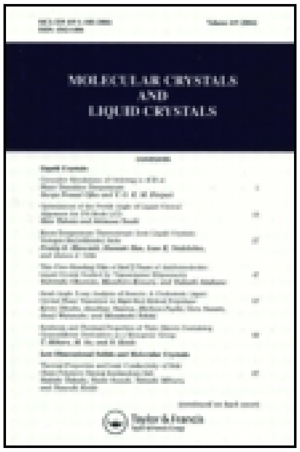

Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

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

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Version of record first published: 04 Oct 2006

Mol. Cryst. Liq. Cryst., 1997, Vol. 304, pp. 145–149
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FAST SWITCHING OF STLM VALVES OPERATING ON THE BASIS OF TWISTEFFECT IN LIQUID CRYSTALS

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Abstract. Prototypes of matrix multichannel spatial-temporal light modulators (STLM) based on liquid crystals (LC) developed so far do not match the operating capacity of optical computing systems by their characteristics (response speed, capacity). One of the ways to increase the speed of response of STLM is to realise the modulation mode that arises under deformation of near-electrode LC layers. This paper presents the results of investigation of the modulation characteristics of the STLM light valves based on twist-effect under conditions of initial distortionof LC-layer director that is caused by contact of the liquid crystal with the periodic structure of the modulator electrodes.

INTRODUCTION

Among a great variety of fast liquid crystal (LC) devices developed so far, matrix spatial-temporal light modulators based on ferroelectric LC's approached practical implementation stage most closely. Fast response speed and bistability of ferroelectric LC's made it possible to use them in storage modulators free from any limitations in terms of multiplexity. Such devices feature high multiplication levels at frequencies comparable with video frame frequency[1]. At the moment, nematic liquid crystals cannot compete in response speed and multiplexing ability with smectic LC's. It should be noted, however, that potentials of nematic LC's are not yet fully unveiled.

EXPERIMENTAL CASES

This paper deals with the investigation of the fast switching mode of STLM valves based on twist effect in nematic LC's, which has been found by us earlier[2]. Investigations were conducted on experimental modulators having various widths of transparent conductive electrode (50...500 μm). To obtain oriented LC layers we used polyviny alcohol films applied on STLM substrate. Liquid crystal mixtures based on tolans were used, whose optical anisotropy is about 0.2 in the operation temperature range. LC layer thickness was determined by the height of supporting pads deposited on the STLM substrates. Fig.1 shows oscillograms characterising switching peculiarities of a twist-effect-based STLM valve. Two processes can be recognised in the switching of the valve - fast and slow. If short control pulses (about 10^{-4} s) are used, fast and slow switching processes can be separated in time (A-C). If the control pulse length is large (over about 10^{-3} s), the two processes superimpose on one another (C).

Within the framework of existing theory describing dynamics of response of an LC cell with T-orientation to external voltage pulse it is impossible to explain the observed switching behaviour of the light valves. Our studies of STLM valve switching modes have revealed that the fast switching process is connected with deformation of near-electrode LC layers causing light modulation rather than with re-orientation of LC molecules and their transition to homeotropical state (as is the case with slow switching).

It is know that in matrix spatial-temporal light modulators periodic electrode system protrudes above the substrate surface by a height determined by thickness of transparent conductive layer (0.05...0.1 μm). Scanning electron microscopy studies (TESLA BS-350) have shown that depositionof orienting coating on electrodes preserves spatial nonuniformity of the surface flatness. If planar orientation direction of LC molecules does not coincide with the direction of electrodes on STLM substrates, there occur initial distortions in orientation of LC molecules in the near-electrode region adjacent to the valve bounds, which propagate to the LC layer depth due to elastic forces.

