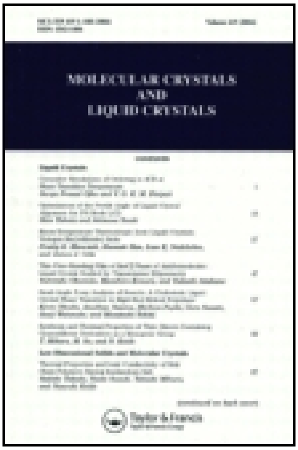

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SPECTRAL RESPONSE IN V-SHAPE CHIRAL SMECTIC LIQUID CRYSTAL DEVICES

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Surface stabilisation of ferroelectric liquid crystals (SSFLC) shows interesting properties: in plane switching, high viewing angle and fast response. Liquid crystal on silicon (LCOS) devices have an active matrix fabricated onto a silicon buffer, which requires metallization of the inner surface to achieve reflectivity. In this work, the influence of the cell thickness on the device colour upon switching has been studied. Little variations of the cell thickness without damaging surface stabilisation change phase delays, selecting the reflected wavelength if the birefringence is unchanged. Light path is double than that in a transmissive cell, thus similar thickness variations cause higher colour deviations.

Keywords: ferroelectric liquid crystal; spectral response; V-shape chiral smectic

INTRODUCTION

Flat liquid crystal displays (LCD) have experienced a great spreading, both in its applications as in its manufacturing technology. One of the branches on which the research is focused is on the Ferroelectric Liquid Crystals (FLCs). Up to now, the SSFLCs have developed interesting properties: in-plane switching, fast response and high viewing angle, among others

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(1). However, these features do not become these materials especially attractive for display applications because they essentially lack continuous gray-scale capability.

Ferroelectric materials are oriented by electric fields. When the SmC material is confined into extremely thin sandwiches, lower than 2 microns, only two states are energetically stable. This is the so-called *surface stabilisation* of this structure. Applying a DC signal, opposite to polarisation, the molecule switches from one state to the other, and without signal the molecules stay in their initial positions. On the other hand, typical antiferroelectric liquid crystal (AFLCs) present double hysteresis (tristability) and analogue gray-scale. Both FLCs and AFLCs show voltage thresshold for the optical switching but associated with different physical mechanisms. More recently, thresholdless, hysteresis-free V-shaped switching was observed in AFLC mixtures.

PHASE DELAYS IN SMECTIC LIQUID CRYSTALS

The optical transmission in a smectic liquid crystal cell depends on the birefringence of the material (difference between ordinary and extraordinary light paths).

In a FLC material, the ideal situation to obtain the maximum optical transmission takes place for a cone angle of $\sim 22.5^\circ$, being the states 45° separated. If the thickness d of the cell and the birefringence Δn are adjusted, so that the product $d\Delta\mathrm{n} = \lambda/2$, the FLC cell behaves as a linear retarder. In this conditions the contrast, brightness and viewing angle of FLC are excellent, better than any TN display.

Switching is achieved changing either the voltage amplitude or the time in which this voltage is applied to the cell. The general expression for the intensity of the transmitted light through the SSFLC cell described between crossed polarisers is (2):

$$I = I_0 \sin^2(2\Phi) \sin^2\left(\frac{\pi \Delta n d}{\lambda}\right)$$

where I_0 is the highest possible intensity transmitted, Φ is the angle between the polariser and the optic director in the sample plane, Δn is the optical birefringence and λ the wavelength of the incoming light. As a consequence, if Φ is 45°, the optical path difference is the one of a half wave plate:

$$d\Delta n = \frac{\lambda}{2} \Rightarrow d = \frac{(2k+1)\lambda}{2\Delta n} \text{ with } k = 0, 1, 2...$$

The cell gap in this case should be around 1.6 µm. If the sample of SSFLC is grown over an aluminium metallized substrate, the device becomes reflective. In this situation, the mentioned condition becomes as

$$d\Delta n = \frac{\lambda}{4} \Rightarrow d = \frac{(2k+1)\lambda}{4\Delta n} \text{ with } k = 0, 1, 2...$$

and so, the thickness values following this condition are halved, because the light crosses the sample twice. The sample thickness could be approximately 0.8 μm (Fig. 1).

