Contributed paper

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Significance of reflection reduction in a TN display for colour visualisation

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This paper contains the results of theoretical considerations about light propagation through the real TN display working in reflective and negative mode. This mode provides us with a possibility to obtain a colour image. We have done mathematical and numerical analyses of a propagation of light wave through liquid crystal (LC) displays with antireflective layer, glass planes, conductive layers, LC layer and polarisers. We have taken into account real conditions of a display operation, i.e., spectral properties of all components, optical anisotropic and dichroic properties of LC layer, reflections from all phase borders and also spectral characteristics of light source and sensitivity of human eye.

Keywords: twisted nematic, negative mode, contrast ratio, computer modelling.

1. Introduction

The aim of our work is to determine the reflection influences on the optical parameters of reflective TN display for colour visualisation. We have chosen the negative mode of TN display, because this mode makes it possible to obtain colour images (through application of colour filters). The reflective displays must be characterised by small values of intensity of reflected light beam. Otherwise the values of optical parameters, such as contrast ratio or luminance in on-state are not high. In this paper we have determined the influence of reflection from phase borders in the reflective TN display on its optical parameters. We have worked out a numerical program, which has made possible us to obtain the contrast ratio and luminance in on-state for a reflective TN display working in real conditions. We have determined the influence of properties of individual elements of a display, such as polarisers, antireflective layers, conductive layer, glass, LC layer and external illumination on it's optical parameters.

2. Results

To determine the optical parameters of LC display we have done an analysis of the propagation light wave through the particular layers of the display. We have assumed the construction of display as in Fig. 1.

According to the above structure we have obtained a formula describing the value of real part of E-vector of a light in any spot of a display, which takes into account:

- real spectral characteristics of polariser and analyser. In this case we have proposed the right way of measurements of spectral characteristics for parallel and perpendicular polarisers, as well as a single polariser (for transmission polariser) and intensity of reflected linear polarised light from analyser stuck to the glass plate (for reflective analyser). We have worked out the method of calculations, which gives us the results as the transmission ratio for linear polarised light propagating in parallel and perpendicularly to the polarisation axis of polariser or analyser. We have taken into account refraction indexes of the polarising films and the glass. Thus, the obtained results enable mathematical calculation of any spectral light passing through the chosen polarising films,
- real absorption ratio of a conductive layer and it's refraction index in the complex form. In this case, we have also proposed the method of measurements for the

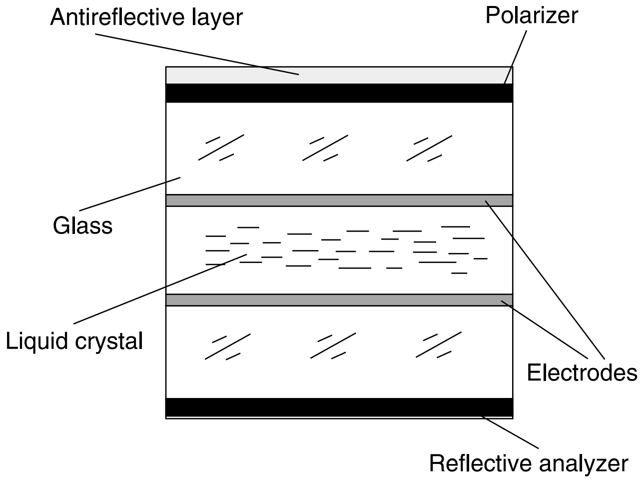

Fig. 1. Scheme of structure of reflective LCD which we have assumed for the analysis.

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structure conductive layer-glass. In the proposed method one can determine spectral characteristic of absorption ratio of conductive layer if the spectral characteristics of the refractive index of the used glass and real part of conductive layer refraction index are given. Additionally, our method takes into account interference of light,

- interference of light passing through the display and reflected from all phase borders,
- real spectral characteristics of light source and sensitivity of human eye,
- any value of tilt angle and dichroic properties of LC layer.

Detailed scheme of the light passing through the TN reflective display assumed the calculations is presented in Fig. 2.

