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Guest–host devices using anisotropic dyes

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An up-to-date review is given of Heilmeier and White–Taylor guest–host displays with their many variations, i.e. positive and negative dielectric anisotropy, positive and negative dichroism, flat and perpendicular boundary orientation, single and double cells, etc. Performance characteristics such as brightness, contrast ratio, operating voltage, field of view and multiplexability are compared with those of state-of-the-art twisted nematic devices. Applications for guest–host displays are discussed and new guest–host materials are suggested to further improve the performance of guest–host displays.

1. Introduction

Guest–host displays operate by the absorption of light by dichroic dye molecules oriented in a liquid crystal. The brightness of the display is varied by applying an electric field, thus changing the orientation of the liquid crystal. The original guest–host displays had to be operated at high temperatures, but they served to demonstrate the feasibility of the guest–host effect (Heilmeier & Zanoni 1968; Heilmeier *et al.* 1969). It was not until after the invention of the twisted nematic display (Schadt & Helfrich 1971) that suitable room-temperature host materials were developed. Since then many other guest–host schemes have been investigated. Probably the most important has been the scheme without polarizers described by White & Taylor (1974). In 1977 photochemically stable anthraquinone dyes with high dichroic ratios became available (Pellatt *et al.* 1980), and today ready-to-use black guest–host mixtures are commercially available.

It has been several years since these last advances were made, and yet guest–host displays have not progressed very far beyond the prototype stage. To understand why guest–host displays are not being manufactured in large quantities, we should investigate the performance of present prototype guest–host displays and compare it with that of commercially available twisted nematic displays. For most applications the positive qualities of guest–host displays, which include wide viewing angle, fewer polarizers and high brightness, are more than compensated for by the positive qualities of the twisted nematic display that must be sacrificed: high contrast, multiplexability and low-voltage operation. Twisted nematic displays are still to be preferred to guest–host displays for most applications. In this paper I shall review the state-of-the-art performance of guest–host displays in terms of viewing angle, contrast ratio and multiplexability. This approach will help to define the applications to which guest–host displays would be best suited. Another goal of this paper will be to extrapolate from present trends in the development of materials and technology to the future performance of guest–host displays.

A large number of guest–host schemes have been described in the literature. I shall not attempt to review all these schemes here, but rather shall cover only the more important effects involving nematic and cholesteric hosts. Smectic guest–host schemes (Pelzl *et al.* 1979; Lu *et al.* 1982) will not be discussed.

2. Heilmeier display

A non-twisted Heilmeier-type guest–host display using present cell technology is illustrated in figure 1. A rubbed polymer layer (not shown) gives flat boundary orientation with approximately 1° of pretilt and glass fibre spacers (also not shown) distributed over the display area maintain a uniform layer thickness, e.g. 8.0 ± 0.2 μm. A single polarizer is arranged in front of the layer so that its transmission direction is parallel to the rubbing direction on the adjacent cell plate. The cell is filled with a liquid crystal mixture having positive dichroism and positive dielectric anisotropy. In the absence of an applied voltage, the E-vector of normally incident light is nearly parallel to the optical axis, the direction of maximum absorption, and the cell appears dark. Where an electric field is present in the cell (the region of electrode overlap in figure 1), the optical axis in the layer is distorted and, in the middle of the layer, approaches a

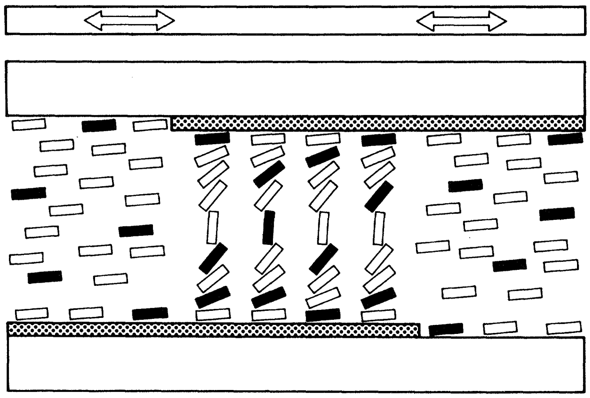

Figure 1. Sketch of original Heilmeier guest–host display. Transmission direction of polarizer is indicated by arrows.

direction parallel to the field. Here the E-vector of the incident light is nearly parallel to the direction of minimum absorption and the field-on region of the cell appears bright. This type of guest–host display is referred to as a negative contrast display because it shows light-coloured symbols on a dark background.

