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Singular analysis of Jones-matrix images describing polycrystalline networks of biological crystals in diagnostics of cholelithiasis in its latent period

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Abstract. Determined in this work are analytical interrelations between orientations of optical axes and birefringence of biological crystals and characteristic values of Jones-matrix elements corresponding to flat layers of polycrystalline networks, which set the conditions providing formation of polarization singularities in laser images. Performed is the complex statistical, correlation and fractal analysis of distributions for the amount of characteristic values inherent to Jones-matrix elements corresponding to bile layers of healthy and sick patients. Also, offered are the objective criteria for differentiation of optical properties typical to polycrystalline networks of human bile in different physiological states, and realized is the Jones-matrix diagnostics of cholelithiasis.

Keywords: laser, polarization, birefringence, Jones matrix, statistical moment, autocorrelation, power spectrum, bile.

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1. Introduction

Among the methods for optical diagnostics of biological layers, widely spread are those of laser polarimetric diagnostics aimed at optical-anisotropic structure inherent to human tissues [1 - 31]. The main "information product" of these methods is obtaining the coordinate distributions for elements of Mueller and Jones matrixes corresponding to biological tissues (BT) [1 - 5] with the following statistical (statistical moments of the first to fourth orders [5, 6, 10, 14, 19, 25, 26, 30]), correlation (auto- and mutual-correlation functions [12, 17, 18, 21, 26]), fractal (fractal dimensionalities [5, 6, 25]), singular (distributions of amounts of linear and circularly polarized states), wavelet (sets of wavelet coefficients for various scales of biological crystals [22, 28]) analyses. As a result, one can determine interrelations between a set of these parameters and distributions of optical axis directions as well as the birefringence value inherent to networks of optically uniaxial protein (myosin, collagen, elastin, etc.) fibrils in optically-anisotropic component of BT layer. Being based on this approach, a large amount of methods for diagnostics and differentiation of pathological changes in BT structure that are related with their degenerative-dystrophic as well as oncological changes [4 - 6, 12, 19, 20-22, 27, 29, 31].

The above methods of studying the matrix images of biological layers have been currently developed using the new approach based on the analysis of coordinate distributions for the so-called characteristic values that describes conditions for formation of polarization singularities [5]. The latter are pronounced as linearly ($L-$ points) and circular ($C-$ points) polarized states. In the case of $L-$ points, the direction of electric field vector rotation is indeterminate. While for $C-$ points, indeterminate is the azimuth of electric field vector polarization. Demonstrated in […] is the efficiency of this approach for Mueller-matrix diagnostics of pathological states observed for human biological tissues. At the same time, there is a widely spread group of optically-anisotropic biological objects that are not comprised yet by the matrix methods of laser polarimetric diagnostics. One can relate to these objects optically-thin (extinction coefficient $\tau \le 0.1$) layers of diverse biological liquids (bile, urine, liquor, synovial liquid, blood plasma, saliva, etc.). These objects are considerably more accessible for direct laboratory analyses as compared with traumatic methods of biological tissue biopsy. Being based on that, it seems topical to adapt the methods of laser polarimetric

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diagnostics to studying the optically-anisotropic structures in polycrystalline networks of biological tissues.

Our work is aimed at searching the possibilities for diagnostics and differentiation of optical properties inherent to polycrystalline networks of human bile by determining the coordinate distributions of Jones-matrix elements with the following statistical, correlation and fractal analyses of distributions typical for their characteristic (singular) values for diagnostics of cholelithiasis in its latent period.

2. Main analytical relations

Our modeling the optical properties of polycrystalline networks observed in human bile is based on the following conceptions developed for optically-anisotropic protein fibrils [1-4, 7, 9, 14, 16, 23-27, 30]. From the optical viewpoint, bile is a multi-component phase-inhomogeneous liquid consisting of three main fractions:

- optically isotropic – optically homogeneous micellar solution with a small amount of cylindrical epithelium cells, leukocytes, leukocytoids, phlegm;
- optically anisotropic – liquid-crystalline phase consisting of a set comprising liquid crystals of three types, namely: needle-like crystals of fat acids, crystals of cholesterol monohydrate, and those of calcium bilirubinate;
- crystalline – solid crystalline phase that is formed due to dendrite and disclination mechanisms of crystallization.

