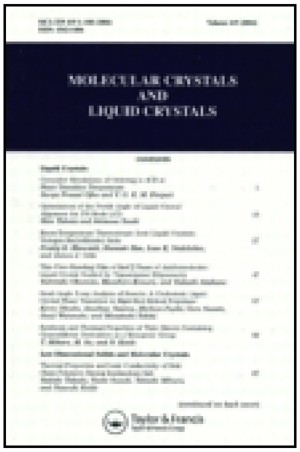

Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl19

Local Optical Limiting Devices Based on Photoaddressed Spatial Light Modulators, Using Ferroelectric Liquid Crystals

Leonid Beresnev [a], Wolfgang Dultz [a b], Arkadii Onokhov [a c] & Wolfgang Haase [a]

[a] Institut für Physikalische Chemie, Technische Hochschule Darmstadt, Petersenstr. 20, 64287, Darmstadt, Germany

[b] Deutsche Telekom AG, Technologiezentrum Darmstadt, Am Kavalleriesand, 3, 64276, Darmstadt, Germany

[c] Optical Research & Development Company “PeterLab., Ltd.”, Lomonosova str., 5, 191011, St.Petersburg, Russia

Version of record first published: 04 Oct 2006

Mol. Cryst. Liq. Cryst., 1997, Vol. 304, pp. 285–293
Reprints available directly from the publisher
Photocopying permitted by license only

LOCAL OPTICAL LIMITING DEVICES BASED ON PHOTOADDRESSED SPATIAL LIGHT MODULATORS, USING FERROELECTRIC LIQUID CRYSTALS

LEONID BERESNEV, WOLFGANG DULTZ*, ARKADII ONOKHOV# and WOLFGANG HAASE
Institut für Physikalische Chemie,Technische Hochschule Darmstadt, Petersenstr.20, 64287 Darmstadt, Germany.
*Deutsche Telekom AG, Technologiezentrum Darmstadt, Am Kavalleriesand, 3, 64276 Darmstadt, Germany.
#Optical Research & Development Company "PeterLab.,Ltd.", Lomonosova str., 5, 191011 St.Petersburg, Russia.

Abstract. The devices for local light discrimination in the field of view of eye or light-sensitive devices (videocamera, etc.) are discussed, using optically addressed spatial light modulators. The deformed helical ferroelectric (DHF) effect in FLC's is considered. Different optical schemes of local optical limiting devices with corresponding driving conditions are discussed and the transmission of devices in dependence on FLC parameters (molecular tilt angle) is estimated. The operation ofdevice prototype for local protection of video camera using OASLM and FLC shutter is shown.

INTRODUCTION.

The problem of protection of eyes and light-sensitive devices takes place during the welding, gas cutting, observation of objects under strong spurious light disturbance (sun, lamps, etc.). Commonly used devices, e.g. safety goggles, have a lot of disadvantages: neutral or polarizing filters decrease proportionally the brightness of the spurious light together with the brightness of observed objects. At decrease of light illumination these filters should be removed mechanically. The goggles with the automatical switching on the absorbing filters after the appearance of strong light, for example welding goggles "Speedglass", close the total field of view.

Much better solution of the problem of eyes or videocamera protection is the local suppression of brightness of strongly illuminated objects only in the field of view, but without suppression of weakly illuminated objects. Such approach can be realized using the optically addressed spatial light modulators (OASLM's). Safety goggles with local modulation based on OASLM's, are discussed in[1], where the twist effect in nematic liquid crystal was used as a light modulating media. The basic disadvantage of nematic liquid crystals is slow switching (tens of milliseconds). Here we report the applicability of much faster deformed helical ferroelectric (DHF) effect in ferroelectric liquid crystals (FLC's) in devices with local modulation, based on OASLM's.

THE GENERAL SCHEME OF LOCAL MODULATION USING OASLM.

