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Polarizerless electro-optic IR shutter based on a cholesteric scattering effect

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The light scattering effect of the focal-conic to homeotropic texture transition of a cholesteric liquid crystal has been exploited to develop an electro-optic liquid crystal shutter for visible and infrared light without the utilization of polarizers. Using small helical pitches, the passive decay time from the homeotropic to the scattering state has been minimized to a size in the order of 2 milliseconds which is necessary for a 50 Hz shutter operation. To get active rise times of the same size without too large an increase in the necessary addressing voltage, while maintaining a good scattering contrast, the remaining cell and material parameters have been optimized. Using CaF_2 substrates, the shutter can be operated in the near and middle infrared region. Its contrast gradually decreases with increasing wavelength.

1. Introduction

In the past, rapid electro-optical liquid crystal shutters have been presented where the double refraction effects of reoriented layers have been used [1–6]. In order to generate a contrast, these cells have to be combined with a pair of polarizers. They are much faster than the usual liquid crystal display cells, since they are using transient reorientation effects in the twisted nematic cell [1, 2], or are exploiting surface modes [3, 4], or effects in ferroelectric liquid crystals [5, 6]. For some applications it may, however, be useful to avoid the dichroic polarizers, for example if they would heat up too much in intense light beams or when intensity losses cannot be afforded. Then optical switches using scattering effects instead of double refraction effects can be preferable. Also in the near and middle infrared wavelength region, especially where dichroic polarizers are no longer effective, scattering effects could be useful [7–9].

Light scattering instability effects in liquid crystals, however, usually have relatively large passive decay times which cannot be controlled by the field. The purpose of this work is to optimize a cholesteric scattering effect in such a way that the decay time becomes as short as the rise time, and that both switching processes are an order of magnitude more rapid than the rise times in conventional TN-cells. Additionally liquid crystal mixtures have to be used which show only a few absorption bands in the near infrared region [10–14]. The refractive indices, which have an important influence on the scattering power, have, according to several measurements [6, 12–15], similar values in the near infrared region to those in the visible.

The decay time from the clear to the scattering state is usually a passive switching time and therefore cannot be shortened in a simple way by applying an electric field. The decay time has to be reduced by optimizing the material properties of the liquid crystal layer and the cell parameters. An adequate procedure is to use a short pitch cholesteric liquid crystal that, after switching off the voltage, rapidly changes from the reoriented quasi-homeotropic state to a scattering state [16–18]. This state is the so-called focal-conic texture, and the effect can be called the 'focal-conic to homeotropic texture transition effect' (FHT effect), or alternatively, the 'nematic cholesteric phase transition effect' (NCPT effect).

The decay time from the clear state to the scattering state becomes shorter the smaller the cholesteric pitch p. Formulae for the decay and rise times t have been given in the paper by Jakeman and Raynes [19]

$$t_d = \eta / K q^2$$

and

$$t_r = \eta / (\varepsilon_a E^2 / 4\pi - K q^2)$$

where η is the rotational viscosity, K the twist elastic constant, E the electric field, ε_a the dielectric anisotropy and $q = 2\pi/p$. They have been applied to twisted nematic and cholesteric deformations. A shutter should be able to work at least at a frequency of 50 Hz where the decay and rise times together comprise not more than 20% of the cycle time. These very moderate conditions however require that each of the two switching times must be reduced to 2 ms in order to achieve the minimum of an acceptable shutter operation. For comparison, the rise times of display cells based on double refraction effects are half an order of magnitude larger, and the decay times are one order of magnitude more.

Unfortunately, if minimizing only the passive decay time by using a short pitch, the rise time is increased, and the switching voltage of the effect is increased. Nevertheless it is of primary importance to reduce the decay time to that size which is indispensable for a shutter application, and afterwards to vary the parameters left free to equalize the rise time to the decay time. The reduction of the rise time, for example by using materials of high dielectric anisotropy and low viscosity, or thinner layers, is only the second step after fixing the decay time. But it does not seem possible to reduce the voltages to values commonly used for display cells because the additional requirement of a high scattering contrast must be fulfilled. This contrast ratio is defined within a certain opening of the effective collection angle which has to be limited by some schlieren blend in order to separate the scattered from the unscattered light. The necessity to provide a high scattering contrast by a short pitch combined with thick layers is again counter-productive to obtaining short rise times.

2. Experimental

Several cholesteric liquid crystal mixtures have been prepared using the Merck standard substances ZLI 1285, 3219 and 3926 in order to test their suitability for the shutter operation. A typical IR transmission spectrum is given in figure 1. Finally a cholesteric mixture was prepared from the Merck nematic substance ZLI 4900–100 doped with the chiral component ZLI 4572. The latter mixture is better suited for higher temperature operation which can become necessary due to warming up in some electronic surroundings. This basic mixture has a clearing point of 85°C and a kinematic viscosity of 59 mm^2 sec^{-1} at room temperature. It was selected mainly because of its high dielectric anisotropy $\Delta\varepsilon = +28$, while the optical anisotropy is $\Delta n = 0{\cdot}16$. The high dielectric anisotropy is of special importance to reduce the high addressing voltage for the FHT effect. A sufficiently high optical anisotropy is needed to achieve a strong light scattering effect without using too thick layers which again would require too high addressing voltages.

