Mechanical and Optical Properties of the LCD's Elements: Requirements and Methods of Control

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ABSTRACT

The principal stages in technological chain of liquid crystal displays (LCD) production are presented for case where the measurement of optical polarization properties is required. Experimental set-up is described and results of LCD's substrates research are given. Influence of rubbing of polyimide layer on phase shift is considered. Analysis of five polyimide layers groups with various structure and dopes is carried out. We have established that optical polarization technique allows to evaluate the degree and homogeneity of rubbing, determine the pre-inclination angle of polyimide molecular chains relatively to the surface of substrate.

Keywords: Liquid crystal display, polarization, birefringence

1.INTRODUCTION

The optical polarization parameters belong to the most significant properties of LCD's elements. The control of these parameters during LCD manufacture permits to reduce essentially a spoilage and to raise a quality of the production. We mark following principal stages of technological chain where polarization measurements are necessary:

a) Birefringence of glass substrates for LCD testifies an existence of residual inner stress and moreover reduces image contrast.

b) Polyimide layer rubbing is accompanied by appearing of optical anisotropy with allows to define a pre-inclination angle of polyimide molecular chains, rubbing degree and homogeneity.

c) The principal parameters which determine optical polarization properties of filled LCD cell are local phase shift, initial director azimuth of liquid crystal molecules and twisted angle. For estimation of image quality it is necessary to know a mean deviation of these parameters relative the nominal values and their distribution on display surface.

d) In some cases a birefringent film may be introduced between liquid crystal cell and polaroid. The control of film phase shift and its principal planes azimuth is required.

2.DESCRIPTION OF THE EXPERIMENTAL DEVICE

For measurement of optical polarization parameters the autocollimation polarimeter was designed[1]. This device permits to define the phase shift and the polarization plane orientation of eigen waves in transparent plate. Unlike device which compensate the component whose polarization is collinear with that of the probe beam[2], our device compensates the reflected beam component, which has a polarization perpendicular to that of the probe beam. The optical configuration of our device is shown in Fig.1.

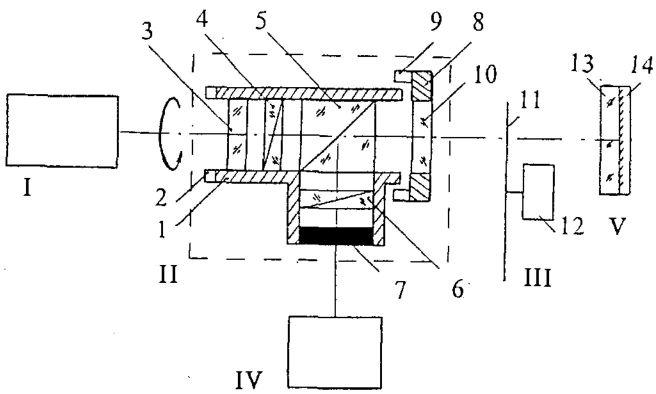

Fig.1. Configuration of the compensation device measuring birefringence: Laser I, polarimetric block II, modulator III, control unit IV, specimen V. 1 and 8 - first and second rotating bodies, 2 and 9 - first and second angle- measuring limbs, 3 and 10- first and second $\lambda/4$ plates, 4 and 6- first and second polaroids, 5- polarization beamsplitter, 7- photodetector, 11- chopper; 12- engine, 13- transparent layer, 14- reflecting surface.

The intensity of the radiation flux of the orthogonal component Φ' in the reflected beam is described by following expression:

$$\Phi' = \{sin(\Delta/2)\ cos2(\varphi-\theta)\ sin2(\varphi-\psi) - cos(\Delta/2)\ sin2(\varphi-\theta)\}^2 R^2 \Phi, \qquad (1)$$

where Φ is the probe beam intensity, R is the amplitude reflectivity of the mirror surface of the specimen, Δ is the phase difference introduced into the beam by the specimen upon double passage of the radiation, φ, ψ and θ are the angular positions of the fast axes of the second $\lambda/4$
plate and the specimen, as well as of the principal plane of the polarization beamsplitter which specifies the polarization plane of the probe beam with respect to the zero direction of the device.

