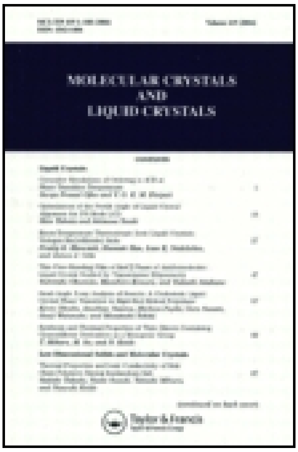

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Marek Sierakowski [a] & Miroslaw A. Karpierz [a]
[a] Warsaw University of Technology, Koszykowa 75, 00-662, Warsaw, Poland
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# APPLICATION OF OPTICAL NONLINEARITY IN LIQUID CRYSTALS TO OPTICAL LOGIC

MAREK SIERAKOWSKI and MIROSŁAW A.KARPIERZ
Warsaw University of Technology, Koszykowa 75, 00-662 Warsaw, Poland

Abstract New configurations of nonlinear liquid crystalline cells utilising an intensity-dependent scattering of light at liquid crystal/glass plate interface are presented. This kind of devices, based on a scattering-mode light modulation, require relatively low light power. Assistance of an additional electric field results in a more stable and a faster device performance.

## INTRODUCTION

Liquid crystals, because of the high anisotropy of physical properties as well as the collective behaviour of molecules under any external field are unique nonhomogeneous anisotropic objects for nonlinear optics. The use of liquid crystals leads to a number of nonlinear optical phenomena arising from molecular reorientation or/and thermal effects[1-6] such as intrinsic bistability, temporal instabilities and stochastic processes for the light-induced reorientation, nonlinear phenomena on a surface and on boundaries, fluctuations and nonlinear light scattering at phase transitions. All these optical nonlinear phenomena seem to be very promising in applications to all-optical computing and data processing.

Recently, we have demonstrated liquid-crystalline light modulator based on the light scattering principle, which we have named the scattering liquid crystal cell (SLC)[7]. The device in its basic version has a typical sandwich geometry, however, in the SLC, the cell-forming glass plates strongly scatter the incident light. The scatter structure is geometrically anisotropic - in our case the surfaces of the both cell electrodes were provided with parallel scratches of irregular dimensions and surface density. Refraction index of the substrate glasses were chosen to coincide with either ordinary ($n_o$) or extraordinary ($n_e$ ) index of the liquid crystalline material. Obviously, the propagating light is scattered if a pronounced optical interface exists in the transparent medium. This situation correspond to the case in which the index of refraction of the glass plates with the scattering texture differs from one of the $n$ value of liquid crystal layer. However, if they are close to each other, the scattering of the light does not occur because optically neither the interface between the LC layer and the glass substrate nor the scattering texture exist. In the SLC cell the optical axis of LC layer can be easily oriented along the direction of the scatter texture (orthogonal orientation is also possible). Since the voltage applied across the cell reorients LC layer and changes its effective refraction index between $n_o$ and $n_e$ , thus it switches the SLC states from scattering to transparent one or vice-versa.

In contrast to the first conception of the SLC modulator which is driven electrically, now we have used the same structure in all-optical configurations. The orientational optical nonlinear effects in liquid crystals is easy observable and owing to the earlier reports the interaction between the LC molecules and laser light seems to be quite well understood. This effect can be utilised to construct optical logic gates with the proper nonlinear output/input characteristics. So far as we focus our interest on optical logic we need at least two different nonlinear devices for accomplishing conventional binary logic functions: devices with a "z" type and a "s" type of nonlinear transmission characteristics. It could be in principle a sufficient tool for realisation, for example, all Boolean logic. For memory function, a bistable performance of a device is desired in addition. Therefore we have examined here the orientational optical nonlinear effect in liquid crystals utilising our SLC light modulator, which has earlier been designed for another optical logic experiment.

## RESULTS OF EXPERIMENT

In the construction of all-optical modulator working in a scattering mode, two versions of the SLC are possible, each with distinct optical characteristics. The one is initially transparent while the other scatters the passing light in the non-activated state. The way of realisation of both modulator versions depends on the type of liquid-crystalline material used for filling-in the cell. We have used the nematic liquid crystalline 6CHBT having a positive dielectric anisotropy.

