12-3: Theoretical study of the optical properties of low voltage stacked cholesteric liquid-crystal displays

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Abstract

We study theoretically optical properties of thin layered stacked monochrome cholesteric liquid-crystal displays. Thin thickness of the layers (~1μm) allows us appreciably to reduce driving voltage and use such displays in smart cards. Good selective reflection is achieved due to stacked structure. Dependence of the reflectivity of this type of displays on the quantity of the layers, their thickness, and liquid crystal birefringence is investigated.

1. Introduction

Among bistable reflective displays Cholesteric Liquid Crystal Displays (ChLCDs) attract a big interest. They do not include polarizers, possess a high brightness, have a good contrast and large viewing angles. On the other hand, ChLCDs require relatively high driving voltage (more than 20V) that is unsuitable for many mobile devices, for instance, smart cards, which are rapidly becoming a commodity in our ordinary life.

One of the main tasks in developing of ChLCDs is reducing their driving voltage. For a ChLCD with uniform pitch, the threshold voltage is expressed as

$$V_{th} = \frac{\pi^2 d}{p}\sqrt{\frac{K_{22}}{\Delta\varepsilon}}, \qquad (1)$$

where d is the cell gap, K_{22} is the twist elastic constant, $\Delta\varepsilon$ is a dielectric anisotropy of the LC employed. From Eq. (1) it is seen that in order to reduce the driving voltage of the display, it is necessary to employ Cholesteric Liquid Crystal (ChLC) with large $\Delta\varepsilon$ and low viscosity. Also we can use a cell with a low gap. However, a thin layer of ChLC contains a small number of periods of the helical structure that causes insufficient selective reflectance[1]. One of the simplest solutions of this problem is a ChLCD that consists of a stack of thin layers of ChLC.

Several papers about stacked ChLCDs have been presented. Some of them are devoted to colour displays[2-4]. Authors of the other ones studied two-layered structures for increasing display brightness[5-8]. All these papers deal with ChLC layers when reflectivity is saturated (does not depend on the thickness). As a rule, ChLC cells reaches saturation of Bragg reflection when cell gap more than 4μm[1].

In this work, for reducing driving voltage we propose to use a ChLCD that consists of several thin layers (Fig.1). As it was mentioned above the thin thickness of layers allows us to have low driving voltage, their stacked structure gives high reflection. Without preliminary study it is impossible to answer on questions: how thin layers must be in the structure and how many of them are enough for good reflection.

In this work, we simulate optical properties of the thin layered ChLCD (Fig.1) and present dependencies of the display reflectivity versus the thickness and quantity of layers. We discuss how LC birefringence and the presence of anisotropic films between the layers influence on the light reflection.

