Selection of electrooptic effects for diffractive LCD.

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Abstract

We reported researches of possibility of the usage of known electrooptical effects (EOE) for diffractive displays (DLCD).We found different EOEs provide the possibility of broad selection of steepness of volt-contrast characteristics at rather large steep of modulation without the usage polarizes. The data are represented much promising for broad development DLCDs.

1. Introduction

Early we report on a new type of colour liquid crystal display (LCD) in which colours selection is made by switchable phase diffraction grating formed in a liquid crystal (LC) layer of a specially constructed LC cell comprising transparence electrodes of relevant configuration (pattern)[1,2]. For a long time we've been developing principal constructive ideas of such a diffraction LCD (DLCD), researching electrooptical and operational DLCD properties, and seeking to adapt the DLCD construction to mass production conditions. As a result of our efforts, there have been a development of a set of patents[3] and manyfacturing of operational model of one DLCD version [4]. Our extensive studies have been confirmed that DLCD's possess a number of advantages compared to the common widespread used types of colour LCD's. Even now DLCD's could be manufactured with the existing industrial equipment of minimal updating, and their mass production would be even cheaper due to elimination of a number of expensive elements and operations from the manufacture process[4]. The latter's are colour microfilters, polarizers and corresponding setting operations of them into LCD device.

In this report, which is the final one in our sets of DLCD investigations, we've in detail settled on a choice of electrooptical effect for DLCD to operate.

2. Background

Early we contended (and keep on contending now) that any electrooptical (EO) effect capable of implementing phase light modulation, may be used for DLCD mode. And it's natural for different EO-effects having to some extent distinguished DLCD performances. We checked the following EO-effects:

- electric field controllable birefringence for originally planar oriented LC, 5μ LC layer thickness;
- 90° twist, 5μ LC layer thickness;
- 180° supper twist for nematics (STN), 3μ LC layer thickness;
- cholesteric-nematic transition, 5μ LC layer thickness;
- ferroelectric LC (FLC) switching, 1.5μ LC layer thickness;

For the sake of better further understanding of the results obtained, let us consider optics of a switchable diffraction as an example of using of simple DLCD version with initially planar LC orientation (Figure 1).