As a base for studying the optical properties of polycrystalline networks corresponding to these main fractions, we took the following conceptions developed for optically-anisotropic biological liquids […….]:

- separate (partial) biological crystals are optically uniaxial and birefringent;
- optical properties of a partial crystal is exhaustively full described with the Jones operator [5]

$$\{J\} = \begin{Vmatrix} J_{11} & J_{12} \\ J_{21} & J_{22} \end{Vmatrix} = \begin{Vmatrix} \cos^2\rho + \sin^2\rho\exp(-i\delta); & \cos\rho\sin\rho[1-\exp(-i\delta)]; \\ \cos\rho\sin\rho[1-\exp(-i\delta)]; & \sin^2\rho + \cos^2\rho\exp(-i\delta); \end{Vmatrix}. \quad (1)$$

Here, ρ is the direction of the optical axis; $\delta = \frac{2\pi}{\lambda}\Delta nd$ – phase shift between orthogonal components E_x and E_y of the amplitude of illuminating laser wave with the wavelength λ; Δn - birefringence index for the crystal with geometric dimension d .

Let us consider the possibility to apply the singular approach to the analysis of Jones-matrix images. From the mathematical viewpoint, a singular value corresponding to the complex value of a matrix element J_{ik} is defined by the following conditions:

$$\begin{cases} (\operatorname{Re} J_{ik})^2 + (\operatorname{Im} J_{ik})^2 = 0; \\ \operatorname{Re} J_{ik} = 0; \\ \operatorname{Im} J_{ik} = 0. \end{cases} \quad (2)$$

With account of (2), the analytical expressions (1) are transformed to the following relations:

$$J_{11} \Leftrightarrow \begin{cases} \sin^2\rho\sin\delta = 0; \\ \cos^2\rho + \sin^2\rho\cos\delta = 0. \end{cases}, \quad (3)$$

$$J_{22} \Leftrightarrow \begin{cases} \cos^2\rho\sin\delta = 0; \\ \sin^2\rho + \cos^2\rho\cos\delta = 0. \end{cases} \quad (4)$$

$$J_{12} = J_{21} \Leftrightarrow \begin{cases} 2\cos^2\rho\sin^2\rho(1+\cos\delta) = 0; \\ \sin 2\rho(1+\cos\delta) = 0. \end{cases} \quad (5)$$

As it follows from (3) to (5), singularities of complex matrix elements J^*_{ik} are related with definite (characteristic) values of orientation ρ^* and phase δ^* parameters of the studied polycrystalline network:

$$\begin{cases} \rho^* = 0^0; \quad \pm 45^0; \quad 90^0; \\ \delta^* = 0^0; \quad \pm 90^0; \quad 180^0. \end{cases} \quad (6)$$

On the other hand, the relations (6) set conditions when optically uniaxial birefringent crystals form polarization singular states $L-$ ($\delta = 0^0;180^0$) and $C-$ ($\delta = \pm 90^0$) of a laser beam. Bearing it in mind, one can determine the characteristic values of Jones-matrix elements J^*_{ik} that corresponds to $L-$ and $C-$ states of polarization inherent to laser images of polycrystalline network:

- values $J_{11} = J_{22} = 0$ correspond to $L-$ states of polarization;
- values $J_{12} = J_{21} = 0$ correspond to $C-$ states of polarization.

It should be noted that the analytical approach (1) to (6) is related to a partial optically uniaxial birefringent crystal. Formed in real biological layers are complex networks of these crystals. Therefore, application of the singular analysis to the Jones matrix of this network needs determination of coordinate distributions for the characteristic values $J^*_{ik}(x, y)$ in the plane of a biological liquid layer.

3. Optical setup for Jones-matrix mapping the optically anisotropic biological liquids

Shown in Fig. 1 is the optical scheme of a polarimeter for measuring the coordinate distributions of Jones-matrix elements corresponding to birefringent layers.