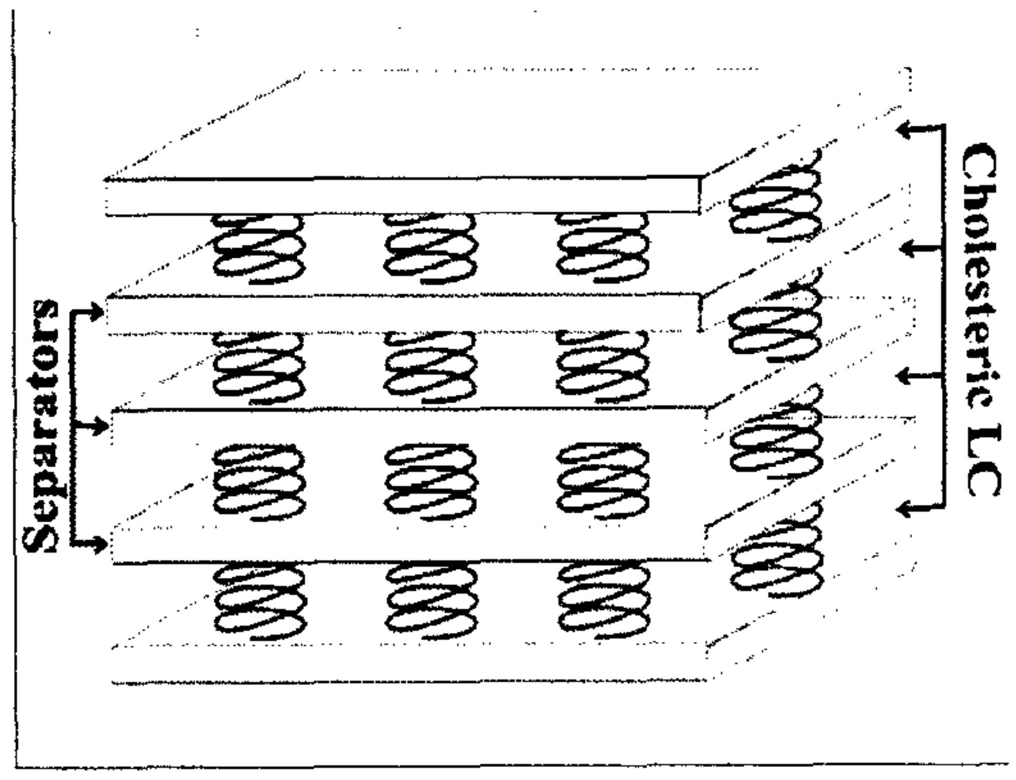

Fig. 1. The multi-layer construction of cholesteric liquid crystal display.

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2. Results and discussions

For sake of simplicity we consider ChLC possessing a uniformly oriented Grandjean texture[9]. The wavelength of the peak selective reflection satisfies the Bragg law:

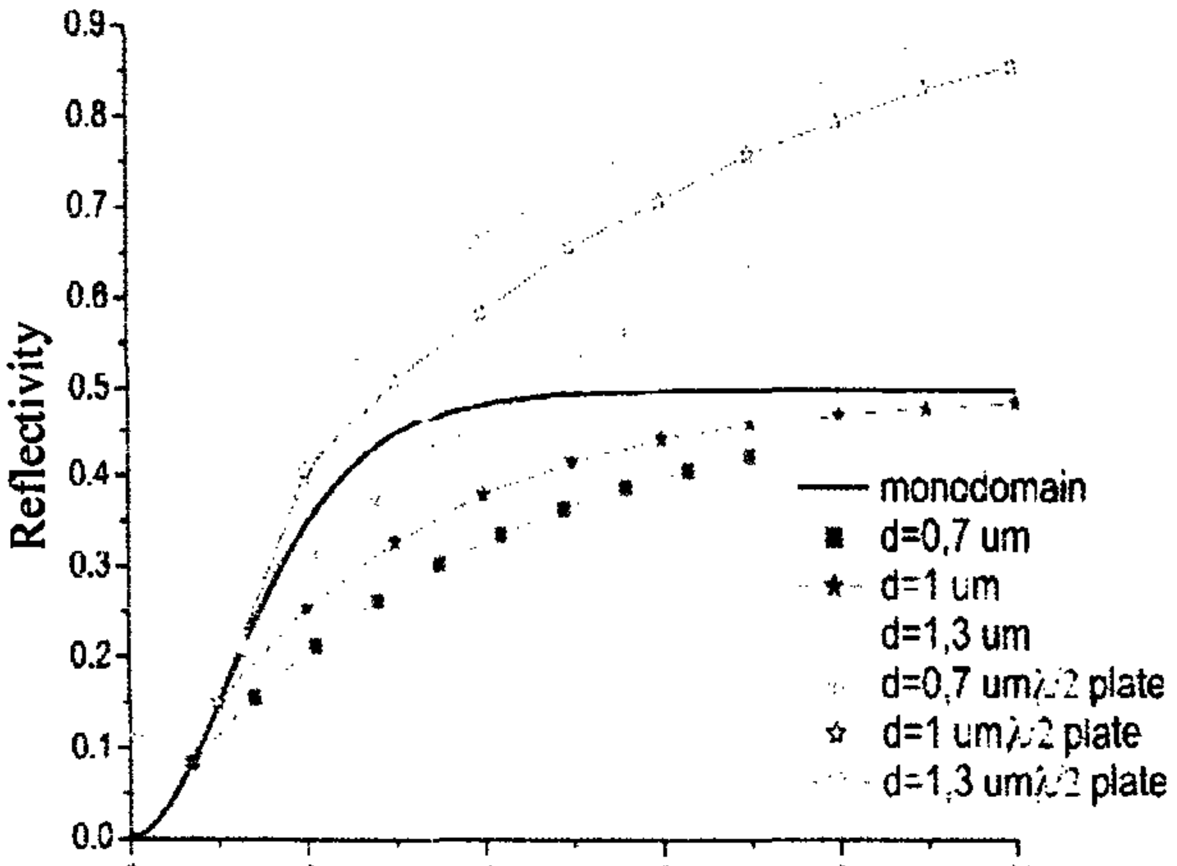
$$\lambda_0 = \overline{n}P, \qquad (2)$$