When the principal planes of the polarization beamsplitter and the second $\lambda/4$ plate coincide (i.e.,. $\varphi = \theta$) Eq.(1) can be put in the following form:

$$\Phi' = sin^2(\Delta/2)\ \ sin^2 2(\psi - \theta)\ R^2\ \Phi, \qquad (2)$$

In this case compensation of the intensity Φ' is achieved by simultaneous rotation of the polarization beamsplitter and the second $\lambda/4$ plate. In the position found, the orientation of the principal planes of the specimen corresponds to the orientation of the principal planes of the polarization beamsplitter.

Furthermore, we install the second $\lambda/4$ plate in such a way that its fast axis makes an angle of 45^o with the fast axis of the specimen, i.e. φ-ψ = 45^o. In this case

$$\Phi' = sin^2\left[\frac{\Delta}{2} - 2(\varphi - \theta)\right]\ R^2\ \Phi, \qquad (3)$$

By rotation the polarization beamsplitter with the second $\lambda/4$ plate fixed, one can attain compensation of the flux Φ' of the orthogonal component. The difference in the azimuths of the beamsplitter an the second λ/4 plate, latter being in the position found, makes it possible to determine the value of the phase shift of the specimen:

$$\Delta = 4(\varphi - \theta) + 360^\circ m, \qquad (4)$$

where m is an integer.

This device enables rather simply to find the fast axis azimuth and phase difference of the reflecting specimen. Besides, due to the compensative method of measuring, a high level of sensitivity is secured. For instance, in our device the threshold of phase difference sensitivity amounts to 0.03°.

The phase shift Δ between the polarization components of laser arises after its passing through the investigated sample. The value Δ is connected with inner stress via linear equation:

$$\Delta = \frac{360^o}{\lambda} Ch(\sigma_{xx} - \sigma_{yy}), \qquad (5)$$

where C is the stress-optical coefficient,
h is the glass substrates thickness,
σ_{xx}, σ_{yy} are the components of a stress tensor,
λ is the laser wavelength.

Hence the formulae for determing the component difference of stress tensor may be given as:

$$\sigma_{xx} - \sigma_{yy} = \frac{\Delta\lambda}{360^o Ch}. \qquad (6)$$

The value Δ is measured in degrees, the parameter C is defined in Brewsters, where $1Br=10^{12}m^2/N$. In our calculation we use C=2.6Br, that corresponds to the ordinary soda-lime glasses.

3.THE EXPERIMENTAL RESULTS OF LCD SUBSTRATES INVESTIGATION

The inner stress presence in substrates leads to increasing of their destruction probability during LCD manufacture and moreover reduces an image contrast. It is shown[4] on the base of tolerance on tensile stress that maximum phase shift in optical elements from soda-lime glasses must be less than 5°/mm at λ=550nm. In ordinary optical elements the ratio of the largest size to the smallest size has an order of 10:1. The LCD surface length is about 100 of its thickness that made them particularly susceptible to cracking. That is why the phase shift tolerance of LCD substrates is one order of magnitude lesser than the tolerance of ordinary optical elements.

We have measured the phase shift in high quality substrates and substrates with cracks. The study was carried out on central and on substrate areas. The inner stress was defined by the formulae (6). Maximal values of specific phase shift and inner stress are presented in Table 1. The next groups containing more than three plates were tested:

1.Quality substrates (Factory "Optik", Lida, BELARUS),
2.Cracked substrates (Factory "Optik", Lida, BELARUS),
3.High quality substrates (Saratov, RUSSIA),
4.High quality substrates (Asahi-Glass, JAPAN),
5.High quality substrates (Post, GERMANY).

