transmission. Waveforms consisted of three voltage levels: a saturation pulse, a well pulse, and a data pulse. Driving schemes, that is, voltage levels of the saturation and well pulses included in the waveform, have been optimized for every particular sample.

Because test cells are passive devices, driving waveforms simulated the whole signal that the LC would see in an active device, that is, the electric field between the pixel electrode and the ground electrode. Levels and times employed in the experiments are summarized in Table 1. Frame time is 8 ms, so the operation frequency is 125 Hz B/W and ~40 Hz in RGB color.

Table 1. Slot times and voltage levels of the waveform applied to the test cell to generate a gray scale.

	Saturation pulse	Well pulse	Data pulse
Time (ms)	2	0.4	5.6
Voltage (V)	10	3	0–7

The dependence of previous transmission gray levels has been researched. Figure 6 shows the results: At the top of the figure four frames of the signal are plotted. Data in frames 1 and 2 are equal in amplitude but have opposite signs. The same is true for data in frames 3 and 4. Data amplitude increases in frames 1 and 2 and decreases in frames 3 and 4, as a result of the first waveform being applied to the following ones. Below the driving signals, the intermediate transmission levels are shown. At the lower portion of Fig. 6, a gray scale versus the selection level voltage is plotted for every frame of the signal, mimicking the transmission in four different pixels. The similarity of these gray scales shows that the memory does not affect the transmission if a saturation pulse with enough voltage level is included in the waveform.

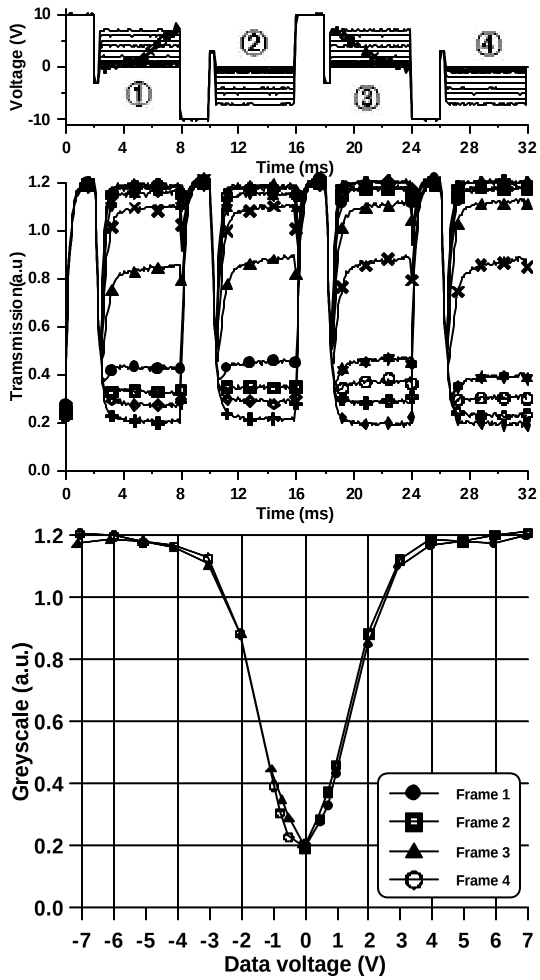

Fig. 6. Effect of saturation pulse on the transmission memory of the LC device.

3.6. Electric and optic responses

The electric and optic responses, as a function of applied field measured at room temperature are summarized in Fig. 7. During these measurements, the layer normal was always kept along one of the polarizers. W-shaped switching was observed when a low-frequency triangular waveform of 7V peak was applied to the cell. Additionally, switching current was also measured and the polarization-applied voltage characteristic was derived.

From these measurements, we can observe the matching between electrical and optical loops of the LC device. The possibility of obtaining a gray scale for this kind of switching has been previously considered and experimentally confirmed.