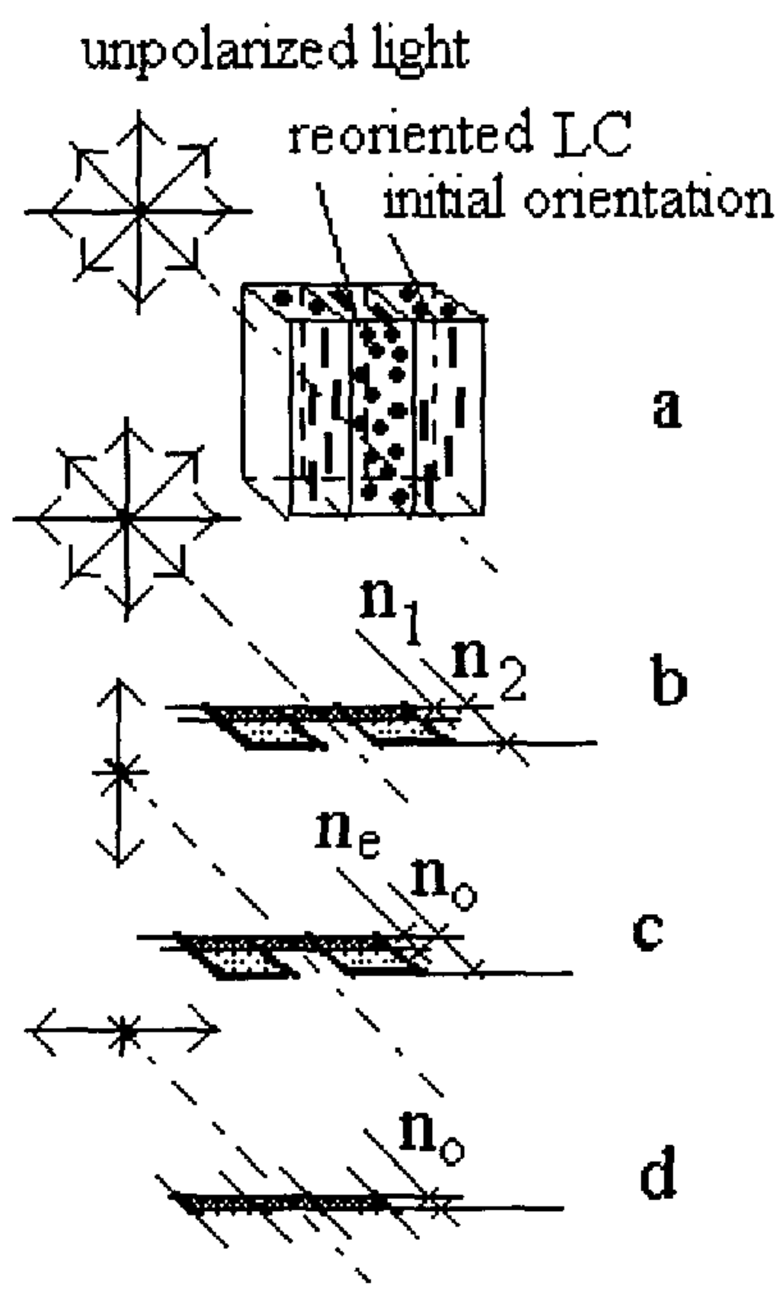

Figure 1 Optics of a phase diffraction grating

Figure 1a shows 3 parts (fragments) of phase diffraction grating. The end parts have planar initial orientation, but the middle part is completely reoriented under an application of the driven electric field. Despite the fact that DLCD is illuminated by natural non-polarized light and is capable to operate without polarizers, polarization effects of diffracted light are inevitable. This is a principle consequence of optical anisotropy of a LC phase grating. If we had a deal with a common non-anisotropic phase grating (Figure 1b), the profile of refraction indices would have a look of a meander-form and would have changed from n_1 to n_2 not depending upon the polarization plane direction of illuminating light. In the case of DLCD we have a deal with an anisotropic phase grating. Its refraction indices profile is dependent upon the polarization plane direction of illuminating light. So, for the vertical plane polarization direction the modulation depth of refraction indices is maximal and changed from n_0 to n_e. For the horizontal plane polarization direction the modulation of refraction indices is absent, and refraction indices profile is a line with a constant value of refraction equaled to n_0. For the intermediate directions of polarization plane, the profile of refraction indices has a meander-form with refraction indices magnitudes changed in the range from n_e to n_0. The diffraction efficiency of the phase grating is known to be proportional essentially to the modulation depth of the refraction index. That's why for isotropic phase grating the diffraction efficiency is independent upon polarization plane direction. For the vertical polarization plane direction the diffraction efficiency has to be maximal (Figure 1c). This fact is confirmed by our experiments and by the data given in publications[5,6].

For the horizontal direction of polarization plane (the modulation of refraction index is absent), diffraction efficiency should be equal to 0. But, in the experiment we have found (and it was by a pleasant surprise for us) that there is an quite effective diffraction in this case. This diffraction is likely to be due to the presence of an intermediate oriented area between parts of LC layer with initial orientation and homeotropically reoriented parts of the layer. The geometry of LC molecules orientation in the intermediate (transitional) area is very complex and doesn't prohibit the presence of layers with refractive index larger than n_0.

The similar considerations can be carried out for the optics of diffraction gratings based on the other EO-effects.

3. Experimental set-up

For the experiments we used the typical EO set-up comprising:

- semiconductor laser with possible mechanical rotation of polarization plane in the range of 360°;
- LC cell holder with possible cell displacement along the vertical and the horizontal and possible cell rotation in the range of 360°;
- Analyzer and polarizer with possible their rotation in the range ±180°;
- Photodetector – photodiode.

As a result, we had a possibility to read EO-characteristics for any combinations of the mutual polarization plane positions of the income light beam and of the initial orientation of LC director.

4. Results and Discussion

Preliminary data obtained have confirmed that EO performances are complicated functions, not giving the analytical presentations. The initial orientation of LC, the type of the EO-effect used, the LC layer thickness, the value of refraction indexes , the period of grating and the accent-to-interspace width ratio and some other factors are involved in diffraction mode (DM) of operation of DLCD's.