The transmission–voltage curve and the angular dependence of the contrast ratio are important parameters of the display performance, which can be computed. The orientation of the local optical axis in the layer can be determined from the elastic continuum theory (Deuling 1978; Scheffer 1981). The optical transmission of the distorted layer can then be determined from Maxwell's equations by approximating the layer as a stack of birefringent, dichroic slices of constant thickness, having uniform orientation of the optical axis within each slice (Berreman 1973).

Figure 2 compares the transmission characteristic computed for twisted (discussed in §3) and non-twisted Heilmeier displays (solid line and dotted line) with that of a twisted nematic display (broken line). The cell parameters and material constants used for this computation are summarized in table 1. For simplicity the absorption constants and refractive indices are assumed to be independent of wavelength. The parallel and perpendicular polarizer transmission constants listed in table 1 refer to the transmission of linearly polarized light by a single polarizer (Scheffer & Nehring 1977). The reduced-voltage scale on the x axis represents the applied voltage normalized by the corresponding Freedericksz threshold voltage. The guest–host curves have been normalized to make the upper border the asymptote of the transmission for infinite reduced voltage.

It is seen in figure 2 that the slope of the transmission characteristic for the non-twisted Heilmeier display is much more gradual than that of the twisted nematic display. A good measure of the steepness of the transmission curve, and hence the suitability for multiplexing, is the ratio of the voltage at 50 % of the optical response to the Freedericksz threshold voltage. For the twisted

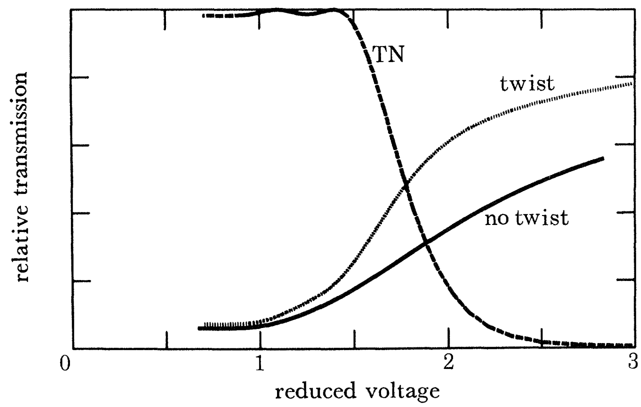

FIGURE 2. Transmission characteristic computed for twisted and non-twisted Heilmeier display compared with that for twisted nematic display. Upper border is transmission asymptote for guest–host curves.

TABLE 1. MATERIAL CONSTANTS† AND CELL PARAMETERS USED IN COMPUTATION

splay elastic constant	k_{11}	11.98×10^{-12} N
twist elastic constant	k_{22}	6.48×10^{-12} N
bend elastic constant	k_{33}	17.11×10^{-12} N
parallel dielectric constant	$\epsilon_{\parallel}$	15.49
perpendicular dielectric constant	$\epsilon_{\perp}$	4.35
extraordinary refractive index	n_e	1.640
ordinary refractive index	n_o	1.492
extraordinary absorption constant	α_e	0.3940 μm^{-1}
ordinary absorption constant	α_o	0.0394 μm^{-1}
Freedericksz k_{11} threshold voltage	U_o	1.095 V
parallel polarizer transmittance	$T_{\parallel}$	0.7360
perpendicular polarizer transmittance	$T_{\perp}$	0.0016
layer thickness	d	8 μm
pretilt at boundaries	α_0	1°

† The material constants k_{11}, k_{22}, k_{33}, $\epsilon_{\parallel}$ and $\epsilon_{\perp}$ were measured at 20 °C by H. Schad (personal communication 1982) on the host material ZLI-1840, from Merck, Germany.

nematic cell of figure 2 this ratio is 1.78, while for the non-twisted Heilmeier cell it is 2.69. The response is less steep for the Heilmeier display because the transmission depends on the orientation of the optical axis throughout the entire layer, and the regions near the cell boundary continue to absorb light until comparatively high voltages are applied. The transmission of the twisted nematic cell depends mainly on the orientation of the optical axis in the central region of the layer, which is nearly vertical for an applied voltage of 2–3 times the threshold voltage. The gradual slope of the guest–host curve means that the Heilmeier-type display is not suitable for multiplex drive even for 2:1 ratios, and that higher voltages are required for direct drive. Materials possessing a lower k_{33}/k_{11} ratio or a smaller $(\epsilon_{\parallel} - \epsilon_{\perp})/\epsilon_{\perp}$ will not significantly increase the steepness of the transmission curve. Schadt (1982) has shown that it is possible to multiplex

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the Heilmeier guest–host display, at least theoretically, up to a factor of 30:1 by employing a dual-frequency addressing scheme.