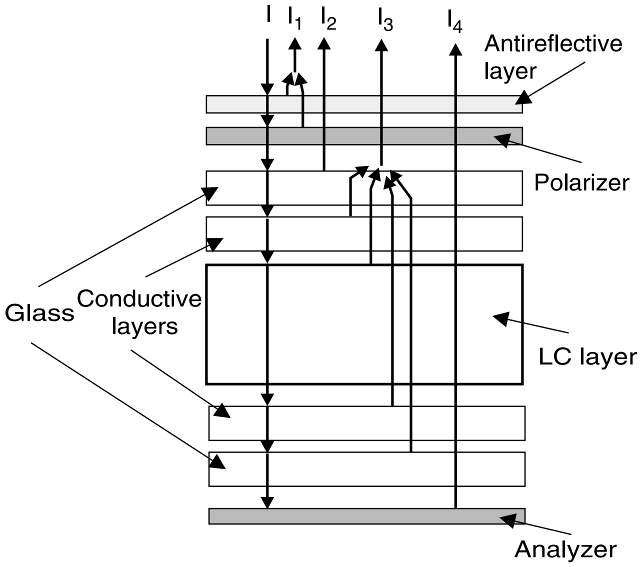

Fig. 2. Scheme of light propagation through the TN reflective display. I denotes the input light beam intensity, I_1, I_2, I_3 and I_4 denote the output light beams intensities, which we must calculate.

Our calculations of the intensity of the light passing through a display have been based on geometry optical approximation method (GOA), but we have taken into account the interference of light, complex forms of refractive indexes of elements of a display and real conditions of the display operation. We have obtained the expressions describing intensity of light in any point of a display for the light linearly polarised according to the axes of co-ordinate system *x'y'*. This co-ordinate system rotates with the axes of indicatrix of refractive indexes ellipsoid of liquid crystal projected on the glass plane (Fig. 3).

$$I_{x'} = (A^n)^2 + (B^n)^2 \quad and \quad I_{y'} = (C^n)^2 + (D^n)^2, \tag{1}$$

where

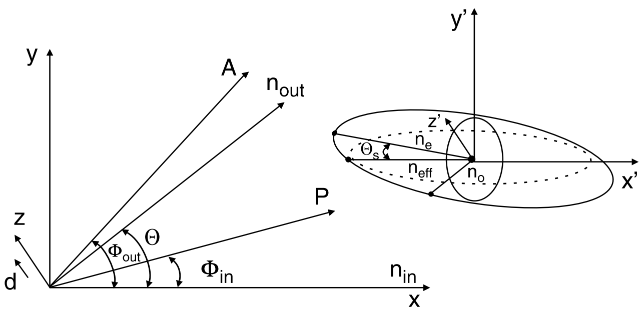

Fig. 3. Co-ordinate systems assumed in our model. The system *x'y'* is the same as system *xy* for the first layer of LC (it is the infinite thin layer of LC situated near of a phase border conductive layer-LC, directly). For the next layers it rotates with ellipsoid of refractive indices of LC. n_{in} is the director's orientation at the input plate (the first infinite layer of LC) overlaps with x axis of the assumed coordinates system, n_{out} is the director's orientation at the output plate (the last infinite thin layer), it is changed by the angle Θ in relation to director's orientation at input plate (texture twist angle – for TN effect $\Theta = 90°$); P is the orientation of a polariser's axis, it gives an angle Φ_{in} with x axis; A is the orientation of an analyser's axis, it gives an angle Φ_{out} with x axis.

$$A^n = \sqrt{e^{-\alpha_{\|}\delta z}}[(A^{n-1}\cos\delta\Theta + C^{n-1}\sin\delta\Theta)\cos\delta_e + , \\ + (B^{n-1}\cos\delta\Theta + D^{n-1}\sin\delta\Theta)\sin\delta_e] \tag{2}$$

$$B^n = \sqrt{e^{-\alpha_{\|}\delta z}}[-(A^{n-1}\cos\delta\Theta + C^{n-1}\sin\delta\Theta)\sin\delta_e + , \\ + (B^{n-1}\cos\delta\Theta + D^{n-1}\sin\delta\Theta)\cos\delta_e] \tag{3}$$

$$C^n = \sqrt{e^{-\alpha_{+}\delta z}}[-(A^{n-1}\sin\delta\Theta + C^{n-1}\cos\delta\Theta)\cos\delta_o + , \\ + (B^{n-1}\sin\delta\Theta - D^{n-1}\cos\delta\Theta)\sin\delta_o] \tag{4}$$

$$D^n = \sqrt{e^{-\alpha_{+}\delta z}}[(A^{n-1}\sin\delta\Theta - C^{n-1}\cos\delta\Theta)\sin\delta_o - , \\ + (B^{n-1}\sin\delta\Theta - D^{n-1}\cos\delta\Theta)\cos\delta_o] \tag{5}$$

where absorption coefficient $\alpha_{\|}$ and α_{+} express absorption of a dichroic layer for the light polarised linearly alongside projection indicatrix of refractive indexes on *x'y'* plane and in perpendicular direction, respectively; δ_e and δ_o are the phase changes for the light linearly (in the same conditions as we have described allow); δz and Θ are the infinitely thin LC layer and right twist angle. The values $A°$, $B°$, $C°$, and $D°$ we have obtained by analysis of the light passing through antireflection layer, polariser, glass, conductive layer (to take into account real conditions of work and other described above properties of elements of a display). After passing the LC layer the light propagates through the next components of the display and then reflects from the analyser. The return way of the light should be analysed in the same way.