In present paper the main attention is paid to the comparative analysis of EO-charachteristics of DLCD,s based on different EO-effects and recommendations are given for the optimal choice of these effects if it is possible.

1.We have confirmed that any of phase EO-

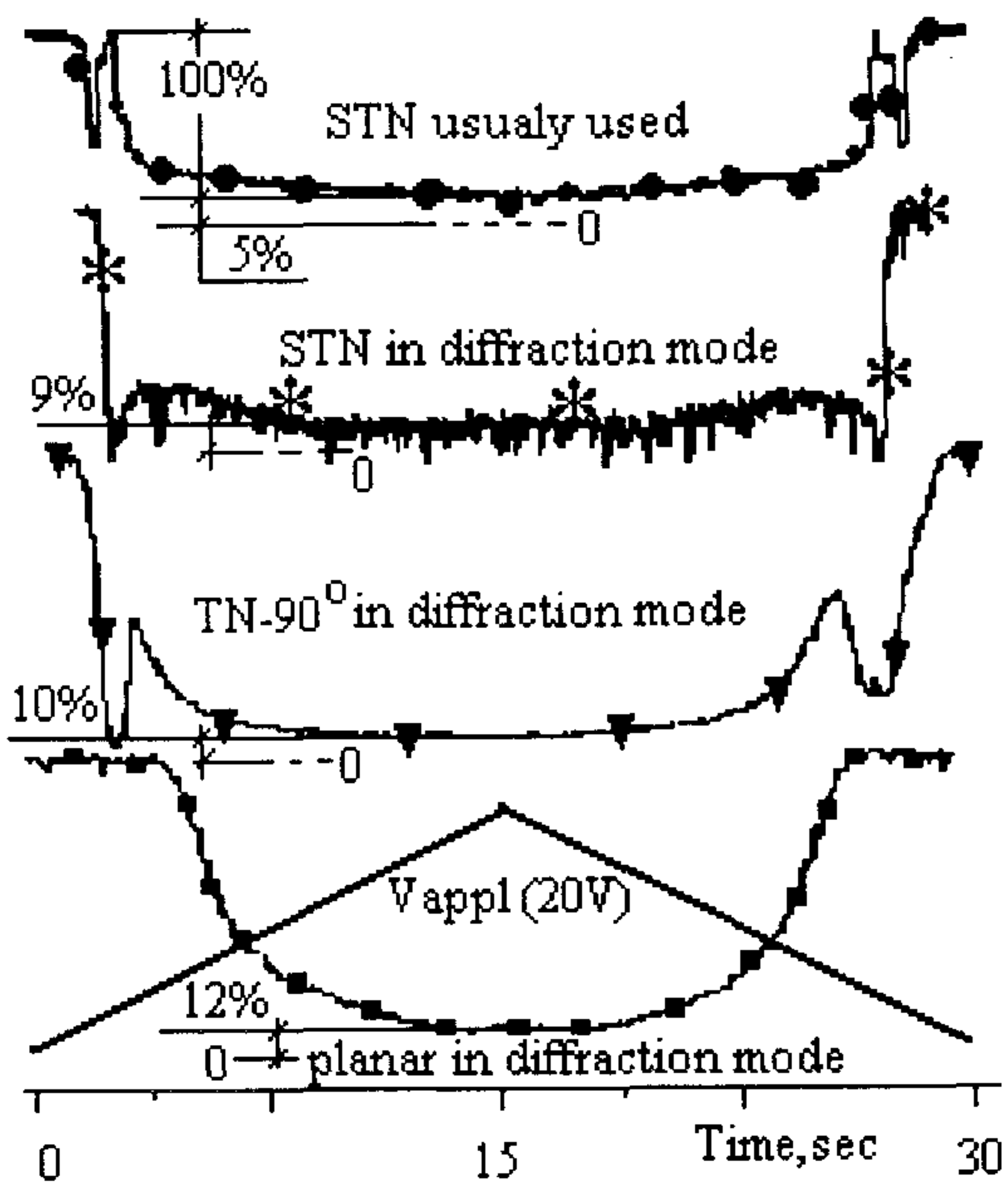

Figure 2 Response forms (0 order)

effects can be used for DLCD's. The result has been obtained that different EO-effects provide essentially different diffraction efficiency and, therefore, the different brightness of images are produced by using the different EO-effects. But for the optimal (from the point of diffraction efficiency) choice of an EO-effect, it is not enough

