P27-b: Optimization of Reflective LCDs with Phase Compensators

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Abstract

Using the optimization criteria, called "Polarization Transformation Efficiency" (PTE), we have obtained the optimum operating voltages that enable to realize perfect dark and bright states in RTN-LCDs with phase compensators between the polarizer and LC cell. The delicate analysis showed, that if the PTE parameter is close to 1 a 700:1 duty ratio of RSTN-LCD with phase compensators having an average brightness of more than 30% and the contrast 9:1 can be realized. We believe that the proposed new method of LCD optimization can be successfully applied for the definition of new advanced LCD configurations with a high brightness, contrast and duty ratio.

1. Introduction

The applications of the phase compensators is an effective method to obtain a perfect image in LCD with a sufficient brightness and high contrast [1]. However a proper choice of the phase compensators is rather complicated problem even in case of the computer modeling of the output LCD parameters [1-3]. Our paper is devoted to the simple method of the optimization of LCD characteristics, when the phase compensators are introduced. We consider black and white (B/W) switching of one polarizer reflective LCD (RLCD) in RTN mode [4,5]. The new effective configurations of highly multiplexed one polarizer RLCD with B/W switching is proposed.

2. Theory

Consider the non-absorbing TN or STN LCD in the transmissive or reflective mode. In this case the 2x1 vector with a complex amplitudes of the two orthogonal electric field components of the output light can be defined as a product of the transfer matrix © to the corresponding input light vector [6-10]. The evaluation of the matrix © in the approximation of low LC optical anisotropy and normal light incidence can be obtained, using the Jones matrix formalism [6,7]. More accurate estimation also for an oblique light incidence was obtained in [8-10]. In any case the transfer matrix © writes as © = c$\hat{T}$, where c is a complex factor with an absolute value $|c|=1$ and $\hat{T}$ is a Hermitian matrix :

$$\hat{T} = \begin{pmatrix} a & b \\ -b^* & a^* \end{pmatrix}$$

Let the "dark" and "bright" states of the LC cell correspond to the controlling voltages $U=U_1$ and $U=U_2$ accordingly. To obtain the minimum transmission/reflection (T/R) in the "dark" state we may announce as the first optimization criterion, while the second one will be the maximum T/R value in the LCD "bright" state. We may introduce the "Polarization-Transformation Efficiency" (PTE or Q) as follows:

$$Q = 1 - \left|\mathrm{Re}\left[\tilde{F}_1^+ \tilde{F}_2\right]_{11}\right|^2$$

where $\tilde{F}_1$ and $\tilde{F}_2$ are the values of the matrix $\tilde{F}$, that correspond to the voltages U_1 and U_2. The matrix $\tilde{F}$ is defined as follows:

$$\tilde{F} = \hat{T}$$

in case of the two-polarizer LCD and

$$\tilde{F} \equiv \hat{T}_R \begin{pmatrix} -1 & 0 \\ 0 & 1 \end{pmatrix} \hat{T}_D$$

where $\hat{T}_D$ and $\hat{T}_R$ are the transfer matrices, which correspond to the direct and return light propagation in case of one polarizer RLCD. The value of Q is defined by the parameters of the LC in $U=U_1$ and $U=U_2$ states, the light wavelength and the viewing angle. The maximum possible LCD transmission R in the "bright" state is $T=2Qt_p^2$ with t_p being the transmission of the non-polarized light enabled by the polarizer at a given viewing angle. In RLCD case the reflectance $R= 2Qt_p^2t_R$, were t_R is the average reflectivity of the mirror at a given direction. The parameter Q has the values between Q=0 and Q=1. If Q is close to 1, all the announced criteria of the optimization are reached. Otherwise, we are unable to solve the optimization problem. The slight dependence of the parameter Q on the light wavelength and viewing angle testifies to the achromatic switching and wide LCD viewing angles accordingly. We shall demonstrate our approach on the concrete examples of LCD optimization. All the computer simulations were made using LCD-OPT software [11].

3. RTN RLCD with B/W switching

Active Matrix RLCD, including LCOS RLCD, operating in RTN mode was found to be very promising [4,5]. The typical reflectance spectra of RTN-LCD in $U=U_1$ and $U=U_2$ states is shown in Figure 1, while Figure 2 provides the voltage dependence of the average reflectance. The color of the "dark" state can be avoided, if we place the phase compensator between the polarizer and the LC cell. Figure 3 shows the dependence of the PTE parameter Q_{550} evaluated at λ=550nm for a normal light incidence of the model RTN LCD on the value of applied voltage $U=U_2$ in case $U=U_1$ is the "bright" state. The U_1 values are shown for various LCDs on Fig. 3. The region of U_2 values, when Q_{550} is close to 1 ($2.2V \le U_2 \le 3V$ for RTN LCD) defines the appropriate operating voltages (Fig.3).