where $\overline{n}$ is the average refractive index of the ChLC and P is its pitch. The spectral width of the reflection peak is given by formula:

$$\Delta\lambda = \Delta n P, \qquad (3)$$

where Δn is the ChLC birefringence.

Let us consider how selective reflectivity of the structure presented in Fig.1 depends on the thickness and on the number of layers. Applying the well-known Berreman 4x4 matrix method[10] and supposing that all layers are identical, we obtained dependencies of the reflectivity versus the total thickness of layers (the curves with filled squares, stars and circles in Fig.2). Calculations were done for normal incidence of unpolarized light, the display consists of layers with thicknesses 0.7μm, 1.0μm and 1.3μm. For comparison we calculate reflectivity of monodomain ChLC versus its thickness. This dependence is presented in Fig.1 by solid curve. Calculations were made for Δn=0.12, P=0.35μm.



Total thickness of layers, μm

Fig. 2. The reflectivity versus the thickness of the ChLC layer.

The obtained results can be explained as follows. Unpolarized light incident onto the planar cholesteric texture splits into two mutually orthogonal circular polarized normal waves. One of them with a rotational sense counter to that of the liquid crystal helices is strongly transmitted through the slab without any significant reflection. The other one (50% of the incident light) is strongly reflected by the each thin layer. The reflected wave forms in the whole periodical volume of the ChLC and all the reflected light is collected. This explains why the reflectivity depends on the thickness of layers and, besides, why the total reflection of the multi-layered structure, the layers of which separated by isotropic plates, is always lower than the reflection of a monodomain one.

As it was demonstrated earlier[4,7,8] a two-layered cholesteric structure can give reflectance more than 50% if layers are separated by half-wave plates ($\lambda_0/2$). So, let us consider the multi-layered structures in the case when anisotropic separators are used. Calculated dependencies for the case when layers are separated by half-wave plates are presented for comparison in Fig. 2 (curves with unfilled squares, stars and circles).

As it is well-known, $\lambda_0/2$-plate changes the light polarization on the orthogonal one. So, the light with polarization that totally passes the first layer of the ChLC starts to reflect from the second one. In this case both normal waves exciting in ChLC are reflected from the multi-layered structure. As a result, the reflectivity of such system can be higher than a monodomain ChLC. For example, in order to reach the reflection more than 50% of the incident light 6 layers of ChLC with thicknesses 0.7μm are enough (Fig. 2). Moreover, the total reflection from the multi-layered structure separated by $\lambda_0/2$-plates is higher comparing with the same one where the isotropic separators are used. Although the $\lambda_0/2$-plates have retardation only for the fixed wavelength, and they are quite expensive, as it was shown reasently[7,8], the requirements for birefrigent plates for multi-layered ChLCDs are not strong as they are usually for the half-wave plate in an optical setup. So that, for considered stacked systems it is possible to use an ordinary anisotropic film that has the retardation near $\lambda_0/2$. This makes such monochrome CLCDs are tolerance in manufacturing.

In order to find the optimal number of layers with desirable thickness we investigated the influence of the ChLC birefringence on reflection and simulated the optical properties of such displays as a function of the quantity of the layers. Calculated reflectivity distributions of a monodomain ChLC in the birefringence - thickness of the layer space are presented in Fig. 3. According to this diagram, we can conclude that the thickness of the ChLC layer, in which the Bragg reflection saturates, becomes smaller when the birefringence is higher. For example, 50% of the incident light reflects from ChLC layer with the thickness of 3μm at Δn=0.20, but in the same time at Δn=0.10 the LC thickness must be up to 6μm (Fig. 3).

Dependencies of minimum number of layers in the stacked ChLCD with isotropic separators, reflectivity of which is more than 0.45 versus the layer thickness are shown in Fig.4. Calculations were made for several values of LC birefringence.

