Evaluation of Electro-Optic Behavior of Chiral Smectic Liquid Crystals Displays with V-Shaped Response

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In the last years, chiral smectic liquid crystals with V-shaped electro-optic response have been reported as one of the most promising technologies for display applications. In this work, some experiments have been made in order to check electrooptical performance of this kind of materials. Particularly, frequency dependence of optical response and memory effect in transmission have been analyzed. Microscopic observations of intermediate transmission levels and measurements of apparent tilt angle and response time have been also carried out.

I. Introduction

V-shaped electro-optic response was first reported in chiral smectic liquid crystal displays in 1995 [1]. Since then, research on a model that explains the molecular arrangement and switching inside the cell, hasn't been an easy task.

In fact, the analogue response has already been showed in other modes [2]. But V-shaped response may be one of the most promising ones for display applications.

There are several theoretical and experimental studies that justify that behavior from different points of view. In this sense, two switching models appeared. The first one is based on the molecular arrangement coherence inside every smectic layer and the molecular tilting randomness in adjacent layers [3]. On the other hand, in the second model the arrangement coherence is maximized between layers and molecules switch collectively. However, inside every layer the director-polarization couple describes a combined elastic deformation twisted-splayed [4, 5].

Probably, the highest interest of these devices is due to the capacity of analogue grayscale generation under an external electric field. V-shaped devices share with ferroelectric liquid crystals typical features like fast switching, excellent contrast ratio and very wide viewing angle. Besides, voltages only up to 5V are usually required for driving the devices and so are compatible with standard microelectronic voltages.

The most direct application might be in active matrices built over silicon wafers, *liquid crystal on silicon,* (LCoS). However, the high price of the silicon wafers makes microdisplays the most profitable applications ones. Particularly, they are used like non-direct vision displays, on projection systems and near eye virtual image devices. At present, LCoS manufacturers employ analogue (TN, ECB) and digital (FLC) liquid crystals. Only some prototypes of devices with V-shaped liquid crystals have been proposed [6].

The goal of the present work is to evaluate the electrooptic behavior and dynamic characteristics of V-shaped liquid crystal materials, as well their capability to be used as high-end display applications (color gamut, gray levels, video rate, etc.). In this sense, several experiments have been carried out.

II. Experimental set-up

A polarized microscope *Nikon Eclipse E600* was used for electro-optical characterization of V-shaped response cells. Driving voltage waveforms were obtained with a digital arbitrary waveform generator *Hewlett Packard 33120A*.

A large area photodiode was used to measure optical transmittance in samples placed between crossed polarizers. Results were displayed and acquired with a digital oscilloscope *Tektronix TDS3052*. Microscopic photographs of the samples were made with a *Cohu* CCD camera. Characterization experiments were applied to a set of cells, all filled with the same liquid crystal material. Test cells were supplied by the Liquid Crystal Group of Polytechnic University of Madrid. In this work, all results reported were obtained from a particular sample included in the mentioned set. Such cell was a monopixel device with an electrode area of 1x1 cm^2 and a thickness of 1.8μm. Alignment protocol was rubbed nylon in both layer sides and parallel assembly. All experiments were realized at room temperature.

III. Results and discussion

A characterization protocol based on a set of experimental measurements was performed to evaluate the electrooptical performance as well as the dynamic behavior of the V-shaped cell.

1. Apparent tilt angle

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

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

The geometrical configuration of the switching molecule is plotted as a cone which vertex points toward the south. Numbers 1 y 2 represent the two positions of the cell, used for measuring the apparent tilt angle. In 1 the polarizer is parallel to the smectic layer normal. In 2 the cell is rotated an angle α until the transmittance reaches the maximum value. So apparent tilt angle is obtained as 45º-α. The average apparent tilt angles varied from 28º to 30º in the cells characterized of the material.

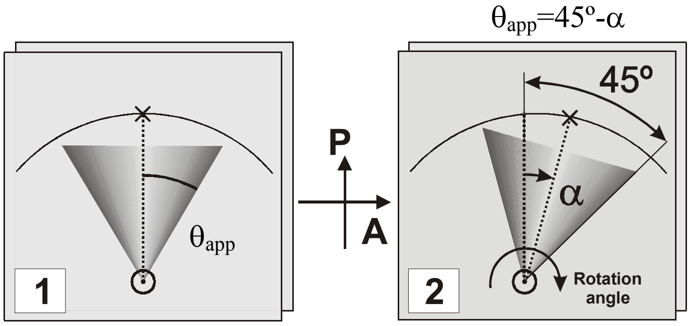

Figure 1: Measurement of the apparent tilt angle.

