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APPLIED FOURIER PROGRAMMING FOR METROLOGICAL CONTROL OF PRINTING MATERIALS OF PACKAGING PRODUCTS

In our manuscript, the materials of analytical substantiation and experimental verification of a new method of digital Fourier processing of polarization images of optically anisotropic polymer layers are presented.

Keywords: applied optics; standardization; metrology method; printing technology; packaging materials; printing materials.

Introduction

Among the many systems for diagnosing and differentiation the optical parameters of birefringence objects [1, 2], a new direction has appeared — matrix polarimetry of microscopic digital images of polymeric printing materials [3, 4]. Analysis of the collected databases on the approximation of linear anisotropy by polycrystalline widely spaced grids. On this basis, a connection was established between a set of statistical moments of the 1st–4th order characterizing the distribution of azimuths and polarization ellipticity of laser images, and the anisotropy parameters of a phase-inhomogeneous sphere [5]. As a result, was developed a new diagnostics method for polarization imaging [6, 7].

For the further development of laser polarimetric diagnostics methods, the problem of optical separation of various mechanisms of optical anisotropy is relevant. Currently, the polarization mapping method does not solve this problem. One of the possible solutions may be the technique of matched spatial-frequency filtering [8]. The idea of such a new method for diagnostic and differentiation applications is based on spatial-frequency filtering of laser images of spatially ordered crystals networks with different mechanisms of anisotropy. The optical implementation of this method includes the following stages: ‘FFT’ — ‘spatial-frequency filtering’ — ‘inverse FFT’ of laser polymer layer images [8–10].

Therefore, the actuality of this manuscript is to develop new technology of polarimetry using coordinated spatial-frequency filtering in differentiation the manifestations of different mechanisms of phase anisotropy of polycrystalline networks of polymers for packaging and printing products. In particular, this manuscript is aimed at investigation the mechanisms and methods of the formation of coordinate azimuth and ellipticity distributions of object fields of laser irradiation, that formed by the mechanisms of linear and circular anisotropy of inhomogeneous polyethylene → networks, in the boundary and the Fourier plane zones.

Methods

The diagnostic application of laser polarimetry methods is based on the formation of a unified model that describes the polarization properties of optically anisotropic inhomogeneous spheres.

The main idea of such modeling is to consider different polymers as a single structure formed by two basic components. The first component — optically isotropic, which does not change the state of polarization of the laser wave (only weakens it) (fig. 1 ({A})).

The second one — optically anisotropic, the effect of which is manifested in the transformation of the state of polarization of laser beam due to the phase modulation between the 0–90 components of the laser wave amplitude. There are two main mechanisms of this modulation — linear (fig. 1(D)) and circular (fig. 1 (C)) birefringences.

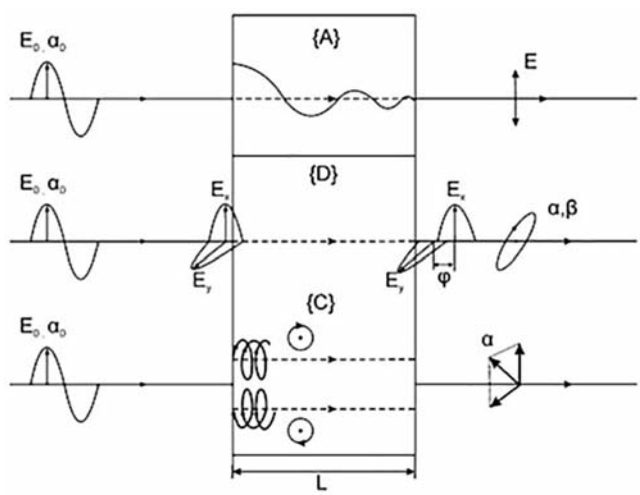

Fig. 1. Model objects: E_0, α_0 — the amplitude and azimuth of the probing beam polarization; E_x, E_y, α, β, φ — the orthogonal components of the amplitude, ellipticity and azimuth, and phase of the laser beam; E; {A}; {D}; {C} — the Jones matrices of the isotropic, linear and circular anisotropy components of the polymer layers

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The optical polarization properties of polycrystalline polymeric objects are considered in the approximation of linear birefringence by the Muller matrix operator for a uniaxial anisotropic crystal of the next type.

