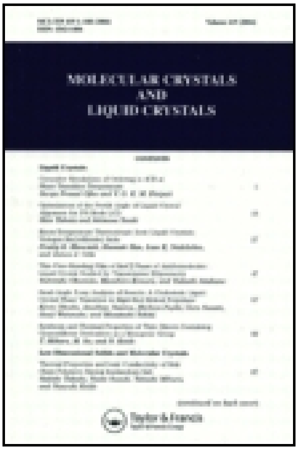


Molecular Crystals and Liquid Crystals Incorporating Nonlinear Optics
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl17

# Liquid Crystal Light Valves with Organic Polymeric Photoconductors

Vladiyir Mylnikov [a]
[a] Mechanical Institute, 198005, Leningrad, USSR
Version of record first published: 13 Dec 2006.

*Mol. Cryst. Liq. Cryst.*, 1987, Vol. 152 pp. 597-607
Photocopying permitted by license only

Printed in the United States of America



# LIQUID CRYSTAL LIGHT VALVES WITH ORGANIC POLYMERIC PHOTOCONDUCTORS

VLADIMIR MYLNIKOV
Mechanical Institute, 198005 Leningrad, USSR

Abstract It has been suggested to use organic polymeric photoconductors in the liquid crystal light valves instead of widely used inorganic ones. Light valves with photoconductive sensibilized polyimides with various types of electro-optical effects in liquid crystals were constructed and tested. The influences of the read-on light regimes and control voltages were analysed. High resolution up to 1500 $mm^{-1}$ at diffraction efficiency 0.1%, and 40% at space frequencies up to 100 $mm^{-1}$ were obtained in pulse regimes. Thin holograms can be effectively read on such modulators in reversible mode in real time. The results obtained permit to come to a conclusion about prospects of the organic polymeric photoconductor usage in liquid crystal light valves and applications of the latter for input and output of the optical information.

Various types of inorganic photoconductors have been widely used in liquid crystal (LC) light valves. Functional possibilities of such systems permit to use them in optoelectronics, holography, laser light modulation etc. New photosensitive materials are needed for such devices for increasing the number of its excellent features. Here we report some characteristics of the spatial light modulator (SLM), where organic polymers were used as photoconductors. The usage of the polymeric photoconductors in LC light valve was first reported in[1-3].

We used SLM with 3 cm in diameter, where the polymeric film of 2-20 $\mu$m thickness and LC film of 2-20 $\mu$m thickness were sandwiched between the transparent indium oxide electrodes on the glass plates. Sensibilized for blue-green or red light photoconductive polyimides and LC mixtures of cyanobiphenyls and azoxybenzene with positive dielectric anisotropy and anisotropy of the index of refraction 0.2 were used. Alignment of the LC molecules was secured by evaporation of the germanium or silicon dioxide in vacuum at the angle of 85° to the substrate. SLM based on the electrically controlled birefringence type, twist effects and cholesteric-nematic phase transition have been constructed and tested. The input image was formed by means of a continuous HeCd laser light at the wavelength of 440 nm or pulse laser at the wavelength of 530 nm in various regimes. The reading of an image was realized by a continuous He-Ne laser at the wavelength of 630 nm or by a white light in a transparency mode. DC voltages were applied to SLM electrodes. Electrical vector direction for the read-out light was perpendicular to the one of the read-on light and coincided with the director direction on the light illuminated SLM side. Sensitivity (W), rise and decay ($T_{on}$, $T_{off}$) times, resolution (R), diffraction efficiency ($\eta$), versus spaee frequency ($\Lambda$) and other parameters were investigated. Sinusoidal grating was constructed on SLM by two interesting, interfering laser beams with 75% modulation depth in the case of the holographic measurements. $\eta$ was defined as the ratio of the light intensity passed in the first order diffraction to the whole intensity of the reading light. The accuracy of the definition is about 15-20%. Response time $T_{on}$ and $T_{off}$ was defined as the time needed for increasing (decreasing) from 0 to 0.9 (from 1 to 0.1) of its maximum values beginning from the switching on of the read-on light. DC control voltages were 10-70 V. High polarity dependence of the modulator parameters has been experimentally established. The positive direction of the abscissa axis on the figures coincides with the positive bias at the photoconductor.