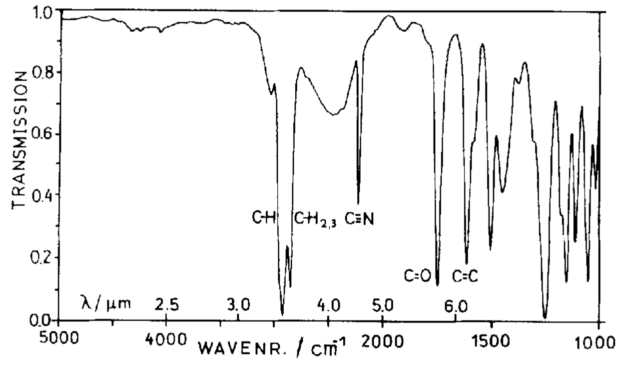


Figure 1. IR absorption spectrum of Merck mixture ZLI 4900-100 containing 0·98 wt % of the chiral dopant ZLI 4572 (MCX). In the near and middle IR, mainly the C–H$_n$ vibrational bands around 3·5 µm and the cyano band at 4·5 µm are found. The C–O band is due to ester components.

The cholesteric pitch of the mixture was evaluated by determining the ratio of the densities of the interference stripes in an empty wedge cell and of the Grandjean lines in the filled cell, multiplied by the wavelength of the light used for observation:

$$p_o = \lambda(n/m)$$

Here n is the number of interference stripes per mm, m the number of the half strength Grandjean disclination lines per mm, and $\lambda = 0{\cdot}589\,\mu m$. Testing mixtures with different concentrations, a good linear relationship between the reciprocal dopant concentration and the cholesteric pitch was found. Using for example a mixture with 4 wt % of the chiral dopant ZLI 4572 in ZLI 4900-100 (mixture MCIX), a pitch of 0·6 µm at room temperature was obtained.

Most of the test cells were prepared from polished glass plates with a size of 30·20·2 mm^3. For measurements in the infrared region, CaF_2 plates transmissive up to wavelengths of 9 µm were used as substrates. But sapphire plates (Al_2O_3) can also be used because they are transparent up to wavelengths of about 5 µm where the transmittivity of a normal liquid crystal begins more or less to disappear [10–14].

The substrate plates were covered with ITO layers serving as electrodes. Their sheet resistivity was about 300 Ω/□ which was high enough to prevent strong absorption in the near infrared. For the determination of the pitch, glasses with rubbed polyimide layers were used. The distance separating the plates was controlled by Mylar spacers and fixed by a UV curable sealant (NOA 61). The spacing was measured spectrometrically by the interference modulated transmission of the empty cell. After filling the cells with the isotropic liquid crystal and degassing them for some minutes, they were sealed with a UV curable sealant of high viscosity (NOA 65).

For measurements at elevated temperatures the specimens were thermostatted in an oven, where the cover of the sample holder was thermally coupled to the heated plate by a heat conductive paste containing coated copper particles. The liquid crystal layer was addressed by a gate modulated and amplified sine wave, which had a frequency of 20 kHz. The electrical and optical data were collected by a double channel storage oscilloscope.

The quiescent state of the cholesteric cells was a light scattering state. This state was reoriented by application of a sufficiently high electric field to give the clear quasi-homeotropic state since the liquid crystal had a positive dielectric anisotropy. After switching off the voltage, the film returned at the first moment into a disturbed state that is much more scattering than the quiescent state after several seconds of relaxation. In the experimental set-up for the determination of the switching times, the maximal angular divergence of the scattered beam hitting the detector was limited by a diaphragm to 2°. The switching times were determined from the time dependent transmission curves by using the gate opening and closing points as reference times. Then the time necessary to reach 90% of the maximum transmission in the homeotropic state was defined as the rise time. Similarly the time to reach 10% of the maximum transmission was defined as the decay time. These times include the dead times and at most one period of the addressing sine wave.

The contrast and the scattering distribution of the cholesteric layer in the visible region were measured using a schlieren optical system as sketched in figure 2. An iris diaphragm with an opening variable up to 25 mm was inserted at the rear focal plane of a Fourier lens with $f = 50$ mm. The liquid crystal was illuminated with a HeNe-laser beam widened to 3 mm in order to reduce the inhomogeneities of the scattering texture. On the other hand, the distances of the scattering layer and of the detector from the Fourier lens, namely g and b, were selected in such a way that the scattering area of the liquid crystal layer was completely imaged on the detector. The half maximum angle of the scattering cone transmitted by the iris diaphragm was about 14°. This angle was sufficient to collect more than 50% of the total scattered light intensity that is mainly scattered in the forward direction. The contrast ratio C_r was evaluated from those intensities that were obtained in the middle of both the ON and OFF time intervals, as determined by the gate function.

