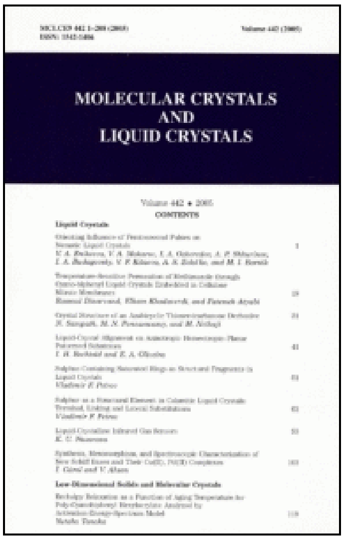

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Fast Response TN Switch - Numerical Analysis of Transmission Function

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Fast Response TN Switch – Numerical Analysis of Transmission Function

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The paper presents the application of the LCD modeling and optimization system for the design and development of the new fast response TN LCD configuration. This switch means in this work the set-up: thin transmissive TN display and detector, which gives the answer for the light impulse passing the display. The analysis was done for different polarizing films, light wavelength and for chosen set of director profile function.

As a results the switching characteristics calculated for given set of director profile function were obtained.

Keywords Fast response liquid crystal switch; optimization procedure; switching time

1. Introduction

Nowadays, liquid crystal displays (LCDs) are widely used in the systems of visualization of information. For these applications new effects with high optical parameters, wide observation angle, right switching times and good color fidelity were worked out. But, in such the displays the switching time values have enough to obtain approximately 100 images per second (100 Hz addressing). Therefore, for such applications the switching times can be of about 8 ms.

But, independently of display market, liquid crystal technology can be applied in very many different applications, for example switches. In this work the fast switch working with twisted nematic effect was analyzed. These fast switches can be used in many system such as light shutters (light valves) in sight protection devices or 3D visualization systems.

In a switch LCD practically works in two states only, completely off and on ones [3], while the other intermediate states, which were very important in display applications to obtain full color visualization, are not used. Additionally, fast switch has to give high contrast ratio (difference between bright and dark states) but this parameter can be obtained in very narrow observation angle and wavelength range, because in a switch the detector with chosen by user sensitivity characteristic is placed

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in one and fixed place. Taking into account the character of such a visualization the passive addressing effects with low switching times were preferred. For these reasons the effects occurring in smectic liquid crystal layers widely were studies [4,5]. Unfortunately, the problems with obtaining time-stable orientation of such a layer and necessity of applications of very think layers caused that interest of such layers gradually decreased. In the same time, the nematic mixtures with high value of Δn were synthesized. Such mixtures make it possible to construct very thin TN switches. In this way, classic and good described TN effect can be used in new applications.

In this work LCD light shutter taking advantage of TN effect was analyzed. The spectral characteristics of positive and negative mode of such a switch were obtained for switching process. The switching characteristics as a function of polarization coefficient of used polarizers, wavelength and optical matching of a liquid crystal layer were calculated for transmissive mode, because such a mode is typical to apply as switches.

It should be underlined in this place, that in this work the properties of a liquid crystal layer are not analyzed and any optimization process of reorientation of the liquid crystal molecules are not carried out. The liquid crystal cell is treated by us as a light modeling device, in which the reorientation process is defined by changing in the time director profile function.

Our goal is to answer the question: how does detector (with different light wavelenght window) influence the measured time of switching (defined as a time between recording by detector given levels of light transmission).

2. Assumptions of Calculations and Obtained Results

To analyze the liquid crystal switch used TN effect, which the schema is presented in Figure 1 was assumed. As one can see it is standard transmissive TN LCD, but with a liquid crystal layer thickness is equal to 2 μm. Such a thickness was assumed, because it just assures short switching times and it is possible to obtain. Certainly, this thickness requires to use a nematic mixture with high birefrigrence, higher than 0.2, but this problem was solved, yet.