Figure 3 compares the iso-contrast diagrams computed for the twisted nematic and non-twisted Heilmeier displays. These diagrams give the contour lines of the constant contrast ratio of 10:1 (good) and 4:1 (lower limit) on a polar coordinate system. These iso-contrast diagrams are analogous to the conoscopic figures seen under the microscope. The azimuthal viewing angle extends completely around the diagram from 0 to 360° and the angle of incidence, measured in air, corresponds to the radial direction starting in the centre of the diagram for normal incidence and extending out to the periphery for grazing incidence at 90°. It is clear from figure 3 that the field of view for acceptable contrast ratio is considerably wider for the Heilmeier guest–host display than for the twisted nematic display.

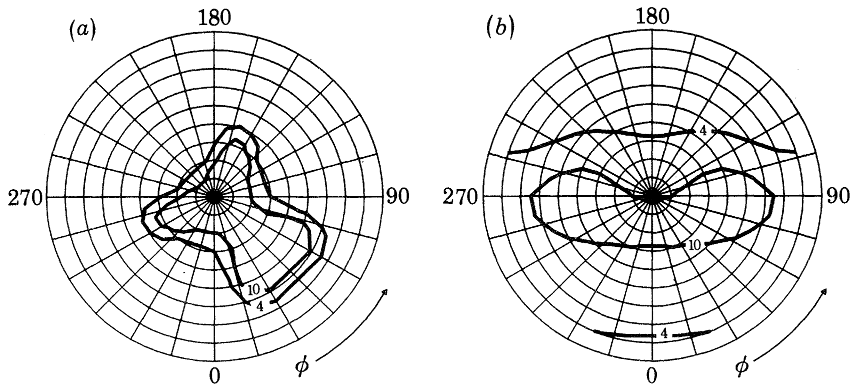

Figure 3. Iso-contrast diagrams computed for (*a*) twisted nematic and (*b*) Heilmeier guest–host displays in transmission. Case shown is for reduced voltage = 3.0 V.

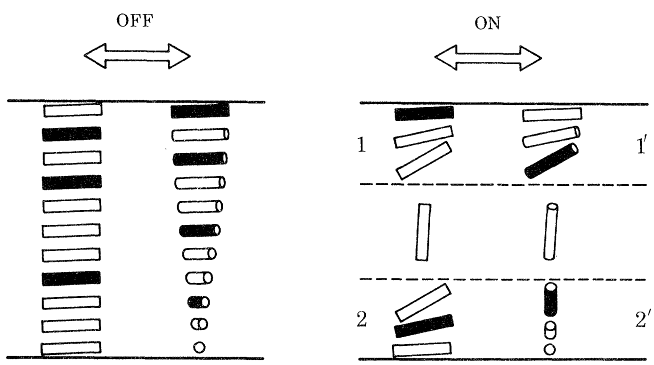

Figure 4. Sketch showing optical axis orientation in boundary regions of twisted and non-twisted Heilmeier cells.

3. Heilmeier display with 90° twist

Uchida *et al.* (1979*a*) have demonstrated that the transmission characteristic of the Heilmeier display can be made steeper by incorporating a 90° twist in the layer. This can be explained by referring to figure 4. In the field-off state (left side) the twisted layer absorbs nearly the same amount of light as the non-twisted layer because, within the Mauguin limit, the elliptical polarized modes propagating through the layer depart only very slightly from linear polarized modes

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(Nehring 1982). The major axis of the ellipse follows very nearly in step with the twisted structure and therefore remains more or less parallel to the optical (absorbing) axis. In the field-on state (right side), however, the twisted layer absorbs significantly less light than the non-twisted layer. The reason for this is that the orientation of the optical axis in the boundary region 2′ on the lower substrate of the twisted cell is at right angles to the E-vector of the polarized light and is therefore non-absorbing.

The transmission curve computed for the twisted Heilmeier display (dotted line in figure 2) is much steeper at intermediate voltages than for the non-twisted display (solid line), but the approach to saturation remains gradual at higher reduced voltages because the upper boundary region 1′ still absorbs light. The 50 % ratio for this case is 1.86, indicating that very limited multiplexing is possible. We computed the iso-contrast diagram for this case to see if the 90° twist had a detrimental effect, but, aside from skewing the contour lines to some extent, the field of view remained about the same.

