UDC 681.7:535.5
DOI: 10.20535/2077-7264.1(75).2022.265686

© O. H. Ushenko, Doctor, Professor, M. P. Horsky, PhD, Associate professor, O. V. Dubolazov, Doctor, Associate professor, O. V. Olar, PhD, Assistant, Chernivtsi National University, Chernivtsi, V. H. Oliinyk, PhD, Associate professor, O. H. Liniuchev, PhD, Assistant, Igor Sikorskyi KPI, Kyiv, Ukraine

COMPUTER ALGORITHMS FOR DETECTING POLARIZATION MAPS FOR POLYMER HOMOGENEITY CONTROL IN PRINTING INDUSTRY

This work is aimed at generalizing the methods of laser polarimetry in the case of partially depolarizing optically anisotropic methyl acrylate layers. A method of differential Mueller-matrix mapping is proposed and substantiated for reproducing the distributions of the parameters of linear and circular birefringence and dichroism of partially depolarizing methyl acrylate layers.

Keywords: polarization; methyl acrylate; Mueller matrix; linear birefringence; circular birefringence; diagnostics.

Introduction

Among the numerous areas of optical diagnostics of polymer layers [1–3], an important place is occupied by Mueller-matrix polarimetry (MMP) [4–6]. The further development and generalization of the MMP techniques for the polycrystalline structure of polymer layers with different light scattering rates or different depolarizing abilities [7–10] is urgent.

Our work is aimed at the development and experimental testing of the method of differential Mueller-matrix mapping for the reconstruction of the distributions of the optical anisotropy parameters of methyl acrylate layers.

Method

Under conditions of multiple scattering, the Mueller matrix of the depolarizing layer changes along the direction of light propagation. Analytically, this dependence is illustrated by the equations

$$\frac{d\{M\}(z)}{dz} = \{M\}(z)\{m\}(z), \qquad (1)$$

where {M}(z) — Mueller matrix to an object in a plane z, {m}(z) — Mueller differential matrix.

For a depolarizing medium, expression (1) can be represented as an average $\langle\{m\}\rangle$ (polarization part {m}(z)) and fluctuating $\langle\{\Delta m^2\}\rangle$

(depolarization part {m}(z)) components

$$\{m\}(z)=\langle\{m\}\rangle+\langle\{\Delta m^2\}\rangle. \quad (2)$$

Note that there is always a feedback between the differential matrix and the Mueller matrix

$$M(z) = \exp(\{m\}(z)). \quad (3)$$

The joint analysis of relations (1)–(3), revealed the expression of the logarithmic matrix algorithm

$$L(z) = \ln\{M(z)\} = L_p + L_d, \quad (4)$$

which is defined as a superposition of antisymmetric L_p (polarization) and symmetric L_d (depolarization) components L(z)

$$\begin{cases} L_p=\langle\{m\}\rangle z; \\ L_d=0,5\langle\{\Delta m^2\}\rangle z^2, \end{cases} \quad (5)$$

where

$$\begin{cases} L_p=0.5\left(L-GL^TG\right); \\ L_d=0.5\left(L+GL^TG\right); \\ G=\mathrm{diag}(1,-1,-1,-1). \end{cases} \quad (6)$$

here G — metric Minkowski matrix.

Taking into account relations (1)–(6), the polarization component of the logarithmic matrix algorithm L(z) takes the form

$$L_p(\{m\})=0,5z^{-1}\begin{Vmatrix} 0 & (l_{12}+l_{21}) & (l_{13}+l_{31}) & (l_{14}+l_{41}) \\ (l_{21}+l_{12}) & 0 & (l_{23}-l_{32}) & (l_{24}-l_{42}) \\ (l_{31}+l_{13}) & (l_{32}-l_{23}) & 0 & (l_{34}-l_{43}) \\ (l_{41}+l_{14}) & (l_{42}-l_{24}) & (l_{43}-l_{34}) & 0 \end{Vmatrix}, \quad (7)$$

where

$$\begin{cases} l_{ik}=\ln M_{ik}; \\ l_{ik}+l_{ki}=\ln\left(M_{ik}\times M_{ki}\right); \\ l_{ik}-l_{ki}=\ln\left(\dfrac{M_{ik}}{M_{ki}}\right) \end{cases} \quad (8)$$

