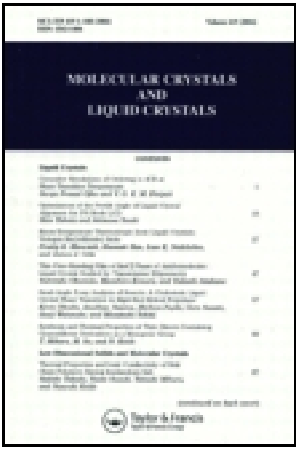

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A Transflective Quarter Wave Plate Dichroic Liquid Crystal Display

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A Transflective Quarter Wave Plate Dichroic Liquid Crystal Display†

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The operational principle of a transflective mode quarter wave plate dichroic liquid crystal display is described. It consists of a dichroic shutter and a polarizer sandwiching two quarter wave plates, one on each side of a transflector. In transmissive mode it acts like a Heilmeier display. The cell construction is discussed and electro-optical measurements are reported. With proper dichroic mixture and cell construction, we have achieved a contrast ratio of 10:1 in reflective mode and 30:1 in transmissive mode. This display is much brighter than TN and Heilmeier mode LCDs as it does not require a polarizer in reflective mode. It also has no unwanted memory effect.

INTRODUCTION

Quarter wave plate dichroic LCD was first reported by Cole and Kashnow in 1977.[1] These displays were operational only in reflective mode and moreover their contrast was low (~6.5:1 in monochromatic light and ~4:1 in white light).[1] Recently Bahadur reported improvement in reflective mode quarter wave plate LCDs (contrast ratio >10:1).[2] However, for many applications we require displays which can be operated in reflective as well as in transmissive mode.[3,4] In this paper we are reporting the techniques by which quarter wave plate display can be made transflective.

OPERATIONAL PRINCIPLE AND DISPLAY CONFIGURATION

The schematic diagram of the display is shown in Figure 1. The dichroic mixture is of positive dielectric anisotropy and alignment is parallel homogeneous align-

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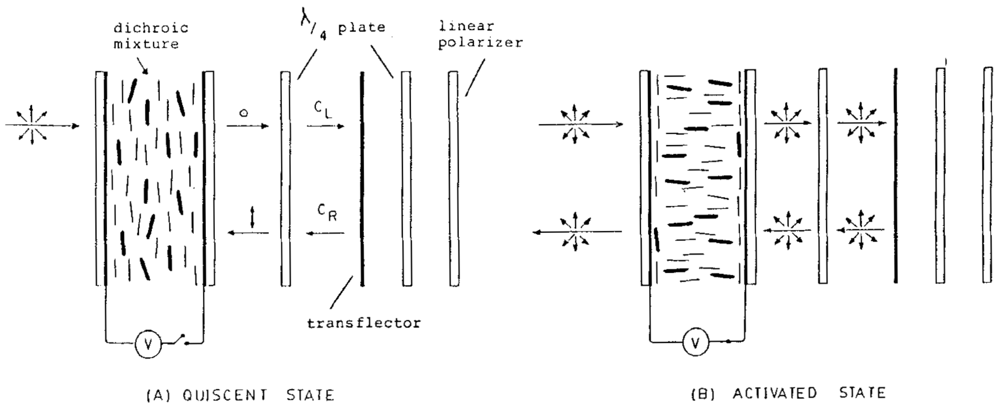

FIGURE 1 The structure and operational principle of the dichroic display incorporating quarter wave plate in reflective mode. [A] quiescent state, and [B] activated state.

ment. The quarter wave plates are mounted making an angle of 45° to the liquid crystal alignment. The quiescent and activated states of the cell in reflective mode are shown in Figure 1 while those in transmissive mode are shown in Figure 2. 90° and 270° twisted alignments can be also used instead of parallel alignments on both the plates.

REFLECTIVE MODE

The operational principle of this geometry is discussed in details by us[2] and Cole and Kashnow[1] in earlier papers. The dichroic mixture absorbs the component of the electric vector of light parallel to its director, and allows the light perpendicular to the director to pass through the cell. This transmitted light which is almost linearly polarized gets transformed to circularly polarized light after passing through the quarter wave plate and then strikes the transflector. The reflection from the metallic transflector converts it to opposite handed circularly polarized light which, after passing through the quarter wave plate, becomes linearly polarized with its polarization axis 90° to that of the originally transmitted light through the shutter. This light is then absorbed by the pleochroic dyes. In off state, the cell looks colored or black depending on the dye composition. With application of the electric field, the dichroic mixture gets aligned in the direction of the field (Figure 1B). In this geometry the electric vectors of the light are more or less perpendicular to the long axes of the dyes and hence the light is not absorbed and the cell looks clear.