4. Guest–host display with negative dichroic mixtures

In the previous sections I have dealt with guest–host mixtures with positive dichroism, i.e. where the extraordinary absorption constant α_e is larger than the ordinary absorption constant α_o. Pelzl *et al.* (1979); Demus *et al.* (1979); Schadt (1979) and Uchida & Wada (1981) have investigated guest–host displays that employ systems with negative dichroism, i.e. $\alpha_e < \alpha_o$. These workers employed derivatives of tetrazine dyes that had been elongated by 3,6 substitution. The direction of the optical transition dipole moment of these dyes is perpendicular to the plane containing the tetrazine ring (and perpendicular to the long molecular axis).

Negative dichroic mixtures can be used to produce positive contrast displays, i.e. displays in which dark symbols are shown against a light background. Very steep transmission curves have been measured for such displays (Pelzl *et al.* 1979). To compute the transmission characteristic for such a negative dichroic system we assumed the parameters given in table 1, except for the absorption constants, which we assumed as $\alpha_e = 0.068$ and $\alpha_o = 0.394$, independent of wavelength. We were therefore considering a black mixture exhibiting a dichroic ratio $R' = \alpha_o/\alpha_e = 5.8$, which is the same as the dichroic ratio we obtained for the red tetrazine dye mixture Lixon GR-63w available from Chisso, Japan. As before, a single polarizer is oriented in front of the layer with its transmission axis parallel to the rubbing direction of the adjacent cell plate. The computed transmission characteristics in figure 5 are indeed much steeper than those of positive dichroic systems (figure 2). This seems reasonable because the change in absorption for a small change in tilt angle is much greater when the direction of maximum absorption is pointing toward the observer rather than when it is at right angles to the observer. The cell with the 90° twist has the steepest curve (dotted line) giving a voltage ratio of 1.22 at 50 % optical response. The transmission characteristic for the non-twisted layer (solid line) has a voltage ratio of 1.29, which is still much lower than the value of 1.78 found for twisted nematic displays (broken line). The twisted layer has a steeper response because, referring to figure 4, the twisted configuration of the lower cell plate allows the lower boundary region 2′ to absorb light in the field-on state, whereas the boundary region 2 is always non-absorbing. The iso-contrast diagram computed for this case (not shown) indicates that an acceptable contrast ratio can be observed through a wide range of viewing angles.

These displays would have probably replaced twisted nematic displays in many applications if a black, negative dichroic mixture with a dichroic ratio of 10 had been available. For reasons of dichroic ratio and colour, however, it seems very doubtful that such a hypothetical mixture will ever be achieved.

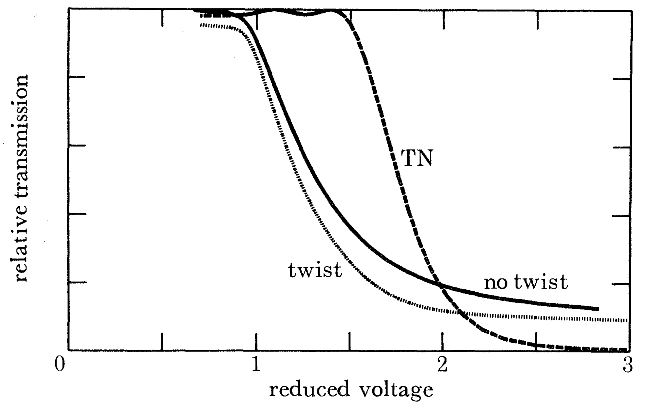

FIGURE 5. Transmission characteristic computed for twisted and non-twisted Heilmeier display with negative dichroism, compared with that for twisted nematic display.

5. GUEST–HOST DISPLAY WITH NEGATIVE DIELECTRIC ANISOTROPY

A positive contrast display can also be achieved in a positive dichroic mixture possessing a negative dielectric anisotropy. In this case the optical axis orients itself perpendicularly to the electric field, which requires a homeotropic orientation of the optic axis in the layer. A small pretilt from the layer normal ensures a defined tilt direction along the transmission axis of the polarizer when the field is applied. This pretilt can be introduced by oblique evaporation of SiO followed by treatment with a homeotropic surfactant (Koshida 1981; Uchida *et al.* 1979*b*), or by other methods such as treatment with a homeotropic surfactant followed by unidirectional rubbing (Uchida *et al.* 1980). Uchida & Wada (1981) have found pretilt angles of 3–5° to be most suitable.

