Low Power LC Shutter with High Contrast Ratio and Fast Response Time

Studentsov S.A., Brezhnev V.A., Gorfinkel B.I., Zhukov N.D.
R&D Institute "VOLGA", Saratov, Russia, e–mail: rdivolga@san.ru, lcspectrum@mail.ru
V.G. Chigrinov, Kwok H.S
Hong Kong University of Science and Technology

Abstract

The optical response delay observed in self-compensated configurations of LC-structures such as OMI is used for increase of contrast and improvement of time characteristics. The display design, including the driving circuitry is described. It is shown, that contrast is improved to 30 %, relaxation time almost twice, and reaction time more than 250 times. Other variants of high-contrast LC-shutters are provided for comparison.

1. INTRODUCTION

Low power liquid crystal (LC) shutters with a high contrast ratio and fast response time can be used for various applications, including welder helmets, modulators for stereoscopic systems, color sequential system for micro displays etc. [1]. An application of a high voltage to LC cell usually results in a large contrast and fast response time, but needs a high power supply for the operation. Moreover, if switching voltage pulses are too separate in time, LC cell transmission fades between the pulses, which lead to the called "frame response" effect with flickering and a subsequent decrease of the contrast [2]. Besides that, the relaxation time increases for the higher applied voltage [3], which is absolutely unacceptable in modulators for stereovision.

The MEMOMI- shutter design, reported by us earlier provides a perfect solution [4,5]. Its major property is optical self-compensation, i.e. optical activity of one part of the LC-layer is equal to another one by value, but opposite by sign. The other necessary condition is minimization of interference phenomena. The latter is provided by orientation of polarizers along the rubbing direction of LC-molecules or perpendicular to it. As the result of it, approximately during half of relaxation process (delay period) the contrast remains maximal, i.e. the frame response is absent.

Using short-term high-voltage pulses with the period equal to relaxation delay period onto such cell, it is possible to achieve the following results: (i) reduction of the power consumption keeping the maximal possible contrast; (ii) shortening of reaction time to tens of micro seconds due to the increase of driving signal amplitude; (iii) decreasing the relaxation time to the delay period (about two times).

2.EXPERIMENTAL

Glass plates with ITO-electrodes and insulating SiO_2 layers have been covered by a polyimide layer enabling a pretilt angle of α_0 =2…3°. The thickness of the LC-layer (3.0 – 3.2 μm) was selected to provide a maximal transmission for a given LC birefringence value. We used MLC-6080 (E.Merck), with optical anisotropy Δn=0.202 (i.e., Δnd=0.6-0.65μ) and viscosity η=18mm^2/s. We used the following LC best contrast electrooptical modes: 90° TN (waveguide mode), 180° OMI (optical mode interference) and 270° STN cell (Table I). The polarizers NPF-G1229DU (Nitto, Japan) were crossed with their transmission axes parallel (or crossed) with LC-molecules (director) on the surfaces.

As seen from Fig.1, 180^0 OMI structure shows the superior characteristics for shutter applications. When the voltage is applied to the initial structure A vertical reorientation of LC-molecules occurs in the central part of the layer (configuration B), so that the director tilt at the bottom substrate is equal but opposite to the director tilt at the upper substrate. Thus the residual ellipticity is self-compensated in 180° OMI cell during the relaxation (A⇒B⇒C⇒C*) and, hence, the contrast is maximal for a chosen location of the polarizers.

Table I. Parameters of the used LC cells (β_0 – rotation angle, P_0 – helix pitch, d – LC cell thickness).

Sample	β_0	P_0, μm	d, μm	d/P_0
A (TN)	90°	100	3,0	0,03
B (OMI)	180°	8,1	3,0	0,37
C (270^0 STN)	270°	4,0	3,0	0,75

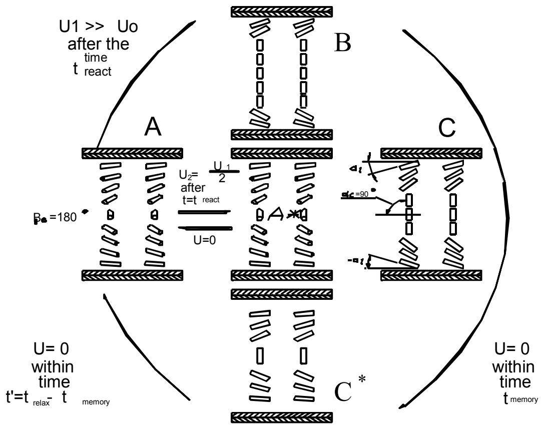


Figure 1. MEMOMI configuration transformations during the application of voltage and relaxation process.