In Fig.1 the general sketch of device with local optical limiting is shown, where OASLM is based on photoconductive (PC) layer and liquid-crystalline film (FLC). For twisted nematic (TN) layer, placed in contact with PC, the light from weakly illuminated objects ("house") can go through the crossed polarizers P_1 and P_2. The light from the strongly illuminated object ("sun"), focused onto the PC layer, induces the local transition from twist to homeotropic state in LC layer due to redistribution of external voltage, applied to OASLM. This transition occurs only in that places of OASLM, where the conductivity of PC increases due to strong illumination, namely where is the image of sun. In this place the light doesn't go through the polarizer P_2 and the brightness of strongly illuminated object ("sun") is suppressed. Lenses L_2 and L_3 present the simplest eye-piece for observing this image.

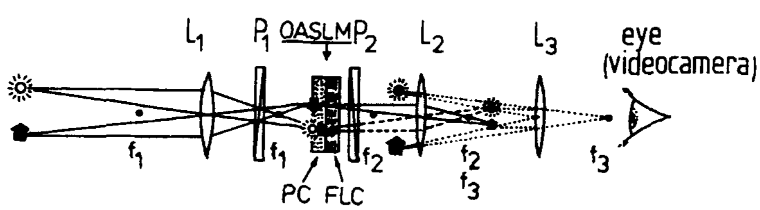

FIGURE 1. Sketch of device with local suppression of brightness of strongly illuminated images using the OASLM. L_1, L_2 , L_3 - lenses, P_1, P_2 - polarizers, OASLM - optically addressed spatial light modulator, PC - photoconductor, FLC - ferroelectric liquid crystal. Strongly illuminated image - the sun, weakly illuminated image - a house. After the polarizer P_2 the brightness of sun image is reduced compared to the brightness of house image.

The optical design of this system can be more complicated, depending on the requirements to size and shape of goggles (prisms, mirrors, etc. can be introduced).

THE BASIC OPTICAL PROPERTIES OF DHF MATERIALS.

Basic feature of DHF mode is the presence of almost linear deviation of optical axis < **n** > of averaged optical indicatrix of ferroelectric liquid crystal with strongly twisted helical structure for small driving voltage[2]. The direction of this axis will be close to the undisturbed equilibrium direction **z** of helix for very small voltage. For high voltages, exceeding the threshold value of untwisting, the director **n** of untwisted FLC layer will take two extreme positions. These positions are described with angles $+\Theta_0$ and $-\Theta_0$ relative to rubbing direction **z**, for positive and negative polarity of applied voltage +E and –E, respectively. Θ_0 is the molecular tilt angle in helical $S_C{}^*$ phase, and axis of undeformed helix is parallel to the rubbing direction **z**. The characteristic response time τ for linear deviation lies in range 100 microseconds and doesn't depend on voltage, whereas the switching time between two untwisted uniform states ("Clark-Lagerwall switching"[3]) can be in microsecond region. Thus, in OASLM we have three extreme states of average optical indicatrix[4]: 1)for positive untwisting voltage +E the deviation of **n** will be equal $+\Theta_0$ relative to **z** direction, 2) for negative untwisting voltage –E the optical axis **n** will be deviated on value $-\Theta_0$, and 3) for small voltages the axis < **n** > will be slightly deviated from **z** direction. Two extreme positions $+\Theta_0$ and $-\Theta_0$ are realized in the strongly illuminated areas of OASLM, where the FLC layer is untwisted.

THE OPTICAL SCHEMES OF DEVICE FOR DIFFERENT MOLECULAR ANGLES OF FLC MATERIALS:

Let us consider the FLC materials with: 1) molecular tilt angle $\Theta_0=45^o$ and 2) $\Theta_0 \neq 45^o$.
1) For $\Theta_0=45^o$ the suppression of light will take place for both polarities of driving voltage, Fig. 2a)b), if the rubbing direction **z** does form the angle $\Theta_0=45^o$ with the