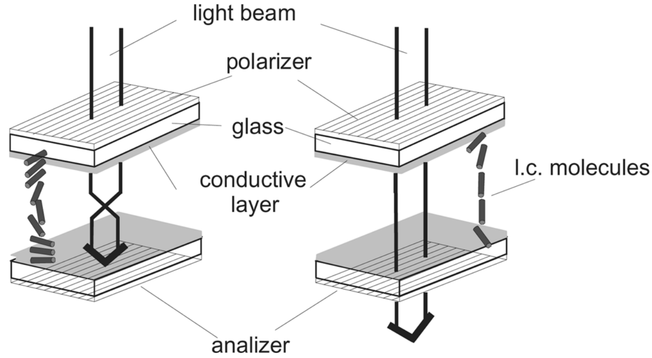

Figure 1. The schema of TN switch assumed in the calculations. Left figure: OFF-state, right one: ON-state.

Table 1. Properties of the polarizing films used in the calculations

No.	Polarization coefficient PC
1	*0.99999*
2	0.99975
3	0.99765
4	0.97802
5	0.95767
6	0.92118

The following parameters of particular layer of TN LCD were assumed in the next calculations:

- glass with refractive index equal to ***1.5267*** (435 nm), ***1.5224*** (486 nm), ***1.5187*** (546 nm), ***1.5178*** (587 nm) and ***1.5143*** (656 nm). It is float sodium glass with thickness equal to ***500*** **μm**;
- conductive layer with the refractive index equal to ***1.832***. It is standard ITO layer with thickness equal to ***25*** **nm**;
- liquid crystal layer with thickness of ***2*** **μm**;
- polarizer and analyzer with the same properties (no dispersion phenomena). The set-up of these films is presented in Table 1.

The first polarizer (described using italic font) is an ideal one.

Our calculations were done by computer program called CSOP (Computer Support of Optimization Process) worked out in our Institute. This software bases on mathematical model (Jones matrix method modified by us) and is described in detail in our previous papers [5–8]. It makes it possible to calculate spectral transmission function and other optical parameters such as luminance, contrast ratio, color coordinate etc. for transmissive and reflective display and for any observation angle. The multi-interference phenomena, absorption, real directions of ordinary and extraordinary waves and polarizations of them are taken into account. This program can calculate the optical parameters of a display for any director profile in a liquid crystal layer.

During our analysis the calculation were done in two groups:

I. Spectral transmission characteristics for the first transmission minimum ($\Delta nd = 0.48$) as a function of polarization coefficient of used films for negative and positive mode were obtained. These calculations were done for given set-up of director profiles in liquid crystal layer presented in Figure 2. This set of profiles represents the states obtained in the switching process. It can be treated as an universal presentation of switching process independent on mixture properties, applied electric fields and anchoring energy. In the other words, each director profile is achieved for different conditions (different time) for given display (switch), but mutual relation between the director profile and optical parameters of a device are fulfilled. To full analyze of a given switch the recalculation function between director profile and time should be used.

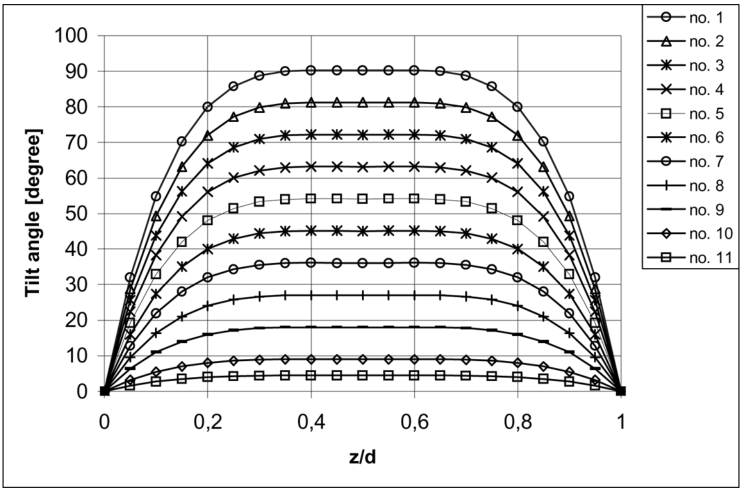

Figure 2. The set of a director profile used in the calculations of a transmission, dynamic characteristics and switching times. Profile no. 1 represents full on-state (dark state in positive and bright state in negative mode, respectively). Profile no. 11 represents full off-state.

The chosen results of a calculated transmission were presented in Figure 3.