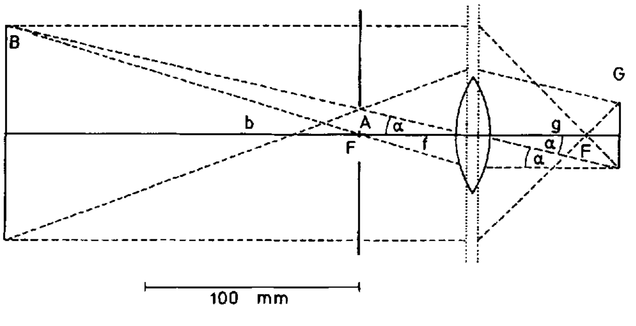


Figure 2. Schematic representation of the optical schlieren system used for the determination of the performance parameters of the cholesteric shutter cells. The scattering area G of the liquid crystal is imaged on the detector B, and the angular cone opening 2α is controlled by an iris diaphragm of diameter $2A$ (mm) in the rear focal plane of the Fourier lens (exaggerated relative sizes of G, B, A and α).

The radial scattering distribution and the corresponding contrast were determined by stepwise changes in the diameter of the iris diaphragm. The differences between the measured total intensities divided by the differences of the respective solid angles gave the scattering distribution as a function of the plane angle. The solid angle ω depends on the plane angle α and is given by

$$\omega = 2\pi(1 - \cos\alpha)$$

or alternatively as a function of the aperture $2A$ in the focal plane at the distance f behind the lens

$$\omega = 2\pi(1 - 1/(1 + A^2/f^2)^{1/2})$$

This measurement had to be carried out during shutter operation with a fixed frequency, and not statically, since the scattering strength in the OFF state slowly decayed to the value of the quiescent state.

3. Results

The predominant parameter of the cholesteric shutter cells to be measured and optimized is the passive switching time, together with the rise time, dependent on the temperature and the driving voltage. At first, the behaviour of the cholesteric layers in the field was examined qualitatively and the optical characteristics were measured. By slowly raising the driving voltage using a ramp function for the modulation, the commencement of local motion within the scattering texture could be observed microscopically at a characteristic voltage. This characteristic voltage is not a sharp threshold because of the non-uniformity of the texture. Upon further raising the voltage, the transmission measured in the (linearly polarized) laser beam showed some oscillations of intensity, though there was no analyser used in the optical path. Lowering the voltage again by a ramp function, these oscillations could be followed back without any hysteresis. This pattern of oscillations shifted with temperature. By switching the cholesteric layer at these limited voltages with a gate modulated sine wave, switching times in the order of 100 μs were observed.

If, however, the voltage exceeds a value about twice the first characteristic voltage, a complete change in the behaviour of the cells occurs. The optical characteristic suddenly breaks down and the liquid crystal layer becomes homeotropically aligned. If the voltage is again lowered, a large hysteresis effect is found and the intensity oscillations observed previously do not show up again. The switching times are now in the order of some ms. Therefore it can be concluded that the cholesteric layer shows two effects of a quite different nature, depending on the size of the addressing voltage.

In this work the high voltage effect that relates to the focal-conic to homeotropic transition effect (FHT effect) is examined and optimized. On switching the layer with a voltage that is high enough to achieve a homeotropic reorientation at a given frequency, the low voltage effect is no longer involved. It is completely masked by the hysteresis of the high voltage effect. The hysteresis of the FHT effect has a width of about 50% of the clearing voltage. It is not used for the operation of the shutter, since the voltage is always switched back to zero and no bias voltage is applied.

In general the scattering contrast depends not only on the liquid crystal cell, but also on the measuring optics. As long as the free diameter of the iris diaphragm of the schlieren system is large enough to transmit the total unscattered beam, the brightness is not dependent on its opening. The contrast, however, decreases rapidly with increasing diaphragm diameter, as more and more of the scattered light is collected in the OFF state instead of being blocked. This is the consequence of the relatively small average scattering angles of the effect. Therefore the optical system with a total cone opening of 1·15°, as schematically depicted in figure 2, was finally used as the standard set-up, not only for the contrast but also for the switching time measurements. A measurement of the intensity of both polarizations with the use of a central stop, instead of the iris diaphragm, showed complete depolarization of the scattered laser light.

After switching off the field, the transmission decreases rapidly and, after forming a foot, the transmission curve reaches a minimum where the scattering is maximal. But then the transmission again increases slowly until the scattering approaches a nearly constant value (see figure 3). Therefore the contrast also depends on the cycle time: if the contrast is measured by the intensities at the centres of the ON and the OFF time intervals, the effect is that the contrast is frequency dependent, and therefore it is called here ‘dynamic contrast’. As shown in figure 4, the contrast ratio has a maximum when the centre time of the OFF state coincides approximately with the transmission minimum in figure 3. For lower frequencies this central point of the OFF window is shifted towards the higher transmission of the quiescent state and for higher frequencies it is shifted towards the foot of the decay curve, both shifts causing a depression of the measured contrast ratio.