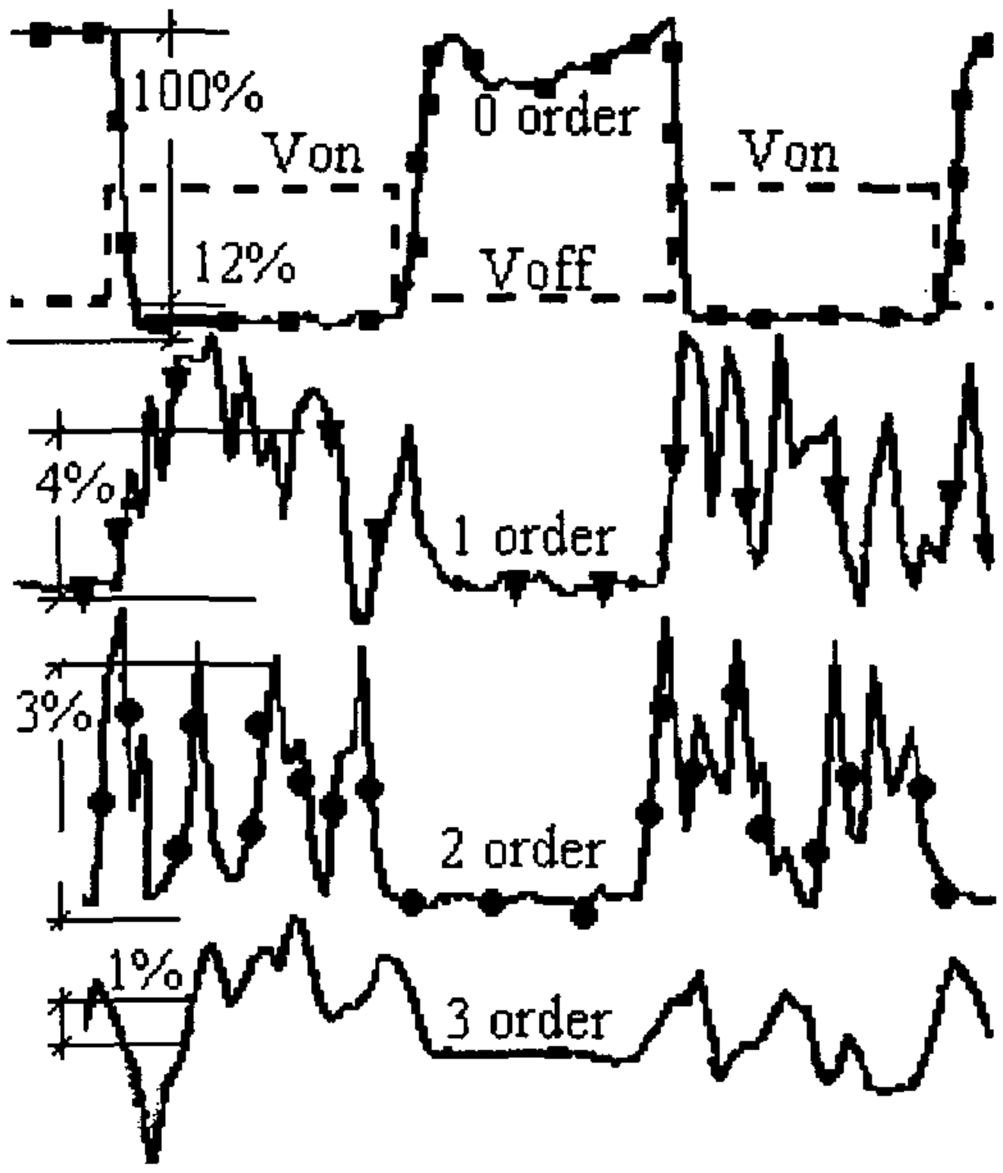

Figure 3 Responce forms (0...3 orders) on square form voltage (5V, period 10 sec)

the experimental data available.