Photosensitivity spectra of SLM are show in Fig.1.

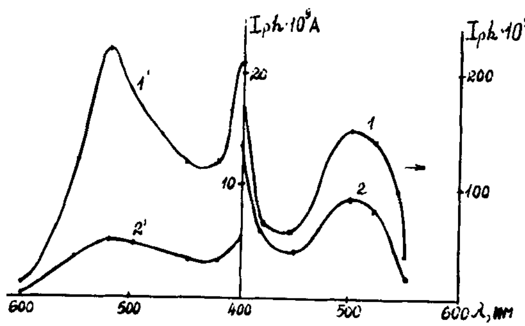


FIGURE 1. Photosensitivity spectra of the photoconductive polymer - liquid crystal structure with positive (right) and negative (left) bias on the photoconductor. Voltages in V 80 (1, 1'); 20 (2, 2').

The sensibilized photosensitivity is spread up to 600 nm and has a maximum at the wavelength 500 nm at positive and 530 nm at negative bias voltages on photoconductor. Positive sign of the dominant charge carriers in polymeric photoconductor seems to be confirmed from comparing the photocurrent values at different bias. The shift of the main maximum of ca 30 nm with the polarity change apparently indicates the potential barrier existence at the photoconductor - liquid crystal interface. The physical nature of such barrier is most probably the same as considered in Ref.[4]. The existance of such barrier was confirmed by current-voltage characteristics of the SLM which were typical for rectifying structures, and photoelectromotive force of ca 0,3 eV, the sign of which was the same no matter which side was lit. Rectification coefficient at 20 V was equal to 20 in the dark and to 3 with the read-on light. The essential influence of this rectifying barrier on all parameters of the light valve has been established. Later on SLM characteristics at various conditions will be considered.

SLM transparency versus the intensity of the read-on light of the continuous He-Cd laser at different voltages for twist type modulator is shown in Fig.2. The threshold character of the electrooptical effect in liquid crystal and asymmetry in transparency versus voltage polarity can be obviously seen. The latter can be explained by the photogeneration of the charge carries predominantly of a one sign (holes) and barrier formation

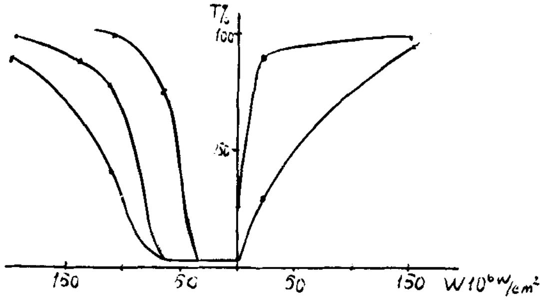


FIGURE 2. Twist type modulator. Transparency versus intensity of the read-on light at control voltages V 25(1); 30(2); 50(3).

at the photoconductor - LC interface mentioned above and described in details[4]. Full contrast sensitivity was $2\cdot 10^{-5}$ $W/cm^2$, contrast ratio -50. Minimal response on and off times were 0,1 and 0,5 sec accordingly in this type of regime. Modulation function of the twist type SLM at continuous time regime is shown on Fig.3. Limiting reso-

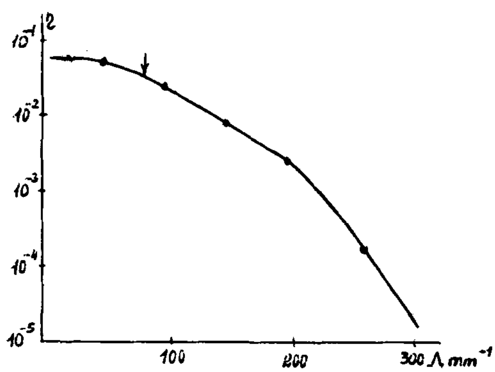


FIGURE 3. Modulation function of the twist type

modulator at continuous read-on light regime.

lution up to 300 $mm^{-1}$ and resolution up to 85 $mm^{-1}$ at the half of the maximum $\eta$ value have been reached. The arrow on the figure shows this position. The limiting resolution was apparently much less than its real value because vibrations of the set up have not been completely eliminated. Holography sensitivity of the SLM was 1 $10^{-6}$ J/ $cm^2$%.