Let us consider the process of LC molecule reorientation in electric field in this case. Let the upper electrode of LC valve be directed along the X axis and the lower electrode along the Y axis. The orientation direction of LC molecules is aligned with the lower electrode direction. Therefore, there are no perturbations of the director in the LC layer near that electrode. It was found that director perturbations (resulting in changes of threshold switching characteristics of LC valves) take place in case of misalignment angles of 3° - 5° degrees between LC orientation and STLM electrode direction. At the same time, near the upper electrode and within its bounds LC molecule deviate from planar orientation through a certain angle ψ_0 at one boundary and by $-\psi_0$ at the other boundary. The arising periodic deformation of LC layer director is described as:

$$n_x = \sin\Theta, \qquad n_y = \cos\psi \cos\Theta, \qquad n_z = \sin\psi, \tag{1}$$

where Θ is the LC twist angle. The deformation period is determined by the electrode spacing and the.angle between LC molecular orientation and STLM electrodes direction. Steady-state distribution of the LC director at electric field E can be found by substituting the expression (1) into the Franc equation for the LC layer free energy density[3]. Following minimisation in one-constant approximation for non-twisted layer, we obtain:

$$\partial^2\psi/\partial y^2 + \partial^2\psi/\partial z^2 + \Delta\varepsilon E^2 \psi/4\pi K = 0, \tag{2}$$

where K is the elasticity modulus, $\Delta\varepsilon$ is the LC dielectric anisotropy.

For the case under consideration the boundary conditions are as follows:

$z = 0, \quad \psi = 0; \quad z = d, \quad \psi = f(y)$ (d is the LC layer thickness).

Let us assume that f (y) describes a linear variation of the molecular tilt angle from - ψ_0 at one electrode edge (Y = 0) to + ψ_0 the other edge (Y = m), i.e.

$$f(y) = \psi_0 (1 - 2y/m).$$

Solving eqn. (2) with the boundary conditions taking into account gives:

$$\psi = \Sigma \{C_0 \sin(\pi zA/d) / j \sin A\} \cos(j \pi y/m), \qquad (3)$$

$$A = [P^2 - (jd/m)^2]^{1/2},$$

where $P = E/E_0$ is the external field strength in threshold units, C_0 is a constant depending on initial orientation distortion angle ψ. Numerical calculation of eqn. (3) has shown that lower harmonics of the distribution angle ψ (j = 1) are characterised by the lowest switching threshold. Therefore, it is these harmonics that will arise first when realignment of LC molecules occurs in external field. It should be noted that their location region is in the middle of the valve ($Z \sim d/2$). Realignment of LC molecules in external field begins at the field values P in excess of the value d/m at the valve edges (Y= 0, Y= m). Molecules located near one edge of the valve have a certain pre-tilt of + ψ_0 and, with external field present, tend to turn in a counter-clockwise (along the ray path); at the same time, at the other edge molecules turn clockwise. As control field is increased, neighbouring LC molecules with a lower pre-tilt get involved in this process and so on. Thus, two domains with opposite distortions are generated. The boundary region between the domains acts like a wall in the electric field.

Within the boundary region, LC molecules do not suffer realignment under external field, because on the one side of the valve they have to turn clockwise while on the other side they turn counter-clockwise. This fact results in a higher realignment threshold for such LC molecules and in nonuniform switching of the STLM valve across aperture[4].

Realignment of LC molecules corresponding to higher harmonics (j>>1) in the distribution of the angle ψ (eqn (3)) has a higher initiation threshold. The region of sinusoidal deformations lies in the vicinity of electrodes, where theirinitiation threshold is lower than that in the central part (over thickness) of the LC layer.

The ordinary slow switching process is determined by realignment of molecules more loosely bound with the substrate, whereas fast switching is associated, in our opinion, with deformation of initial orientation distortions in electric field due to contact of LC molecules with periodic system of STLM electrodes having a certain thickness. Switching behaviour of STLM valves is dictated by the ratio of the rates of the two processes. In a pure sense, fast switching is only observed at high control voltages (due to high initiation threshold) and short pulse durations (due to different development rates of the fast and slow switching processes).

Fig. 2(A-C) shows oscillograms of the light valve optical response, which illustrate slow switching observed in the case of STLM controlled with a pulsed voltage

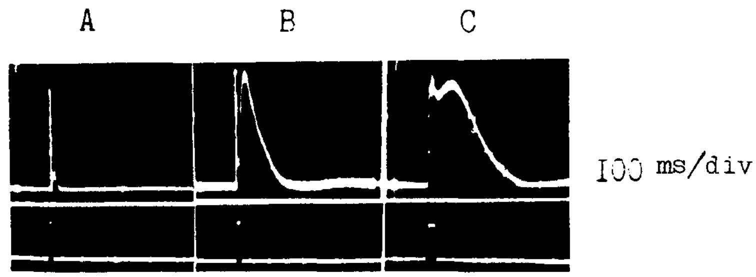

Fig. 1. Oscillograms of LC valves switching for various control pulse durations: 0.2 ms (A); 1.0 ms (B); 5.0 ms (C). Pulse amplitude is 120 V.