We computed the transmission characteristic for this display by using the material constants measured for the nematic mixture Lixon EN-24 from Chisso, Japan (Schad 1982). We assumed extraordinary and ordinary absorption constants of 0.483 and 0.0483 and a pretilt angle of 1° away from the layer normal. Layer thickness and polarizer characteristics are given in table 1. The transmission characteristic shown in figure 6 is quite steep; the voltage ratio for 50 % optical response is 1.23, which is comparable with the transmission characteristics computed for the negative dichroic mixtures. This is reasonable, because just above threshold the axis of maximum absorption is perpendicular to the layer, where it can produce a large change in absorption for a small change in tilt angle. Saturation is only gradually approached because higher voltages are required before the boundary layers begin to absorb light. Introducing a 90° twist in the layer does not improve the transmission characteristic for this case.

The field of view for this device is illustrated by the iso-contrast diagrams of figure 7 computed for both transmission and reflexion (computed with half the dye concentration). In the transmissive mode an acceptable contrast ratio can be obtained over a wide range of viewing angles, but in the reflective mode the wide range of viewing angles is spoiled by 'holes' where the contrast is reversed. The birefringence of the layer is responsible for this effect. The holes occur at the angle of incidence for which the homeotropic layer behaves like a quarter-wave plate. Polarized light incident at this angle is completely extinguished at the azimuthal angles of 45°, 135°, 225° and 345° where the extraordinary and ordinary rays have equal amplitudes. Assuming an 8 μm layer thickness and a birefringence of 0.083 we computed this angle of incidence to be 42.0° (Françon 1956). This effect is also present in the turned-on state of the Heilmeier-type displays

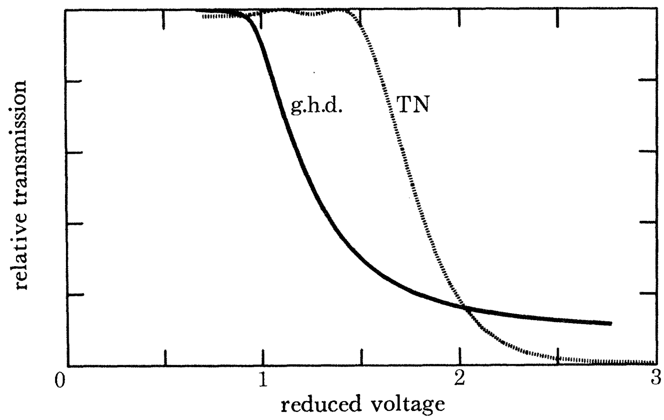

FIGURE 6. Transmission characteristic computed for guest–host display with negative dielectric anisotropy compared with that for twisted nematic display.

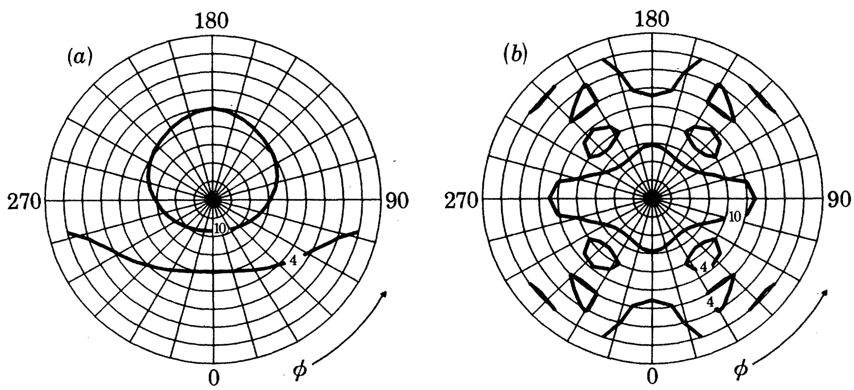

FIGURE 7. Iso-contrast diagrams computed for (*a*) transmissive and (*b*) reflective guest–host display with negative dielectric anisotropy. Case shown is for reduced voltage = 3.0 V.

(§§2 and 3), but it is not as apparent because it only affects the character segments rather than the whole display background. These holes do not appear with negative dichroic dyes (§4) because the homeotropic state is the dark state and in the parallel-oriented state only one of the optical modes is excited.

New mixtures are required to take advantage of the excellent multiplexibility of this effect. Stable nematic hosts as well as dyes with adequate solubilities and dichroic ratios in these new hosts will have to be synthesized. The host materials must be free of ionic impurities to prevent the occurrence of electrohydro-dynamic effects in the display. Furthermore, a new cell technology based on pretilted homeotropic alignment would have to be developed.