The switching time measurements were carried out during continuous cycling of the cell through the ON and OFF states at a reasonable frequency. A typical time dependent transmission curve is shown in figure 5. At the bottom of the figure the duration of the gate controlled sinus voltage of 20 kHz is marked, while the upper curve shows the relative transmission. In this example the transmission rises to a rather constant plateau whose value is mainly determined by the reflection at the different glass interfaces. The voltage is selected in such a manner that the rise time is the same (1·5 ms) as the decay time, which itself does not depend on the voltage. As the liquid crystal layer in this example is rather thick, the scattering contrast ratio, measured over a cone with a total opening of 1·15°, has a value of about 60.

Cells of various thickness versus pitch ratios have been prepared. The influence of layer thickness alone on the passive switching times was rather small. Only for cells thinner than about 20 μm was a small increase

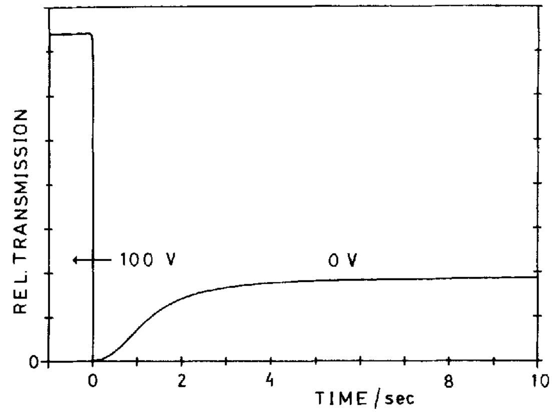


Figure 3. Long term transmission behaviour of a cholesteric shutter cell after switching off the field (MCIX: $p_0 = 0{\cdot}6\,\mu m$; $d = 19\,\mu m$; $T = 50°C$). The transmission, reaching a minimum after switching off, increases again within a few seconds to adopt the constant value of the quiescent state.

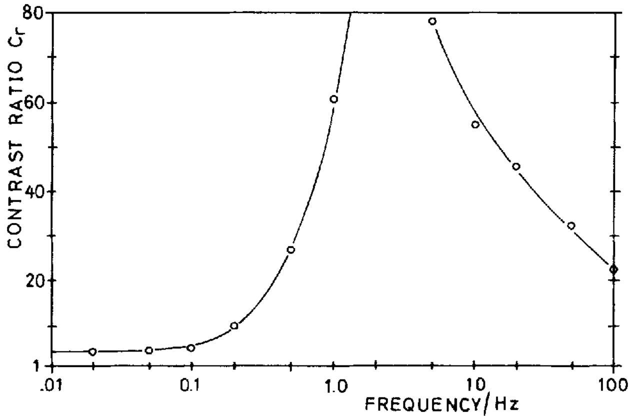


Figure 4. Dependence of the scattering contrast on the frequency (same specimen as in figure 3). The contrast has a maximum when the centre of the OFF-time interval coincides with the scattering maximum. It becomes smaller when it shifts towards the quiescent state (lower frequency) or towards the foot of the decay curve (higher frequency).

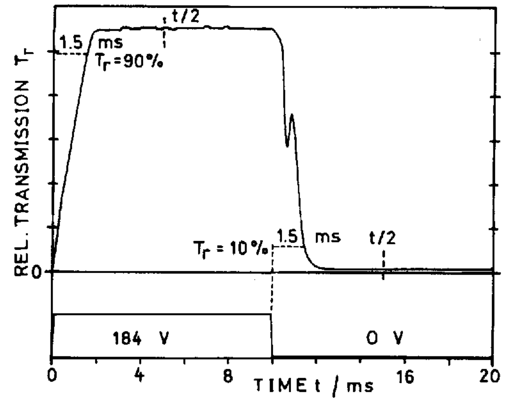


Figure 5. Transient optical behaviour of a cholesteric shutter cell using the scattering FHT effect. At the bottom of the figure the gate function for the addressing sine wave is shown (MCIX: $p_0 = 0{\cdot}6\,\mu$m; $d = 38\,\mu$m; $T = 60°$C).

found, attributable to the hindered rotation of the director near the surface (see figure 6). On the other hand, the active switching time increases with increasing thickness as the field decreases at constant voltage.

As expected, there existed a strong dependence of the active switching time on temperature. Surprisingly this effect is less pronounced for the passive switching time, as can be seen in figures 7(*a*) and 8(*a*), where both switching times are depicted for constant voltage. As a consequence the two curves for the temperature dependent switching times intersect at a certain temperature. Moreover, there exists a minimum in the passive decay time at a certain temperature before it begins to rise again when approaching the clearing point. Possibly this rise in the decay time can be explained by an increase in the pitch in the vicinity of the transition to the isotropic phase. The temperature of the decay time minimum is the optimal shutter operation point for the given cell, if the active rise time can be made of equal size by the choice of an appropriate voltage.