Another effect is implicit in this discussion: besides the direct dependence of the phase delay with wavelength, there is an indirect dependence

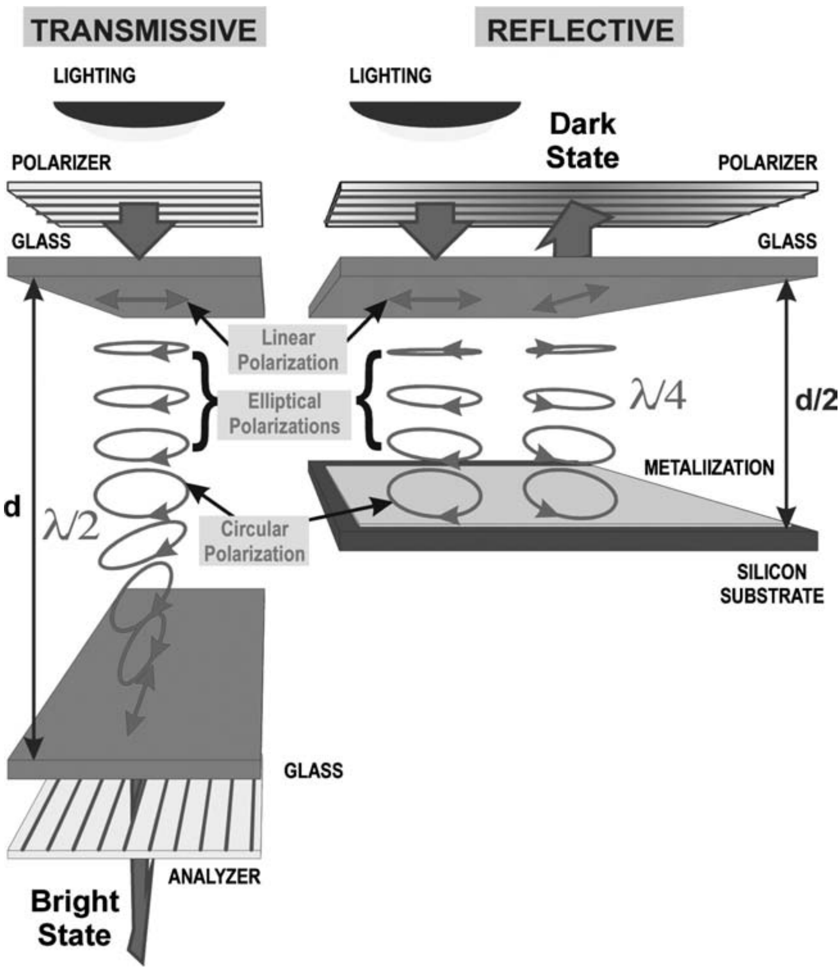

FIGURE 1 Light polarisation states for a transmissive (left) and a reflective (right) SSFLC cell.

of the birefringence with λ. These two dependences cannot be mutually cancelled: in FLC mixtures, as the wavelength increases the Δn decreases. As a result, the blue spectral interval of the incoming light shows a larger delay than the red interval. This can lead to a colour shift that can be measured in terms of colour coordinates. This effect becomes more critical when using reflective samples, as the dependences with the thickness d in the optical path are doubled. As a consequence, similar thickness deviations cause higher colour deviations in reflective devices.

On the other hand, some phases of chiral smectic liquid crystal have shown a thressholdless electro-optic response with V-shape (3,4,5). Electro-optical response of these mixtures is symmetric respect to null voltage, without hysteresis and without switching threshold. The electro-optic response in these materials could be affected by the same effect described above.

In the present work, the influence of the cell thickness on the device colour upon switching has been studied. Thickness fixes the specific wavelength of the light reflected from the device when the sample is relaxed (at zero volts). Modifying lightly the cell thickness without damaging the surface stabilisation, the new phase delay selects another wavelength while the birefringence is unchanged. As the device is reflective, the optical path crossed by light is double than that in a transmissive cell.