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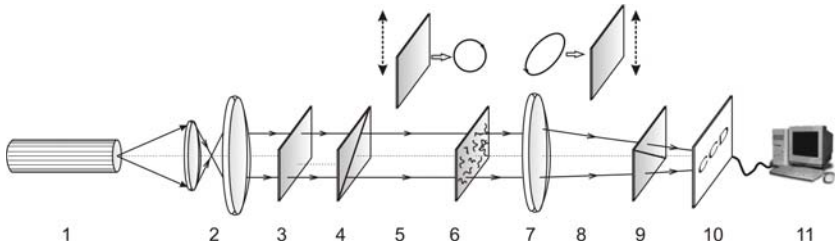

Fig. 1. Optical scheme of the polarimeter: 1 – He-Ne laser; 2 – collimator; 3 – stationary quarter-wave plate; 5, 8 – mechanically movable quarter-wave plates; 4, 9 – polarizer and analyzer, respectively; 6 – object of investigation; 7 – micro-objective; 10 – CCD camera; 11 – personal computer.

Illumination of bile samples was performed using a parallel beam (∅ = 10^4 μm) of He-Ne laser (λ = 0.6328 μm, W = 5.0 mW). The polarization illuminator consists of quarter-wave plates 3, 5 and polarizer 4, which provides formation of the laser beam with an arbitrary polarization state. Using the micro-objective 7 (magnification 4x), images of bile layers were projected onto the plane of light-sensitive area (800x600 pixels) of the CCD-camera 10 that provided the range for measuring the structural elements from 2 to 2000 μm. The analysis of laser images was carried out using the polarizer 9 and quarter-wave plate 8.

In our experiments, distributions of characteristic values for Jones-matrix images of bile layers were determined in the following manner. Two-dimensional arrays $J_{ik}(m \times n)$ were scanned along horizontal direction $x \equiv 1, \quad ..., \quad m$ with the step $\Delta x = 1 pix$. Within the limits of every local sampling $(1_{pix} \times n_{pix})(^{k\ =\ 1,2,\ \ldots,\ m})$, we calculated the amount (N) of characteristic values $J_{ik}(k) = 0$, - ($N_{ik}^{(k)}$). Thus, we could determine the dependences $N_{ik}(x) \equiv (N_{ik}{}^{(1)},\ N_{ik}{}^{(2)},\ ...,\ N_{ik}{}^{(m)})$ for the amount of characteristic values corresponding to coordinate distributions of Jones-matrix elements $J_{ik}(m \times n)$ for human bile layers in various physiological states.

4. Criteria for estimating the amount of characteristic values corresponding to Jones-matrix images of bile layers

$N_{ik}(x)$ distributions for characteristic values of Jones-matrix elements $J_{ik}(m \times n)$ are characterized with the set of statistical moments of the 1-st to 4-th orders M; σ; A; E calculated using the following relations [5, 6, 25, 30]:

$$M = \frac{1}{D}\sum_{j=1}^{D}\left|(N_{ik})_j\right|, \qquad \sigma = \sqrt{\frac{1}{D}\sum_{j=1}^{D}(N_{ik})_j{}^2}, \qquad A = \frac{1}{\sigma^3}\frac{1}{D}\sum_{j=1}^{D}(N_{ik})_j{}^3, \quad E = \frac{1}{\sigma^4}\frac{1}{D}\sum_{j=1}^{D}(N_{ik})_j{}^4. \qquad (7)$$

where D is the amount of characteristic values N_{ik} within the limits of coordinate distribution for Jones-matrix images of J_{ik} elements.

To analyze the coordinate structure of $N_{ik}(x)$ distributions, we used the autocorrelation method with account of the following function [12, 21, 26]

$$G(\Delta x) = \frac{1}{X_0}\int_{1}^{X_0}[N_{ik}(x)][N_{ik}(x - \Delta x)]dx. \quad (8)$$

Here, Δx is the step for changing the coordinates $x = 1 \div X_0$.

As parameters characterizing the dependences $G(\Delta x)$, we chose the set of correlation moments of the 1-st to 4-th orders $K_{l=1;2;3;4}$ that are determined like to relations (7).