Using the results obtained in this step, the universal quasi-dynamic characteristics (as a function of a director profile achieved in a layer during reorientation process) were obtained. These characteristics were obtained for given wavelength, from

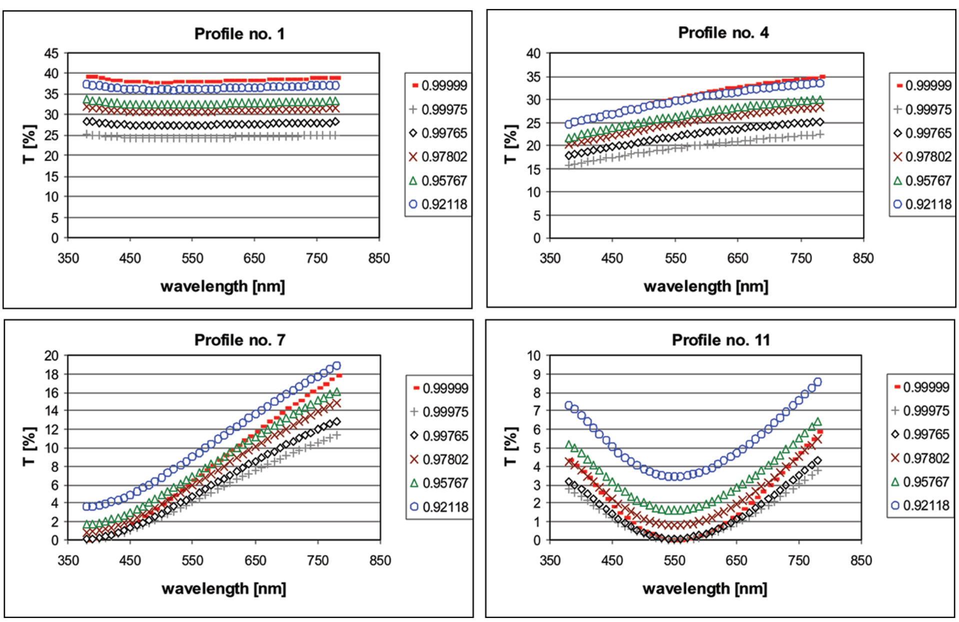

Figure 3. Spectral characteristics for negative mode of an analyzed TN switch obtained for profiles no. 1, 4, 7 and 11 as a function of used polarizers.

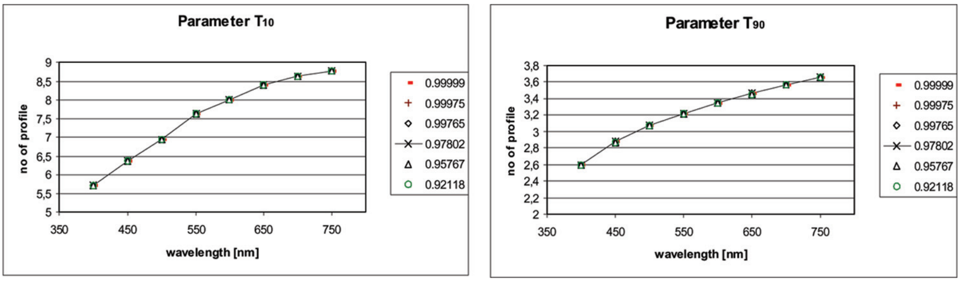

Figure 4. The switching times calculated for analyzed negative mode TN switch as a function of light wavelength passing the switch. The optical matching point is equal to $\Delta nd = 0.48$. One can see a lack of relationship between used polarizers and times (no. of achieved profile).

400 nm to 750 nm with a step equal to 50 nm. In the next step the switching parameters (represents by number of profile) T_{10} (for 10% of transmission) and T_{90} (for 90% of transmission) were calculated from this characteristics for all analyzed polarizers and wavelengths. The calculations were carried out for the both mode: positive and negative ones. The results are presented in Figure 4 and are very interesting, because proofed that these switching parameters do not depend on used polarizing films and are the same for the both modes of a work (it should be remember, that parameter T_{10} for negative mode responds parameter T_{90} for positive and inversely). Additionally, one can see that these parameters strongly depend on light wavelength. It is interesting, because it give the information, that to obtain the faster switch, independently on construction of a liquid crystal cell, the detector with the proper sensitivity characteristics should be used. Certainly, separately problem is a value of an obtained contrast ratio, which is a different for any polarizers and wavelength (for given optical matching Δnd), but this is a other problem, which should be analyzed and solved in the case of specific application.