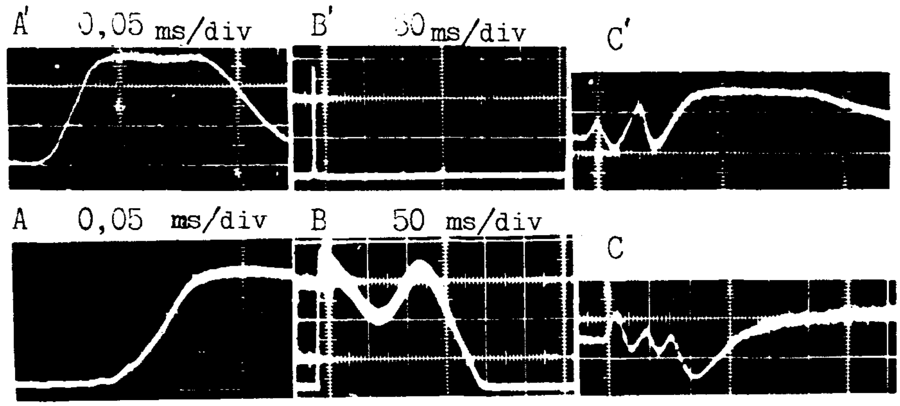

Fig. 2. Light valves switching for various control pulse amplitudes: 50 V (A, B, C) and 130 V (A', B', C'); oscillograms A, A' and C,C' - leading and trailing edges of the recorded pulse; oscillograms B, B' switching pulses for an LC valve rotated by 45° relative to polarizer axis.

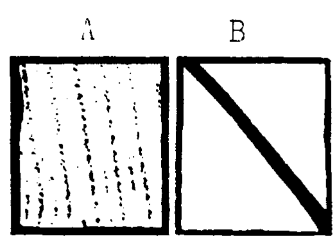

Fig. 3. Photographs of switched-on valves for fast (A) and slow (B) switching. LC layer thickness - 10 μm; electrode width - 50 μm.

amplitude of about 100 V. By comparing the oscillograms A and B we find that Mogen regime is cut off only when optical anisotropy of LC molecules changes after realignment by such an amount that results in three complete light oscillations. In this case, the valve switching time is about 200 ms.

In case of STLM controlled with pulsed voltage amplitude over 120 V and duration less than about 0.3 ms, fast switching is observed, as illustrated by oscillograms in Fig.2(B'-C'). By comparing the oscillograms A and B, A' and B' it is seen that, in fast switching of the STLM valves, switch-on of the cell occurs before cut-off of the Mogen regime (there occurs only two oscillations of light) and is due to phase modulation of light (coincidence of curves A' and B' upon switching of the valve). Fig. 3 presents photographs of switched-on STLM valves in case of fast (A) and slow (B) switching. Fast switch-on gives rise to sinusoidal deformations of domain-type, which can be readily observed in switched-on valves. The domain period value of 2...3 μm suggests that they lie within near-electrode regions. Light incident on the valve is deflected on deformations of the near electrode LC layer director (if domain orientation is normal to the light polarisation plane) and propagates at an angle to the LC twist axis. In this case, optical anisotropy of the central LC layers (where molecules have not changed their position due to low realignment speed) is decreased, which may be accompanied by cut-off of the Mogen regime and phase modulation of light. Following switch-off of the field, there occurs fast relaxation of LC tilt angle to initial state because deformation of the layers is localised in the near-electrode regions where molecules are strongly bound with the STLM substrates. The valve relaxation time is about 0.1 ms, which makes it possible to increase the response speed of nematic twist-effect-based light modulators almost three-fold. In slow switching mode, the valve is switched on nonuniformly, with the wall formed (see Fig. 3(B)). Slope of the voltage-contrast (V-C) characteristic of a twist-effect LC STLM operating in fast switching mode is three times as large as the V-C characteristic observed with twist-effect modulators in ordinary slow switching operation[5].

In conclusion, the fast switching mode in matrix twist-effect STLM's in conjunction with a relatively simple technology provide a possibility of making matrices with high scanned lines density and response speed unrivalled for this effect.

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