P-55: Contrast and Brightness Enhancement of RTN-LCDs Using Antireflective Layers

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Abstract

New constructions of RTN-LCDs with antireflective (AR) coatings were proposed. Both one polarizer and Polarizer Beam Splitter (PBS) variants were considered. The AR coatings can be made both in the outer surface of the one-polarizer RTN-LCD and on the upper substrate between the glass plate and aligning layer. The damping of the LCD reflection in the "dark" state of one-polarizer RLCD by introducing AR layers considerably improves the contrast ratio and only slightly affects the brightness of RLCD. The application of AR-layers in PBS-RLCD results in an improved brightness.

1. Introduction

The rapid growth of the research in the field of Reflective LCDs (RLCDs) is observed recently due to the possibility to a considerable decrease of power consumption, while keeping the high brightness and contrast of RLCDs [1]. The new types of Active Matrix LC displays on silicon (LCOS) with a high aperture ratio were becoming the basic elements of micro-display[2] and projection-display systems[3].

The optimal construction of the one-polarizer Reflective TN-LCD with a high brightness ($d\Delta n = 0.527\mu$, $\phi = 52^\circ$, where d , Δn , ϕ - LC layer thickness, optical anisotropy and twist angle respectively) was proposed recently [4]. Another construction with generalized mixed mode reflective LCDs used a Polarizer Beam Splitter (PBS)[3].

One of the main factors, that deteriorates the quality of RLCD image proves to be the parasitic reflection (glare) both from the outer surface of RLCD and from the conducting and aligning layers. The introduction of the corresponding antireflective (AR) coatings results in a considerable improvement of the RTN-LCD contrast. In case of PBS Reflective LCD the application of AR layers leads to an increase of the brightness in the off state.

2. Contrast and brightness of RLCD

We obtained our results of optimization of RLCD construction with AR layers using MOUSE-LCD modeling software [5]. We calculated the reflection of RLCD for incident quasi-monochromatic light, taking into account multiple reflections. The program is based on the *transfer 8x8 matrices method* for fast calculation of reflectance and transmittance of a complicated planar structure of "thin" and "thick" layers for quasi-monochromatic incident light [6]. The multibeam interference is properly taken into account in thin layers (e.g. AR, conducting and aligning films), while it was neglected in a LC layer to obtain the smooth wavelength dependence of the LCD reflectance curve for the different light wavelengths (the absence of multibeam interference in "thick" layers (polarizer, glass substrate) is assumed).

In our calculations we used the following parameters of the LC layer: $K_{11} = 1.3 \cdot 10^{-6}$ dyne, $K_{33}/K_{11} = 1.5$, $K_{22}/K_{11} = 0.546$, $\epsilon_{\parallel} = 15.1$, $\epsilon_{\perp} = 3.8$, $n_{\parallel}(546\text{nm}) = 1.623$, $n_{\perp}(546\text{nm}) = 1.523$, $d = 5.3\mu\text{m}$, twist angle $= 52^\circ$, pretilt angle $= 2^\circ$ and assume a quasi-ideal sheet polarizer with only Fresnel reflections losses for one of the polarization and practically total absorption of its perpendicular component. We used also the following data on conductive (ITO), polyimide aligning layers (PI) and glass (G): $n(\text{ITO}) = 2.05$, $d(\text{ITO}) = 30\text{nm}$, $n(\text{PI}) = 1.6$, $d(\text{PI}) = 100\text{nm}$, $n(\text{G}) = 1.52$, $d(\text{G}) = 1\text{mm}$.

The construction of RTN-LCD with a system of AR layers is shown in Figs 1,2. The AR layers can be placed both on the output RLCD polarizer (Fig.1) and between the glass substrate and the aligning layer (Fig.2). In the latter case the configuration with the electrode between the two AR layers is preferred (Fig.2). The optimal parameters of AR-layers were found in our optimization procedure.

We used the following parameters of the AR layers in our calculations (l-layer thickness, n-refractive index):

one AR-layer on the outer surface (Fig.1):

$l = 100\text{ nm}$, $n = 1.38$, e.g. MgF_2 ;

three AR-layers on the outer surface (Fig.1):

$l = 90\text{nm}$, $n = 1.45$, e.g. SiO_2 ;

$l = 120\text{nm}$, $n = 2.2$, e.g. TiO_2 ;

$l = 80\text{ nm}$ and $n = 1.7$, e.g. $\text{SiO}_2 + \text{TiO}_2$;

two AR layers at the glass substrate (Fig.2):

$l = 86\text{ nm}$, $n = 1.79$ e.g. $\text{SiO}_2 + \text{TiO}_2$ for each with ITO electrode ($l = 30\text{ nm}$, $n = 2.05$) between them.