Estimating the degree of self-similarity and repeatability for different geometric (d) scales of the structure inherent to $N_{ik}(x)$ distributions of characteristic values corresponding to the Jones matrix elements $J_{ik}(m \times n)$ of polycrystalline networks was performed by calculating the logarithmic dependences for power spectra $\log J(N_{ik}) - \log(d^{-1})$ that were approximated using the least-squares method to the curves $\Phi(\eta)$. For the straight parts of the curves $\Phi(\eta)$, determined were the slope angles η_i and calculated were the values of fractal dimensionalities for N_{ik} distributions by using the relations [5, 6, 11, 25]

$$D_i(g) = 3 - tg\eta_i. \quad (9)$$

Classification of $N_{ik}(x)$ distributions for characteristic values of matrix elements $J_{ik}(m \times n)$ was carried out in accord with the criteria offered in [5]. If the value of the slope angle $\eta = const$ in the dependences $\Phi(\eta)$ for 2 or 3 decades of changing the sizes d, then the distributions $N_{ik}(x)$ are fractal. Under condition that several constant slope angles are available in the curve $\Phi(\eta)$, the $N_{ik}(x)$ sets are multi-fractal. When no stable slope angles are available over the whole interval of changing the sizes d, the sets $N_{ik}(x)$ are considered as random.

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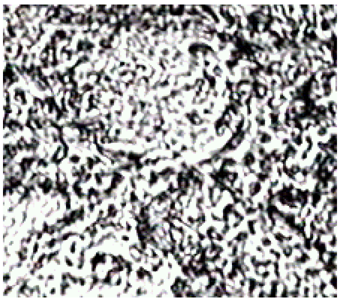
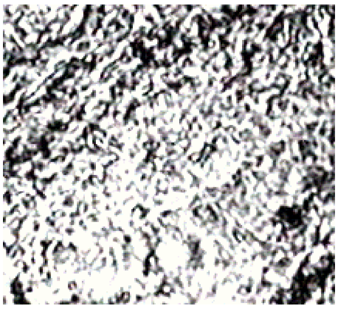


a



b

Fig. 2. Polarization-visualized images of polycrystalline networks inherent to bile layers for patients in different physiological states. See explanations in the text.

To make this comparative analysis of $\log J(N_{ik}) - \log(d^{-1})$ dependences more objective, let us introduce the conception of spectral moments from the 1-st to 4-th orders $S_{j=1;2;3;4}$ - the relation (7).

5. Jones-matrix differentiation of polarization properties inherent to the optically anisotropic component of bile for healthy and sick patients

As investigated objects, we used smears of bile taken from healthy (18 samples) and sick with cholelithiasis (17 samples) patients.

Fig. 2 shows laser images of optically anisotropic structures corresponding to samples of both types, which were obtained in the case of crossed transmission planes of the polarizer 4 and analyzer 9 in the laser polarimeter (Fig. 1).

As follows from the comparative analysis of laser images inherent to bile smears of both types, geometric structures of optically anisotropic clusters are similar. The higher level of bleaching in bile images for the sick patients is indicative of a higher level in birefringence $\delta(m \times n)$ of polycrystalline network. Therefore, we have focused on investigation of diagnostic possibilities of the complex statistical, correlation and phase analysis aimed at distributions of the amount of characteristic values for Jones-matrix elements $J_{12;21}(m \times n) = 0$ describing optically-thin bile layers of both types.

Depicted in Figs 3 and 4 are the results of studying the coordinate $J_{12;21}(m \times n) = 0$ (fragments (a)), quantitative $N_{12;21}(x)$ (fragments (b)), autocorrelation $G_{12;21}(\Delta x)$ (fragments (c)) and logarithmic $\log N_{12;21}(x) - \log d^{-1}$ (fragments (d)) dependences that characterize the structure of