TRANSMISSIVE MODE

In transmissive mode, the display basically operates as a Heilmeier display (Figure 2). The linearly polarized light becomes circularly polarized after passing through the first quarter plate which passes through the transflector; then after passing

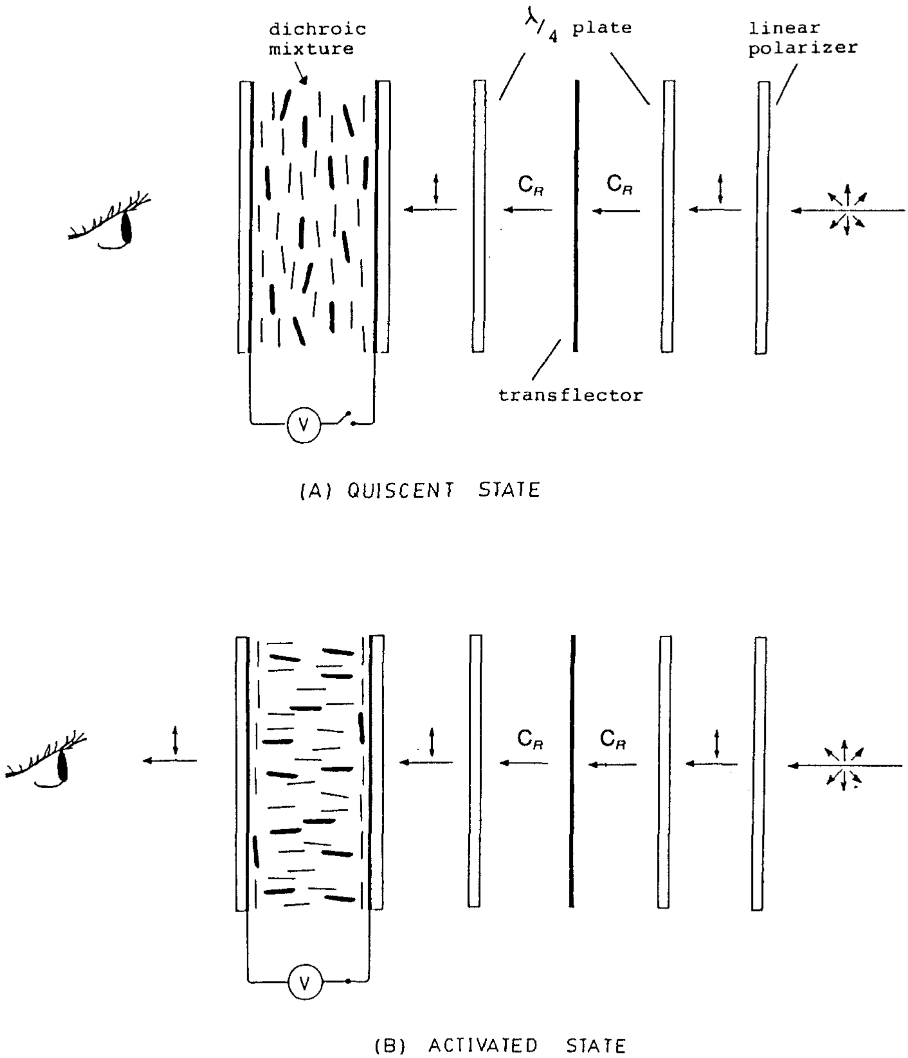

FIGURE 2 The structure and operational principle of the dichroic display incorporating quarter wave plate in transmissive mode. [A] quiescent state, and [B] activated state.

through the second quarter wave plate becomes linearly polarized again. The polarizer and quarter wave plate are mounted in such a way that the polarization direction of this linearly polarized light falls along the alignment direction of the rear glass. This way linearly polarized light is along the long molecular axis of the dye and hence gets absorbed. When voltage is applied, the dye molecules stand in the direction of the field and hence the polarization axis of the light is perpendicular to the long molecular axis of the pleochroic dye. In this case light is not absorbed and reaches the observer's eye.

Depending on the order parameter of the dye and the efficiencies of quarter wave plate and the polarizer, one can get a very high contrast ratio in transmissive mode. The transmissive contrast can also be increased by increasing the dye concentration and cell gap. However, these actions increase the switching times.

EXPERIMENTAL

The dichroic cell was made using the standard procedure.[2] Thin λ/4 plate, obtained after dissolving the protective polymer layer, were cut at 45°. These sheets along with an aluminum metallic transflector were bonded on the cell using UV curable optical adhesive. Then another λ/4 plate and a high efficiency polarizer (Sanritsu 9218) were pasted on. The transflector was chosen so that it should not depolarize the light.

