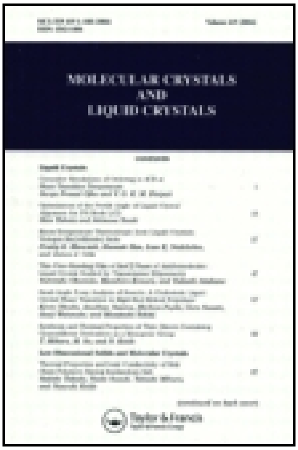

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Optimization of “Guest-Host” Liquid Crystal Display

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Optimization of "Guest-Host" Liquid Crystal Display

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Using MOUSE-LCD software we analyze, how the parameters of the "guest-host" cell effects such basic characteristics of LCDs as the contrast, brightness and magnitude of the viewing angles. The basic construction of "guest-host" LCD includes one input polarizer and reveals a negative contrast. We showed, that to increase the average contrast, transmission and viewing angles of "guest-host" LCDs we have to use the LC cells with the twist angle of 90°, while the thickness of the LC layer should be sufficiently high. The concentration of the dye must be optimized for the applied values of LC cell thickness and twist angle. The higher values of LC optical anisotropy Δn results in the increase of the display contrast in our case, contrary to the non-polaroid variant of "guest-host" LCDs.

One-polarizer construction of a transmissive «guest-host» LCD with a phase retardation plate was also analyzed. The application of a phase compensator in GH-LCDs allows to use thin LC cells with a high concentration of dichroic dye to get a maximum contrast and transmission for minimum response times. Our calculations may be helpful for the production of the new efficient "guest-host" LCD configurations

Keywords: "guest-host" effect; LCD; contrast; brightness; dichroic dye

INTRODUCTION

«Guest-host» LCDs found their applications in large information boards, car dashboards, advertising and information displays in vehicles, stations, airports etc[1]. The GH-LCDs possess wide viewing angles, high contrast and require either one or no polarizers. One polarizer GH-LCDs are characterized by a sufficiently high contrast, with low brightness (slightly more than 10% in open state) in a homogeneous LC configuration or more bright displays (>20%)with a small contrast ratio in 90^0 twisted LC configuration [1-3].

In this paper we propose one polarizer transmissive GH-LCD with high contrast and brightness. We show ways, how to improve the LCD quality by varying the LC layer thickness, LC twist angle, the concentration of the dichroic dye in LC bulk and LC optical anisotropy. The optimization of the construction can be also made with the help of a properly chosen phase compensator, placed between the polarizer and LC cell .

OPTIMIZATION PROCEDURE

We obtained our results of optimization using MOUSE-LCD modeling software [4]. In our calculations we used the parameters of Merck LC mixture ZLI-4714/3 and NIOPIK dichroic dye KD-1 [1] with a positive dichroism and an order parameter S=0.73 together with a neutral polarizer NPF-1205 DU. The «guest-host» mode with a negative contrast (the brightness was defined as a transmission in the «on» state) has been optimized in our calculations.

We optimize the following parameters of the GH-LCD.

1. The average transmission:

$$Y= T(\lambda)y(\lambda)d\lambda/\ y(\lambda)d\lambda\ , \qquad (1)$$

where the integration is made over the range of the visible spectrum 380nm $\leq \lambda \leq$ 780nm, $y(\lambda)$ – the function of the eye sensitivity and $T(\lambda)$ – the GH-LCD transmission at the wavelength λ.

OPTIMIZATION OF "GUEST-HOST" LCDs

2. The average transmission Y_{on} in the "on" state. The applied voltage exceeds the threshold voltage 5-10 times.
3. Average contrast

$$K = Y_{on} / Y_{off}, \quad (2)$$

where Y_{on} (Y_{off}) – the transmission of the "on" ("off") state respectively. The applied voltage does not exceed the threshold value in the "off" state.
4. The dependence of the average contrast on viewing angles. The polar and azimuthal angles of light incidence are defined as usual from the normal to the LC cell and projection of the LC director to the substrate plane at the center of the twist structure respectively[1,4].
The optimization of the GH-LCD parameters were made in dependence of the LC layer thickness, rotation angle and the dichroic dye concentration. We consider also the GH-LCD construction with a phase compensator, located at the angle of 45^0 with respect to the axis of the entrance polarizer.

OPTIMIZATION RESULTS

The first parameter, used for GH-LCD optimization was the LC structure rotation angle Φ. We investigate , how the display brightness and contrast vary with the LC structure rotation angle Φ (Fig.1). As seen from Figure 1, the GH-LCD contrast decreases monotonously with the rotation angle, while the brightness assumes a maximum value at $\Phi \approx 90^0$.