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6. Reflective guest–host displays with quarter-wave plate

Cole & Kashnow (1977) investigated a reflective guest–host scheme that employs a metallic reflector behind a quarter-wave retardation plate oriented with its optical axis at 45° with respect to the optical axis of a parallel-oriented guest–host layer. In the field-off state the guest–host cell acts like a polarizer, and this combination strongly absorbs light. In the field-on state the polarization effect is turned off and the layer appears bright. This display is brighter than the other guest–host displays discussed so far because no polarizing sheet is present. However, the contrast ratio is lower because the dichroic ratio of the guest–host layer (*ca.* 10) is not as high as the dichroic ratio present in commercial polarizers (10–65) (Scheffer & Nehring 1977).

Uchida & Wada (1981) suggest that the field of view of this display will be restricted because of the angular dependence of the quarter-wave plate. However, the iso-contrast diagram that we computed for this display indicates that an acceptable contrast ratio can be observed for all angles of incidence up to 50°, regardless of the azimuthal angle. We found that the wavelength variation of the phase retardation is a minor effect when the quarter-wave plate is matched to the peak wavelength response of the eye occurring at 550 nm. This display effect is not only limited to the parallel Heilmeier guest–host cell. A positive contrast device, for example, can be realized by using the display cells described in §§4 or 5.

7. Double-layered guest–host displays

A technologically more complex guest–host scheme that also does not require a polarizer is the double-layer scheme (Uchida *et al.* 1981; Sawada & Masuda 1982). Two parallel-oriented Heilmeier guest–host cells are placed over each other so that the directions of the optical axes on adjacent faces are at right angles. In the field-off state the system acts like a pair of crossed polarizers and no light is transmitted; application of an electric field turns off the absorption. This display has identical electrode patterns in each cell, which are activated in pairs. To minimize parallax, the display is constructed with three glass plates, the central one being in contact with the liquid crystal on both sides. The twisted layers of §3 would also work with this scheme and improve the steepness of the transmission characteristic. A positive contrast display could be made by using the guest–host layers described in §§4 and 5.

Double-layered guest–host displays absorb unpolarized light more efficiently than any other guest–host system without polarizers. Nevertheless, the contrast ratio is not as high as for single-polarizer guest–host schemes because of the low dichroic ratio of the guest–host layer. Double-layered guest–host displays operating in the reflective mode can employ either a metallic reflector or a diffuse, depolarizing reflector.

8. White–Taylor display

In the display devices discussed so far, the optical modes propagating through the guest–host layer are linearly or almost linearly polarized. In order to absorb unpolarized light efficiently, these displays require an additional external element, such as a polarizer, quarter-wave plate or an additional guest–host layer. The White & Taylor (1974) guest–host display differs in that it does not require any additional element. In this display the liquid crystal has a highly twisted structure in the field-off state, obtained by doping the nematic with a chiral additive. The optical modes propagating in a layer with short pitch are highly elliptical and therefore very efficiently absorb unpolarized light. More details about the absorption and reflexion of light from twisted structures can be found in the article by Nehring (1982).

White–Taylor guest–host displays can be made with either homeotropic or flat boundary orientation. The type of boundary orientation has a large effect on the performance of the display.

(*a*) *Cells with homeotropic orientation*

The field-off state of a cell with homeotropic orientation adopts the 'scroll' texture (Kawache *et al.* 1978), which very slightly scatters light. An advantage of homeotropic orientation is that the scroll texture is re-established without the formation of disclinations when the voltage across the layer is switched off, even if there is a relatively large number of turns of the cholesteric helix within the layer. Because it is possible to have a large number of turns in the layer, the optical absorption is more efficient (shorter pitch and more circular modes) than with flat orientation, even though the boundary regions in the homeotropic cell make almost no contribution to the absorption.

At relatively low applied voltages this texture transforms to the highly scattering focal-conic texture, where the helical axis is oriented in the plane of the layer. At higher voltages the pitch of the helix increases until above a certain critical voltage the pitch becomes infinite and a homeotropic structure is adopted within the whole layer. This state only weakly absorbs light. The homeotropic state becomes metastable in a certain range of voltages below this critical voltage. A number of ingenious schemes have been developed that make use of this hysteresis effect to obtain high multiplex rates in phase-change devices without added dye (Ohtsuka *et al.* 1973; Tsukamoto & Ohtsuka 1974; Alder & Shanks 1976; Walter & Tauer 1978). All these schemes employ a holding voltage within the bistable range where either of two optical states can be present. Within the bistable range the homeotropic state slowly reverts to the focal–conic state through a nucleation process initiated by dust particles and other disturbances in the cell. This means the display must be continually refreshed, which limits the number of lines that can be multiplexed. This refreshing and the rather low contrast that exists between the focal conic and homeotropic states when dye is added have prevented their practical application for guest–host displays.

