Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

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Version of record first published: 14 Jun 2011

To cite this article: Marek Olifierczuk & Jerzy Zieliński (2011): Analysis of Switching Time of Transmissive TN Cell - Light Detector Structure, Molecular Crystals and Liquid Crystals, 544:1, 165/[1153]-169/[1157]

To link to this article: http://dx.doi.org/10.1080/15421406.2011.569396

Mol. Cryst. Liq. Cryst., Vol. 544: pp. 165/[1153]–169/[1157], 2011

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421406.2011.569396

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Analysis of Switching Time of Transmissive TN Cell – Light Detector Structure

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Liquid crystal cells can be used not only as an element of a display, but also as a part of other devices, for example fast optical shutter. In such a situation the response time of whole device depends not only of switching time of liquid crystal layer, but the mutual relation between optical matching of liquid crystal cell and spectral characteristic of light detector sensitivity also influences it. In this work the analysis of a switching time of whole device including thin twisted nematic cell (TN) and light detector with different Gaussian characteristics of sensitivity was done. As a results the influence of sensitivity characteristic of used light detector (wavelength of maximum and half-width) on dynamic characteristics of fast light shutter with transmissive TN cell is presented.

Keywords Liquid crystal switch; optimization procedure; switching time; TN cell

1. Introduction

Liquid crystal cell, for example TN cells, can be used not only as a main part of systems of visualization, but also as a part of optical shutter (light valves), not mechanical and very fast switches. Such switches could be applied, for example, in sight protection devices or 3D visualization systems. The main optical parameters in this case is contrast ratio, especially low level of luminance of dark state, and switching times. These last parameters are the most important and as one can see from our previous paper [1] can be obtained for example using a TN thin layer. Additionally these parameters are a function of not only reorientation process of liquid crystal layer director, but also mutual relation between optical matching of liquid crystal cell and spectral characteristics of applied light detector.

In this paper light shutter using cell with TN effect was analyzed. The results as special switching characteristics for the both modes of a LC cell: positive and negative ones were presented. These characteristics were obtained in theoretical calculation way for ideal polarizers and as a function of spectral characteristics of used light detector with Gaussian filter with different position of maximum of sensitivity and different half-width. In this place it should be underlined, that any properties of a liquid crystal layer are not analyzed and optimized in this work. The main aim of

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our analysis is to shown of influence of mutual relation between optical matching of TN cell and sensitivity curve of a light detector with Gaussian characteristics. It turn out that the same process of molecules reorientation in liquid crystal cell is detected in different way. In the other words, the different switching time is ''observed'' by detector in depending on it's sensitivity characteristics.

2. Assumptions of Done Calculations

As a liquid crystal cell the TN thin layer placed between standard float sodium glass with ITO layer matching to the first transmission minimum was used. For fast TN switch the thickness should be about 2–3 μm [2] – we assumed 2 μm, therefore birefringence equals to 0.24. The polarizer and analyzer with the same ideal properties (polarization coefficient equal to 1) was assumed. Such films were used, because our previous analysis shown that its polarization coefficient does not influence on switching characteristics detected by detector. The detector's sensitivity characteristic was assumed in Gaussian form with different position of maximum and different half-width.

The results were obtained by mathematical calculations of a light intensity after passing the liquid crystal cells taking into account sensitivity of a detector. The light source A type was assumed. To the calculations computer program called by us CSOP (Computer Support of Optimization Process) and worked out in our Institute was used. This program basing on mathematical model of modified Jones matrix method [3–6] makes it possible to obtain spectral transmission function and the other optical parameters (luminance, contrast ratio, color coordinate etc.) for liquid crystal display with any director profile in a layer and for any observation angle. The absorption phenomena, multi-interference, real directions of the both waves: ordinary and extraordinary one together with proper polarization directions of them are taken into account.

Spectral transmission characteristics needed to calculate the luminance ''observed'' by detector for the first transmission minimum ($\Delta nd = 0.48$), ideal polarizers for negative and positive mode of a TN cell were obtained. These calculations were done for given set-up of director profiles in liquid crystal layer presented in Figure 1. This set of profiles represents the states obtained in the switching process independent on mixture properties, used electric field and anchoring energy. In the other words, each director profile function appears for different conditions and time for given switch, but a mutual relation between the director profile and optical parameters of a whole device are the same. To do complete analyze of a given switch the function makes it possible to recalculate director profile to time should be used. Such a function can be obtained for given light detector and used liquid crystal cell.