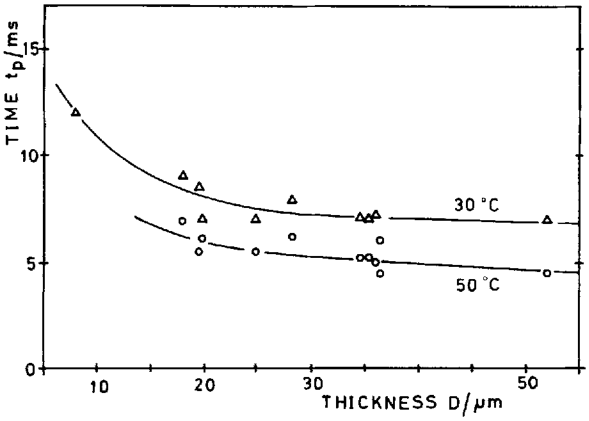
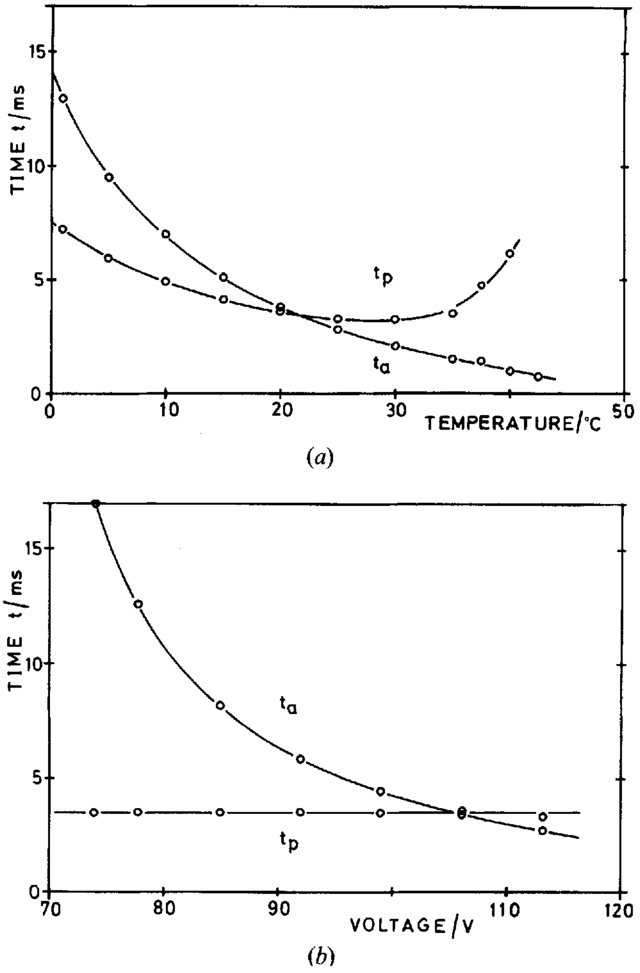


Figure 6. Dependence of the passive decay time t_p of the FHT effect on the thickness of the cholesteric layer at two different temperatures. The decay time is rather constant and begins to rise in layers thinner than 20 µm (MCIII: ZLI3926 + 9·9 wt % CB15; $p_0 = 1{\cdot}2\,\mu$m at room temperature).

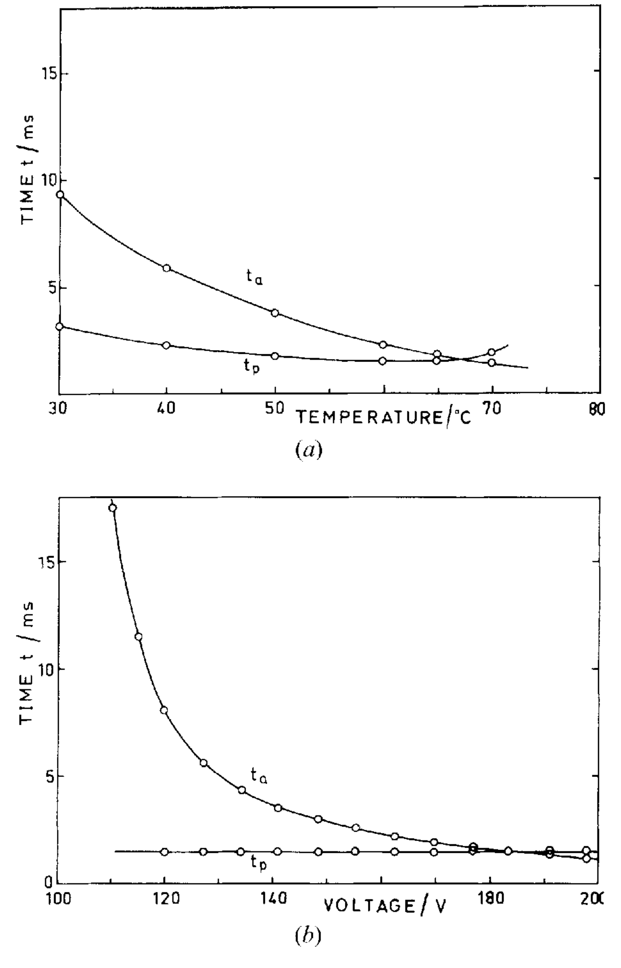


(*a*)