EXPERIMENTAL SETUP

Colour variations in V-shape reflective test cells were studied using an experimental setup (6) as shown in the Figure 2. Light coming from a

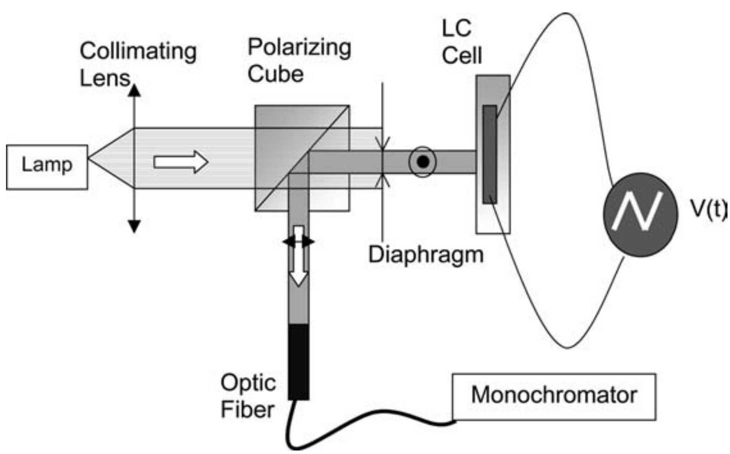

FIGURE 2 Experimental setup for the measurements performed in this work.

halogen tungsten lamp is collimated and then distributed in a polarising cube (acting as a beam splitter). A fraction of the light crosses the cube, linearly polarised in a first direction, it reaches the cell and is reflected in the inner surface, crossing backwards the sample and getting again through the cube. The inner face of the cube directs the linearly polarised part of it (perpendicular to the first director) towards the entrance of a fibre optic bundle. This bundle ends in a linear arrangement that is settled up in front of the entrance slit of a monochromator.

The monochromator is a SpectraPro 300i from Acton Research Co., which can acquire optical spectra ranged from 300 to 1000 nm. The dispersed light is directed towards a photomultiplier (PM) tube (Hamamatsu) after the output slit. This PM is controlled by a PC, which collects the measured spectra or the digital levels for a fixed wavelength.

Measured stability of the lamp intensity is around 0.6% below 400 nm, 0.2% above 400 nm, and less than 1% in wavelength for the whole range explored. Optical emission spectral features of the lamp are similar to a CIE D65 illuminant, slightly shifted to the red in the spectrum.

For this experiment, test cells were filled with experimental mixtures of V-shape material supplied by Military University of Warsaw. Several cells with different thickness were checked. The sample thickness was measured using a Perkin-Elmer Lambda 2 spectrometer, for UV and visible spectral ranges. The final colour that the sample shows is directly related to this parameter.

Reflected radiance from the test cells was measured, while low frequency (0.2Hz) switching signals were applied to them. The spectral range explored is 360–830 nm with a step of 1 nm. In addition, the voltage level was simultaneously measured.

RESULTS AND DISCUSSION

The samples were addressed with a low frequency triangular waveform (7). Different amplitudes were checked, in order to reach the saturation state. Light intensity at different wavelengths was measured during several periods of the triangular waveform, and afterwards a complete spectrum was derived.

As input data for this experiment, CIE 1964 standard observer and CIE 1931 colour chart were used (8). The illuminant as well as samples colour are checked using these colour diagrams.

Results from two sample cells with thickness 1.6 and 2 μm are shown in the Figures 3, 4 and 5. As it can be seen, the different thickness of the used samples leads to chromatic differences between them. This can be specially verified comparing the spectral dependence of the reflected light, which