$$\{Q\} = \begin{Vmatrix} 1 & 0 & 0 & 0 \\ 0 & q_{22} & q_{23} & q_{24} \\ 0 & q_{32} & q_{33} & q_{34} \\ 0 & q_{42} & q_{43} & q_{44} \end{Vmatrix}, \qquad (1)$$

where

$$q_{ik}(\kappa,\phi) = \begin{cases} q_{22} = \cos^2 2\kappa + \sin^2 2\kappa \cos\phi; \\ q_{23;32} = \cos 2\kappa \sin 2\kappa (1-\cos\phi); \\ q_{33} = \sin^2 2\kappa + \cos^2 2\kappa \cos\phi; \\ q_{34;43} = \pm\cos 2\kappa \sin\phi; \\ q_{24;42} = \pm\sin 2\kappa \sin\phi; \\ q_{44} = \cos\phi. \end{cases}, \qquad (2)$$

here κ — the orientation of the optical axis, that determined by the orientation of the anisotropy layer; $\phi = {}^{2\pi}/_{\lambda}\Delta nd$ — phase shift between the 0–90 components of the laser wave amplitude with length λ, passing through a layer with geometric thickness d and birefringence index Δn.

For a more complete description of the optical birefringence of a polymeric layers, it is necessary to use the matrix operator of optical activity

$$\{\Psi\} = \frac{1}{2}\cdot\begin{bmatrix} 1 & \cos 2\psi & \sin 2\psi & 0 \\ \cos 2\psi & \cos^2 2\psi & \cos 2\psi \sin 2\psi & 0 \\ \sin 2\psi & \cos 2\psi \sin 2\psi & \sin^2 2\psi & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}, \qquad (3)$$

where ψ — angle of the polarization plane rotation.

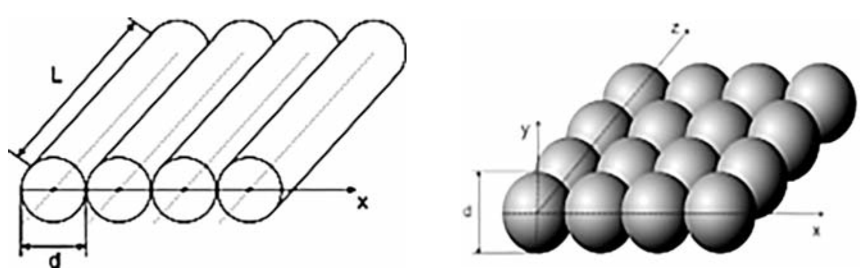
The basic optical anisotropy matrix {J} of a partial polymer networks we can use in the next form of the corresponding Muller operators.

$$\{J\} = \{Q\}\{\Psi\}. \qquad (4)$$

Results

To determine the relationship between the optical and geometric characteristics of the anisotropy of spatially ordered polymer networks and their coordinate distributions of polarization (azimuths and ellipticity) in the Fourier plane, we performed computer simulations.

We used next two types of objects as virtual polymer networks with birefringence. The first one was a network of birefringence cylinders arranged in the directions of the optical axes and located in the same plane (fig. 2, a).



a b

Fig. 2. Analysis of the representation model. Explanation in the text

The second type of objects — an ensemble of birefringence spheres, which lie on the same plane (fig. 2, b).

The geometrical parameters of anisotropic cylinders are as follows: cross-sectional diameter — d = 50 µm, cylinder length — L = 200 µm. Total number of cylinders — N = 50. Linear birefringence of cylinders — $\Delta n_1 = 1,5 \cdot 10^{-2}$.

Birefringent spheres are characterized by the next geometric parameters: spheres diameter — d = = 50 µm, total number of spheres — N = 10×10 = 100. Circular birefringence of such elements — $\Delta n_2 = 1,5 \cdot 10^{-2}$.

The choice of such optical and geometric parameters of virtual polycrystalline grids allowed us to compare the influence of the features of the geometric construction of optically inhomogeneous objects on the polarization-inhomogeneous structure of the field of scattered laser radiation in the Fourier plane. The practical results of the computer simulation FIPM (Fourier images of polarization maps) of polarization properties are presented by a series of fragments in fig. 3, 4.

The coordinate distributions of random values of the azimuth (fig. 3) and ellipticity (fig. 4) maps of the object polarization field were estimated by constructing histograms with further calculation of a set of statistical moments.

Comparison of the statistical structure of FIPM networks of this type demonstrates the results of calculating a set of statistical moments (table).