The decrease of the contrast is explained by the violation of the wave-propagating «Mauguin regime» in a twisted LC structure, when the polarization of the light does not coincide with the direction of the dye absorption oscillator. As a result of this, the transmission in the closed «off» state increases and the GH-LCD contrast ratio falls. At the same time the violation of the wave propagating regime with Φ leads to the decrease of the absorption in the boundary layers in the «on» state, thus the transmission in the open «on» state increases and the display becomes brighter. As seen from Figure 1, the decrease of the brightness is slower, than the fall of the contrast, because the contribution to the absorption of the boundary layers is much smaller, than the total absorption of the LC layer. Let us note that in nonpolarizer (phase-change) GH-LCD the increase of the rotation angle results in the increase of the contrast[2].

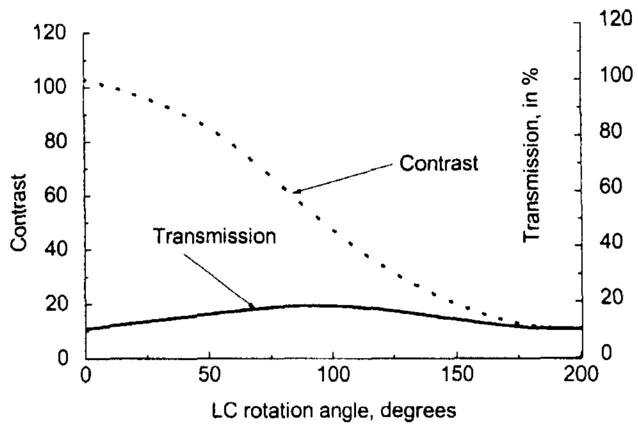


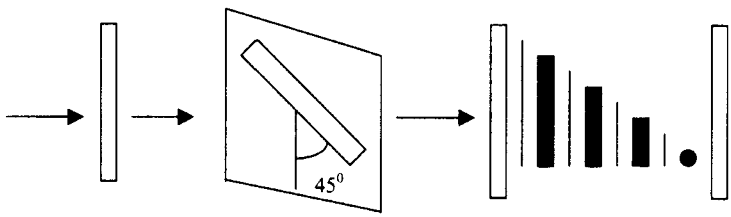
FIGURE 1. Dependence of the GH-LCD average transmission and contrast on the LC rotation angle.

The rise of the transmission in a twisted LC structure is observed only in case of a linear polarized light, while the eigen-modes in a twisted LC layer with the dye absorption are elliptically polarized. Consequently the properly chosen phase plate, which makes the input light elliptically polarized may change the situation, resulting in a maximum absorption in the «off» state. The transmission in the "on" state is not affected by the phase compensator as the LC layer is almost homeotropic in sufficiently high electric fields. Thus the contrast ratio of the one-polarizer GH-LCD with a subsequent phase retardation plate, placed at the angle of 45^0 with respect to the polarizer may considerably improve the contrast. At the same time the display brightness is kept on a sufficiently high level (Table1). Thus the optimum construction of GH-LCD includes a polarizer, a phase compensator, placed at the angle of 45^0 with respect to the former and 90^0 twisted LC cell with a positive dichroic dye (Fig.2).

OPTIMIZATION OF "GUEST-HOST" LCDs

TABLE 1 Effect of a phase compensator on optical characteristics of GH-LCD.

Optical characteristics	GH-LCD with a phase compensator	GH-LCD without a phase compensator
Transmission in the «off» state, T_{off}, %	0.163	0.36
Transmission in the «on» state, T_{on}, %	20.5	20.6
Contrast ratio T_{on} / T_{off}	125	57



Input light Polarizer Phase retardation plate GH-LC cell (90^0 rotation)

FIGIRE 2. GH-LCD with a phase retardation plate.

We should note, that the thickness and the wavelength dependence of the birefringence of the phase compensator have to be optimized, taking into account the absorption band of the dye. In particular the optimal thickness of the phase compensator with the optical birefringence at various wavelengths λ:
Δn (420nm) = 0.00343, Δn (500nm) = 0.0032, Δn (610nm) = 0.003 corresponds to 182 microns (Fig.3).

Let us note, that the application of the black dye mixtures GH-LCDs with phase compensators is complicated, as the latter are sensitive to the wavelength of the light. However the phase compensators might be useful in triple GH-LCD constructions, where the color switching is based on a subtractive color approach [5].

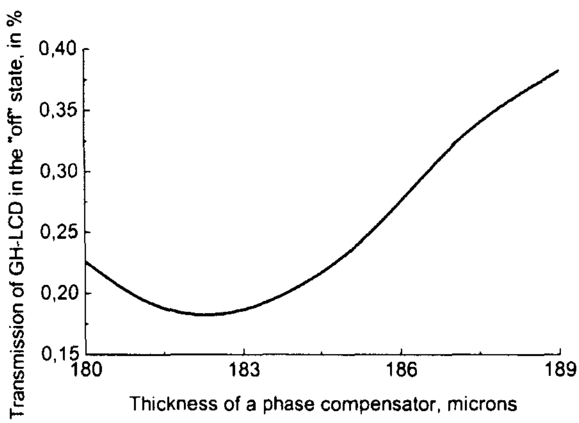


FIGURE 3. Dependence of the GH-LCD transmission in the "off" state on the thickness of the phase compensator.