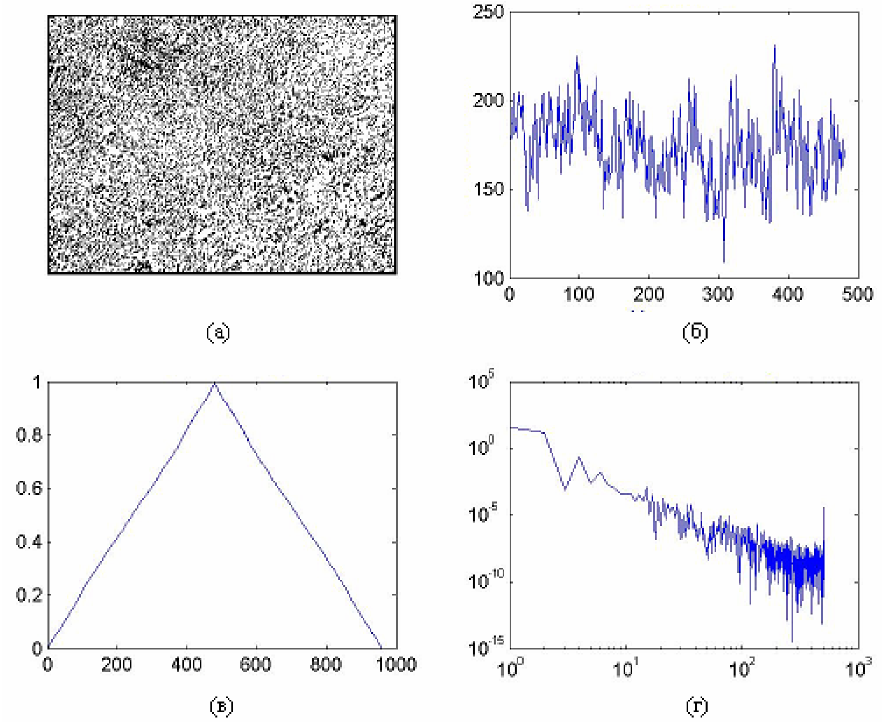


Fig. 3. Coordinate (a), quantitative (b), correlation (c) and spectral (d) distributions for characteristic values of the Jones-matrix elements $J_{12;21}$ for the bile polycrystalline network of a healthy patient.

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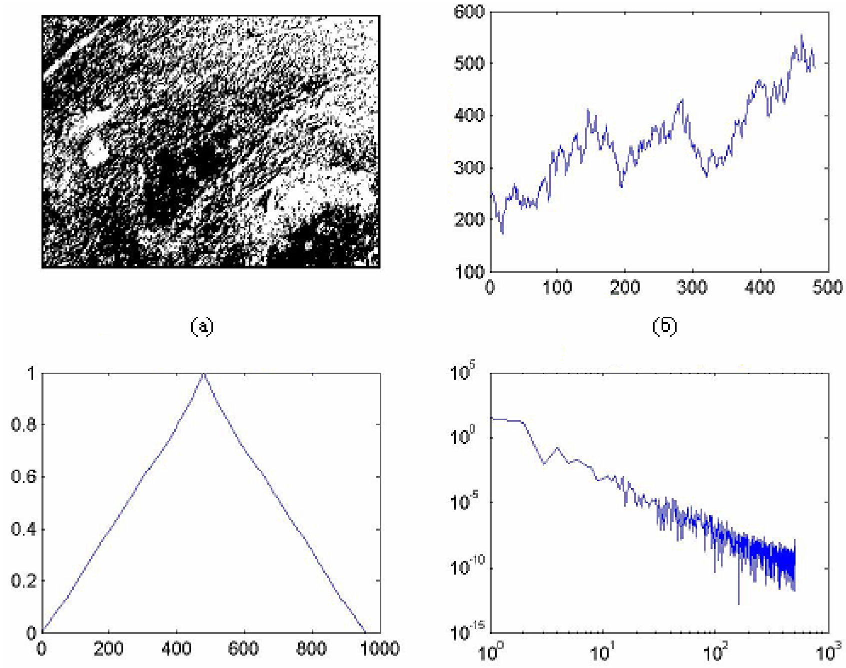

Fig. 4. Coordinate (a), quantitative (b), correlation (c) and spectral (d) distributions for characteristic values of the Jones-matrix elements $J_{12;21}$ for the bile polycrystalline network of a patient with cholelithiasis.

distributions for characteristic values inherent to the Jones-matrix elements $J_{12;21} = 0$ corresponding to bile polycrystalline networks of healthy (Fig. 3) and sick (Fig. 4) patients.