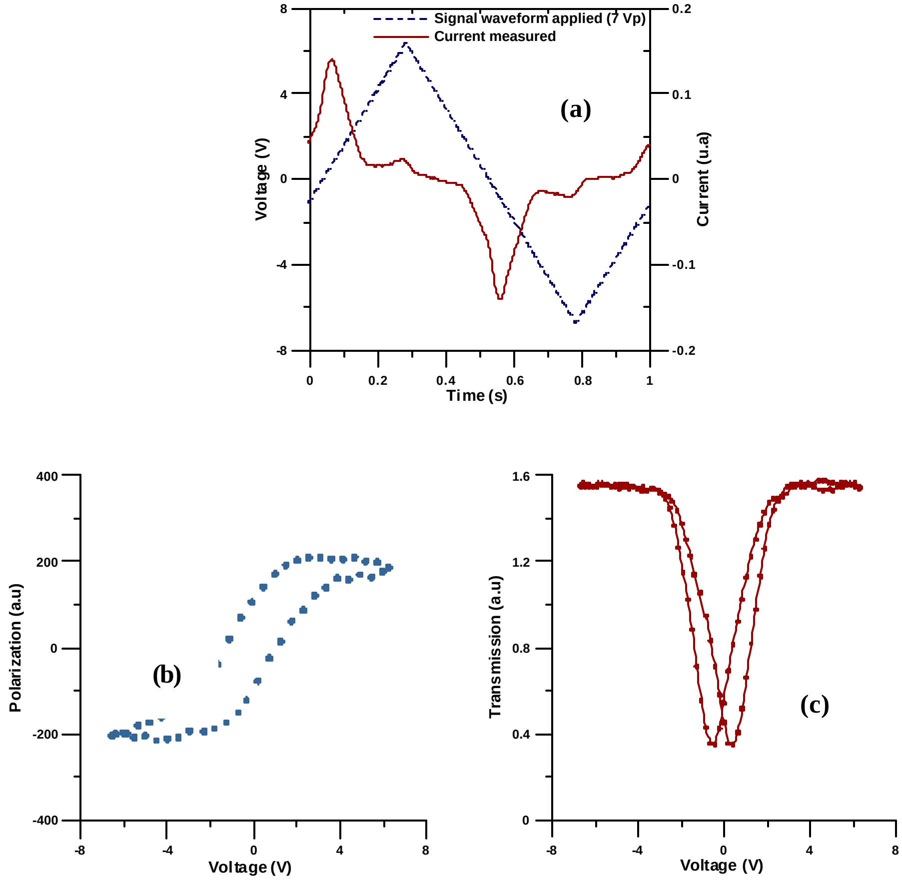

Fig. 7. (a) Triangular waveform applied to the cell and measured switching current, (b) polarization-voltage characteristic obtained, and (c) W-shaped optical transmission measured for the LC device studied.

4. Conclusions

A characterization protocol to evaluate potential display applications of V/W-shaped chiral smectic LCs has been developed. In this way, optical and electrical measurements in test LC cells have been performed. Waveform frequency dependence of the transmission profile and response times have been checked. Microscopic observations of the intermediate transmission levels have also been presented.

Analog gray scales were generated by the application of waveforms where data values were increased and decreased between successive signals. Memory effect dependence on transmission has been analyzed.

Smectic LCs with V/W-shaped electro-optic response have shown their potential for use in video-rate display applications. This switching mode exhibits attractive display characteristics, which suggests potential for active matrix (AM) or thin-film transistor (TFT) addressing in display devices. New manufacturing processes may improve the contrast ratio and response times of the device. Other tests that involve the spectral response are being developed at present.

Acknowledgments

This research was partially supported by the Spanish Ministry of Science and Technology, grant TIC2003-09212-C02-01, and by European Union grant IST-2001-37386. The authors thank Liquid Crystals Group (CLIQ) of Polytechnic University of Madrid (UPM) for supplying us with the LC devices characterized.