(*b*)

Figure 7. Active rise time t_a and passive decay time t_p of a cholesteric shutter cell (MCII: $p_0 = 1{\cdot}1\,\mu$m; $d = 19{\cdot}5\,\mu$m): (*a*) dependence on the temperature for a constant addressing voltage of 113 V, the optimum for shortest decay times is in the temperature range between 20 and 30°C; (*b*) dependence on the addressing voltage at a constant optimum temperature of 25°C, the decay time t_d is independent of the preceeding ON-state voltage, identical rise and decay times are obtained for an addressing voltage of 106 V.

The dependence of the rise times on the voltage for the same mixtures at the fixed (optimum) temperatures is depicted in figures 7(*b*) and 8(*b*). Also shown is the decay time which does not depend on the voltage of the preceding addressed state. The voltage required to get equal rise and decay times is rather high, but unfortunately reducing the necessary voltage by reducing the cell thickness too much or enlarging the pitch leads to a loss of scattering contrast.



(*a*)

(*b*)

Figure 8. Active rise time t_a and passive decay time t_p of a cholesteric shutter cell (MCIX: $p_o = 0{\cdot}6\,\mu m$; $d = 38\,\mu m$): (*a*) dependence on the temperature for a constant addressing voltage of 160 V, the optimum for shortest decay times is in the temperature range around 60°C; (*b*) dependence on the addressing voltage at a constant optimum temperature of 60°C, the decay time t_p is independent of the preceeding ON-state voltage, identical rise and decay times are obtained for an addressing voltage of 184 V.

So far the measurements of the switching times have been carried out using parallel light from a widened HeNe-laser beam. For the contrast measurements in the infrared region, spectrometers were used, but the exact switching times could not be measured because of the slow time constants of the detectors. The switching times are predominantly times of a mechanical change, and the optical scattering effect is directly linked to the mechanical deformation. Further, it is known that the refractive indices have the same order of magnitude in the near infrared as in the visible [12–15], though this was not measured explicitly in this work. Therefore it was concluded that there are, if at all, negligible differences between time constants measured at different wavelengths, and that no separate measurements in the infrared region were necessary.

On the other hand, it is to be expected that the scattering contrast is wavelength dependent. Therefore transmission measurements in the region from the visible up to the middle infrared were carried out. As the beam divergence of the spectrometer changed with wavelength, the contrast measurements in the spectrometer had to be extended to the HeNe-wavelength, in order to compare and adapt the results. Measurements of the angular distribution of the scattering could only be made with the parallel HeNe-beam and the variable schlieren optics as described above.

An example of the variation of the contrast ratio with changing aperture of the iris diaphragm in the rear focal plane of the Fourier lens is shown in figure 9, where the OFF-state transmission was measured 5 ms after switching off the voltage. The contrast ratio rapidly decreases with increasing aperture. The limiting value of 1 will not be reached with the half of the total solid angle, as there is some back scattering. Additionally, the contrast decreases with temperature more rapidly the closer the clearing point is approached.

In order to detect the wavelength dependence of the contrast, infrared measurements up to a wavelength of 2·5 μm were carried out with the Perkin-Elmer PE 330 and λ19 spectrometers, and for wavelengths from 1·5 to 5 um with a Fourier transform spectrometer PE 1760X. A typical measurement of the transmission in the visible and the near infrared is shown in figure 10 for the mixture MCVI (ZLI 3219+9·9 wt% of CB15). The upper curve represents the clear ON state and the lower

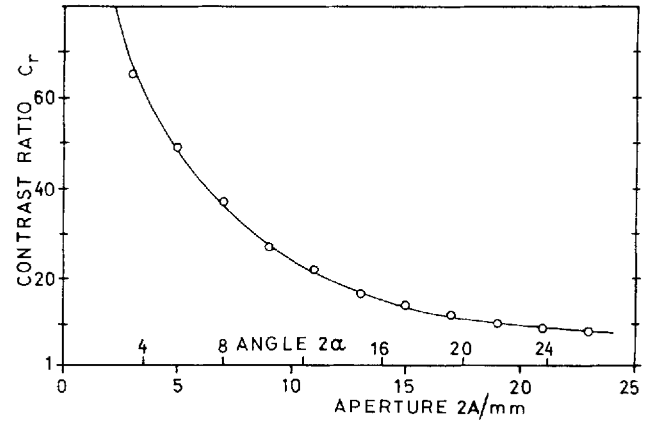


Figure 9. Contrast ratio of a cholesteric shutter cell as a function of the opening angle 2α of the scattering cone passing the iris diaphragm of free diameter 2*A* (mm) in the rear focal plane of the Fourier lens (MCIX: $p_o = 0{\cdot}6\,\mu m$; $d = 38\,\mu m$; $T = 40°C$; OFF-intensity taken 5 ms after switching).