(*b*) *Cells with flat orientation*

The planar Grandjean texture is adopted in layers with flat or nearly flat boundary orientation. Practical devices must have less than about two turns of the cholesteric helix because layers that contain more turns exhibit disturbing after-images when the display element is switched off, caused by light scattering from disclinations. With only one or two turns in the layer, the operating voltage can be low, but the contrast ratio is not as high as that achieved with homeotropic boundaries because of the longer pitch. The layer tolerance must be rigidly controlled in these displays to avoid the occurrence of Grandjean–Cano disclinations, which are highly visible because of the stepwise change in brightness appearing across them.

Hysteresis behaviour is also observed with flat boundary orientation, but here the transmission characteristic exhibits a true threshold voltage, above which the grid pattern distortion occurs (de Zwart *et al.* 1979). At higher voltages this pattern gives way to the focal-conic fingerprint texture, and at still higher voltages a uniform untwisted structure is established. The approach to saturation is gradual because of the boundary regions, which reorient only at relatively high voltages. A very important advantage of this display is that it can be multiplexed to a limited

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extent by using conventional waveforms (Suzuki *et al.* 1981). Aftergut *et al.* (1981) have measured the angular dependence of the contrast ratio in layers with many helical turns and find good agreement with Saupe's (1980) computations. No azimuthal dependence was observed. We computed a significant amount of azimuthal dependence in layers with fewer helical turns, in agreement with de Zwart's (1982) measurements.

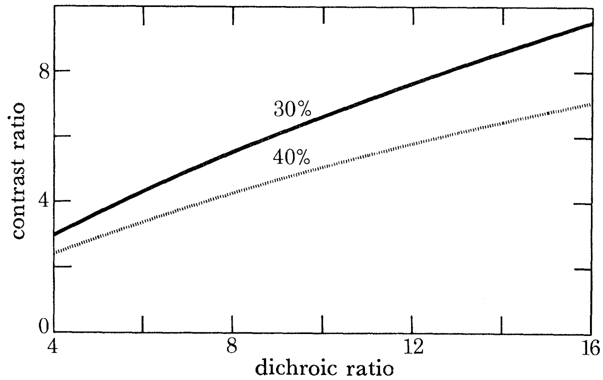

FIGURE 8. Computed dependence of contrast ratio on the dichroic ratio for single-turn White–Taylor display. Brightness of field-on state is held constant at 30 and 40 %. Voltage applied is five times the Freedericksz k_{11} threshold.

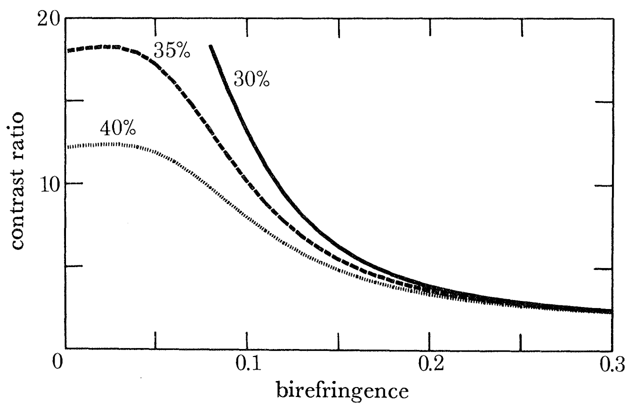

FIGURE 9. Computed dependence of contrast ratio on host birefringence for single-turn White–Taylor display. Brightness of field-on state is held constant at 30, 35 and 40 %. Voltage applied is five times the Freedericksz k_{11} threshold.