It follows from the obtained data upon statistical, correlation and fractal structures of the distribution for the characteristic sampling $J_{12;21} = 0$ in Jones-matrix images $J_{12;21}(m \times n)$ of bile layers for both groups that:

- General amount of characteristic values $J_{12;21} = 0$ in the coordinate distribution $J_{12;21}(m\times n)$ for the bile layer in the case of cholelithiasis is practically 2-fold increased (Figs 3 and 4, fragments (a) and (b)). This fact indicates increase in birefringence owing to growth of the concentration of the optically anisotropic component in bile of the sick patient.
- Autocorrelation functions for the distributions of the amount of characteristic values $N_{12;21}(x) \equiv (N_{12;21}{}^{(1)}, \; N_{12;21}{}^{(2)}, \; ..., \; N_{12;21}{}^{(m)})$ for bile samples of both types decay monotonically (Figs 3 and 4, fragments (c)), which is indicative of homogeneity in the coordinate distribution $J_{12;21} = 0$.
- Sets of values $N_{12;21}(x) \equiv (N_{12;21}{}^{(1)}, \; N_{12;21}{}^{(2)}, \; ..., \; N_{12;21}{}^{(m)})$ are fractal, since the Log –log dependences for power spectra (Figs 3 and 4, fragments (d)) corresponding to the distribution of the amount of values $J_{12;21} = 0$ are characterized with the only slope angle.

From the quantitative viewpoint, statistical, correlation and self-similar structures of distributions for the amount of characteristic values in Jones-matrix images $J_{12;21}(m\times n)$ corresponding to bile smears of both types (Fig. 1) are illustrated by the set of moments from the 1-st to 4-th orders, magnitudes and change ranges of which have been summarized in Table 1.

As it follows from the data summarized in Table 1, main criteria for diagnostics of cholelithiasis in its latent

Table 1. Statistical, correlation and spectral parameters for distributions of characteristic values in Jones-matrix images of the element $J_{12;21}(m\times n)$ corresponding to human bile in different physiological state.

Parameters	Statistical		Correlation		Spectral	
State	norm	pathology	norm	pathology	norm	pathology
1-st moment	0.18±0.038	0.51±0.11	0.48±0.092	0.41±0.083	0.17±0.036	0.19±0.043
2-nd moment	0.29±0.066	0.19±0.034	0.18±0.041	0.23±0.049	0.16±0.035	0.13±0.024
3-rd moment	0.47±0.099	0.84±0.189	0.16±0.029	0.21±0.041	0.11±0.023	0.17±0.035
4-th moment	0.38±0.075	0.65±0.15	0.25±0.053	0.32±0.065	0.18±0.041	0.25±0.054

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period can be based on statistical moments of the 1-st to 4-th orders that characterize distributions of the amount of characteristic values $J_{12;21} = 0$ in Jones-matrix images of $J_{12;21}(m \times n)$ elements corresponding to optically anisotropic networks in human bile. Also ascertained are the following differences between M; σ; A; E values (relations (7)) that characterize dependences $N_{12;21}(x)$ for Jones-matrix images describing bile samples taken from patients of the reference group and from those with cholelithiasis:

- M - increase up to 3 times;
- σ - decrease down to 1.53 times;
- A - increase up to 1.7 times;
- E - increase up to 1.8 times.

The differences between values of correlation ($K_{i=1;2;3;4}$) and spectral ($S_{i=1;2;3;4}$) moments that characterize $N_{12;21}(x)$ distributions for bile samples of various types are insignificant and lie within the range 10 to 40%.

6. Conclusions

1. Offered is the method that allows estimating the characteristic values for coordinate distributions of Jones-matrix elements to describe polarization properties of birefringent polycrystalline networks in human biological liquids.