In order to obtain a required bahaviour of the modulator we have established homeotropic alignment in the cell, although the construction of a "twist cell" is here also possible. For measurements we have prepared SLC modulators in three variants A, B and C. The SLC cell of each variant consisted of 35 μm thick LC layer inserted between two parallel glass plates in a typical "sandwich" geometry. On the front (light-source side) plate a scattering texture was formed: we have polished it with diamond powder M14 of average diameter 14 μm (it appeared however to be too rough). The glasses after polishing were quite opaque in the air and showed a strong scattering of laser beam. One of the plates in the cells of A and C variants are equally polished in two perpendicular directions while in the B variant, the polishing was unidirectional. The second glass substrate of each cell was an ordinary neat plate. In this way we were able to obtain a homeotropic alignment of LC layer in variants A and C simply by surfactant (lecithin). In the B variant, which glasses were formerly additionally provided with standard ITO electrodes, we have applied to the cell a 100 Hz electric field with a rectangular form. Refraction indices of 6CHBT are $n_o$=1.52, and $n_e$=1.69, thus the front scattering plates were made from glass BK7 with $n$=1.52, for the variants A and B, and from heavy glass SF4 with $n$=1.71, for the variant C. So we have obtained two groups of cells (A and B) almost transparent in non-activated state, due to the matching of the refraction indices of scattering plates and LC medium, and cells of the group C, scattering the light. As a result of some treatment imperfections small amount of scattered light was detected also in the A and B cells.

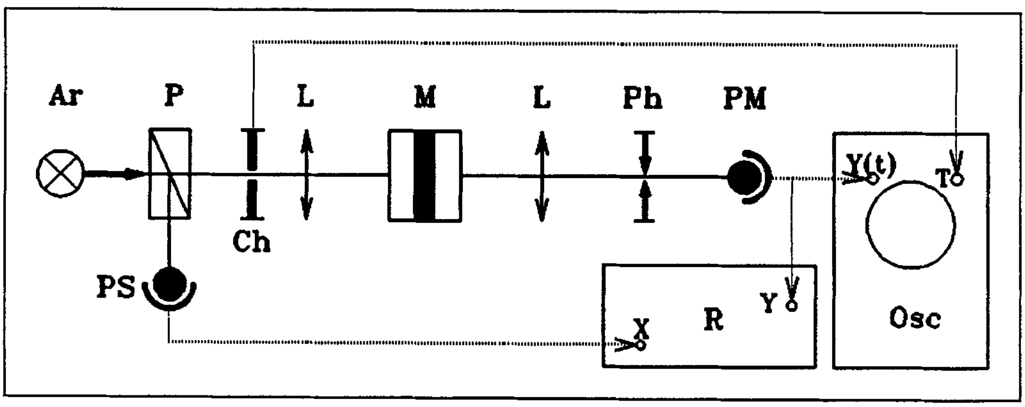


FIGURE 1 Schematic drawing of the experimental arrangement. Ar- argon laser, P- polarizer, Ch- chopper, L- collimating lens, M- liquid crystalline cell, Ph- pinhole, PM- photomultiplier, PS- light power meter, R- recorder, Osc- oscilloscope.

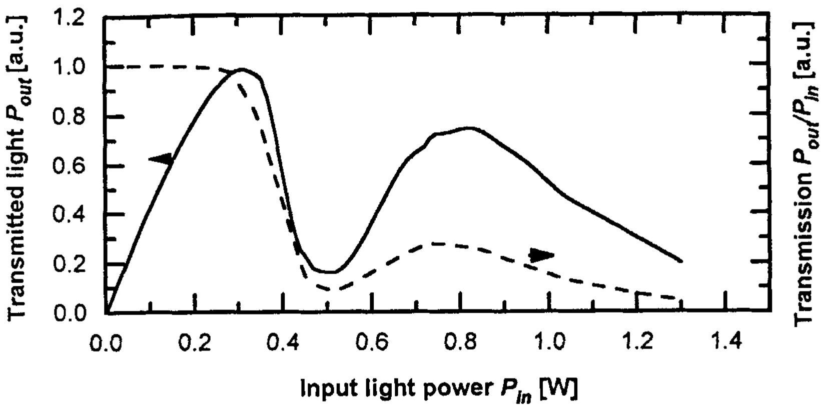


FIGURE 2 The experimentally detected dependence of the light transmitted power $P_{out}$ *vs.* the input light power $P_{in}$ and the transmission characteristic for the cell of 'A' type.

Consequently, reorientation of the initial alignment gave rise to a light scattering state in A and B cells while it made the C cells transparent. All the cells were examined by means of a visible argon laser beam of maximum power 1.5 W c.w. and $\lambda$=516nm. Simple measuring arrangement, which is shown on fig 1. , consisted of argon laser Ar, collimator L, examined modulators M, pinhole Ph, and usual optical assistant accessories. The setup optics was focused on the pinhole in front of photomultiplier. In the measurements, we have not used any probe beam - instead we have attenuated activating beam before it reached PM. The power beam was focused on the modulator to a spot of about 1 mm . The experimentally detected characteristics are shown in fig 2,3, and 4. In general, all the results were repeatable, what concerns the shape of characteristics, although certain differences in the signal level were observable.

Fig 2. shows input-output characteristics of the modulator of variant A. The cells initially transparent, allow collimated laser beam to reach photomultiplier trough the central pinhole. As the light intensity reaches the level affecting the molecular alignment of LC layer, light scattering appears and output intensity (in the axis of the setup) decreases rapidly. After it reached minimum the signal again increases. In this point we could observe the onset of usual nonlinear phenomena. As a first appeared self-focusing leading to the local maximum of the recorded curve, then came diffraction rings diminishing the intensity in the central region of the beam. Fig.2 presents also the transmission dependence vs. the input power.