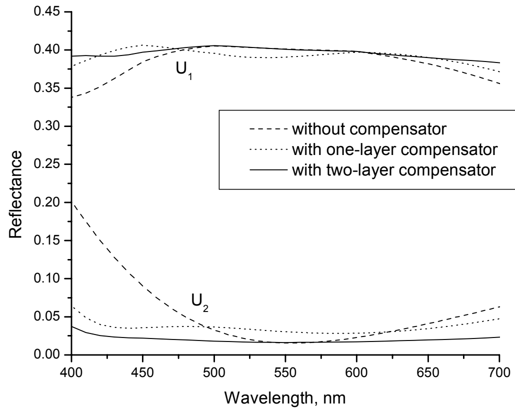

Figure 1. Reflectance spectra of RTN-LCD. The voltage U_1=0 in the "bright" state. U_2=2.65 V and U_2=2.73 V for the "dark" state without and with compensator respectively. <u>RTN RLCD</u>: K_{11}=1.32x10^{-6} dyne, K_{22}=6.5x10^{-7} dyne, K_{33}=1.38x10^{-6} dyne, $\varepsilon_{\|}$ = 8.3, $\varepsilon_{\perp}$ = 3.1; principal refractive indices: $n_{\perp}$=1.48, $n_{\|}$=1.58 at wavelength 550 nm. Twist angle =52^0, pretilt angles= 4^0, LC layer thickness d=5.36 μm. <u>Phase compensator:</u> principal refractive indexes $n_{\perp}$=1.5, $n_{\|}$=1.58, thickness L_1=4.3μm, orientation angle φ_1=92.8^0, polarizer angle β=9.5^0.<u>Two phase compensators:</u> $n_{\perp}$=1.5, $n_{\|}$=1.58, L_1=6.07μm, φ_1=86.05^0, L_2=1.66μm, φ_2=2.41^0, β=2.96^0.

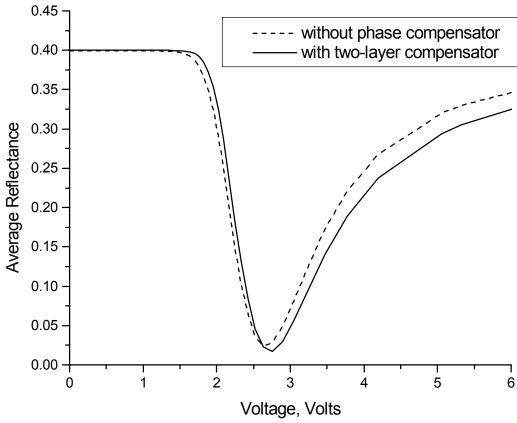

Figure 2. Voltage dependence of average reflectance of RTN-LCD.

Figure 4 provides the spectral dependence of the PTE parameter Q for RTN-LCD at various voltages U=U_2, when U_1 =0V. As seen from Fig.4, if we choose U_2 =2.73 V, we can obtain an achromatic and highly transparent "bright" state, as the parameter Q is close to 1 within the whole region of the visible spectra. Indeed, if we minimize the average RLCD reflectance at U_2 =2.73 V, we can get the desirable reflectance in the "bright" and "dark" states (Fig.1). The best parameters of the phase compensation are obtained, when we apply the two uniaxial compensators, however we provide for comparison also the results with one uniaxial compensator.

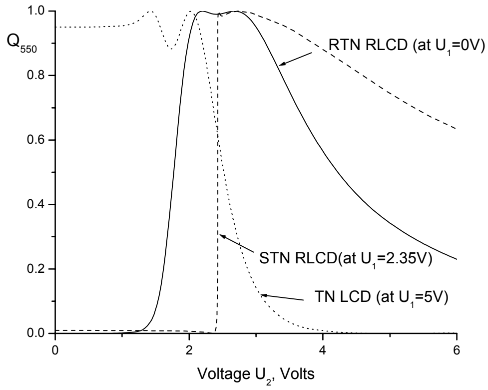

Figure 3. Voltage dependence of PTE Q_{550} for various LCDs. <u>STN RLCD</u>: K_{11}=1.28x10^{-6} dyne, K_{22}=7.25x10^{-7} dyne, K_{33}=2.06x10^{-6} dyne, $\varepsilon_{\|}$ = 11.07, $\varepsilon_{\perp}$ = 3.61; principal refractive indices: $n_{\perp}$=1.5, $n_{\|}$=1.6 at wavelength 550 nm. Twist angle =240^0, pretilt angles= 4^0, d/p_0=0.5, where p_0 is natural helix pitch. The parameters of <u>RTN-LCD</u> are given above (see Fig.1) The parameters of <u>TN-LCD</u> are typical [1].

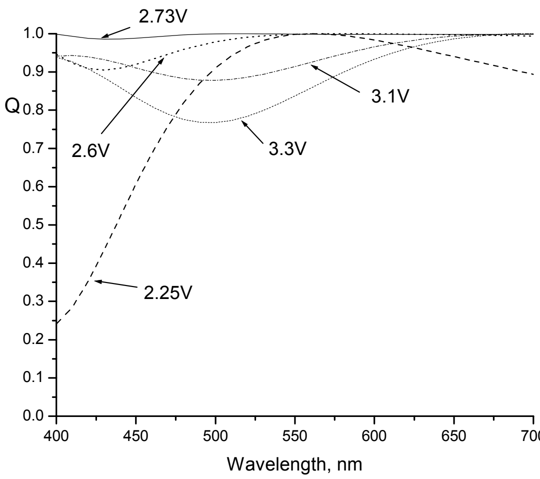

Figure 4. Wavelength dependence of the PTE parameter Q for RTN-LCD at various voltages U=U_2, when U_1 =0V.