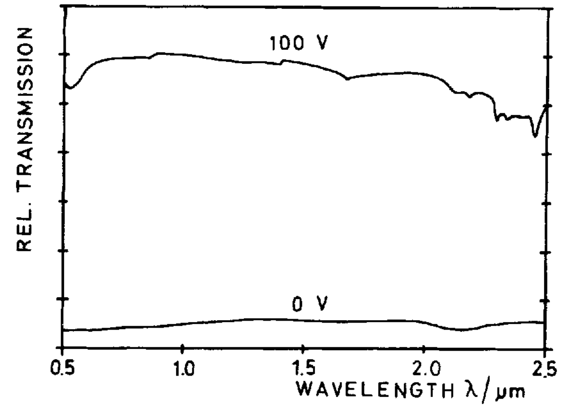


Figure 10. Wavelength dependent static transmissions of the clear ON and the scattering OFF states of a cholesteric shutter cell (MCVI: ZLI3219+9·9% CB15; $p_0=1{\cdot}4\,\mu m$; $d=52\,\mu m$; $T=60°C$). The intensity ratio decreases from the value of 16 to 7 with increasing wavelength, except in the region of partial selective reflection around 2·2 μm.

curve the scattering OFF state. The latter curve shows a shallow dip at about 2·2 μm. This transmission depression can be attributed to the partial selective reflection of the scattering state of the cholesteric liquid crystal, which of course disappears completely in the homeotropically reoriented state.

The contrast ratio derived from these two curves, which are both static curves, slowly decreases with increasing wavelength from a value of 16 to 7, except in the region of selective reflection. For comparison, the dynamically measured contrast ratio in the parallel HeNe-beam at 0·633 μm exceeded 50. The difference is due to the higher transmission in the quiescent OFF state than that immediately after switching off the field. Similar measurements with the Fourier transform spectrometer revealed a further steady, but not dramatic decrease of the contrast with increasing wavelength which may be attributed to the divergence of the infrared beam of the spectrometer.

A better picture of the infrared transmission in the transient scattering state is found by a measurement where the voltage is switched on and off alternately during the wavelength run. The measurement from long to short wavelengths is shown in figure 11. It can be seen that the transmission after each switch off in the field reaches first a minimum and then begins to increase slowly again, as similarly shown in figure 3. This can be seen much better in the contrast curve of figure 12, where the transmission from figure 11 has been divided by the transmission (measured separately) in the clear homeotropic state. The contrast ratio reaches a peak value of about 45 immediately after switching off the field, a value similar to the contrast measured in the HeNe-beam. On the other hand, the contrast ratio

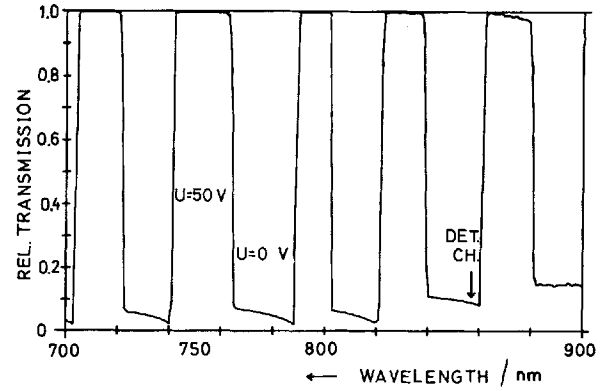


Figure 11. Infrared transmission of a cholesteric shutter cell during spectrometer operation from long to short wavelengths where the addressing voltage is alternately switched on and off (MCX: $p_0=2{\cdot}5\,\mu m$; $d=40\,\mu m$, $T=40°C$). The intensity is normalized with respect to the transmission in the static homeotropic state.