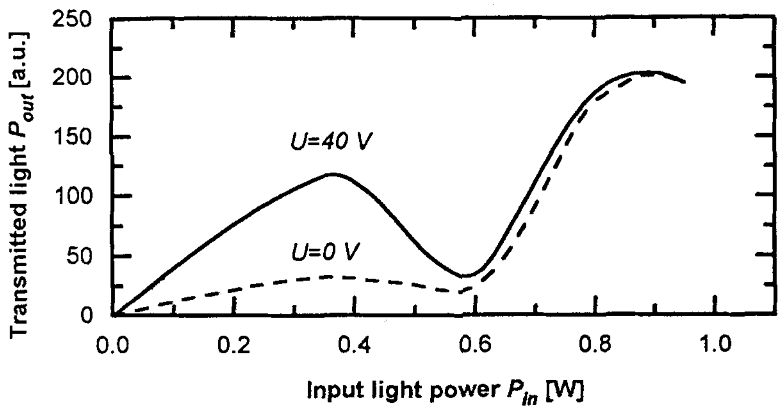


FIGURE 3 The output characteristics for the device of type 'B' with and without a bias voltage.

Similar dependence of output intensity on input power showed modulators of B type, which in the initial LC alignment was forced by voltage. Fig 3 shows output curves of B modulator with and without an applied voltage. It is to seen the ordering effect in a LC layer caused by voltage . The voltage forces LC molecules to orient homeotropically depressing the light scattering and thus bringing the modulator to a more transparent state in comparison to the disordered state of LC layer. It should be point out that the applied field and the laser light are counterplaying with respect to the LC alignment. Moreover we have noticed that all the effects observed in the B cells with voltage were much more stable than in other cells, ordered by surfactant.

The behaviour of C variant of the modulator was in contrast with the former A and B modulators. Initially scattering, the C cells transmitted very little light (fig.4.). Then increasing light power realigned the LC molecules and increased the output intensity dramatically. The effect was amplified by closely following self-focusing, so that the rise was indeed very sharp. Subsequently appeared diffraction and output intensity diminished.

It should be mentioned that by the measurements of the input-output intensity dependencies we have often observed a small shift of the curves between forward- and back sequences. The shift was seen as a small hysteresis loops in the input-output characteristics.

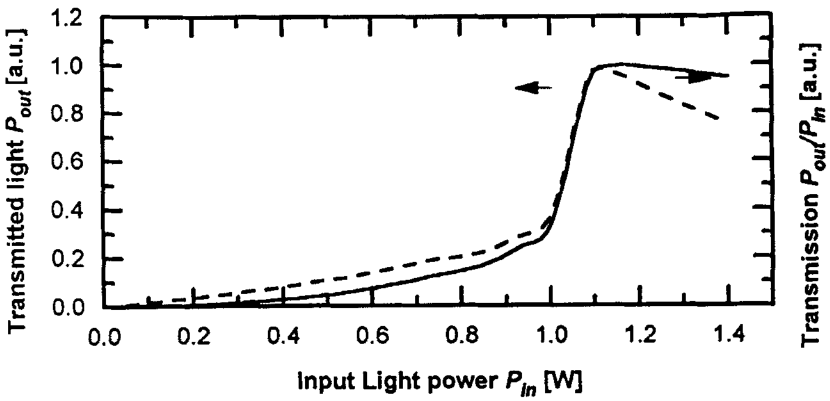


FIGURE 4 The same as fig.2 for the cell of the 'C' type.

We have estimated also the dynamic of the measured effect. The dynamic characteristics of the modulators are quite typical ralaxation curves, usually observed for orientational effect of liquid crystalline layer by outer fields[8]. From the time-dependent traces of output response on pulsed laser light we could evaluate the rise and decay (relaxation) times of the effect. Obviously, the rise time is strongly influenced by incident light intensity and, for all the modulators in our experiment by full power it was of the order of milliseconds. On the contrary, significant differences in the decay times were observed. For the A and C cells the decay time, as determined by the free relaxation, was measured to be several hundred milliseconds. However, the rise time in the B cells could be substantially decreased by increasing the applied ordering voltage.

## CONCLUSIONS

By examination of the optically driven SLC modulators we were able to obtain in-axis performance of experimental setup with two types of nonlinear characteristics: "z" type (A and B cells in fig.2 and fig.3) and "s" type (C cell in fig.4). They can be a basis for accomplishing all Boolean logic functions in relatively low range of activating light power. Therefore, continuing the experiment we intend to replace bulk optics of our arrangement by fiber optics, preserving its performance. On the other hand, we have not observed any distinct bistable behaviour of the setup, which would be desired if one want to realise optical logic memory.

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