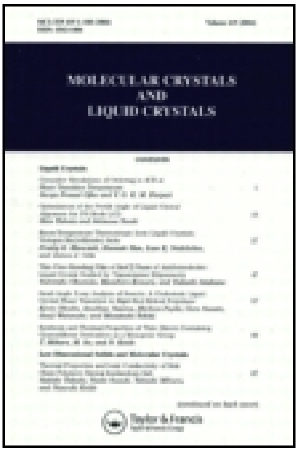

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APPLICATION OF PHASE TRANSITIONS IN LC VISION

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Abstract A thin layer of NLC applied on the surface of a material as a free film can visualize through a polarizing microscope different types of surface defects. We developed a new modification of this LC vision based on phase transitions in NLC, which increase the contrast or the size of defect's images. The behavior of nematic phase is explained using a simplified Landau approach. For the first time the film thickness, varying because of the molecules reorientation, is taken into account.

INTRODUCTION

A thin layer of homogeneously oriented nematic liquid crystal (NLC) applied on the optical quality surface of materials as a free film may visualize, through a polarizing microscope, the images of different types of defects. It allows observation of the invisible distribution of low-power physical fields, local physical and chemical modifications of the surface, structural and microrelief defects [1-3]. The simplicity in use and easiness of detecting valuable information opened wide areas for its application [4-10]. The main problem of LC vision is to receive the defect's images with high quality in order to obtain exact information about their nature. In this paper we describe a new modification of the LC vision based on phase transitions in NLC.

THE BASIC PRINCIPLE OF LC VISION

The initial molecular ordering when NLC film is applied on the surface under investigation forms the physical basis for visualizing the defects . This order may be locally disturbed under the influence of surface defects. The recording of defect's images becomes possible if NLC deformed layer is illuminated in the transmission or reflection mode and the appearing interference pattern is studied in crossed polarizers against the background of non-deformed layer. The light intensity over the NLC layer (x,y), modulated by the deformed LC structure, is described by well known equation[1]:

$$I(x,y) = I_0 \mathrm{Sin}^2[\Phi\,(x,y)/2] \quad (1)$$

The phase delay Φ (x,y) caused by the NLC birefringence is equal to:

$$\Phi(x,y) = 2\pi/\lambda\ [-n_o H + \int_0^{H(x,y)} n(x,y,z)dz\ ], \quad (2)$$

where H is the thickness of NLC film, n(x,y) is the film refractive index in the deformed zone, n_o is the refractive index of the non deformed zone. If the orientation field has no twist deformation, then only orientation bending occurs, hence:

$$n(x,y,z) = [n_e^{-2}\mathrm{Sin}^2\varphi(x,y,z) + n_o^{-2}\cos^2\varphi\,(x,y,z)]^{-0.5}, \quad (3)$$

where φ (x,y,z) is the deflection angle of the molecule long axis with respect to the surface normal; n_o,n_e are the reflective indices of the NLC layer for the ordinary and extraordinary polarizations.

The resolution of NLC film is more than 1500 l/mm reliable results in visualiing surface defects are obtained by repeated applying and removing the NLC layers and observing the stable defect's images. The heating of NLC to the temperature of the isotropic phase makes the film thickness and alignment more uniform. During the NLC film heating or cooling, we also observed phase transitions which gave new information about surface defects.

THE THEORY OF NLC FILMS ELASTICITY AND ITS RELATION TO OPTICAL TRANSFER FUNCTION

For theoretical analysis of the NLC films' elasticity on the solid surface, we assumed that the substrate appears as a potential relief that interacts with the film and changes its elasticity elongation energy. On this basis the distribution of elongation elasticity potential appears and, as a result, the relief of the film surface is determined. The minimization of the Landau free energy integral[11] permits one to derive the partial differential equation for the potential of elongation elasticity and to state the boundary value problem allowing for some approximations [12]:

$$\left[K_{11}\left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}\right) + K_{33}\frac{\partial^2}{\partial z^2}\right]U(x, y, z) = 0 \quad (4)$$

where K_{11} is transverse bending, K_{33} - elongation bending modules, and the substrate is assumed to be in the XOY coordinate plane. After the isotropization of coordinate space made in the equation (4), we get the potential as the harmonic function and its normal gradient meets the boundary condition for the substrate surface energy relief. The upper film surface coincides with the equipotential surface. The phase delay can be calculated by formula (2).

To obtain the optical parameters of the visual picture,we have to solve equation (4). Its solution can be derived as the expansions using the basis of harmonic functions and the expansion coefficients are determined via the substrate energy relief as the bounday value. When the solution is obtained we can evaluate the module of the transfer function from formulas (1) and (2) by means of the approximate expression:

$$N(\nu) = C\, e^{-\varepsilon \nu H} \tag{5}$$

where C is the normalization coefficient, ν - the spatial frequency, H is the film thickness and $\varepsilon = K_{33} / K_{11}$.

The optical spatial resolution can be evaluated as ν_0^{-1} where ν_0 is the solution of the functional equation $N(\nu_0) = 0{,}05$ according to the Raleigh's criterion $U(x,y,H) =$ Const. The contrast limit (the sensitivity of LC vision) can be obtained as the tangent gradient of $\Phi(x,y)$ (2). When the potential relief is of the rectangular step character, the resolution of the equation (4) can be obtained in analytical form and the sensitivity δ can be evaluated as being proportional to the expression:

$$\delta \cong \frac{\gamma}{H^2 + \varepsilon^2} \tag{6}$$

where H is the maximum of the film thickness and γ is the surface energy of interface separation of LC states.