Transition to the commutational regimes and electrically controlled birefringence type modulators permitted to improve substantially the structure parameters[2]. Diffraction efficiency, on and off times versus voltage are shown in Fig.4 for laser

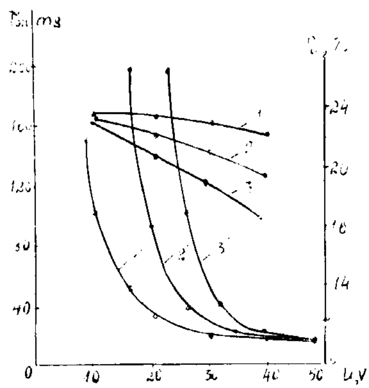


FIGURE 4. Electrically controlled birefringence type modulator in commutative regime. Diffraction efficiency versus voltages in space frequencies in $mm^{-1}$. 10(1); 28(2); 51(3). Turn on response time versus voltages at space frequencies in $mm^{-1}$ 10(1');36(2');60(3').

light intensity $5 \cdot 10^{-4}$ W/cm$^2$. The writing has been made by laser light pulses of wavelength 530 nm lasting from o.1 to 2 sec. Diffraction efficiency value of 23% at 10 V was obtained and this value has not been practically changed up to $\Lambda$ = 60 mm$^{-1}$. Monotonic decrease of the diffraction efficiency has been observed with voltage increase for high $\Lambda$ more rapidly than for low $\Lambda$ . For example resolution, defined as $\Lambda$ attributed to 0.8 $\eta$ value was 45 mm$^{-1}$ at 40 V. On-times for different $\Lambda$ values were ca 15 msec at voltages more than 40 V (Fig.4). It was established that $\eta$ and $T_{on}$ depended on the read-on light intensity up to 3 $10^{-4}$ W/cm$^2$. Holographic sensitivity, defined as the read-on light exposition needed for reaching 1% diffraction efficiency value, was 3 $10^{-7}$ J/cm$^2$% at V = 40 V and $\Lambda$ = 28 mm$^{-1}$. Storage time of the image can vary from seconds to hours for different regime types.

The most remarkable results were obtained in the case of laser light pulses lasting ~ 20 nsec and energy density up to 2 mJ/cm$^2$. One can expect the following results in such a regime of the read-on light : 1. increase of the SLM resolution due to decrease of the transverse spreading of the charges in photoconductor and its interface with liquid crystal; 2. $T_{on}$ decrease due to the photocurrent increase at high exciting power; 3. exclusion of the set up vibrations.

Modulation function for this type regime has been shown at different light intensities of the read-on light in Fig.5. Resolution, defined at 0.5$\eta$

value increase from 230 $mm^{-1}$ to 320 $mm^{-1}$ with energy density increase from 10 $mJ/cm^2$ to 320 $mJ/cm^2$.

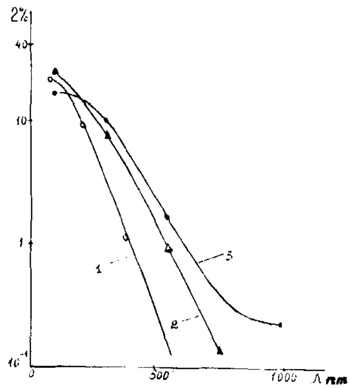


FIGURE 5. Modulation function of the electrically controlled birefringence type modulator at pulse laser read-on light lasting 20 nsec and power density in $J/cm^2$ 10(1); 30(2); 250(3)

Maximum value of the diffraction efficiency was 36% at $\Lambda$ = 100 $mm^{-1}$ Limiting registered resolution was 1500 $mm^{-1}$ with $\eta$ = 0.1%. As far as we know such resolution is the highest for LC light valves. $T_{on}$ and $\eta$ versus voltages are shown in Fig.6. The experimentally reached minimum $T_{on}$ was 200 $\mu$sec. $T_{off}$ varied from 0.3 to 1 sec. It was established that $T_{on}$ and $T_{off}$ were independent from $\Lambda$ . Holographic sensitivity was 5 $10^{-6}$ $W/cm^2$%.