Table 1. The specific phase shifts Δ/h and residual inner stresses $\sigma_{xx}-\sigma_{yy}$

Group number	Central area		Outer area	
	Δ/h, deg/mm	$\sigma_{xx}-\sigma_{yy}$, MPa	Δ/h, deg/mm	$\sigma_{xx}-\sigma_{yy}$, MPa
1	0.6	0.4	0.7	0.5
2	2.0	1.4	5.7	3.8
3	<0.3	<0.2	<0.3	<0.2
4	<0.2	<0.1	<0.2	<0.1
5	<0.2	<0.1	0.4	0.3

4.THE EXPERIMENTAL RESULTS OF POLYIMIDE LAYERS RUBBING STUDY

It is known that a polyimide layer phase shift which appearing because of polyimide molecular chain ordering at rubbing has a value of the order 1°. As it follows from the results presented above, the substrate phase shift may be quite beyond this magnitude. It is necessary to use the substrates with minimal birefringence for study of polyimide layers rubbing. We carried out our investigation with substrates which had a phase shift less than 0.04°.

The phase shift appearing due to rubbing was measured in five groups of polyimide layers:
1.Polyimide layers with side branches of molecular chains (specimens with 10th and 20th rubbing cycles).
2.Polyimide layers with side branches of molecular chains, parallel lacing and silicone (specimens with 10th and 20th rubbing cycles).
3.Polyimide layers with side branches of molecular chains and parallel lacing (specimens with 5th, 10th and 20th rubbing cycles).
4.Linear polyimide layers with silicone (specimens with 10th and 20th rubbing cycles).
5.Laeyers from commercial polyimide AD 91-03 (specimens with 10th and 20th rubbing cycles).
6.Polyimide layers without rubbing.

The measurements have been carried out in various substrate's points in order to determine the rubbing homogeneity. The results obtained are shown in Table 2. The phase shift value is denote as γ.

We determine the phase shift as a function of beam incidence angle for the central point of the substrate # 3-20. The substrate was turning about an axis which was perpendicular to rubbing direction. Experimental results are presented on Fig.2. As it is shown, the maximum phase shift takes place when the incidence angle is 4°. This value is in agreement with pre-inclination angle of polyimide molecular chains which appeared because of rubbing.

5.CONCLUSION

1.As it follows from measured data of high quality LCD's substrates, the specific phase shift can not be more than 0.5°/mm.

2.An increase in number of rubbing cycles rises the polyimide layer phase shift. In particular, it varies from 0.01° after 20th rubbing cycles for polyimide layers not consisting a silicone. The phase shift of polyimide layers with silicone shows the lowest sensitivity to rubbing.

3.It is revealed that the phase shifts varies substantially along the substrate area (up to 30%), because of rubbing inhomogeneity. It is denoted that the phase shift value reduces with time.

Table 2. The phase shift of polyimide layers γ at normal incidence of laser beam

Group number	Count of rubbing cycles	Average value γ, deg.	Variation range γ, deg.
1	10	0.52	0.48-057
	20	0.83	0.68-1.02
2	10	0.43	0.36-0.53
	20	0.59	0.55-0.61
3	5	0.42	0.35-0.41
	10	0.65	0.61-0.72
	20	0.88	0.80-1.12
4	10	0.53	0.40-0.65
	20	0.62	0.48-0.71
5	10	0.44	0.37-0.55
	20	1.08	0.8-1.2
6	0	0.01	0-0.32

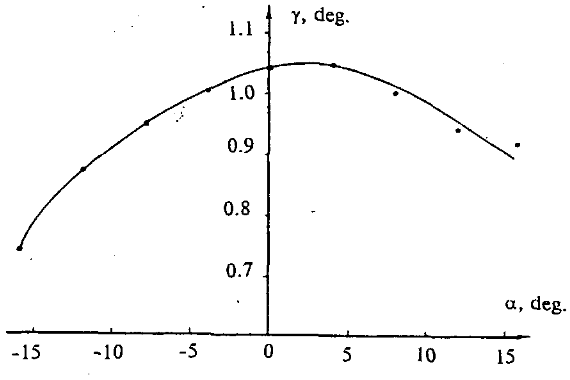

Fig.2. Dependence of phase shift γ on incidence angle α.

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