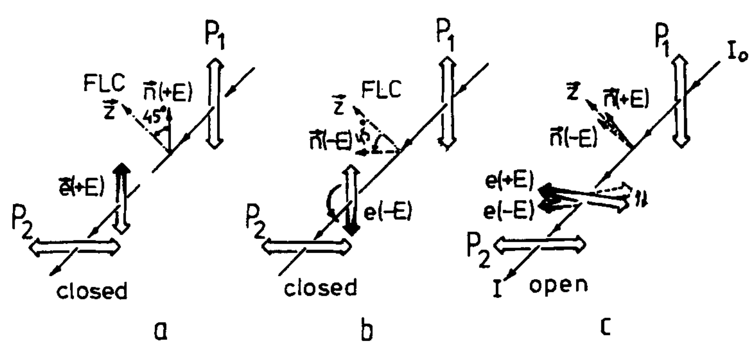

FIGURE 2. The use of DHF material with the molecular tilt angle $\Theta_0=45^o$.

polarizer P_1. In the weakly illuminated areas of OASLM the averaged optical indicatrix will vibrate near the direction of undisturbed helix **z**. Considering the simplest case of the thickness d of FLC layer, satisfying to the condition "λ/2"
($\langle \Delta n \rangle d = \lambda/2 + N\lambda$), we obtain the almost total transmission of light, because of the polarization plane **e**(±**E**) will be rotated on 90° and will vibrate around direction P_2, Fig. 2c).

2) In real DHF material the molecular tilt angle Θ_0 is not equal to ideal case 45°, $\Theta_0 < 45°$. For example in this work the DHF material was developed with $\Theta_0 = 31°$ (20°C). The orientation of OASLM should be arranged in such a manner, that rubbing direction **z** forms the angle $\Theta_0 = 31°$ with the direction of polarization plane P_1 of light. For positive polarity +**E** of driving voltage the total suppression of light, going through strongly illuminated areas of OASLM, takes place, Fig.3a), whereas the appreciable transmission $\mathbf{I} = \mathbf{I}_0 \cos^2(2\Theta_0)$ of light will remain for negative polarity (−**E**), with blinding the observer.

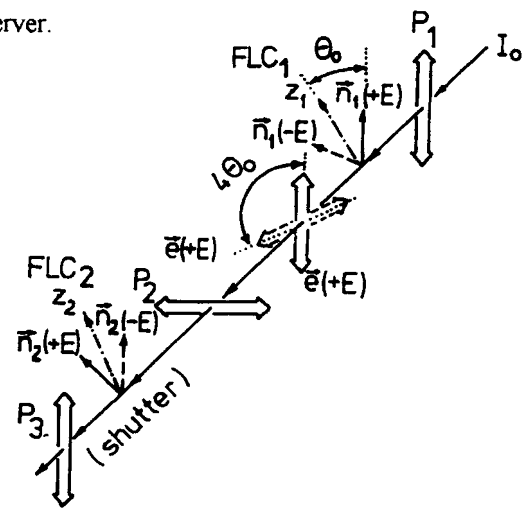

FIGURE 3. The use of DHF material with the molecular tilt angle $\Theta_0 < 45°$.

The scheme with shutter.

To avoid the blinding the eyes or videocamera during the negative polarity of driving voltage the fast shutter can be used, also based on FLC, Fig.4. In Fig's 3,4 this shutter is designated as FLC_2 together with outgoing polarizer P_3, which is crossed with the polarizer P_2. In this case the director $\mathbf{n}_2(-E)$ of FLC_2 should coincide with the direction of polarizer P_3. The best version for FLC_2 will be if the molecular tilt angle

Θ_o=22.5° and thickness of FLC_2 layer does satisfy to "λ/2" condition. In the case of symmetrical alternating current pulses (meander) the maximum transmission from nonilluminated objects will be $I=I_o\sin^2(2\Theta_o) \approx 78\%\ I_o$ (for Θ_o=31°) at positive polarity of voltage. The real average transmission will be two times less due to closed