3. Driving Method

LC cells can be driven by two methods: (i) Static driving, when the voltage on cells in "on" state is applied continuously. The amplitude of such voltage is equal to root-mean-square (rms) value of the voltage; (ii) Dynamic driving, when the cells in "on" state are subjected to short pulses of the increased voltage with off-duty factor Q. The rms voltage U_{RMS} at such driving is defined from the amplitude voltage U_{AMPL} as: $U_{RMS} = U_{AMPL} / \sqrt{Q}$, where duty factor Q is equal to the ratio of the frame time τ_{frame} to a pulse duration τ_{pulse}. In our case τ_{frame} = 10 ms; τ_{pulse} =160 μs; Q =64. In the "off" state, in both cases, the zero voltage was applied. The threshold voltages were independent on the driving method and were equal to 1.5V for 90° TN cell, 1.9V for 180° OMI cell and 2.1 V for 270° STN cell. The static and dynamic driving variants are shown in Fig. 2(a-c) accordingly.

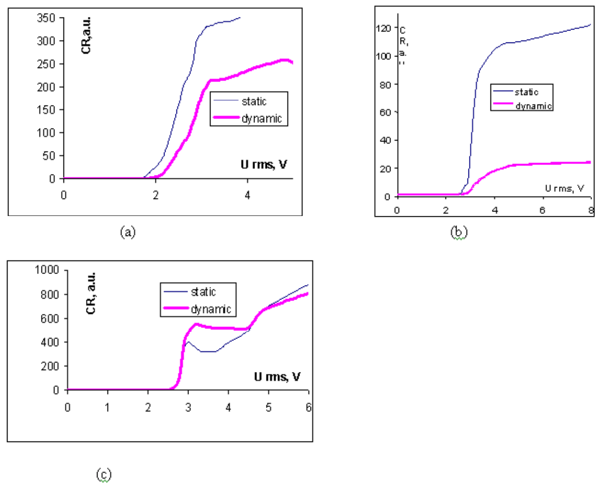
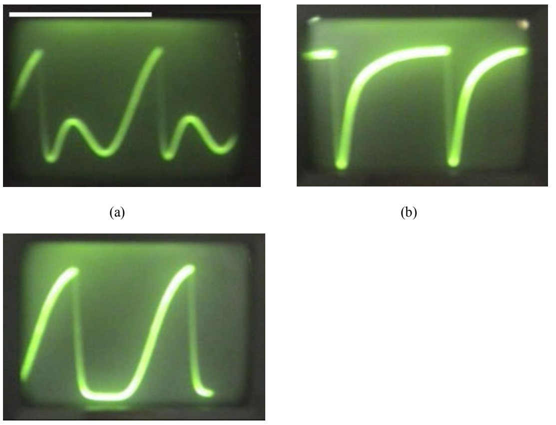


Figure 2. Measured contrast of various LC cells versus rms voltage at static and dynamic driving: (a) 90° TN; (b) 270° STN; (c) 180° OMI.

It is clear, that only for OMI-cell the dynamic mode has advantages over the static mode. For TN and STN, contrast in a dynamic mode is always lower than in static mode. This difference is especially noticeable for STN cell.

The contrast-rms voltage characteristics of OMI-cell exhibit three main parts for the static and dynamic driving regimes: (i) From a threshold voltage U $\approx U_{th}$ ≈1.9V up to approximately U ≈1.5 U_{th}, the curves are absolutely identical, i.e. the optical delay is rather small due to the small LC deformation; (ii) When voltages are higher (from U ≈1.5 U_{th} up to U ≈2.0-2.2 U_{th}) – the difference is maximal, i.e. at the same rms voltage at static driving, contrast is 1.5 times lower than the contrast for dynamic driving. In this case, the absence of the frame response effect is the most pronounced; (iii) For the voltage of U ≈2.2-2.5 U_{th} the curves practically coincide, i.e. the static driving regime appears more convenient.

The oscillograms of optical response for the three modes in a dynamic regime are shown in Fig. 3 (a-c) for duty ratio Q=1/128 (τ_{frame} = 20 ms; τ_{pulse} =160 µs).



(a) (b)

(c)

Figure 3. Typical oscillograms of various modes in a dynamic driving regime: (a) 90° TN; (b) 270° STN; (c) 180° OMI.

In TN cell the decrease of the contrast when voltage is zero is caused by transmission fluctuations, arising because of a back flow effect (Fig. 3a) [1]. For 270° STN the role of back flow is not so high and consequently the relaxation time is minimal (Fig. 3b). However, the frame response effect results in a 22 times lower contrast in comparison with a static mode (Fig.2b). On the contrary, for 180^0 OMI, the contrast does not considerably decrease, when the voltage is zero. As the voltage increases, the delay time also increases. At voltage amplitude of 28V and duty ratio Q=1/64 (U_{RMS} =3.5V) the delay is equal to the period of high-voltage pulses applying, i.e. 10 ms (Fig. 4). At the static mode, the contrast is considerably smaller for the same voltage U_{RMS} =3.5V (Fig. 2c), as the LC deformation is not high enough.