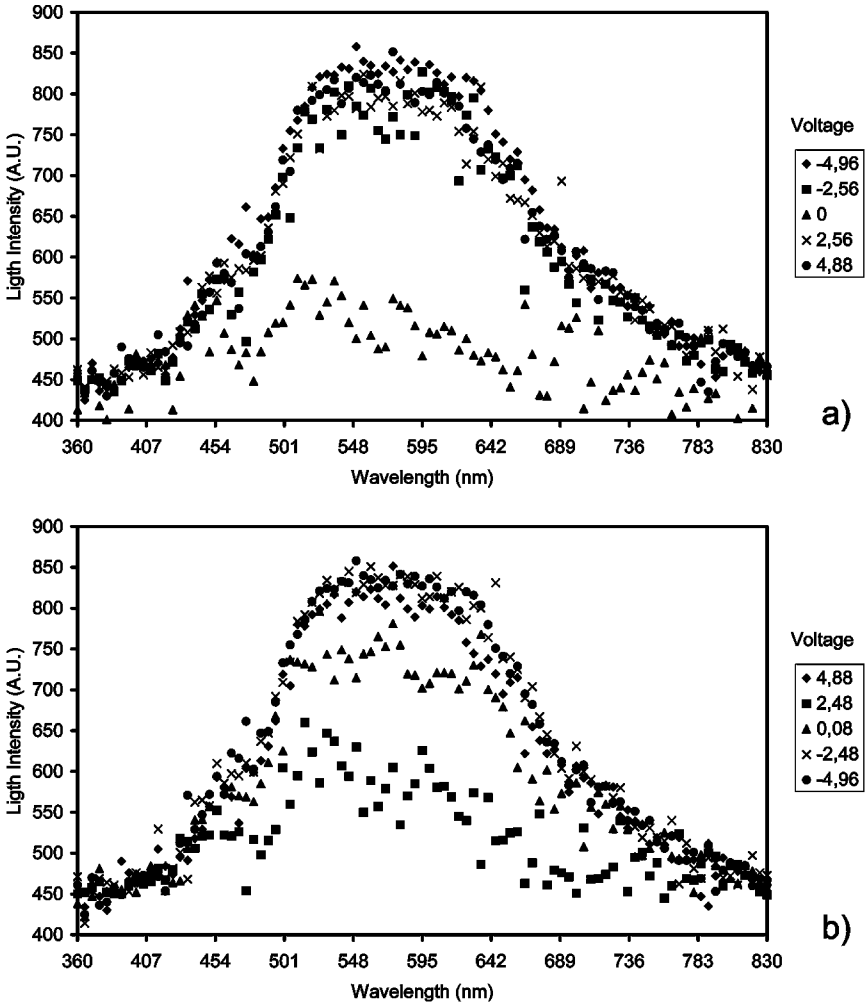

FIGURE 3 Spectral reflectance for a cell thickness of 1.6 μm, measured during a) positive slope and b) negative slope of the triangular addressing waveform.

shows clear differences between both cases. The thinner cell presents a high transmission at wavelengths located in the half of visible spectrum (from 500 to 650 nm) producing a green–yellowish colour. On the contrary, two marked intervals arise in the transmission of the thicker cell, one located in the blue (peak at 460 nm) and another in the red part of the spectrum (it is actually doubled, with two similar peaks around 645 and