Found and grounded are criteria for laser polarimetric diagnostics of cholelithiasis in its latent period by using the statistical analysis of distributions typical for characteristic values of Jones-matrix images corresponding to birefringent polycrystalline networks in human bile.

References

1. W.-F. Cheong, S. A. Prahl, A. J. Welch, “A Review of the Optical Properties of Biological Tissues,” *IEEE J. Quantum Electron*, Vol. 26, pp. 2166-2185, Dec. 1990.
2. S. A. Prahl, M. Keijzer, S. L. Jacques, A. J. Welch, “A Monte Carlo model of light propagation in tissue,” *SPIE Proceedings of Dosimetry of Laser Radiation in Medicine and Biology*, Vol. IS 5, pp. 102-111, 1989.
3. E. Wolf, “Unified theory of coherence and polarization of random electromagnetic beams ,” *Phys. Lett. A.*, Vol. 312, pp. 263-267, 2003.
4. Alexander G. Ushenko and Vasilii P. Pishak, “Laser Polarimetry of Biological Tissue: Principles and Applications”, in Handbook of Coherent-Domain Optical Methods: Biomedical Diagnostics, Environmental and Material Science, vol. I, Valery V. Tuchin, Ed. Boston: Kluwer Academic Publishers, 2004, pp. 93-138.
5. O. V. Angelsky, A. G. Ushenko, Yu. A. Ushenko, V. P. Pishak, “Statistical and Fractal Structure of Biological Tissue Mueller Matrix Images”, in Optical Correlation Techniques and Applications, Oleg V. Angelsky, Ed. Washington: Society of Photo-Optical Instrumentation Engineers , 2007, pp. 213-266.
6. O.V. Angelsky, A.G. Ushenko, Yu.A. Ushenko, V.P. Pishak, and A.P. Peresunko, “Statistical, Correlation, and Topological Approaches in Diagnostics of the Structure and Physiological State of Birefringent Biological Tissues”, in Handbook of Photonics for Biomedical Science, Valery V. Tuchin, Ed. USA: CRC Press, 2010, pp. 21-67.
7. Alexander G. Ushenko, “Polarization structure of laser scattering fields,” Optical Engineering, vol. 34(4), pp. 1088-1093, November 1995.
8. A.G. Ushenko, “Laser diagnostics of biofractals,” Quantum Electronics, vol. 29(12), pp. 1078–1084, December 1999.
9. O.V. Angel'skii, A.G. Ushenko, A.D. Arkhelyuk, S.B. Ermolenko, D.N. Burkovets, “Structure of matrices for the transformation of laser radiation by biofractals,” Quantum Electronics, vol. 29(12), pp. 1074-1077, December 1999.
10. O.V. Angel'skii, A.G. Ushenko A.D. Arheluk, S.B. Ermolenko, D. N. Burkovets, “Scattering of Laser Radiation by Multifractal Biological Structures,” Optics and Spectroscopy, vol. 88(3), pp. 444-448, March 2000.
11. A.G. Ushenko, “Polarization Structure of Biospeckles and the Depolarization of Laser Radiation,” Optics and Spectroscopy, vol. 89(4), pp. 597-601, October 2000.
12. A.G. Ushenko, “Stokes-correlometry of biotissues,” Laser Physics, vol. 10(5), pp.1286-1292, May 2000.
13. A.G. Ushenko, “The Vector Structure of Laser Biospeckle Fields and Polarization Diagnostics of Collagen Skin Structures,” Laser Physics, vol. 10(5), pp. 1143-1149, May 2000.
14. A.G. Ushenko, “Laser polarimetry of polarization-phase statistical moments of the object field of optically anisotropic scattering layers,” Optics and Spectroscopy, vol. 91(2), pp. 313-316, February 2001.
15. A.G. Ushenko, “Polarization contrast enhancement of images of biological tissues under the conditions of multiple scattering,” Optics and Spectroscopy, vol. 91(6), pp. 937-940, August 2001.
16. A.G. Ushenko, “Laser probing of biological tissues and the polarization selection of their images,” Optics and Spectroscopy, vol. 91(6), pp.932-936, August 2001.
17. A.G. Ushenko, “Correlation processing and wavelet analysis of polarization images of biological tissues,” Optics and Spectroscopy, vol. 91(5), pp.773-778, June 2002.