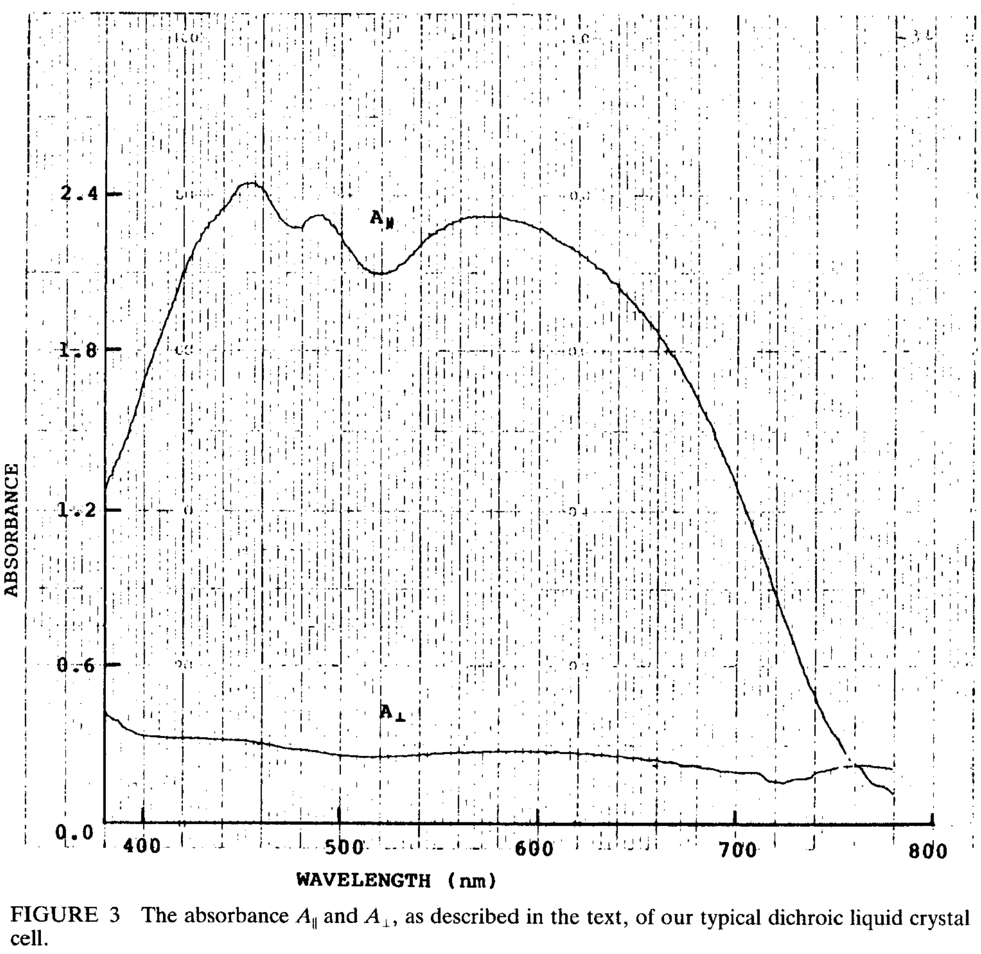

FIGURE 3 The absorbance $A_{\parallel}$ and $A_{\perp}$, as described in the text, of our typical dichroic liquid crystal cell.