2. Optical response for low-frequency waveforms

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

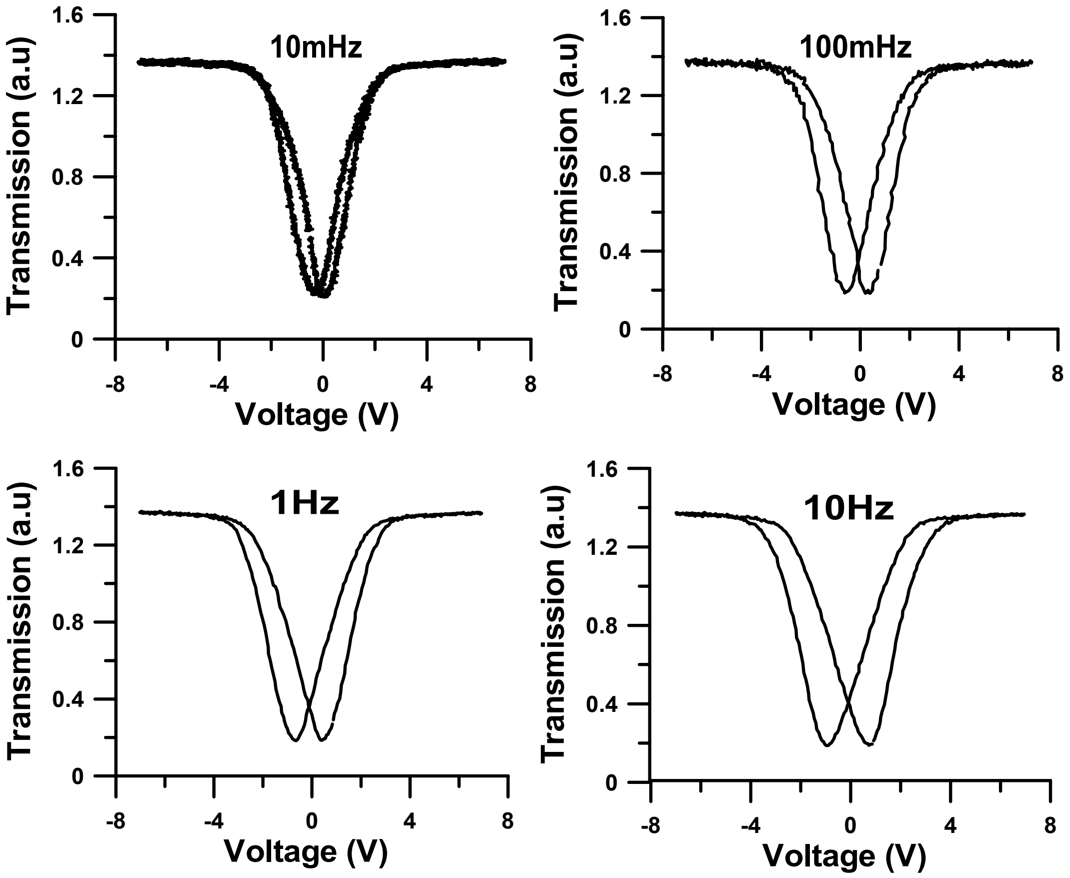

Figure 2: Optical transmission for several frequencies of the triangular waveform applied to the cell.

In this work, frequency dependence in profile transmission was measured. The frequency of the triangular signal was changed from 10mHz to 10Hz. The results for the tested cell are plotted in Figure 2.

The optical responses show a W profile that widens as frequency increases. Transmission at 10mHz suggests that V-shaped response can be obtained at lower frequencies.

3. Response time

A simple waveform consisting on a selection pulse and a reset time, Figure 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 difference between times in which transmission reaches 10% and 90% of this final value. Figure 3 (b) shows the results in the cell under study.

This cell presents a high rise time (520µs) with regard to the results obtained in other samples of similar characteristics, whereas fall time (780µs) is in the same order of magnitude. This slow fall time forces the inclusion of a well pulse to speed up the optical relaxation [8].

