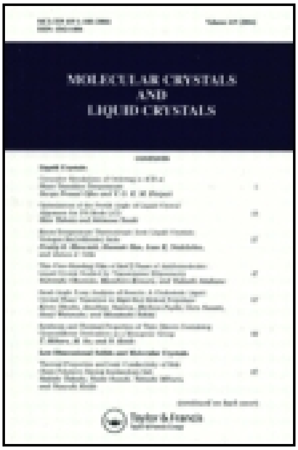

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NEW PHYSICAL METHOD TO STUDY CHARACTERISTICS OF THE SURFACES COATED BY NEMATIC LIQUID CRYSTALS

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Abstract The properties of NLC thin layers, applicated upon an optical surface to visualize the defects of the latter, non-detectable by standard means,are studied here in polarized light.

INTRODUCTION

It was discovered that thin layers of homogeneously oriented NLC applied to an optical quality surface as a free layer, may visualize the microrelief or structure defects of that surfaces due to local deformations of NLC layers themselves[1]. Fig.1 (b,c) shows elastic deformation of NLC layer corresponding to the microdefects or structural inhomogeneity zones of the surface thereunder. A thin NLC layer allows to visualize the distribution of weak electric and magnetic fields upon the surface non-observable through common optical microscope: Fig.1 (d)[2].

On this basis a new method to study surface characteristics has been developed and the areas of its applications are shown here.

THE ESSENCE OF THE METHOD

Local deformations of NLC layer allow us to obtain patterns of inhomogeneous fields, as in a particular case, surface defects by means of checking the definite distribution of the light intensity over the layer:

$$I(x)=I_0\sin^2\phi(x)/2. \qquad (1)$$

The phase delay $\phi(x)$, caused by NLC layer anisotropic properties, is equal to:

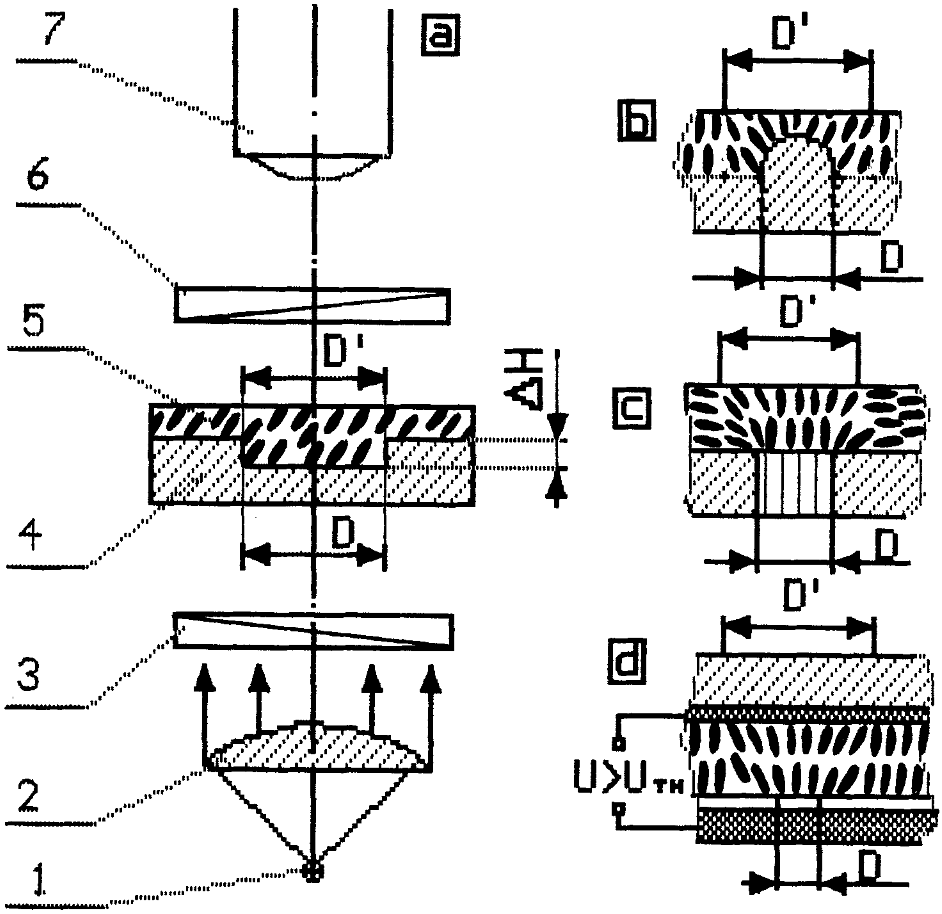

FIGURE 1. Scheme for visualizing defects of optical surfaces and patterns of NLC deformation layer in vicinity of most typical defects.

1 - radiation source; 2 - condensor lense; 3 - polarizer; 4 - sample; 5 - NLC layer; 6 - analyzer; 7 - microscope.