In our construction both LC layer thickness and the dye concentration can be chosen to improve the contrast ratio of the GH-LCD. The increase of the layer thickness considerably enhances the contrast for the higher LC rotation angles, but usually we can not do this without deteriorating the response times[2]. We show, that sufficiently high contrast can be obtained even for the small LC layer thickness, at the optimal dye concentration (Fig.4). The optimal dye concentration is varied with the layer thickness and LC rotation angle. Thus both high contrast ratio and fast response times can be realized in GH-LCDs.

The optical anisotropy of the LC layer Δn effects the contrast ratio of one-polarizer GH-LCD. The transmission in "on" state does not depend on the value of Δn, as the homeotropic LC layer can not change the characteristics of the transmitted light. According to our calculations larger values of Δn can improve the contrast of one-polarizer GH-LCD due to the corresponding decrease of the transmission in the "off" state. Thus contrary to the phase-change GH-LCD[2] the average contrast of one-polarizer GH-LCD increases with the value of Δn.

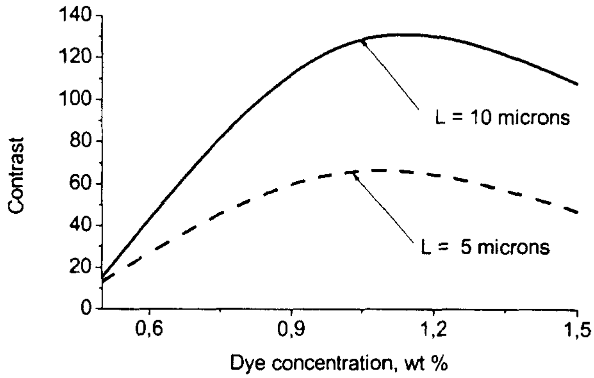


FIGURE 4. Contrast of phase compensated GH-LCD for different concentrations of the dichroic dye and LC layer thickness.

Let us consider the viewing angle dependence of one-polarizer GH-LCD. In this case the most important parameters are the layer thickness and LC rotation angle Φ. The increase of the rotation angle deteriorates the contrast and results in the narrow viewing angles. If we increase the LC layer thickness, keeping constant the average optical density and the order parameter of the dye, we observe increase of the contrast both for the oblique and normal light incidence.

Figure 5 shows the maximum viewing angles of GH-LCD versus the LC rotation angle for light incident at 50^0 with respect to the layer normal. The viewing angles were defined as the values of the azimuthal angles resulting in contrast larger than 10.

Contrary to the conventional TN-LCD the increase of the LC optical anisotropy improves the contrast ratio at oblique incidence and widen the viewing angles of GH-LCD.

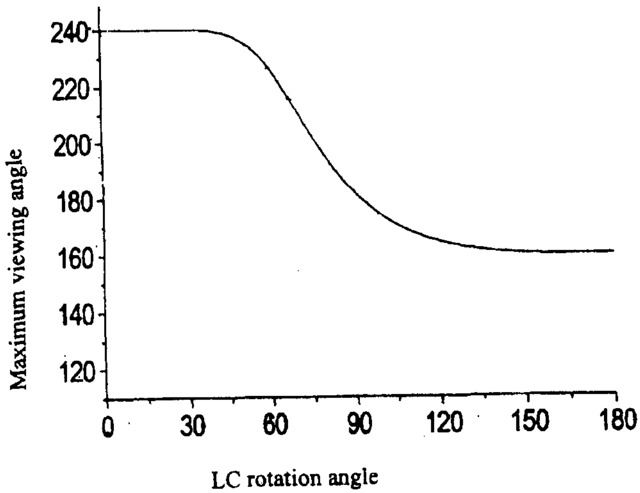


FIGURE 5. The maximum viewing angle of one-polarizer GH-LCD versus LC rotation angle.

CONCLUSION

The basic construction of "guest-host" LCD with one input polarizer and a negative contrast was analyzed using MOUSE-LCD software[4]. We showed, that to increase the average contrast, transmission and viewing angles of "guest-host" LCDs we have to use the LC cells with the twist angle of 90°, while the thickness of the LC layer should be sufficiently high. The concentration of the dye must be optimized for the applied values of LC cell thickness and twist angle. The higher values of LC optical anisotropy Δn results in the increase of the display contrast and viewing angles , contrary to the non-polaroid (phase-change) "guest-host" LCDs.

One-polarizer construction of a transmissive «guest-host» LCD with a phase retardation plate was also proposed. The application of a phase compensator in GH-LCDs allows to use thin LC cells with a high concentration of the dichroic dye to get a maximum contrast and transmission for minimum response times. The construction could be in particular useful for the triple GH-LCD configurations with subtractive colors. Our calculations may be helpful for the production of the new efficient "guest-host" LCD configurations.

Acknowledgements
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