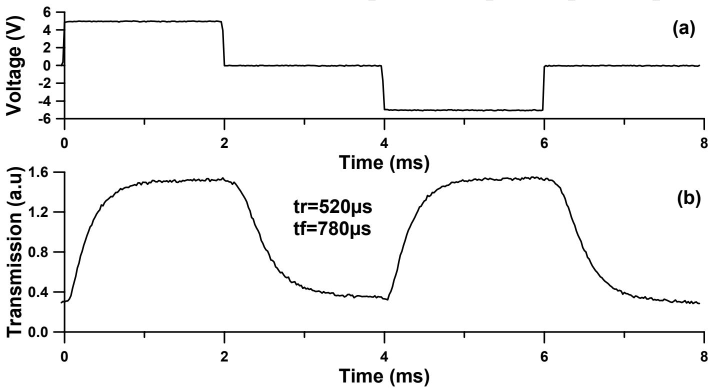

Figure 3: Voltage waveform (a) and optical transmission (b) in the time domain.

4. Microscopic observation

A similar driving signal to the previous one was used to obtain intermediate levels of transmission. The waveform consisted on 16 different levels of data, as shown in Figure 4 (a).

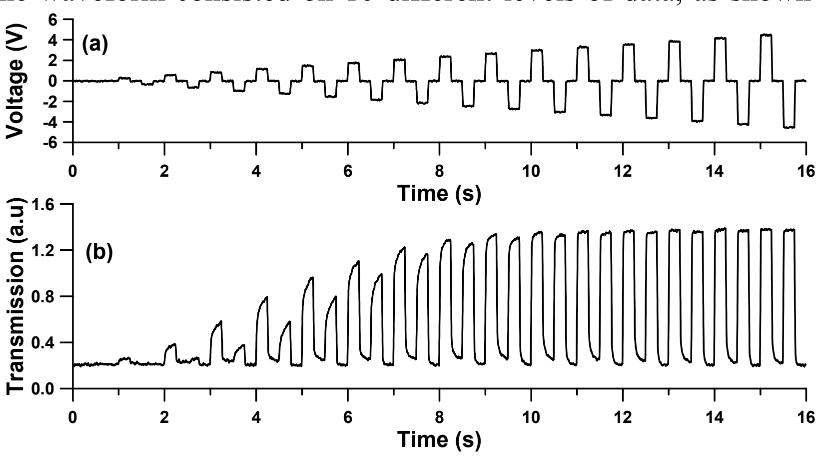

Figure 4: Driving waveform (a) and the grayscale obtained (b) in the time domain.

Reset and data times were of 250ms length to achieve more stability in the gray levels. Figure 4 (b) shows unbalanced transmission when the polarizer is parallel to the smectic layer normal.

Microscopic observations with an objective of x10 magnification were made. Some photographs were captured with a CCD camera. Figure 5 shows 11 distinct gray levels when data voltages are increased. Particular voltages applied in each case are also displayed.

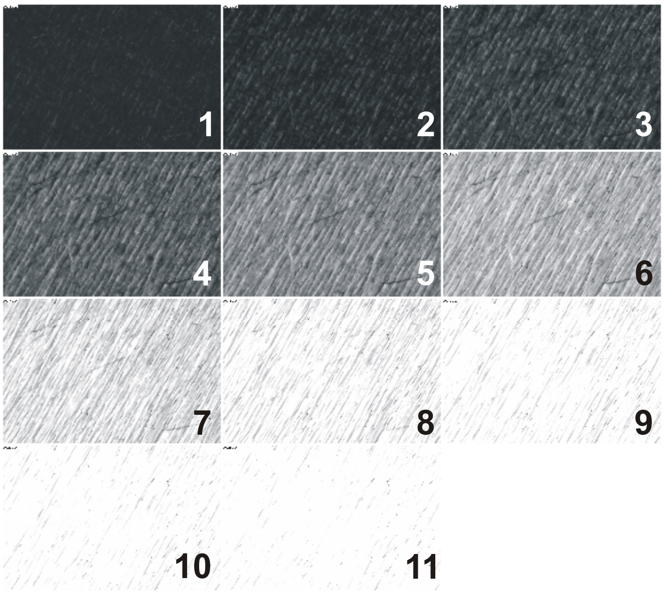

Photo Number	Voltage (V)
1	0
2	0.27
3	0.54
4	0.81
5	1.08
6	1.35
7	1.89
8	2.16
9	2.43
10	2.7
11	2.97

Figure 5: Microscopic photographs of the grayscale generated.

5. *Analogue grayscale generation*

Analogue grayscale 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, liquid crystals that are under consideration share the problem of the 'memory' with the antiferroelectric liquid crystals. That is, a transmission level depends on the previous one.