2.Any of the investigated EO-effects in diffractive mode has larger steepness and shorter switching times compared with the application of the EO-effects in conventional modes. STN is leadership on steepness in diffractive mode too. The examples of

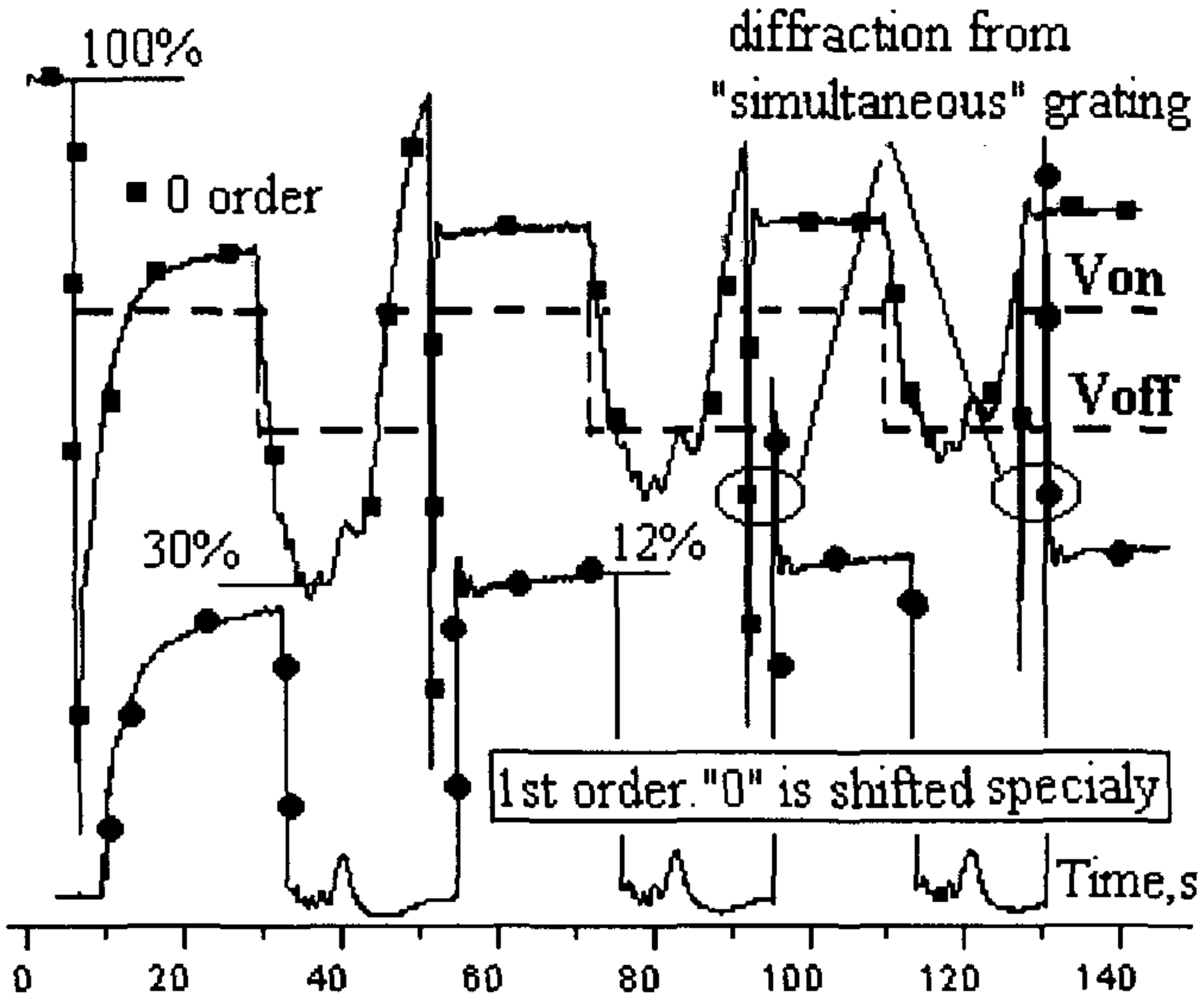

Figure 4 Intensity light modulation in 0,1 orders and from "simultaneous" grating

light modulation by the different EO-effects in the 0 diffraction order are given in Figure 2. One of the example set of the light intensity redistribution between 0,1st , 2nd and 3^{d} orders of diffraction is given in Figure 3. It is seen, that at the usage of switchable diffraction grating the modulation percentage is rather large (without usage of polarizers!). Also there is a possibility of selection of types of volt -contrast characteristics (VCC) for active or passive addressing.

