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New opportunities of differential diagnosis of biological tissues polycrystalline structure using methods of Stokes correlometry mapping of polarization inhomogeneous images

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ABSTRACT

A new method of Stokes correlometry of polarization-inhomogeneous images of biological layers is presented. Analytic relations are determined for the phase of complex parameters of the Stokes vector. A method for measuring the coordinate distributions of the magnitude of the phase of two-point parameters of the Stokes vector is proposed. Objective criteria for differentiating the optical anisotropy of the histological sections of tissue biopsy of the female reproductive tissue (FRT) of different pathologies have been found. An excellent level of balanced accuracy of differential diagnostics has been achieved.

Keywords: Stokes vector, correlometry, polarization, diagnostics.

1. INTRODUCTION

The main theoretical positions of laser polarimetry of optically anisotropic biological layers are given in a series of publications [1-29].

This research aims to study fundamental potentiality of the new Stokes-polarimetry approach to polarization-correlation mapping of microscopic images of histological sections of the biopsy of the wall tissue of female reproductive system (FRS) with different pathologies by determining the coordinate distributions of "two-point" Stokes vector parameters, which were theoretically introduced for the first time by T.Setola, Ya.Tervo and A.T.Friberg [30,31]. As an applied aspect the possibility of differential Stokes-polarimetry diagnostics[32-35] of the change of optical anisotropy of histological sections of biopsy of the wall of healthy and abnormal tissues of female reproductive sphere (FRS) will be discussed.

2. THEORY OF THE METHOD

To describe the correlation structure of the stationary distributions of the fields of complex amplitudes of laser light converted by optically anisotropic biological layers, one can use the following mutual spectral density matrix [30,31]

$$W_{i,j}(r_1,r_2) = E_i^*(r_1) \cdot E_j(r_2), i,j = x,y \quad (1)$$

Here r_1 and r_2 - the coordinates of the neighboring points in the field of laser radiation.

Relations for the analytic description of the module of two-point parameters of the Stokes vector were found

$$S_1 = W_{xx}(r_1,r_2) + W_{yy}(r_1,r_2);$$
$$S_2 = W_{xx}(r_1,r_2) - W_{yy}(r_1,r_2);$$
$$S_3 = W_{xy}(r_1,r_2) + W_{yx}(r_1,r_2);$$

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$$S_4 = i\left[W_{yx}(r_1, r_2) + W_{xy}(r_1, r_2)\right]$$

$$\left\{ ArgS_1 = arctg\left[\frac{\sin(\delta_2 - \delta_1)}{ctg\rho_1 ctg\rho_2 + \cos(\delta_2 - \delta_1)}\right]. \right. \quad (3)$$

$$\left\{ ArgS_2 = arctg\left[\frac{\sin(\delta_2 - \delta_1)}{ctg\rho_1 ctg\rho_2 - \cos(\delta_2 - \delta_1)}\right]. \right. \quad (4)$$

$$\left\{ ArgS_3 = arctg\left(\frac{\sin\delta_2 - ctg\rho_2 tg\rho_1 \sin\delta_1}{\cos\delta_2 + ctg\rho_2 tg\rho_1 \cos\delta_1}\right); \right. \quad (5)$$

$$\left\{ ArgS_4 = arctg\left(\frac{\cos\delta_1 + ctg\rho_2 tg\rho_1 \cos\delta_2}{\sin\delta_1 + ctg\rho_2 tg\rho_1 \sin\delta_2}\right). \right. \quad (6)$$

Here $\left|S_{i=1;2;3;4}\right|$ - modulus, $ArgS_{i=1;2;3;4}$ - SCP phase

3. MATERIALS AND METHODS

Measurement of the coordinate distributions of the values of $Arg(S_{i=3}(\Delta x;\Delta y))$ and $Arg(S_{i=4}(\Delta x;\Delta y))$ was carried out in the experimental arrangement of Stokes-polarimeter [9,13,17].