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18. A.G. Ushenko, "Polarization correlometry of angular structure in the microrelief pattern or rough surfaces," Optics and spectroscopy, vol. 92(2), pp. 227-229, June 2002.
19. O.V. Angelsky, A.G. Ushenko, Ye.G. Ushenko, "2-D Stokes Polarimetry of Biospeckle Tissues Images in Pre-Clinic Diagnostics of Their Pre-Cancer States," Journal of Holography and Speckle, vol. 2(1), pp. 26-33, April 2005.
20. Oleg V. Angelsky, Alexander G. Ushenko, and Yevheniya G. Ushenko, "Complex degree of mutual polarization of biological tissue coherent images for the diagnostics of their physiological state," J. Biomed. Opt., vol. 10(6), Article ID 060502, November 2005.
21. O. V. Angelsky, A. G. Ushenko, and Ye. G. Ushenko, "Investigation of the correlation structure of biological tissue polarization images during the diagnostics of their oncological changes," Physics in Medicine and Biology, vol. 50(20), pp. 4811-4822, September 2005.
22. Oleg V. Angelsky, Alexander G. Ushenko, Yevheniya G. Ushenko, Yuriy Y. Tomka, "Polarization singularities of biological tissues images," J. Biomed. Opt., vol. 11(5), Article ID 054030, September-October 2006.
23. O.G. Ushenko, S.G. Guminetsky, A.V. Motrich, "Optical properties of urine, blood plasma and pulmonary condensate of the patients with pulmovnary form of tuberculosis," Photoelectronics, vol.16, pp. 133-139, June 2007.
24. S.H. Guminetskiy, O.G. Ushenko, I.P. Polyanskiy, A.V. Motrych, F.V. Grynchuk, "The optical method for investigation of the peritonitis progressing process," Proceedings of the SPIE, vol. 7008, Article ID 700827, April 2008.
25. Alexander Ushenko, Sergej Yermolenko, Alexander Prydij, Stepan Guminetsky, Ion Gruia, Ovidiu Toma, Konstantin Vladychenko, "Statistical and fractal approaches in laser polarimetry diagnostics of the cancer prostate tissues," Proceedings of the SPIE, vol. 7008, Article ID 70082C, April 2008.
26. A.G. Ushenko, A.I. Fediv, Yu.F. Marchuk, "Correlation and fractal structure of Jones matrices of human bile secret," Proceedings of the SPIE, vol. 7368, Article ID 73681Q, July 2009.
27. A.G. Ushenko, Yu.Ya. Tomka, V.I. Istratiy, "Polarization selection of two-dimensional phase-inhomogeneous birefringence images of biotissues," Proceedings of the SPIE, vol. 7388, Article ID 73881L, December 2009.
28. A.G. Ushenko, A.I. Fediv, Yu.F. Marchuk, "Singular structure of polarization images of bile secret in diagnostics of human physiological state," Proceedings of the SPIE, vol. 7368, Article ID 73681S, July 2009.
29. S.B. Yermolenko, A.G. Ushenko, P. Ivashko, "Spectropolarimetry of cancer change of biotissues," Proceedings of the SPIE, vol. 7388, Article ID 73881D, December 2009.
30. A.G. Ushenko, I. Z.Misevich, V. Istratiy, I. Bachyns'ka, A. P. Peresunko, Omar Kamal Numan, and T. G. Moiysuk, "Evolution of Statistic Moments of 2D-Distributions of Biological Liquid Crystal Net Mueller Matrix Elements in the Process of Their Birefringent Structure Changes," Advances in Optical Technologies, vol. 2010, Article ID 423145, March 2010.
31. O.V. Dubolazov, A.G. Ushenko, V.T. Bachynsky, A. P. Peresunko, and O. Ya. Vanchulyak, "On the Feasibilities of Using the Wavelet Analysis of Mueller Matrix Images of Biological Crystals," Advances in Optical Technologies, vol. 2010, Article ID 162832, March 2010.

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