II. After previous analysis, the second part of calculations was able done for only one mode and one polarizer. We have done our calculations for negative mode and ideal polarizing film using the same layer's properties as in advance. The aim of these calculations was to obtain the switching parameters T_{10}, T_{50} (for 50% of transmission) and T_{90} as a function of light wavelength for different optical matching point (Δnd). As one can see, we wanted find the relationship between Δn of used liquid crystal mixture (because thickness of a layer is assumed as constant) and maximum of used detector sensitivity characteristic. From the results presented to this, the switching parameters depend on analyzed light wavelength and additionally, the difference between T_{90} and T_{10} depends too. Therefore, not only switching parameters depends on used detector (for given TN cell), but also steepness of this characteristic.

To do this analysis the calculations of transmission characteristics and in the next step the quasi-dynamic characteristics for Δnd from 0.05 to 1.2 with the step equal to 0.05 were done. Next, using these characteristic the switching parameters T_{10}, T_{50} and T_{90} were determined for given Δnd (the optical matching point) and light wavelength. The results for wavelength equal to 400 nm, 500 nm, 600 nm and 700 nm are presented in Figure 5.

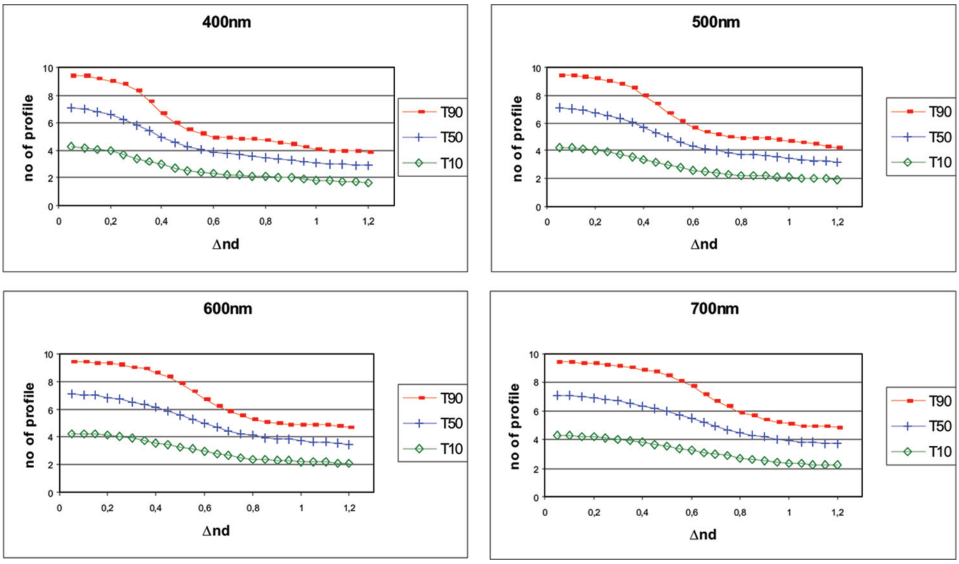

Figure 5. The function of the switching times for given light wavelength obtained for different values of Δnd. TN switch with thickness equal to 2 μm was analyzed.

3. Conclusions

The obtained and presented in previous figures, especially Figure 5 results include very important information about the operation of the switch using TN thin cell and light detector with the narrow sensitivity characteristic in visible range. As one can see for given Δnd the director profile which corresponds with proper switching time is different for different wavelength. This difference is very high, for example for Δnd equal to 0.35 number of profile for which T_{90} is obtained changes from 4.39 (400 nm) to 5.13 (750 nm). These differences are lower for high Δnd, but even in this case are high. For example, for Δnd = 1.05 it is respectively (for T_{90}) equal from 2.19 (400 nm) to 2.80 (750 nm). For this reason, such the characteristics as presented in Figure 5 can be very useful to proper construct the fast TN switch.

Presented results shown, that to obtain the best solution not only optimization procedure for construction of a TN display should be done. The proper matching of TN cell and detector with optimized sensitivity characteristic can significantly improve the properties of such a switch.

Acknowledgments

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