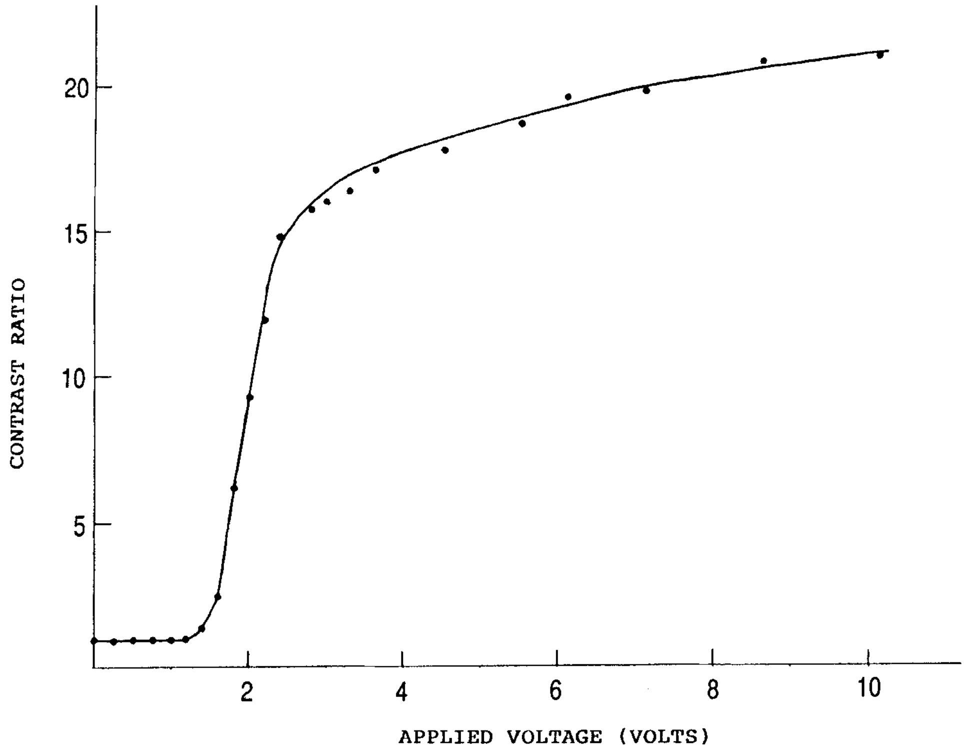

FIGURE 4 The threshold characteristic of the quarter wave plate dichroic display.

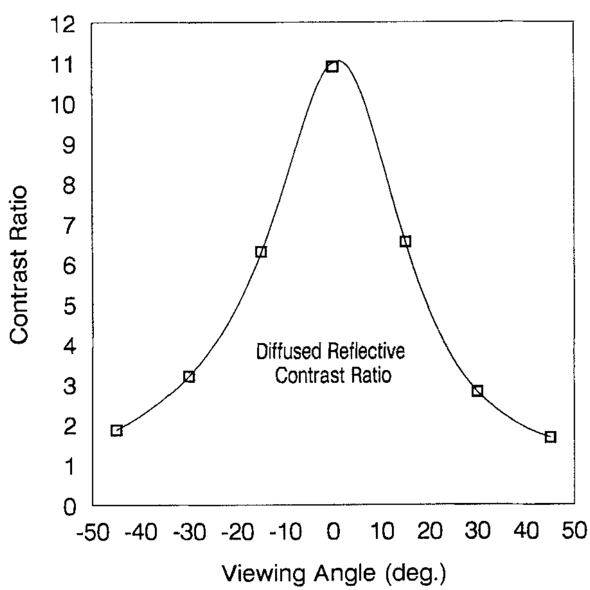

FIGURE 5 Viewing angle dependence of the diffused reflective contrast ratio.

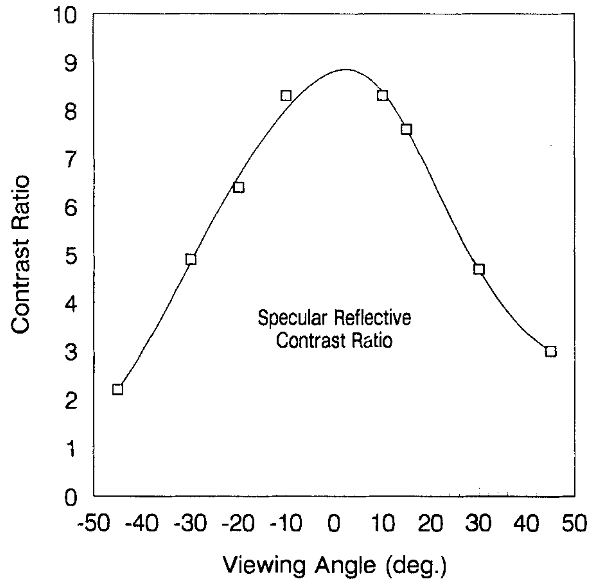

FIGURE 6 Viewing angle dependence of the specular reflective contrast ratio.

RESULTS AND DISCUSSIONS

The operational principle of this type of display suggests that the photopic extinction ratio of the dichroic liquid crystal cell is an important parameter. Extinction ratio is the ratio of the light transmitted through the cell with polarizer perpendicular and parallel to the liquid crystal alignment direction in quiescent mode. It is related to the effective dichroic ratio of the cell, $D(\text{eff})$, in the visible range. Empirically, $D(\text{eff})$ is defined as

$$D_{\text{eff}} = \frac{\int_{380}^{780} A_{\parallel}(\lambda)\, d\lambda}{\int_{380}^{780} A_{\perp}(\lambda)\, d\lambda}, \tag{1}$$

where $A_{\parallel}$ and $A_{\perp}$ are the absorbance for light polarized parallel ($A_{\parallel}$) and perpendicular ($A_{\perp}$) respective to the alignment direction. Figure 3 shows the $A_{\parallel}$ and $A_{\perp}$ of a 15 μm cell filled with ZLI-3499 black mixture. A direct measurement of the extinction ratio of this cell by a Spectra Scan Photometer model 1980A with a photoptic filter is about 97. The extinction ratio can be increased by increasing the dye concentration, cell gap and D_{eff}. However, the first two methods decrease the brightness of the cell.