The worked out numerical program for calculations of optical parameters of TN LCD (we have named it NAOP

LCD – numerical analysis of optical parameters of LCD) gives us the results in the following form:

- luminance of on-state and off-state L_{ON} and L_{OFF},
- contrast ratio CR,
- colour co-ordinate,

for the given Δ*nd* and for all wavelengths within visible range.

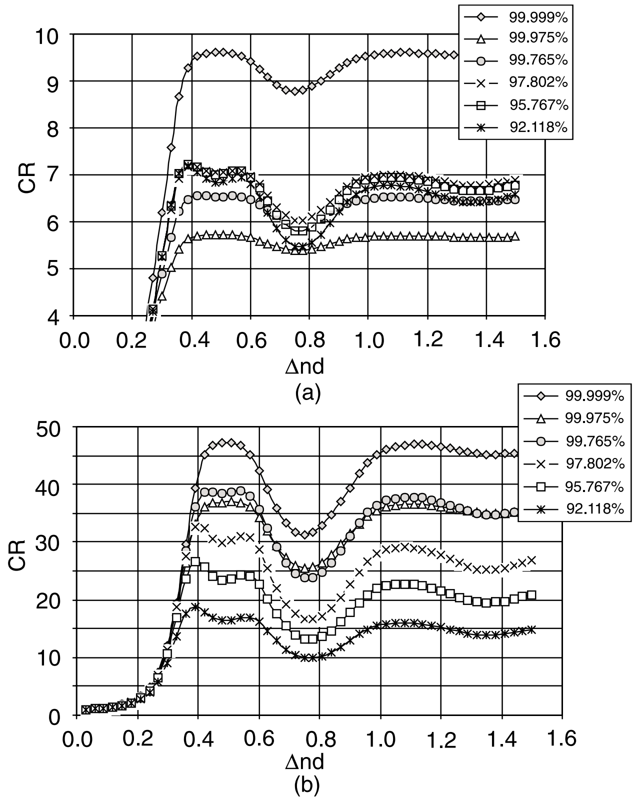

Fig. 4. The function CR = *f(Δnd)* for TN reflective display with different polarisers (in the description there is given a polarisation coefficient). The calculations are done for real conditions (sodium glass, ITO, source A and daily sensitivity of human eye). Illustration (a) represents the situation without an antireflective layer, (b) with an antireflection layer.

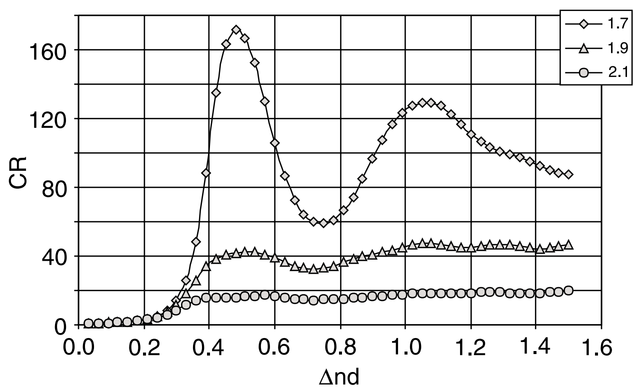

Fig. 5. The function CR = *f(Δnd)* for TN reflective display with different values of real part of a refractive index of conductive layer. The calculations are done for sodium glass, source A, daily sensitivity of human eye, antireflective layer and idea polariser and analyser.

Using our computer program we have obtained the results presented in Figs. 4 and 5.

3. Conclusions

The obtained results show us how important is elimination of harmful reflections in reflective TN displays. Application of an antireflective layer is a necessary condition for obtaining high value of contrast ratio, but matching of the proper values of refractive indexes of each constituent is very important, too. Our program enabled to do the calculations for different conditions of a display work. It provides us with information, which are necessary for constructors of the displays. From the presented results it appears, that application of the antireflective layer increases the value of CR about 4 times, but improper selection of the refractive indexes of elements of a display can decrease CR, e.g. about 8 times.

Our work is an attempt to construct a mathematical model of real TN displays. It can considerably make easier to analyse of LCD to search the optimal structure of such displays. We think that we are in position to perform it successfully for a normal direction of light propagation.

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