4. Highly multiplexed achromatic one-polarizer STN-RLCD

The highly multiplexed achromatic STN RLCD is desirable for the displays of cellular phones, PDAs, e-books etc. The region of the operating voltages U_2 in this case is defined above in case of U_1 =2.35V (Fig. 3). If U_1=0V, the corresponding values of the PTE quality parameter Q for various LCD thickness and operating voltages U=U_2 are presented in Fig.5. The most drastical change of Q is found for the LCD cell thickness between 6.5 and 7.7 μm. However if U_1= 2.35V (Fig.3) the optimal LCD cell thickness should be 7.4μm.

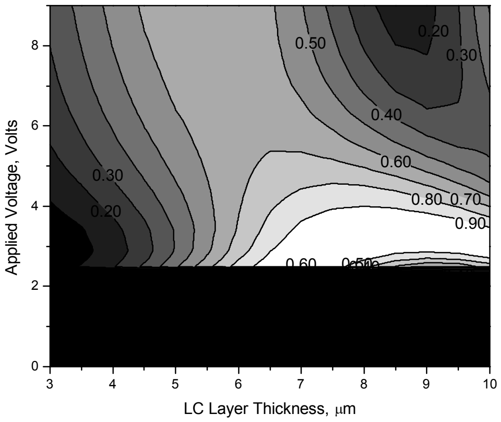

Figure 5. The PTE parameter Q of STN RLCD for various operating voltages U=U_2 and LCD thickness (U_1=0V).

Figure 6 shows the wavelength dependence of the parameter Q for U_1=2.35V and U_2=2.44 V. In this case STN RLCD can provide a multiplexing ratio 700:1. The reflective spectra of STN-RLCD and the reflectance-voltage dependence and are given in Figs.6 and 7 respectively. The optimal parameters of STN RLCD are obtained by the application of the two phase compensators (two-layer compensator) between the input polarizer and STN RLCD cell. As seen from Fig.7 the contrast of STN RLCD is more, than 9:1 and average reflectance is higher, than 30%.

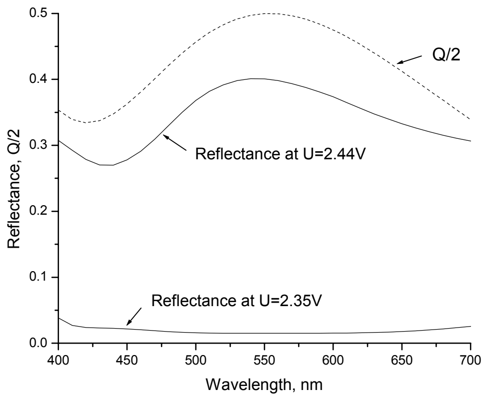

Figure 6. Spectral dependence of optimized reflectance of STN RLCD with the two phase compensators between the polarizer and STN RLCD cell. The two-layer compensator has the following parameters: $n_\perp$=1.5, $n_\parallel$=1.58, L_1=5.48μm, φ_1=125.9^0, L_2=1.42μm, φ_2=89.6^0, β=45.3^0. For the definitions of the parameters see Fig.1.

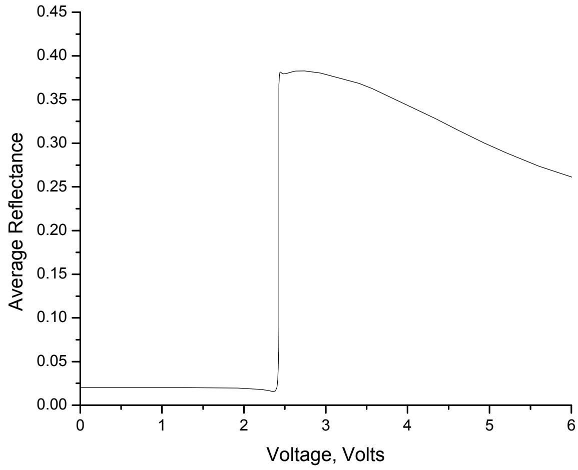

Figure 7. Reflectance-voltage characteristic of optimized STN RLCD with the two phase compensators.

5. Conclusion

Using the optimization criteria, called "Polarization Transformation Efficiency" (PTE), we have obtained the optimum operating voltages and LC layer thickness that enable to realize perfect dark and bright states in various types of LCDs. We demonstrated our approach using reflective LCDs in RTN and STN-RLCD modes with phase compensators. The delicate analysis showed, that if the PTE parameter is close to 1, a 700:1 duty ratio of STN RLCD with phase compensators having an average brightness of more than 30% and the contrast 9:1 can be realized. We believe that the proposed new method of LCD optimization can be successfully applied for the definition of new advanced LCD configurations with a high brightness, contrast and duty ratio.

6. References

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