3. We have found out that light intensity at the diffraction maxima has a smooth running under smooth driving voltage changing. At square-form driving impulse applied, power short-time intensity pulses may be observed at diffraction maxima, with time duration being equal to that of the time-rise of the driving pulse. Then, light intensity is stabilized at some smaller value during the entire driving pulse time. Observed phenomenon is quite explained by the following. During the forming process of the final phase grating under some driving voltage applied, a set of intermediate "simultaneous" gratings are formed. One (or a few) of them possesses an optimal combination of parameters that results in larger diffraction efficiency than that of the final grating. If someone were able to get an analytical expression for dependence of light intensity at the diffraction orders versus a combination of all parameters, finding the optimal combination of parameters would have presented no difficulty. However, in practice this is an undecidable problem. In literature there are some analytical expressions for very simple cases [5,6]. So, in [5] the case of planar LC orientation and polarized light is considered. By the way, here it is shown (including the experimental results) that at least for this specific case, it is possible to produce the diffraction efficiency close to 100%. In [6] the case of twist orientation is considered, but also in a simplified version.

4.There is a possibility of inverse light modulation at the 0-diffraction-order for the different orientation of polarization plane of incoming light. The phenomenon is observed with the usage of planar orientation of nematic LC or ferrroelectric LC. The common feature of the last is a small phase shift gained at the reorientation process. This effect becomes apparent in the following case. In the measurements of outcoming polarized light at the 0-diffraction-order without polarizers, it is possible to detect non-effective (40-50%) light modulation compared to the initial level of 100%. With the analyzer usage, the light intensity is turned out to be opposite phase modulated for the orthogonal polarizations, with the modulation depth of each polarization being possibly different. So, at the driving voltage applied the light intensity of one of the orthogonal polarizations is decreased while is increased for the other (orthogonal) one. In observations without analyzer, the modulation depth is defined by the sum of light intensity of each polarization. If the modulation depth of both polarizations is equal to each other, than in the case of analyzer unused the net modulation depth will be