The threshold characteristics of the quarter wave plate dichroic liquid crystal display is similar to that of Heilmeier display.[5] Figure 4 plots the threshold characteristics of our typical display. The minimum operational voltage is about 2.5 volts at which the majority of the liquid crystal molecules and the dye molecules align with the external electric field. With increase in the applied voltage more and

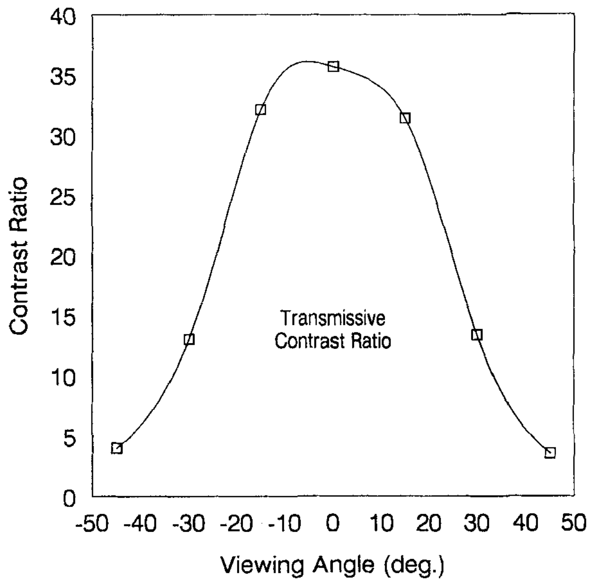

FIGURE 7 Viewing angle dependence of the transmissive contrast ratio.

more dye molecules near the liquid crystal-glass interfaces get aligned in the field direction and the contrast ratio increases. The contrast ratio can be further optimized by decreasing the anchoring strength of the alignment layers. The data shown below were measured with an applied voltage of 12 V.

The viewing angle dependence of the reflective contrast ratio of our display is shown in Figure 5. Viewing angle is the angle between the normal of the display and the photometer. For all the measurements shown in Figure 5, the fiber optics light source is rotated along with the Pritchard Photometer keeping the angle between them always less than 10 degrees. Normal to the display the contrast ratio is more than 10. The contrast ratio gradually drops to about 2 at ± 45 degrees. The decrease at large viewing angle is mainly due to the off axis property of the quarter wave plate. The reflector used in this display is an aluminum film etched by sodium hydroxide solution to thin enough to use in transmissive mode. The transmitted intensity is a few percent. The resultant film surface is far from mirror-like; this account for the mostly diffusive scattering nature of this measurement.

The specular reflective contrast ratio is also measured. In this case for each viewing angle measured, the light source is adjusted such that the photometer collects mainly the specular reflected light from the fiber optics. The contrast ratio is about 2 at normal and drops to 1.2 as the viewing angle increase to about ± 45 degrees.

The specular reflective contrast ratio can be improved by using a semi-transparent aluminum mirror reflector. Figure 6 shows the contrast ratio obtained using this type of reflector on the same liquid crystal cell. The full width half maximum of the contrast ratio is about 20° wider than that in Figure 5. The diffusive reflective contrast ratio, using this reflector with a diffused light source kept at a fixed direction (less than 10° from the photometer), is about 2 at normal and about 1 at

30° viewing angle. Therefore, for different application different types of reflector, or different treatment of the reflector might be required to optimize the display performance.

The transmissive contrast ratio is shown in Figure 7. At normal, the contrast ratio is about 36, and at ±45 degrees it drops to about 4. This decrease in contrast ratio is also mainly due to the off normal property of the quarter wave plates. The reflector has no particular function in transmissive mode. The contrast ratio would not depend on its thickness. However, the transmission would decrease exponentially with increasing reflector thickness.

The rise time of our quarter wave plate display is about 20 ms and the fall time is about 155 ms. It does not show memory effect as in White-Taylor display.[6]

CONCLUSION

We have demonstrated a highly bright transflective dichroic cell with high contrast ratio and wide viewing angle in both transmissive and reflective mode.

Acknowledgments

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