If we increase voltage amplitude up to 40V, the reaction time of the OMI-cell (i.e., time of self-compensating structures formation) decreases to 63 µs, while the delay time will be the same 10 ms (Fig.5). If time of voltage pulse applying is also 63 µs, duty ratio Q will be 159 and the corresponding U_{RMS} =3.1V. The contrast, which is fixed at these conditions, achieves 520:1. It is higher than at static driving (360:1) for the same value of rms voltage. Thus, applying short pulses of a high voltage to the OMI-cell, and using a delay of the optical response at zero voltage, we obtain minimum rms voltage on the LC cell without loss of the contrast. Applying the 40V voltage in a dynamic regime instead of 3.1V rms voltage in a static regime results in a decrease of reaction time from 15 ms up to 63 µs (more than 250 times). The relaxation time for the dynamic OMI cell driving is 13ms, which is almost 2 times better than at static driving.

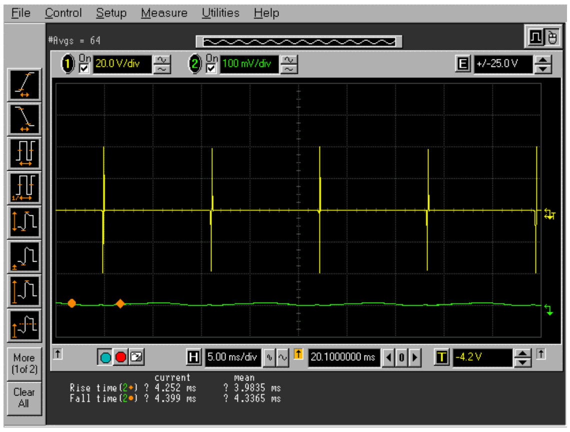


Figure 4. The frame response at dynamic driving with off-duty ratio 1/64 for a sample B (180° OMI, MLC-6080). The voltage amplitude U_{AMPL} = 28V (U_{RMS} =3.5V). The delay time 10 ms equals to frame response time τ_{frame}.

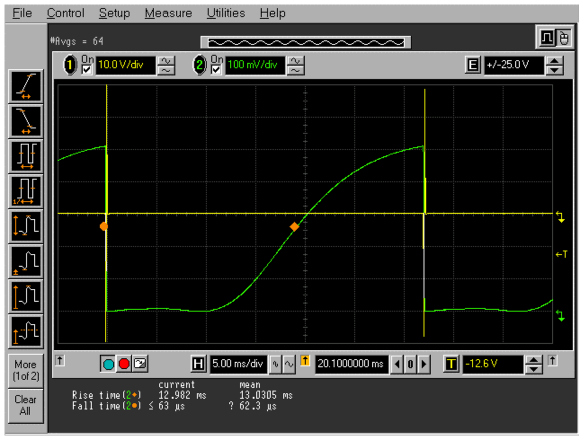


Figure 5. The frame response at dynamic driving with off-duty ratio 1/64 for a sample B (180° OMI, MLC-6080). The voltage amplitude is U_{AMPL} = 40V (U_{RMS} =3.1B). A delay time is 10 ms. Relaxation time is 13 ms.

4. Summary

Low power liquid crystal (LC) shutters with a high contrast ratio and fast response time were proposed by dynamic driving of 180^0 OMI cell. The MEMOMI-shutter design with optimized driving provides the contrast increase approximately to 30%, while the relaxation time decreases almost two times and reaction time decreases dramatically (250 times). The shutters can be used for welder helmets, modulators in stereoscopic systems, color sequential system for micro displays etc.

5. References

[1] V.G. Chigrinov, *Liquid Crystal Devices: Physics and Applications*, Artech-House, Boston-London, 1999.

[2] T.Scheffer, *Information Display*, 14, No.10, p.12 (1998).

[3] D.W.Berreman *J. Appl. Phys.*, **46**, 3746 (1975).

[4] G.V. Simonenko, S.A. Studentsov, V.A. Brezhnev, V.G. Chigrinov, *Eurodisplay'2002 Digest*, p. 873 (2002).

[5] S.A. Studentsov, V.A. Brezhnev, B.I. Gorfinkel, N.D. Zhukov, G.V. Simonenko, V.A. Ezhov, *Eurodisplay'2002 Digest*, p. 437 (2002).