To predict the extent to which improvements in materials will influence the performance of this type of guest–host display, we computed the dependence of contrast ratio on the dichroic ratio of the black mixture for the constant on-state brightnesses of 30 % and 40 %. For this computation we used the material constants $k_{33}/k_{22} = 2.0$, $k_{33}/k_{11} = 1.5$, $(\epsilon_{\parallel} - \epsilon_{\perp})/\epsilon_{\perp} = 2.5$, $n_e = 1.64$ and $n_o = 1.49$ for an 8.0 μm thick cell with one helical turn and a metallic reflector. A voltage corresponding to five times the k_{11} Freedericksz threshold was applied to the layer. Figure 8 shows that the efforts required to increase the dichroic ratio from its present value of 10 to 12 or to even 14 are likely to be rewarded with only a marginal increase in the contrast ratio of the display. This insensitivity to the dichroic ratio results from the fact that neither the field-on nor the field-off brightness is determined by a single absorption constant but always by both α_e and α_o. Under these conditions even an infinite dichroic ratio would give a finite contrast ratio. It should be emphasized that the conclusions drawn from figure 8 apply only to the multiplexable guest–host display with flat boundary orientation described above. Figure 8 does not apply to cells with homeotropic boundary orientation or to cells with flat boundary orientation operating at very high applied voltages.

The computed dependence of the contrast ratio on the host birefringence (figure 9) for a dichroic ratio of 10, i.e. present values, shows that large gains in contrast ratio can be obtained by decreasing the birefringence of the host material. The black mixture ZLI-1841 (Merck, Germany), has a birefringence of 0.15. According to figure 9 contrast ratios could be approximately doubled while maintaining the same brightness by employing a host material with a birefringence of 0.10. The contrast ratios that can be obtained with very low birefringence would correspond to the contrast ratios that can be obtained with the double cells discussed in §7.

9. Cholesteric display with negative host

Analogous to the Heilmeier display, a positive-contrast White–Taylor–type display can be made by employing a host material with a negative dielectric anisotropy and a cell with homeotropic boundaries (Gharadjedaghi 1981; Gharadjedaghi & Voumard 1982). To maintain a homeotropic orientation in the field-off state, the thickness:pitch ratio d/p must satisfy the requirement $d/p < k_{33}/2k_{22}$, which limits the number of turns of the helix in the field-on state to about one. For a practical display, allowing for thickness and temperature variations, this means that there will be less than one turn of the cholesteric helix in the layer, and so a host material with a low birefringence is absolutely necessary. No hysteresis is observed in the transmission characteristic and the curves are steep enough to allow for limited multiplexing (Nagae *et al.* 1981). The cell technology is simpler than with the scheme discussed in §4 because no pretilt from homeotropic orientation is required.

10. Quasi-positive schemes

Quasi-positive guest–host schemes refer to those guest–host effects that inherently give negative contrast but that can be made to appear like a positive contrast display. Gharadjedaghi & Saurer (1980) and Uchida & Wada (1981) have examined several quasi-positive schemes in which the boundary alignment is different in the regions where the displayed symbols appear (either on one or both substrates) than on the remaining background regions. Gharadjedaghi & Saurer (1980) also describe a quasi-positive White–Taylor guest–host scheme where a few micrometres of glass has been etched out from one of the substrates under the symbols to make the guest–host layer thicker there. Quasi-positive behaviour can also be obtained by inversely driving the display, i.e. addressing the background region and those elements that are not to be seen and applying zero voltage to those regions that are to appear dark (Scheffer & Nehring 1980). A particularly simple quasi-positive scheme employs the White–Taylor effect with homeotropic boundaries in a cell with two compartments (Oh & Kramer 1982).

11. Applications

Guest–host displays are finding application in areas where they perform better than twisted nematic displays or where it is impossible to employ twisted nematic displays. An example of the former case is the liquid crystal oscilloscope display (Shanks *et al.* 1979), which has recently become a commercial product (Scopex Instruments Ltd, private communication 1982). Here the full viewing angle of a White–Taylor display with scattering reflector is used with a 128×256 point matrix because no multiplexing is required for single-valued oscilloscope waveforms. The guest–host effect is also finding application in reflective-mode matrices where the liquid crystal is in direct contact with thin-film transistors (Ymasaki *et al.* 1982; Crossland *et al.* 1982) and varistors (Levinson *et al.* 1982), where an opaque substrate prohibits placement of the rear polarizer required for the twisted nematic effect. These devices are still at the prototype stage, but the market potential is large. Guest–host displays also have some potential application for car dashboards where a wide viewing angle is essential and polarizers are not suitable because of their poor environmental stability under conditions of high humidity and high temperature. However, these devices are slower than twisted nematic devices because of the increase in the host viscosity due to the dissolved dye. This increase in viscosity can slow down the display response to such an extent that the display no longer satisfies present safety regulations, which specify a response time of about 1 s at −30 °C. However, the requirements for car clocks and car radios are not so stringent and application of guest–host displays in these areas is possible today. Even more applications are expected when improved guest–host mixtures become available.

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