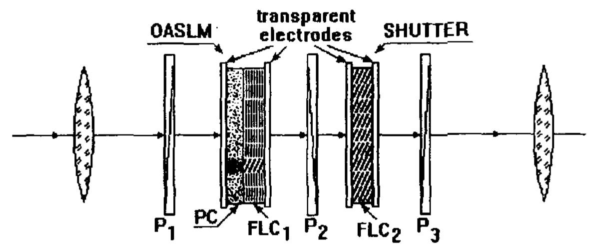

FIGURE 4. The optical scheme of goggle with fast shutter FLC_2.

state during the negative polarity, I_{total}=39%. To enhance the average transmission of the device the open period τ(+E) (positive voltage) could be made longer than closed period τ(-E) (negative voltage). For example τ(+E)=3τ(-E). In this case the average transmission I will be about 58.5%I_o. Here we don't take into account another losses (reflections, dispersion of white light, losses in polarizers,etc.).

The schemes with fast "compensator".

It is possible to increase two times the effective transmission of device, using the second FLC layer FLC_2 not as a shutter, but as a fast working "compensator". Both FLC layers should be placed between crossed polarizers P_1 and P_2 , Fig.5. Cell thickness d and optical anisotropy Δn of FLC_2 layer in untwisted state should be equal to those parameters of FLC_1 layer.

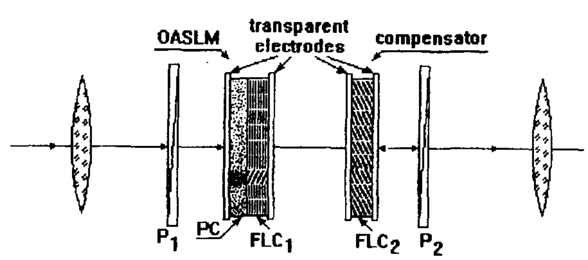

FIGURE 5. The scheme of device with the fast switchable "compensator" FLC_2.

The switchable tilt angle Θ_c of FLC_2 material can be equal to Θ_o or 45°-Θ_o. For first case $\Theta_c=\Theta_o$ the directors $\mathbf{n_1}$ and $\mathbf{n_2}$ of FLC_1 and FLC_2 layers should form the angle

90^o for both polarities of driving voltages, applied to layers. In case of $\Theta_c=45^o-\Theta_o$ the mutual positions of rubbing directions of FLC_1 and FLC_2 layers should be fitted in such a manner, that for one polarity the director $\mathbf{n_1}$ in strongly illuminated areas of OASLM will coincide with director $\mathbf{n_2}$ of FLC_2 layer and with polarization plane of polarizer P_1 (or P_2). For opposite polarity the directors $\mathbf{n_1}$ and $\mathbf{n_2}$ should be crossed. The second case, $\Theta_c = 45^o-\Theta_o$, allows us to use for compensator the FLC material with small switchable angle Θ_c or electroclinic material with electrically induced angle Θ_c. The transmission **I** will be enhanced if the FLC material for FLC_1 layer will have large tilt angle $\Theta_o=35^o-40^o$. In this case the maximum transmission can be 88-97%. Owing to small necessary value of switchable angle $5-10^o$ for FLC_2 in case of Θ_o = $40-35^o$, the electroclinic material with small induced tilt angle $\Theta_c=5^o-10^o$ can be used. Such choice allows us to fit the necessary value of angle $\Theta_c=45^o-\Theta_o$ changing the voltage, applied to electroclinic layer FLC_2.

EXPERIMENT.

Samples.

We have realized a prototype of the device with local optical limiting using the version "with shutter", Fig. 3,4. The basic elements of this device- OASLM and shutter, were fabricated on the basis of our own technology. Photoconductive polycrystalline (quasi-amorphous) *ZnSe* film of high optical uniformity with thickness about 1μm was obtained by means of evaporation in quasi-closed volume using the technique, developed in PeterLab., Ltd. (St.Petersburg, Russia). The laser ablation technique was used for preparation of transparent ITO electrodes as well as for preparation of thin (~1000 A) smooth and insulating HfO_2 film. The polyvinyl-alcohol (*PVA*) was deposited onto circular substrates with the diameter 35 mm by means of spin-coating.. After annealing the polymeric film was rubbed with cotton tissue in unidirectional manner. The gap of cells FLC_1 and FLC_2 was about 5.5 μm, that gives us the optical condition approximately "3λ/2" for green light. The cells were filled in the isotropic phase of FLC material and cooled till room temperature. The basic parameters of the DHF material FLC-396, developed in this work, are:

- phase transitions: Cr (< -10^oC) S_c* (52^oC) S_A (59^oC) Isotr.,
- the spontaneous polarization: $P_s \approx 200$ nC.cm^{-2},
- pitch of helix $p_o \approx 0.27$ μm,
- tilt angle $\Theta_o=31^o$ (20^oC).

The shear technique with simultaneous application of a.c. electric field[10] with moderate amplitude and frequency (e.g. ±50 V, 1-1000 Hz) was used for preparation of both FLC layers with enhanced optical uniformity (the average contrast was better 200 on the area 5 cm^2). This technique allowed us to construct earlier[5,6] the DHF based OASLM's.

Characteristics of OASLM's.

Fabricated OASLM's were tested using the special set-up[11] based on two-path microscope, supplied with videocamera, frame-grabber, videorecorder and computer. In Fig. 6 the illustration of spatial resolution is presented for fabricated OASLM, measured by means of this set-up. The blue light for writing the TV test table 0683 and red light for read-out the resulting image were used. The square-shape driving voltage (meander) with the amplitude ±7.5 V and with frequency 50 Hz was applied. It is seen in Fig.6 that spatial resolution of presented OASLM exceeds 40 lp/mm on the level of

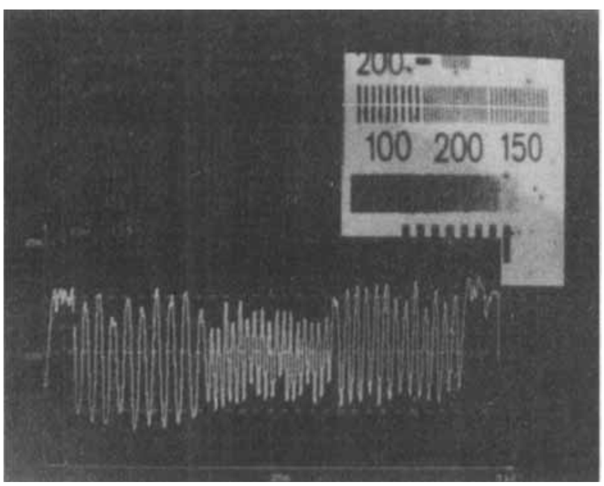

FIGURE 6. Read-out image of test target, focused on OASLM based on *ZnSe*+DHF. The size of image 1.5 mm x 1.5 mm. Numbers in image 100, 200, 150 correspond to spatial resolution 20, 40, 30 lp/mm, respectively. The photo from the computer display.

modulation depth about 50%. The resolution for only one polarity of driving voltage can exceed 100 lp/mm on the same level of modulation depth and measure of limit value is restricted with the projection scheme.

Operation of the device with local optical limiting .

For testing the device operation the tungsten halogen 100W lamp was used as a bright light image. The white paper with written word ("goggles") was used as an observed image and was placed behind the lamp. The parameters of elements of optical scheme with "shutter", according to designations of Fig.1, were the following: f =4cm, f =2cm, f =1 cm. Between last lense L_3 and videocamera the green filter was introduced to suppress the infra-red and ultraviolet regions of light spectrum, which goes through the polarizers P_1-P_3. It should be noted that parameters of lenses used are not optimal, and a lot of light losses takes place due to small aperture of lenses, multiple reflections and so on. Nevertheless, it is seen in Fig.7 the drastical difference of the observed picture at different periods of the device operation. Using the stroboscopic approach we have found that very bright images (lamp filament) does induce the self-suppressing effect with short time 1-5 ms after switching the polarity of voltage, applied to OASLM, and simultaneous opening the shutter. Then the suppression of brightness of less illuminated object does begin, and strong suppression of whole image takes place after about 100 ms.For good average transmission we close the system by means of shutter FLC_2 5-10 ms after beginning the OASLM operation and simultaneously switch the polarity of driving voltage. Next 5-10 ms device is closed. After this the positive voltage pulse follows again and all cicle repeats with period 10-20 ms (100-50 Hz, respectively).