The LC thickness are less or close to the distance between neighbouring lines ( $\Lambda$ ) of the record grating in all the modulators investigated.

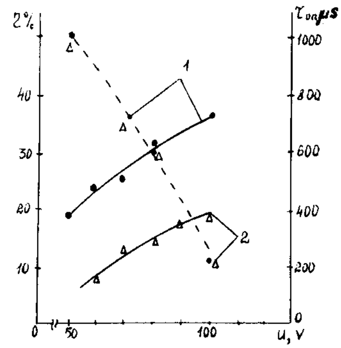


FIGURE 6. Diffraction efficiency and turn-on times in the pulse regime versus voltages at energy density of the read-on light $4\cdot10^{-4}$ J/cm$^2$ and space frequencies 100 mm$^{-1}$ (1) and 330 mm$^{-1}$(2).

So the structure presents a thin phase hologram, diffraction efficiency of which obeys the formula

$$\eta = J_1^2(\Delta\varphi) = J_1^2\left(\frac{2\pi\Delta n d}{\lambda}\right)$$

where $J_1$ - Bessel function of the first order, $\Delta\varphi$ - modulation depth, $\Delta n$ - amplitude of the index of refraction modulation. $\eta$ has its maximum value at $\varphi$ = 2 radian. Sinusoidal charge distribution can be concentrated on the photoconductor - LC interface or in the photosensitive material itself according to the theory developed in[6]. We have find a correlation between theory and experimental results, if the volume distribution of the charges in the photoconductor was taken into account. Maximum $\eta$ = 40% obtained, practically coincide with limiting theoretical values for thin phase holograms if high po-

wer density of the read-on light sinusoidal distribution of the charge turning into the rectangular one is taken into account. The $T_{on}$ decrease to 200 $\mu$s at high power pulses has been conditioned by the characteristic charge time decrease in such a regime. The calculation of the charge time of the equivalent scheme in the form of series connected resistances of the photoconductor and LC shunted by its capacitances has yield the value 300 $\mu$sec. The independence of the response times from $\Lambda$ in the pulse regime demonstrates the negligible transverse charge spreading during its transit across the photoconductor and accumulation at the polymer - LC interface. Transit time definition of the drift mobility obtained gave the value of $2\cdot10^{-5}$ $cm^2/Vsec$.
High values for diffraction efficiency and resolution permitted to reproduce classical Gabor experiment, writing of the lens hologram. High efficiency of the SLM with photoconductive polymer as the phase reversible material permits to use this type of structures as the elements for input and output of the optical information, in optoelectronics, for in- and out- resonance modulation of the laser light. Not only parameters but record regime optimization are necessary for solutions of concrete problems. Experimentally obtained parameters at the pulse write-on regime are practically very close to the theoretical values for thin phase hologram. High resolution, mechanical and electrical stability make the usage of the organic polymeric photoconductors in

SLM very perspective.

I am greatly indebted to drs Kotov and Vasilenko for polyimide films.



## REFERENCES

1. V.S. Mylnikov, E. Morosova, N.A. Vasilenko, B.V. Kotov, These of the organic semiconductor conference (Moscow, 1984), p. 48.; Dokl. AN USSR, v. 281, N. 4, pp. 897-900 (1984); Journal of the technical phisics (USSR), v. 55, N. 4, pp. 749-753 (1985).
2. V.S. Mylnikov, M.A. Grosnov, N.A. Vasilenko, B.V. Kotov, L.N. Soms, Journal of the technical phisics (USSR), Letters, v. 11, N. 1, pp. 38-41 (1985).
3. V.S. Mylnikov, A.M. Ivanov, Journal of the technical phisics (USSR), v. 57, N. 3, pp. 598-600 (1987).
4. V.S. Mylnikov, E.A. Morosova, Journal of the technical phisics (USSR), v. 53, N. 10, pp. 2045-2049 (1983).
5. K.K. Schwarz, V.I. Gotlieb, V.J. Kristapson, Optical registrations materials (Sinathne, Riga, 1976), p. 194.
6. M.P. Petrov, S.I. Stepanov, A.V. Chomenko, Photosensitive electro-optical materials in holography and optical information processing (Leningrad, Nauka, 1983), p. 268.