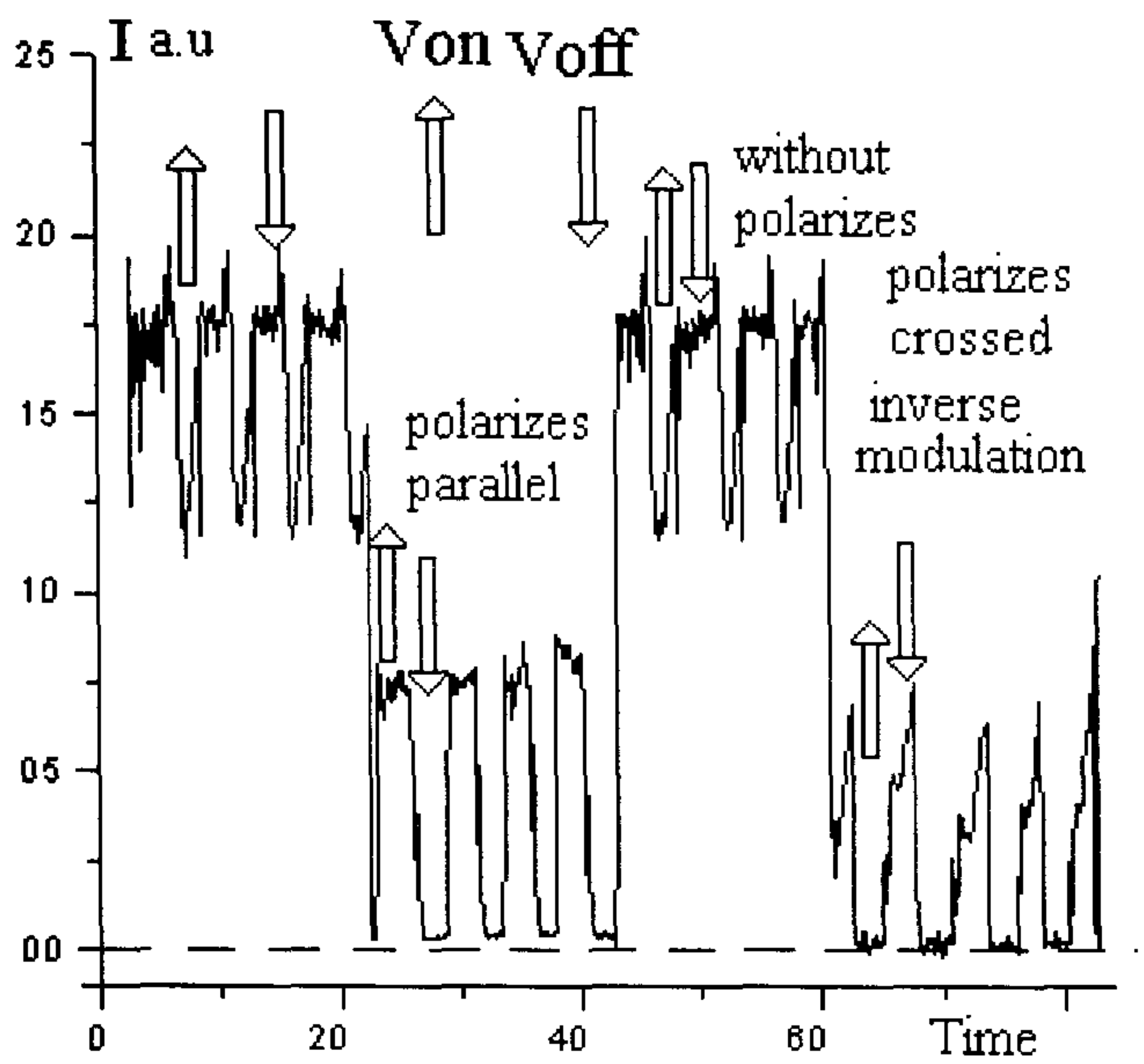

Figure 5 Intensity modulation (0 order) by different polarizes combination

small, or won't be observed at all. If the modulation depth of each polarization is essentially different in value, than the net modulation depth with analyzer unused will be substantial, and with the modulation depth of one polarization is equal to zero, the net modulation depth will be maximal. All these cases have been observed in our experiments.

It is reasonable that intensity modulation depth at the zero-diffraction-order determines the light intensities of diffraction maxima of nonzero-diffraction-orders. If modulation depth of the zero-diffraction-order is small (there occurs the redistribution of light intensity between the polarizations of the zero-diffraction-order), the light intensity of nonzero-diffraction-orders is also small, and vice versa. All these cases we have observed experimentally and found out that polarization phenomena are most pronounced for thin LC cells of planar orientation (the net phase shift is about of 2π), for ferroelectric LC-cells of extremely small layer thickness.

5. Polarization phenomena do not practically observed with the usage of STN-layers and layers operating at cholesteric-nematic transition.

5.Conclusion

1. Our studies confirmed that any EO-effect capable playing phase modulation may be used for DLCD and there is no any preference to one of them with the point of diffraction efficiency criterion. That gives to DLCD manufacturers very wide possibilities for a choice of DLCD design.

2. Polaroidless EO-effects, utilized in diffraction phase modulation mode of operation, possess the same main parameters (steepness of the VCC, switching times) compared to those they have in their common LCD usage. The most steep curve of VCC was observed to possess the STN-based mode of operation and the most flat one to do the electric field controlled birefringence mode.

3. DLCD operation based on EO-effects of diffraction phase modulation has some features, in particular:

- because of the presence of residual polarizing dependencies, it is possible for the zero-order-diffraction the light intensity swapping from one orthogonal polarization to the other counterpart and, as a consequence, small diffraction efficiency and low image brightness;
- in a transient process of switchable grating formation under driving voltage applied, there may be formed "simultaneous" phase gratings with higher diffraction efficiency than that for the stationary one.
- The absence of analytical expressions describing the phenomena does not allow us to determine optimal parameters of these "simultantaneous" gratings, but there is an assurance of their existence and their determining possibly in the experiments.

4.Our present studies confirm that DLCD's possess high consumer wants and their production cost is lower compared to the commonly used types of color LCD's. Even now DLCD's could be manufactured with the existing industrial equipment of minimal updating.

6. References

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