a b c

FIGURE 7. The operation of device with local optical limiting based on OASLM with ZnSe photoconductive film, thickness ≈1μm, and DHF effect in FLC, thickness of FLC layer 6μm. Scheme with "shutter", see Fig's 3,4. a) no voltage on OASLM, shutter is open, strong blinding of videocamera. b) the voltage +10 V is applied to OASLM, shutter is open. The brightness of lamp filament is strongly suppressed, whereas the object behind of lamp, paper with word "goggles", is visible without blinding, meander 10V, 1Hz; c) shutter is closed, very weak brightness of lamp filament.
(See Color Plate XI).

Some examples of *ZnSe*+DHF based OASLM's allowed us to use the frequencies of meander up to hundreds Hz at fine tuning of bias field and position of OASLM between crossed polarizers P_1 and P_2. Owing to high operation rate the observation of moving objects is possible at the background of blinding objects, like sun, without blinding the eye and without bluring the image.

CONCLUSION:

The principles of using the DHF based OASLM's in automatical protection of eyes or videocamera from bright light sourses are described and the suppression of light brightness of strongly illuminated images in the field of view is demonstrated. The search of DHF FLC materials with the angle $\Theta_0=45^o$ as well as fast semitransparent photoconductive films are desirable. The further developments of device should consider also the schemes with dynamical FLC "compensator".

ACKNOWLEDGEMENTS.

The financial support from Volkswagen Stiftung (Project I/70668) and personal support (L.A.B.) from Deutsche Telekom AG (Contract 4160/65024) are gratefully acknowledged.

REFERENCES.

1. M.G.Tomilin, A.P.Onokhov and D.Yu.Polushkin, Mol. Cryst. Liq. Cryst., **222**, 119 (1992).
2. L.A.Beresnev, V.G.Chigrinov, D.I.Dergachev, E.P.Pozhidaev, J.Fünfschilling and M.Schadt, Liquid Crystals, **5**, 1171 (1989).
3. N.A.Clark and S.T.Lagerwall, Appl. Phys. Lett., **36**, 899 (1980).
4. B.I.Ostrovsky, A.Z.Rabinovich and V.G.Chigrinov, in Advances in Liquid Crystals and Applications, edited by L.Bata (Pergamon Press, Oxford-Akad. Kiado, Budapest, 1980), p. 469.
5. L.A.Beresnev, L.M.Blinov and D.I.Dergachev, Ferroelectrics, **85**, 173 (1988).
6. L.A.Beresnev, L.M.Blinov, D.I.Dergachev, A.I.Zhindulis, I.S.Klimenko, S.I.Payeda and A.A.Sergeev, Pis'ma Zh. Techn. Fiz. (Sov.J.Techn.Phys.-Lett.), **14**, 263 (1988).
7. J.Fünfschilling and M.Schadt, Jpn. J. Appl. Phys., **30**, 741 (1991).
8. S.A.Pikin, L.A.Beresnev, S.Hiller, M.Pfeiffer, and W.Haase, Molecular Materials, **3**, 1 (1993).
9. L.A.Beresnev, E.Schumacher, S.A.Pikin, Z.Fan, B.I.Ostrovsky, S.Hiller, A.P.Onokhov and W.Haase, Jpn. J. Appl. Phys., **34** 2404 (1995).
10. A.Jakli and A.Saupe, Mol. Cryst. Liq. Cryst., **237**, 389 (1993).
11. L.A.Beresnev, A.P.Onokhov, W.Dultz, V.V.Nikitin, V.P.Savinov and W.Haase, (to be published).