Expression (7), taking into account relations (8), can be rewritten as follows

$$\langle\{m\}\rangle=0,5z^{-1}\begin{Vmatrix} 0 & \ln(M_{12}M_{21}) & \ln(M_{13}M_{31}) & \ln(M_{14}M_{41}) \\ \ln(M_{12}M_{21}) & 0 & \ln\left(\dfrac{M_{23}}{M_{32}}\right) & \ln\left(\dfrac{M_{24}}{M_{42}}\right) \\ \ln(M_{13}M_{31}) & \ln\left(\dfrac{M_{32}}{M_{23}}\right) & 0 & \ln\left(\dfrac{M_{34}}{M_{43}}\right) \\ \ln(M_{14}M_{41}) & \ln\left(\dfrac{M_{42}}{M_{24}}\right) & \ln\left(\dfrac{M_{43}}{M_{34}}\right) & 0 \end{Vmatrix}. \quad (9)$$

Results

The results of investigation of the two-dimensional structure of the elements

$$\left(\langle m_{12}\rangle=\langle m_{21}\rangle\right);\left(\langle m_{13}\rangle=\langle m_{31}\rangle\right);$$
$$\left(\langle m_{14}\rangle=\langle m_{41}\rangle\right);\left(\langle m_{23}\rangle=-\langle m_{32}\rangle\right);$$
$$\left(\langle m_{24}\rangle=-\langle m_{42}\rangle\right);\left(\langle m_{34}\rangle=-\langle m_{43}\rangle\right)$$

of the 1st order differential matrix of methyl acrylate layers are illustrated by a series of dependences (maps and histograms of distributions), which are shown in fig. 1 and fig. 2.

As you can see, the histograms of distributions $N_{j=1-6}\left(\langle\{m_{ik}\}\rangle\right)$ are characterized by a wide range of changes in the value of all off-diagonal elements $\langle\{m_{i\neq k}\}\rangle$ of the first-order differential matrix — fig. 2. The revealed fact indicates the presence of a complex polycrystalline structure of a polymer layer of this type with individual manifestations of various mechanisms of birefringence and dichroism. Quantitative parameters cha-racterizing the distributions of the magnitude of the set of elements of the first-order differential matrix of the partially depolarizing methyl acrylate layer are shown in table.

ISSN 2077-7264. Технологія і техніка друкарства. 2022. № 1(75)

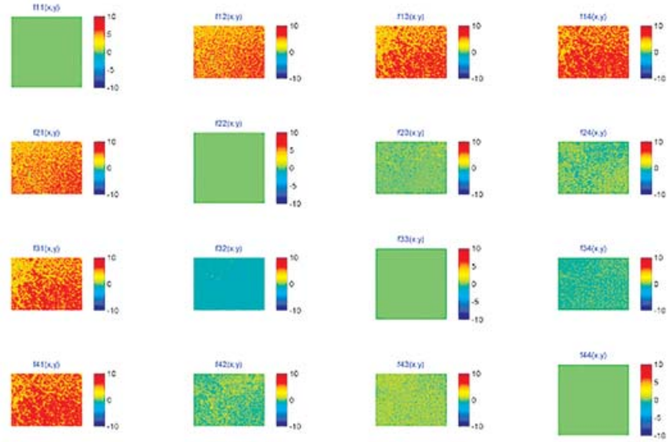

Fig. 1. Element maps of the 1st order differential matrix of the methyl acrylate layer (z = 60 μm; τ = 0,21; Λ = 43 %)

Discussion

Analysis of the presented data of statistical analysis revealed that due to the different probabilities of absorption events and the formation of phase shifts between the orthogonal components of the amplitude of laser radiation in the volume of the methyl acrylate layers, significant differences are formed (within one order of magnitude) between the statistical moments of the 1st–4th orders, characterizing the distribution of the values of the parameters LB; CB; LB' and LD; CD; LD' — table.

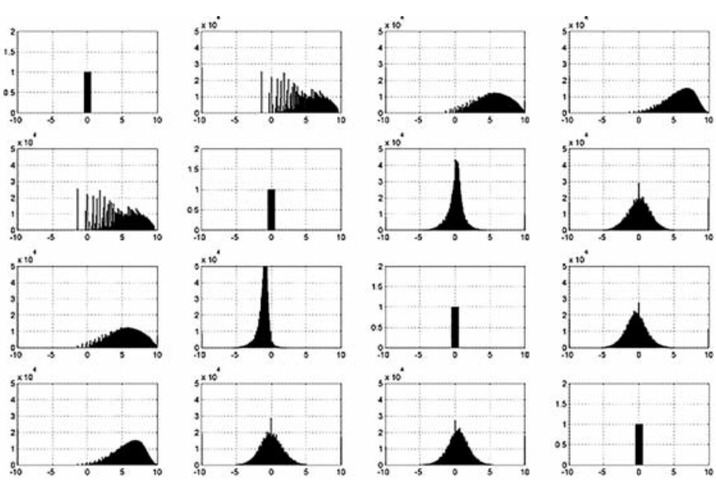

Fig. 2. Histograms of the distribution of the magnitude of the elements of the 1st order differential matrix of the methyl acrylate layer (z = 60 μm; τ = 0,21; Λ = 43 %)