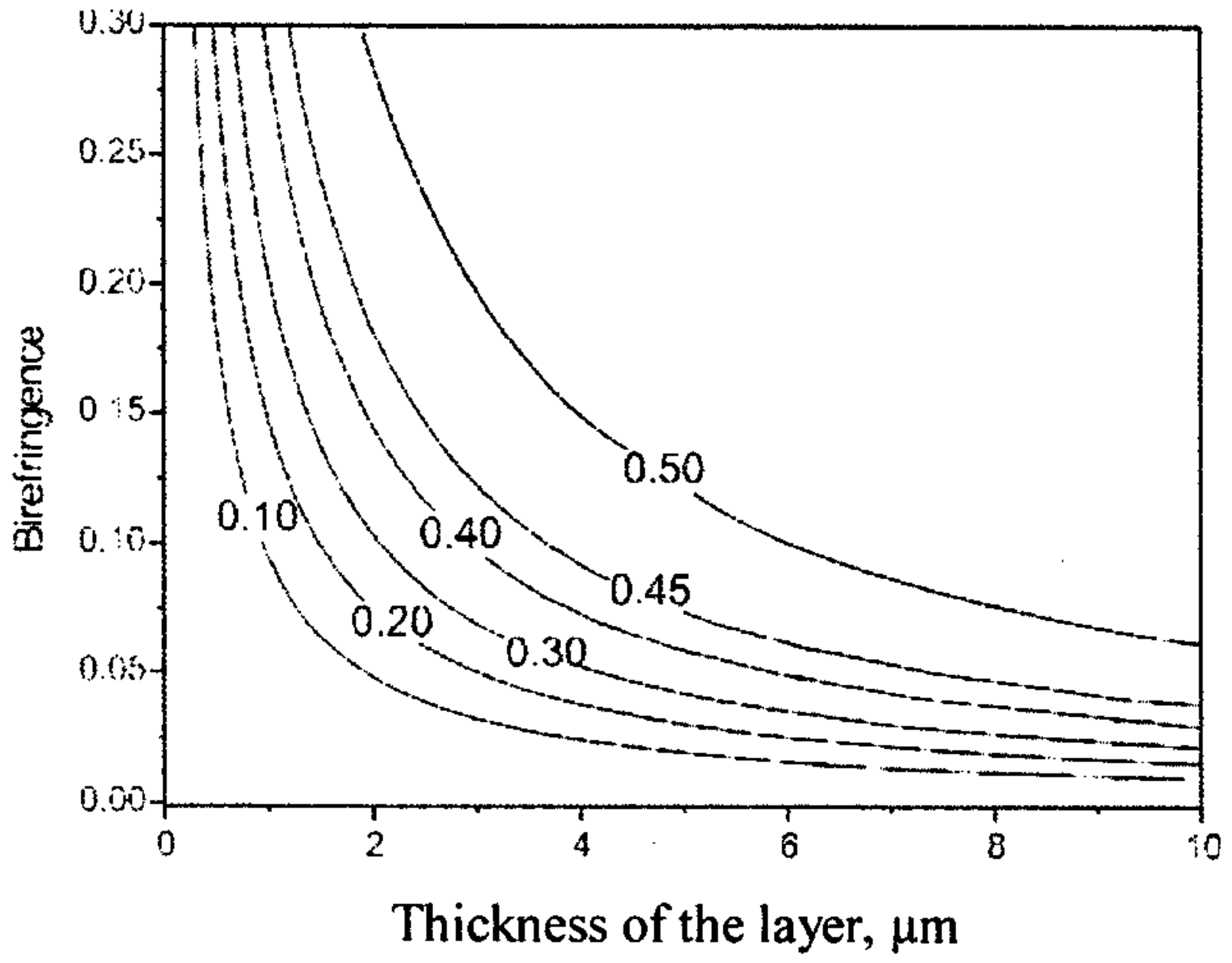


Fig. 3. Reflectivity distributions of ChLC versus the birefringence and the thickness.