Using the profile characteristics presented in Figure 1 the luminance of ON-state and OFF-state for negative and positive modes of TN liquid crystal cell and also contrast ratio were calculated taking into account the assumptions presented above. The following wavelengths of maximum of detector sensitivity characteristic were used: 450, 500, 550, 600, 650 and 700 nm. For each position of maximum the half-widths of sensitivity function were as follows: 5, 15, 30 and 50 nm. The obtained results are presented in Figures 2 and 3.

The same results but for negative mode of used TN cell are presented in Figure 3.

Using the results obtained to this end, the switching characteristics of whole devices (TN cell and detector) as the universal quasi-dynamic characteristics

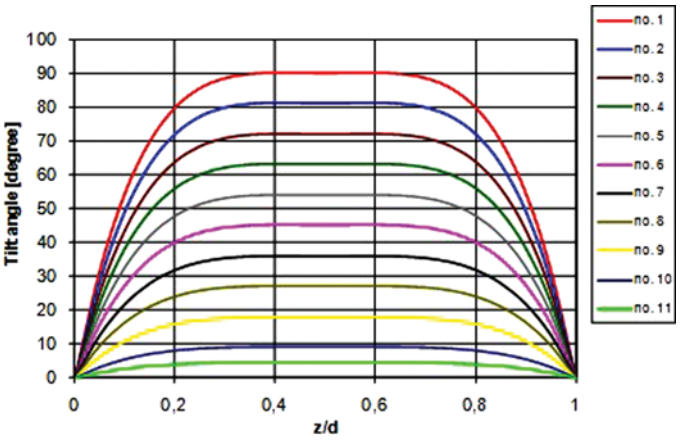

Figure 1. The set of a director profile used in the calculations of a transmission, dynamic characteristics and switching times. Profile no. 1 represents full ON-state (dark state in positive and bright state in negative mode, respectively). Profile no. 11 represents full OFF-state.

(function of a director profile during reorientation process) were obtained. These characteristics were obtained for given wavelength of maximum of detector sensitivity function, from 450 to 700 nm with a step equal to 50 nm, and for different half-width from 5 to 50 nm. Next, the switching parameters, which were represent by number of profile and called T_{10} (for 10% of transmission) and T_{90} (for 90% of transmission) were calculated from this characteristics for the both TN cell modes: positive and negative one. The results are presented in Figure 4. Its are very

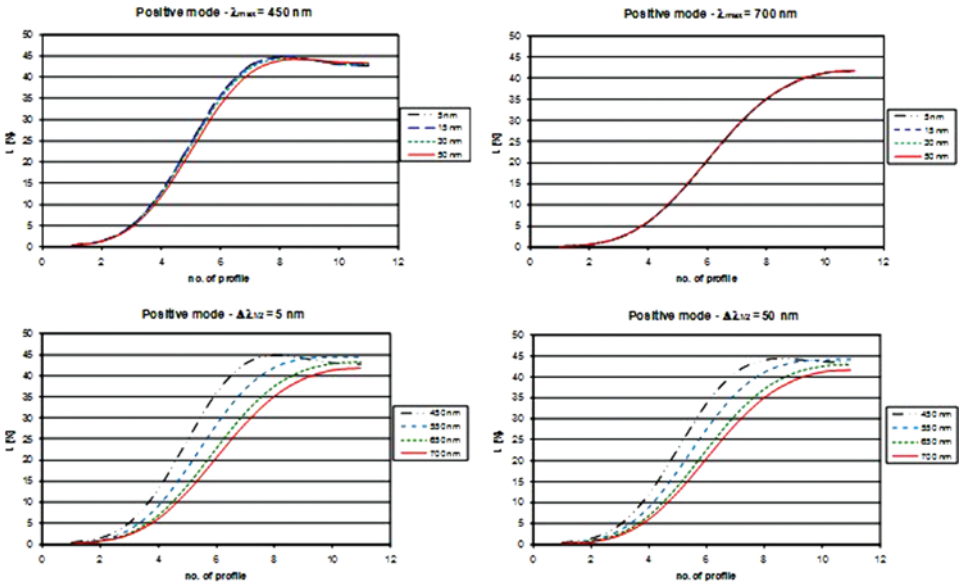

Figure 2. The switching characteristics for positive mode of TN cell and light detector with different sensitivity function. (Figure appears in color online.)