Figure 1. One-polarizer RLCD construction with AR layers.

The gain in RLCD reflectance in the black state is shown in Figures 3,4. It is seen, that the contrast increases more than an order of magnitude for some wavelengths.

Glass substrate	Glass substrate	Glass substrate
AR-layer	AR-layer 1	AR-layer 1
Electrode	Electrode	AR-layer 2
Aligning layer	AR-layer 2	Electrode
LC layer	Aligning layer	Aligning layer
	LC layer	LC layer

Figure 2. The system of AR layers between the glass substrate and aligning layer in RLCD construction of Fig.1. The construction of AR layers with ITO electrode between them is preferable.

Figure 3. The decrease of the “dark” reflectance in the “on” state of one-polarizer RTN-LCD without AR layers (curve 1) and with various AR-layers configurations (curves 2-4). The parameters and configurations of AR layers are given in the text.

Figure 4. The reflectance of one-polarizer RTN-LCD versus voltage at the wavelength $\lambda = 550$ nm without AR layers (curve 1) and with various AR-layers configurations (curves 2-4). The parameters and configurations of the AR layers are the same as for Figure 3.

The curves 1-4 correspond to the following configurations of AR layers: curve 1- AR layers are absent; curve 2- one AR layer on the outer surface (Fig.1); curve 3- one AR layer on the outer surface and two AR layers at the glass substrate with ITO electrode between them (Fig.2); curve 4 - two AR layers at the glass substrate with ITO electrode between them and three AR layers at the outer substrate. Figure 4 presents the voltage dependence of the reflectance at the wavelength $\lambda = 550$ nm, showing a considerable growth of the contrast of RLCD. In our optimization we used all the three constructions of AR layers, shown in Fig.2. The application of only one AR layer does not allow to avoid glare reflections within the whole spectral region of visible light. The highest contrast of RLCD for a white light is obtained, when we used two AR layers on the glass with an electrode between them (Fig.2). In this case the average glare reflection in the conducting and aligning layers of RLCD decreases more than 15 times (this glare reflection is about 0.03 in the absence of AR layers).

An interesting example of the construction with two AR layers placed between the glass and electrode (fig.2) includes the use of the two ITO layers separated by a thin film of MgF_2 ($l = 35$ nm, $n = 1.38$). Figure 5 shows the gain in RLCD contrast averaged over the visible region in case the glare reflection in conducting and aligning layers is dominant. The average spectral reflectance in the dark state (figure of merit) can be diminished about 5 times in this case. The implementation of this construction will enable the minimum additional cost of the RLCD manufacturing. The deviation of the AR layer thickness of 20% will deteriorate the figure of merit by only 10% in this case (Figure 5). Thus the technological process of the AR layers fabrication will not be expensive, as the required accuracy of the AR layer thickness is not very high. The subsequent experiments to verify the validity of our calculations are in progress. Finally let us show, that the AR layers in PBS RLCD-construction [3] does not change the contrast, but increase the brightness of the PBS-RLCD in the off state (Fig.6).

Figure 5. The gain in contrast averaged in the visible region, as a function of the thickness of the AR layers in the system ITO (AR layer 1) – MgF_2 (AR layer 2)-ITO.

Figure 6. RLCD with a PBS [3] (upper part); The reflectance of one-polarizer RTN-LCD versus voltage at the wavelength $\lambda = 550$ nm without AR layers (curve 1) and with various AR-layers configurations (curves 2,3) (bottom part). The parameters and configurations of AR layers for the curves 2,3 are the same as for the Figs. 3,4.

4. Conclusion

We use the original method of taking into account the multiple reflection in RLCD construction. Our method allows us to make an effective smoothing of the LCD reflectance curve [5,6]. New constructions of RTN-LCDs with antireflective (AR) coatings were proposed. The damping of the LCD reflection in the “dark” state by introducing AR layers considerably improves the contrast ratio and only slightly affects the brightness of one-polarizer RTN-LCD. The gain in the contrast averaged over the visible region is not critical to the AR layer thickness nonuniformity. In PBS-RTN-LCD the application of the AR layers results in an increase of the contrast in the off state.

5. References

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