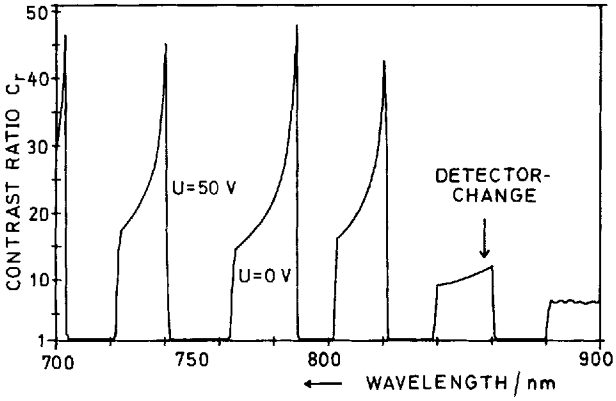


Figure 12. Contrast ratio of a cholesteric shutter cell as determined from the infrared transmission shown in figure 11, as normalized by the transmission in the static homeotropic state. For wavelengths larger than 0·857 μm, the detector is too slow to resolve the transient contrast.

within a time interval of some seconds decreases to a value of about 15 until the voltage is again switched on. The peak contrast cannot be detected by the infrared detector at wavelengths longer than 0·857 μm, because its time constant is too long. From the infrared measurement of the peak contrast, it can be seen that the shutter has about the same contrast in the visible and the near infrared region, and it can be concluded that this tendency continues into the middle infrared region.

4. Discussion

The central problem for the realization of a polarizerless cholesteric shutter, using the scattering FHT effect, is to improve simultaneously the passive switching time on the one side and the active switching time with respect to the switching voltage and the scattering contrast on the other side. Unfortunately, these performance parameters are adversely dependent on the cholesteric pitch. Since shortening of the passive switching time of the FHT effect is the main task in constructing a shutter, the pitch is the first material and cell parameter to be fixed. Only then can the other performance values be improved by optimizing material and cell parameters further, followed by a final minor readjustment of the pitch.

Comparing the performance parameters achieved for the polarizerless shutter with values published for shutters based on double refraction effects with polarizers, it is evident that the latter are an order of magnitude faster and that they need an addressing voltage which is an order of magnitude lower. Therefore the shutter proposed in this work cannot challenge these shutters in their operation range. However, when a shutter has to work at wavelengths where dichroic polarizers are no longer effective, the scattering shutter can be used. Another advantage is that there is no heating of absorptive layers in intense light beams. Because of the necessary schlieren stop, the use of the shutter is limited to applications where enough space is available.

Mainly two prototypes of cholesteric shutter cells have been developed; one type works optimally at room temperature and the other has its optimum working temperature around 60°C. With the first version, at room temperature, switching times of 3 ms could be obtained on both sides. This is more rapid than comparable PDLC-films, where decay times of 6 and 8 ms have been reported, respectively [8, 20]. Decay times of 4 ms have been obtained by a group from Philips for the FHT effect [21]. Although this is an improvement of one order of magnitude with respect to normal display cells, this is not yet satisfactory for a shutter operation. The high temperature version of the FHT shutter presented here reached switching times on both sides in the order of 1·5 ms, if high enough voltages were applied. This allows a shutter operation with a frequency of more than 60 Hz with plateau times of 80%. In both cases, the rapid switching times were obtained with rather thick layers, so that it was possible to achieve a contrast ratio of more than 50 (HeNe-laser) with a collection angle limited to 1·15°. In the infrared region, the scattering contrast slowly decreases with increasing wavelength.

In some papers, there have occasionally been mentioned much shorter switching times for cholesteric scattering effects in the visible wavelength region [19, 22, 23]. Besides reporting mainly on the FHT effect, these papers also deal with incomplete reorientations of the cholesteric structures, with the helix axis predominantly perpendicular to the field. The switching times of the latter effect have not been clearly defined and no contrast values have been reported. As described above, such a rapid effect has also been observed here in connection with the FHT effect; the switching times were about 100 μs and the necessary switching voltage was one quarter of that needed for a complete FHT transition.

Common to these more rapid scattering effects seems to be the fact that the helix structure is deformed only locally within each half period, without destroying the helix itself, and that no material flow and no defect formation is involved. The much longer switching times of the FHT effect are due to the singular character of the large number of defects in the focal-conic texture and due to the material flow during switching. The fast effect can be called the 'deformed helix of cholesterics effect' (DHC effect) by analogy with the 'deformed helix of ferroelectrics effect' (DHF effect) [24, 25]. The quasistatic aspect of the effect has been described theoretically in the framework of the helix unwinding theory by de Gennes [26] and Meyer [27], where the helix is locally deformed before unwinding, and by Dreher [28] who supposed a pitch p fixed by the boundaries of the cell.

The dynamics of the effect seem to have been investigated only poorly. The formulae for the rise and decay times as given in the paper by Jakeman and Raynes [19] are valid only for small reorientations without flow. Therefore they cannot be applied to the cholesteric–nematic transition [29]. More reasonably they may be applied to the rapid reorientation effect, because here only partial reorientations take place.

Unfortunately, the contrast of this DHC effect is rather small because there is some residual scattering in the reoriented state and a weaker scattering in the quiescent state. Also the temperature and voltage ranges of operation seem to be rather restricted. Therefore the FHT effect with its complete reorientation is to be preferred for the polarizerless shutter operation. A sufficient contrast of the shutter in combination with a 50 Hz operation is only possible because the short passive decay times also occur in thick cholesteric layers, though this condition necessitates a rather high addressing voltage for the clear state.

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