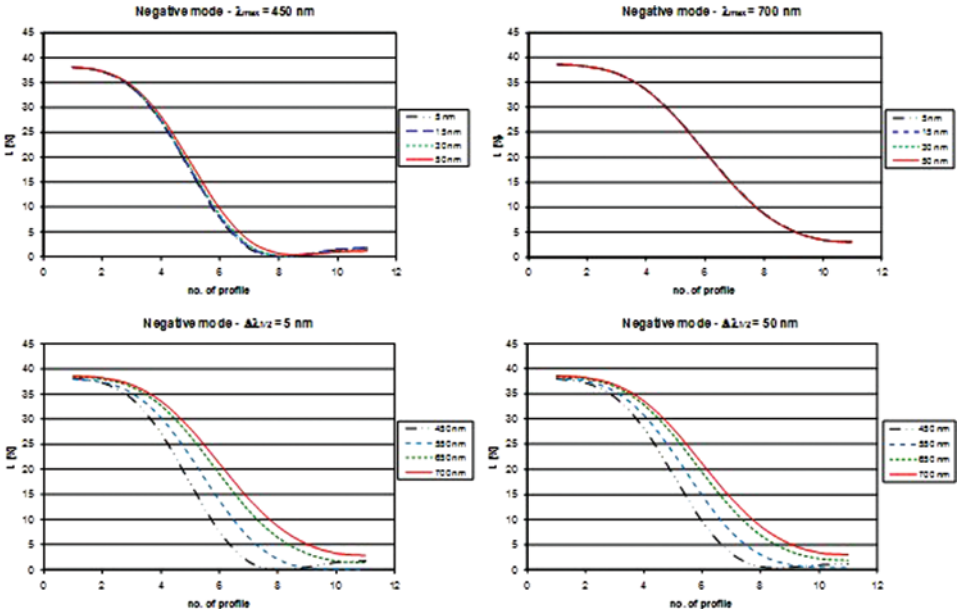

Figure 3. The switching characteristics for negative mode of TN cell and light detector with different sensitivity function. (Figure appears in color online.)

interesting results, because show that these switching parameters do not depend on used display mode (parameter T_{10} for negative mode responds parameter T_{90} for positive one and inversely). Additionally, one can see that these parameters strongly depend on light wavelength of maximum of detector sensitivity, but week depend (especially for wavelength of detector sensitivity maximum higher than 550 nm) on half-width of this characteristic. It is interesting, because it gives information, that to obtain a faster switch, independently on construction of a liquid crystal cell, the detector with the proper sensitivity characteristics should be used.

As one can see from the obtained results presented in figures above, the proper choosing of the mutual relation between optical matching of a TN cell, position of maximum of light detector sensitivity characteristic and it's half-width influence very strong on the switching parameter of a whole optical switching device.

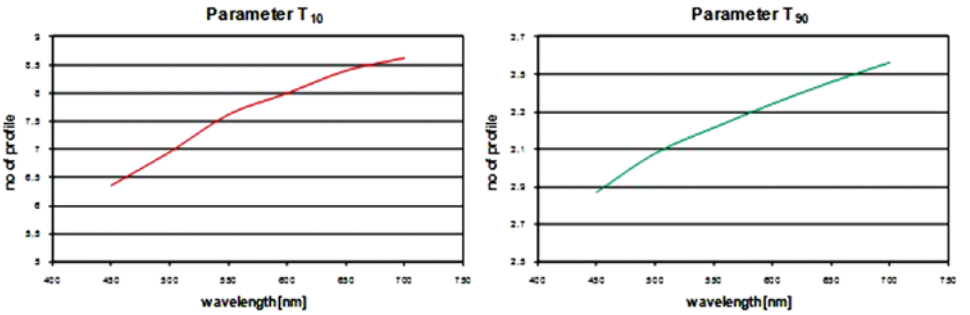

Figure 4. The switching times calculated for analyzed TN switch as a function of light wavelength of a maximum of detector sensitivity characteristic. (Figure appears in color online.)

3. Conclusions

The obtained and presented results include very important information about the operation of the switch using TN thin cell and light detector with the different Gaussian sensitivity characteristic in visible range. As one can see the director profile which corresponds with proper switching time is different for different wavelength of maximum of sensitivity characteristic. This difference is very high, for example in negative mode for 450 nm number of profile for which T_{10} is obtained changes from 4.42 (450 nm) to 8.53 (700 nm) and for T_{90} changes from 2.84 (450 nm) to 3.54 (700 nm). For this reason, such the characteristics as presented in Figures 2, 3 and 4 can be very useful to proper construct the optical switch using TN cell.

Acknowledgment

This paper has been done in 2010 year under financial support the Polish Ministry of Sciences and Higher Education, Key Project POIG.01.03.01-14-016/08 "New Photonic Materials and their Advanced Applications".

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