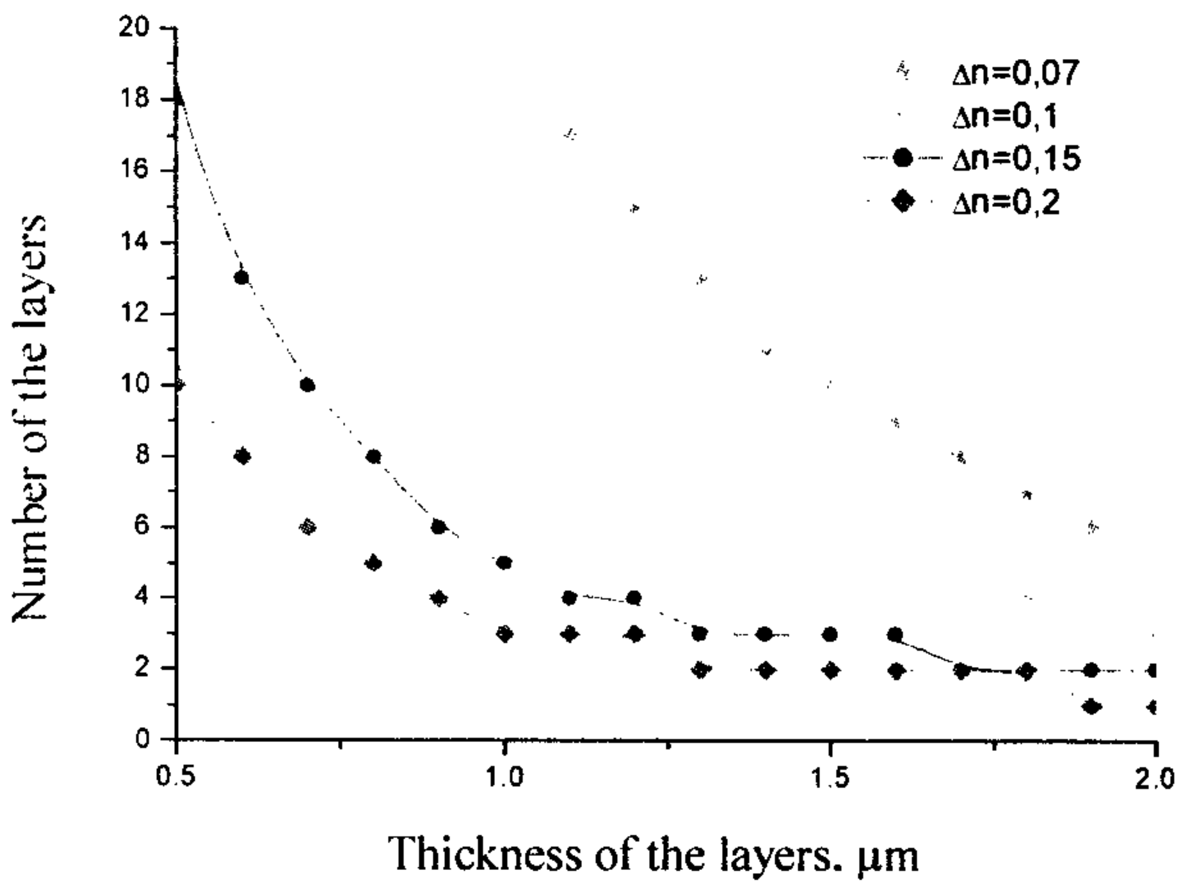


Fig.4. Minimal number of layers in the stacked ChLCD versus the layer thickness.

It is easy to see, that with lower birefringence and a smaller thickness of the layers, a bigger quantity of layers are necessary to employ for obtaining good selective reflection. It is interesting to note, that when the thickness of LC layers is ~1.1μm at the value of LC birefringence more than 0.15, then approximately 2 - 5 layers are enough to obtain the saturated reflectivity of a system.

3. Conclusions

We have simulated optical properties of thin layered ChLCD, when reflectivity of each layer is not saturated.

Our investigations have shown that the total reflection of the multi-layered structure, the layers of which separated by isotropic plates, is always lower than the reflection of a monodomain one. In addition, the total reflection from the multi-layered display separated by birefringent plates is higher comparing with the same one where the isotropic separators are used. Thin thickness of the layers (~1μm) allows us appreciably to reduce driving voltage. In addition, for $\Delta n \geq 0.15$ only 2 - 5 layers are enough to obtain the good selective reflection. This has a huge impact when applying multi-layered ChLCDs in many mobile devices, such as smart cards.

The presented results can be applied to optimize the driving voltage and the reflective properties of ChLCDs.

4. References

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