Statistical moments of the 1st–4th orders characterizing the distributions of the magnitude of the elements of the 1st order differential matrix of the methyl acrylate layer (z = 60 μm; τ = 0,21; Λ = 43 %)

Z_i	$\langle m_{12;21} \rangle$	$\langle m_{13;31} \rangle$	$\langle m_{14;41} \rangle$	$\langle m_{23;32} \rangle$	$\langle m_{24;42} \rangle$	$\langle m_{34;43} \rangle$
Z_1	3,21	5,12	6,37	0,12	0,11	0,09
Z_2	4,73	4,22	3,92	0,21	0,24	0,21
Z_3	1,86	0,62	1,65	0,33	0,16	0,12
Z_4	0,95	0,53	0,77	0,57	0,21	0,33

Conclusions

1. A method of differential Mueller-matrix mapping is proposed and substantiated for reproducing the distributions of the parameters of linear and circular birefringence and dichroism of partially depolarizing methyl acrylate layers.

2. Coordinate distributions of the magnitude of the elements of the first-order differential matrix of methyl acrylate layers are determined (z = 60 μm; τ = 0,21; Λ = 43 %).

References

1. Tuchin, V. V. (2007). Tissue Optics: Light Scattering Methods and Instruments for Medical Diagnosis, second edition, PM 166, *SPIE Press*, Bellingham, WA.

2. Wang, X. G., Yao, & Wang, L.-H. (2002). Monte Carlo model and single-scattering approximation of polarized light propagation in turbid media containing glucose. *Appl. Opt.,* 41, 792–801.

3. Wang, X., & Wang, L.-H. (2002). Propagation of polarized light in birefringent turbid media: a Monte Carlo study. *J. Biomed. Opt.*, 7, 279–290.

4. Ghosh, B. N., & Vitkin, I. A. (2011). Tissue polarimetry: concepts, challenges, applications and outlook. *J. Biomed,. Opt.,* 16, 110801.

5. Ghosh, N., Wood, M. F. G., & Vitkin, I. A. (2010). *Polarized light assessment of complex turbid media such as biological tissues via Mueller matrix decomposition.* Handbook of Photonics for Biomedical Science. London: CRC Press, Taylor & Francis Group, 253–282.

6. Tynes, H. H. & others (2001). Monte Carlo and multicomponent approximation methods for vector radiative transfer by use of effective Mueller matrix calculations. *Appl. Opt.*, 40(3), 400–412.

7. Ushenko, Y. A., Boychuk, T. M., Bachynsky, V. T., & Mincer, O. P. (2013). *Diagnostics of Structure and Physiological State of Birefringent Biological Tissues: Statistical, Correlation and Topological Approaches.* Handbook of New York: Coherent-Domain Optical Methods, Springer Science+Business Media, p. 107.

8. Ushenko, V. A., & Gavrylyak, M. S. (2013). Azimuthally invariant Mueller-matrix mapping of biological tissue in differential diagnosis of mechanisms protein molecules networks anisotropy. *Proc. SPIE 8812, Biosensing and Nanomedicine VI*, 88120Y.

ISSN 2077-7264. Технологія і техніка друкарства. 2022. № 1(75)

9. Ushenko, V. A., & Gorsky, M. P. (2013). Complex degree of mutual anisotropy of linear birefringence and optical activity of biological tissues in diagnostics of prostate cancer. *Optics and Spectroscopy*, 115(2), 290–297.

10. Ushenko, V. A., & Dubolazov, A. V. (2013). Correlation and self similarity structure of polycrystalline network biological layers Mueller matrices images. *Proc. SPIE 8856*.

У статті в стислій та систематичній формі представлено нові результати традиційних методів лазерної поляризаційної інтроспекції для дослідження полікристалічної архітектоніки фазово-неоднорідних полімерних шарів, які, крім лінійного та кругового подвійного променезаломлення, також мають оптично анізотропне поглинання.

Ключові слова: поляризація; метилакрилат; матриця Мюллера; лінійне двопроменезаломлення; кругове двопроменезаломлення; діагностика.

Надійшла до редакції 28.05.22