D - the size of defect; D′ - the size of its pattern in NLC layer.

$$\Phi(x)=(2\pi/\lambda)(-n_0H+\int_0^H n(x,y)dy), \quad (2)$$

where H is the thickness of the NLC layer, n(x,y) - its refractive index in the defect zone, n_0 - non-deformed NLC layer's refractive index . If the orientation field has no twist, then only orientation bending occurs, hence:

$$n(x,y)=[n_e^{-2}\sin^2\varphi(x,y)+n_o^{-2}\cos^2\varphi(x,y)]^{-1/2}. \quad (3)$$

Here $\varphi(x,y)$ is the deflection angle between the long axis of the molecules and the sample of Y-direction, n_e and n_o are the refractive indices of the NLC layer for the extraordinary and ordinary rays.

Occurence of orientation deformation in NLC layer in defect zone is stimulated by the equality of moments in NLC volume and on its surface. The equation of moment balance in volume is:

$$k_1\vec{l}\ \mathrm{grad\ div}\vec{l} - k_3\vec{l}\ \mathrm{rot\ rot}\vec{l} +$$

$$(k_3-k_2)\left\{2(\vec{l}\,\mathrm{rot}\vec{l})(\vec{l}\times \mathrm{rot}\vec{l})+\mathrm{grad}(\vec{l}\,\mathrm{rot}\vec{l})-\vec{l}[\vec{l}\,\mathrm{grad}(\vec{l}\,\mathrm{rot}\vec{l})]\right\}= 0. \quad (4)$$

Here k_1,k_2,k_3 are torsion and bending modules of orientational field force lines $\vec{l}(x,y,z)$. Surface moment balance equation is:

$$\vec{\mu} = \vec{M}. \quad (5)$$

Here $\vec{\mu}$ are moments, caused by deformed NLC layer, and $\vec{M}$ are substrate balancing moments. The M moment is derived from the anisotropy of absorbed layer between NLC and the substrate.
Considering the thickness of absorbed layer being undependable upon the layer deformations, the surface energy W of NLC interaction with substrate may be detected by the correlation:

$$W = W(x,y,\vec{l}\vec{\nu},\vec{l}\vec{\tau}), \quad (6)$$

where $\vec{\nu}$ is normal to the surface and $\vec{\tau}$ is the direction along the surface.
The evident form of this function is determinated by forces of polar and dispersion molecular interactions. From this point of view the cases of strong and week anchoring can be considered.

The equation (4) is simplified if rotation angles of NLC molecules are considered to be in plane OYX:

$$k_1\vec{l}\ \text{grad div}\vec{l} - k_3\vec{l}\ \text{rot rot}\vec{l} = 0;\ \vec{l}^2 = 1. \qquad (7)$$

This equation cannot be solved for two-dimensional situation. As an approximation the equation may be written in the case of angular function[3]:

$$\nabla_K^2 \varphi = \text{æ}_0(\varphi), \qquad \nabla_K^2 \equiv \sqrt{\frac{K_1}{K_3}}\frac{\partial^2}{\partial x^2} + \sqrt{\frac{K_3}{K_1}}\frac{\partial^2}{\partial y^2}. \qquad (8)$$

The quantity æ is equal:

$$\text{æ} = \frac{K_3 - K_1}{\sqrt{K_3 - K_1}} \sin^2 \varphi_m \qquad (9)$$

φ_m - the maximum angle in a case. æ is the very small value to be ignored.
The solution of (8) may be found in a form of power series for the parameter æ :

$$\varphi(x,y,K_1,K_3) = \varphi^0(x,y) + \text{æ}\varphi'(x,y) + \text{æ}^2\varphi''(x,y) + \cdots . \qquad (10)$$

The solution of (10) for different degrees of approximation may have the form of Laplace and Poisson equations:

$$\nabla_K^2 \varphi^0 = 0, \qquad \nabla_K^2 \varphi' = 0(\varphi^0), \qquad \nabla_K^2 \varphi'' = 0(\varphi'). \qquad (11)$$

An analysis shows that NLC layers can be used for creation of a new physical method to study surface characteristics. The areas of its applications are[3]:

- nondestructive testing the physical inhomogeneities of the optical crystals (Fig.2);
- quality testing of optical coatings and relevant surfaces;
- visualization of the different patterns of practical use;
- measuring the defects of microrelief of value less than 0.5 μm on outside and inside surfaces of optical elements

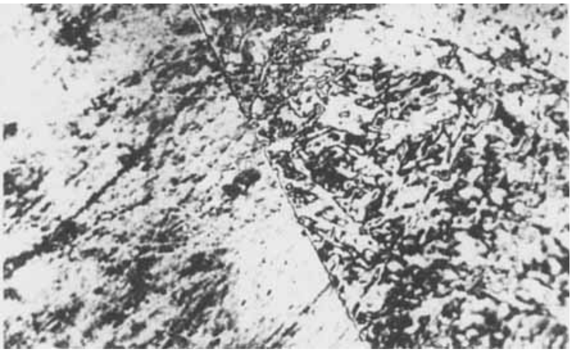

FIGURE 2. Visualization of twinning growth in Iceland spar by means of NLC. 100* magnification.

SUMMARY

The simplicity in use and easiness of detecting valuable information can be obtained by this method opening wide areas for its application in nondestructive testing in optical manufacturing, engineering as well as in many scientific applications, for example microscopy and scientific photography.

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