When being heated, the film passes the state of different LC phases and at these temperature points the sensitivity of LC vision significantly increases according to formula (6) in proportion to the γ , which depends on the temperature difference bet ween phase transitions in the different substrate regions. The theory that is considered here allows us to determine the dependence of the optical parameters on the geometrical, potential and elastic characteristics of the substrate material and to determine the trends in the experiment planning.

THE APPLICATION OF PHASE TRANSITION FOR ENHANCING THE DEFECT'S IMAGES CONTRAST

In our view, the most important application area of the NLC technique is the structural analysis of material surfaces that can improve the quality of many high-technology products. Let us discuss, for example, the application of LC vision for visualizing the twinning growth in Iceland spar. This material is most used among natural crystals for fabrication of polarizing elements. The twinning growth may be visualized by etching but it destroy the polished surface. The NLC film also allows to visualize twinning growth and blocks with enhanced resolution (Figure 1a), however, with low contrast. The contrast of twinning growth image can be highly enhanced using the transition from nematic to isotropic phase. The reason is that different twinning of Iceland spar has different anchoring energy. As a result, in the process of heating at temperature t_1 a part of NLC, which was in contact with one of the twinnings, transfers to the isotropic phase while another part of NLC is still in mesophase (Figure 1b). In this case, the twinning boundary can be observed through a polarizing microscope with the highest contrast. If heating continues another part of NLC film, which is in contact with the second twinning, also transfers to the isotropic phase at temperature t_2. The difference in temperature t_2 - t_1 for different Iceland spar samples was 1-2^0 C and may characterize the difference in anchoring energy for twinning. The idea of phase transition may be used as LC vision modification in different investigations of solid crystals structural inhomogeneities.

APPLICATION OF PHASE TRANSITION FOR INCREASING THE DEFECT'S IMAGES SIZE

The stacking faults (SF) determine many of surface properties and their decoration by NLC film brings valuable information. This refers to visualization of latent electrophotografic images of microstructure. Figure 2a illustrates the SF and saucer pits defects in KTP crystal visualized by conventional NLC technique. The size of such defect's images may be significantly increased using the transition from nematic to smectic B phase. The reason is that the surface defects look like the centers of crystallization for mosaic smectic B structure that appears from nematic phase in the process of NLC cooling. We used tolan compositions synthesized by Dr. Adomenas group at Vilnius University.

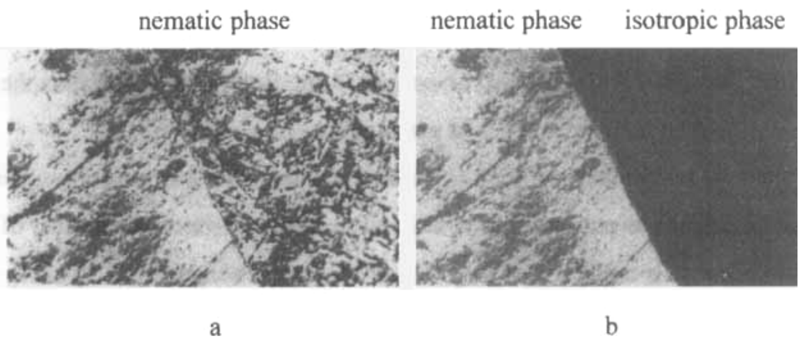

FIGURE 1 The application of phase transition in NLC for enhancing the defect's images contrast. Vizualization of twinning growth in Iceland spar by conventional NLC technique (a) and using phase transition (b).

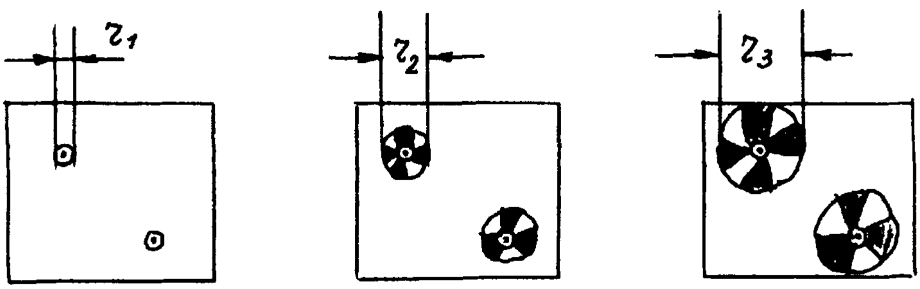

FIGURE 2 The application of phase transition in NLC for increasing the defect's images size: r_1 - the defect's image size in conventional LC vision; r_2, r_3 - the increasing of defect's images size using mosaic SmB structure growth.

The mixture had the parameters: $\Delta\varepsilon = +3.0$; $T = 66\ ^0C$ and it transfers to the smectic B phase at the room temperature. In the process of cooling from isotropic phase, NLC at the first step decorates the SF and at the second step SmB begins to form mosaic structures from the centers of SF. Each center was surrounded by growing grains that looked like flowers (Figure 2b).This transition to the SmB phase increased the size of defect's image by more than an order of magnitude.

The mixture had the parameters: $\Delta\varepsilon = +30$; $T = 66\ ^0C$ and it transfers to the smectic B phase at the room temperature. In the process of cooling from isotropic phase, NLC at the first step decorates the SF and at the second step SmB begins to form mosaic structures from the centers of SF. Each center was surrounded by growing grains that looked like flowers (Figure 2b).This transition to the SmB phase increased the size of defect's image by more than an order of magnitude.

The new modification of the LC vision based on phase transition from nematic to .isotropic or smectic B phases may enhance the contrast or increase the size of surface defect's images. This modification may be used for exact nondestructive testing of solid crystal defects and inhomogeneities. The theory describing the dependence of the optical parameters on the geometrical, surface and elastic characteristics of the material is developed.

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