Some experiments were carried out in order to obtain analogue grayscales and study the 'memory' dependence of the optical transmission. Waveforms consisted on three levels: a *saturation* pulse, a *well* pulse (optional) and a *data* pulse. Driving schemes have been optimized for every particular sample.

Due to test cells are passive devices, driving waveforms simulated the whole signal that liquid crystal 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 of 125 Hz B/W and about 40 Hz in RGB color.

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

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

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

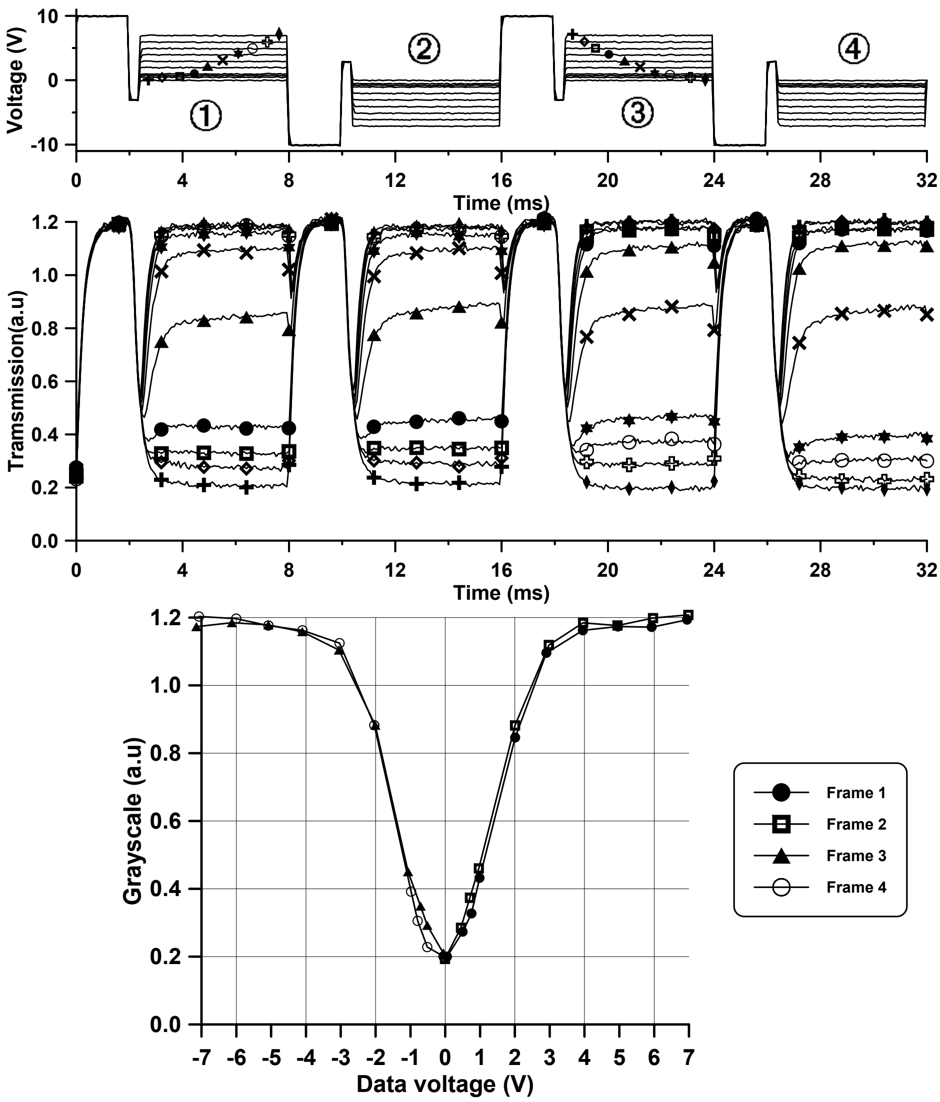

Figure 6: Effect of saturation pulse on the transmission memory.

IV. Conclusions

A fairly complete set of measurements in V-shaped liquid crystal cells have been made in order to predict the potential applications of the V-shaped liquid crystal materials. Waveform frequency dependence of the profile transmission and response times have been checked. Microscopic observations of the intermediate transmission levels have also been presented.

Analogue grayscales were generated applying waveforms where data values were increased and decreased between consecutive signals. Memory effect dependence on transmission has been also analyzed.

In summary, smectic liquid crystals with V-shaped response have showed their potential capability to be used in video rate and full color display applications. New manufacturing processes may improve the contrast ratio and response times of the device. Other tests involving the spectral response are being developed at present to predict new potential applications.

V. Acknowledgements

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VI. References

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