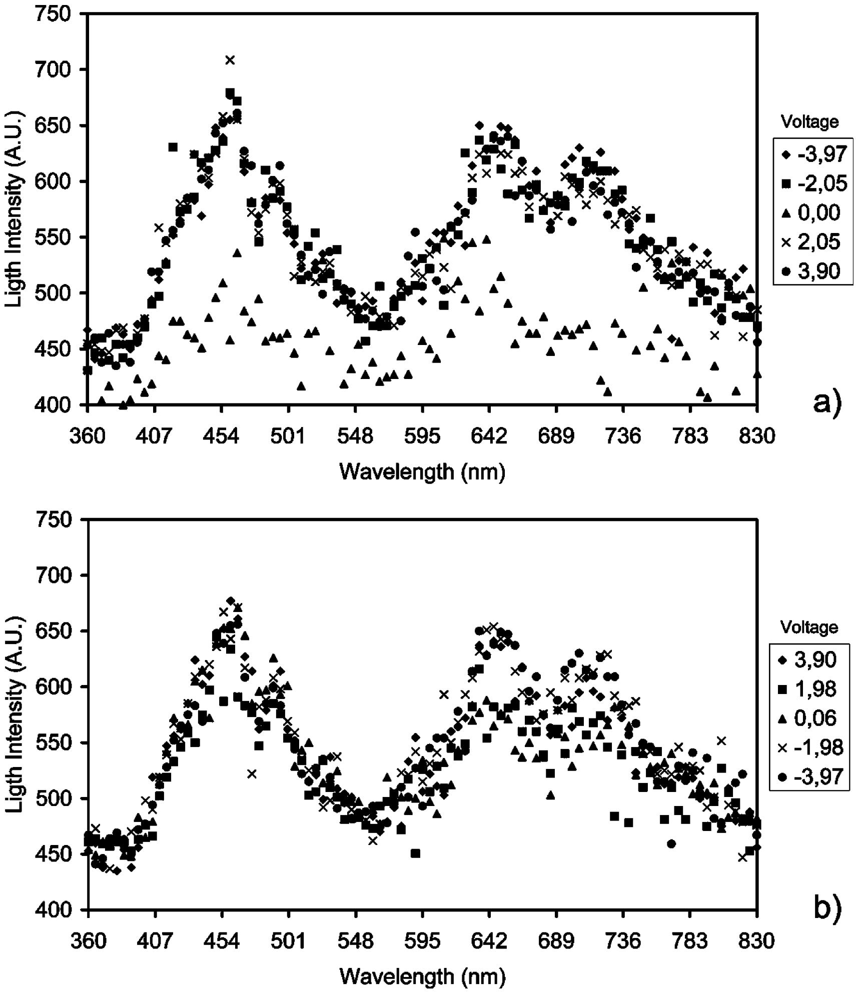

FIGURE 4 Spectral reflectance for a cell thickness of 2.0 μm, measured during a) positive slope and b) negative slope, of the triangular addressing waveform.

710 nm), leading to a bluer final colour, because of the different sensitivity of the human eye to these intervals.

The colour variations for the V-shape cell are translated into the CIE 1931 colour chart using the CIE-1964 standard observer and the spectral emission of the lamp as illuminant. However, the differences observed in the colour due to thickness variations are more relevant than the differences that switching voltages can provide. Keeping the same thickness,

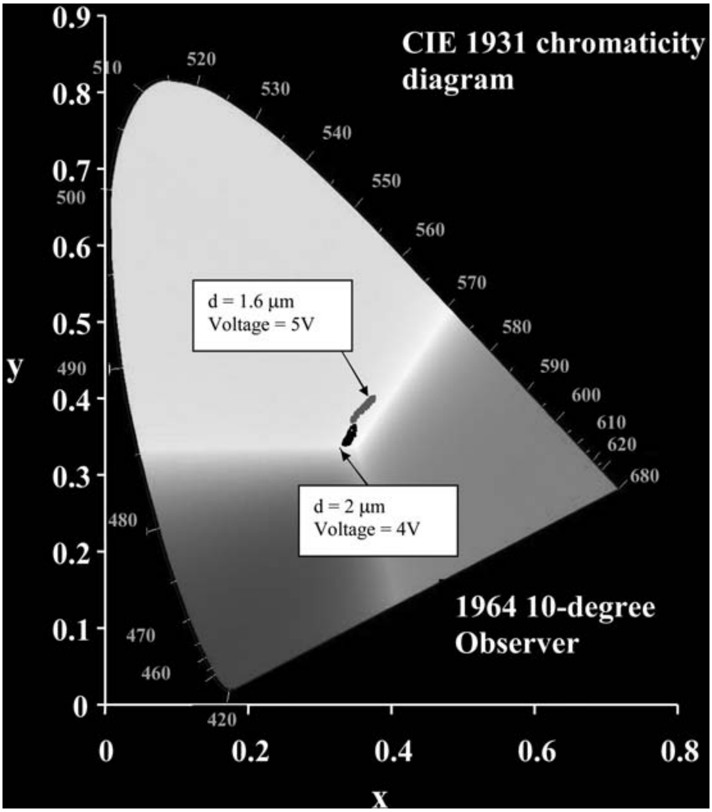

FIGURE 5 Chromaticity diagram and colour variation for two cells measured.

y-colour coordinate ranges 0.03 while switching. But, when different thickness are checked, the interval in which the variation takes place for the y-coordinate is, from 0.34 to 0.37 in the 2 µm cell, and from 0.37 to 0.4 for the 1.6 µm cell. For the x-coordinate also substantial changes can be observed for the latter cell.

CONCLUSIONS

An experimental setup to measure colour variations in V-shape cells has been proposed. The preliminary results show the spectral dependence of optical transmission of these devices. Such a dependence has been translated onto the CIE 1964 chromaticity diagram. The influence with the switching voltage as well as the thickness of the device in the colour of the reflected light has been studied. The thickness becomes the most critical parameter to select the spectral dependence of the light through the cell. The translation into the chromaticity diagram is not so clear as in the plots with spectral dependence, because some of the effects at different wavelengths could be balanced by others, which are not the target of this work.

A potential application for this kind of devices is proposed on the basis of the performed studies: filtering of the incoming white light selecting the output wavelength by applying appropriate driving signals. Future works on the subject introduced in this paper will allow the study of this ability for a fine spectral selection.

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