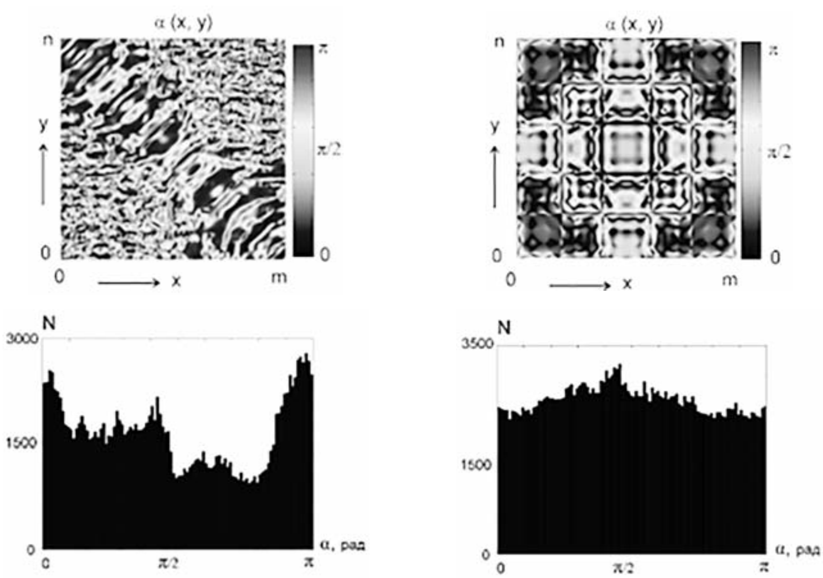


Fig. 3. Coordinate distributions and histograms of random values of the azimuth maps in Fourier plane of the laser irradiation field

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Statistical (1st–4th order) moments of the azimuths and ellipticity in the Fourier plane

M_i	Net of optical anisotropic cylinders	Net of optical anisotropic balls
$\alpha(x, y)$		
M_1	0,17	0,24
M_2	0,13	0,16
M_3	1,85	0,99
M_4	1,27	1,93
$\beta(x, y)$		
M_1	0,088	0,11
M_2	0,12	0,16
M_3	0,63	0,38
M_4	0,44	0,23

Discussion

The results of the conducted investigations are shown that all statistical moments are not equal to 0. This demonstrates the complex statistical structure of the probabilistic coordinate distributions of azimuth maps and polarization ellipticity maps in the Fourier plane.

There are also differences in the optical-geometric structure of model polycrystalline networks in different values of statistical moments of 1–4 orders, which characterize such distributions. The most sensitive from the point of view of diagnostics are the statistical moments of higher orders (3rd and 4th).

Conclusions

1. A new model of a virtual polymer layer was proposed and analytically substantiated, which is a superposition of linear and circular birefringence.

2. Statistical analysis of the coordinate distributions of polarization maps in the Fourier plane, the field of scattered laser radiation by

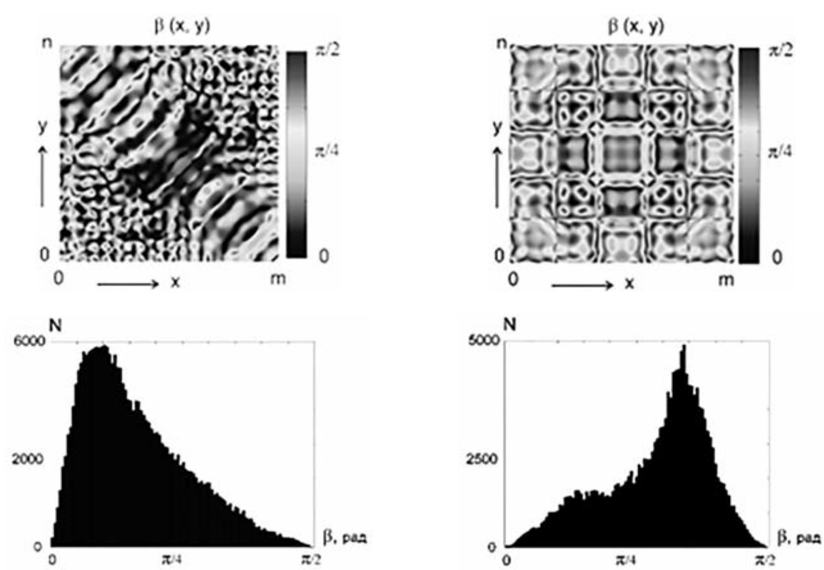

Fig. 4. Maps and histograms of the distribution of random values of the ellipticity in the Fourier plane of the laser irradiation field

such polycrystalline grids showed a polarization-inhomogeneous structure of polarization laser images of optically inhomogeneous birefringent crystals.

3. The dependences of the parameters of statistical moments on their geometric and optical parameters of virtual ordered cylinders and balls are established.

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Наведено матеріали аналітичного огляду та експериментального застосування нового поляриметричного методу Фур'є алгоритмічної обробки поляризаційних зображень оптично неоднорідних мереж полімерних шарів.

Ключові слова: прикладне програмування; метрологія; стандартизація; поліграфічні та пакувальні матеріали; матеріалознавство.

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