$Arg(S_{i=3}(\Delta x;\Delta y))$ and $Arg(S_{i=4}(\Delta x;\Delta y))$ were calculated by the following ratios

$$\left\{ ArgS_3 = arctg\left(\frac{\left[\sqrt{I_0(r_1)I_{90}(r_2)}\sin\delta_2 - \sqrt{I_0(r_2)I_{90}(r_1)}\sin\delta_1\right]}{\left[\sqrt{I_0(r_1)I_{90}(r_2)}\cos\delta_2 + \sqrt{I_0(r_2)I_{90}(r_1)}\cos\delta_1\right]}\right). \right. \quad (7)$$

$$\left\{ ArgS_4 = arctg\left(\frac{\left[\sqrt{I_0(r_2)I_{90}(r_1)}\cos\delta_2 + \sqrt{I_0(r_1)I_{90}(r_2)}\cos\delta_1\right]}{\left[\sqrt{I_0(r_2)I_{90}(r_1)}\sin\delta_1 + \sqrt{I_0(r_1)I_{90}(r_2)}\sin\delta_2\right]}\right). \right. \quad (8)$$

$$\delta(r) = arctg\left[\left(\frac{S_4(r)S_2(r)}{S_3(r)}\right)\left(\frac{1 + \frac{I_{90}(r)}{I_0(r)}}{1 - \frac{I_{90}(r)}{I_0(r)}}\right)\right]. \quad (9)$$

Here I_0 and I_{90} - the intensities at the orientation of transmission plane of polarizer 0^0 and 90^0; δ_i - phase shifts between the orthogonal components of the amplitude of the laser radiation in the points with coordinates r_1 and r_2.

4. BRIEF DESCRIPTION OF THE RESEARCH OBJECTS

Optically thin (attenuation coefficient $\tau \prec 0.01$) samples of histological sections (geometrical thickness $l = 20\mu m \div 25\mu m \quad 0.0091 \leq \tau \leq 0.0095$) of biological tissues of internals of two statistically significant (36 samples each) groups of FRS – healthy ones and those with prolapse were studied.

5. EXPERIMENTAL RESULTS AND DISCUSSION

Fig. 1 - Fig. 4 show the SCP-maps of the modulus $Arg(S_{i=3}(\Delta x;\Delta y))$ values distribution (Fig. 1, Рис. 3) and $Arg(S_{i=4}(\Delta x;\Delta y))$ (Fig. 2, Fig.4) of microscopic images of histological sections of tissue biopsies of healthy FRS (Fig.1, Fig. 3) and patients with prolapse (Fig. 2, Fig. 4).

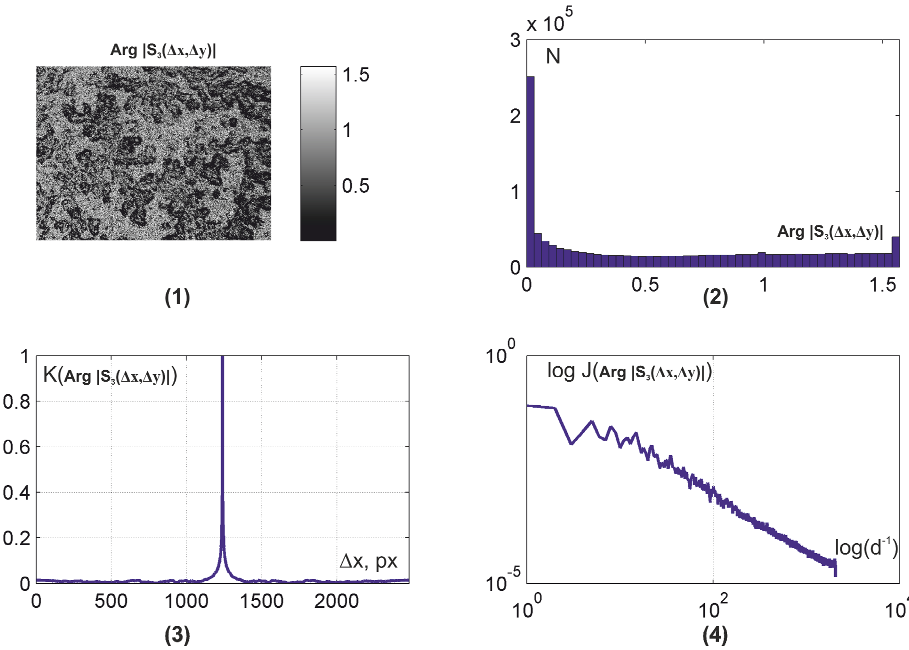

Figure 1. Maps (coordinate distributions (1), histograms (2), autocorrelation functions (3), logarithmic dependences of power spectra (4) of SCP phase $Arg(S_{i=3}(\Delta x;\Delta y))$ of polarization-inhomogeneous images of histological sections of biopsy tissues of FRS (normal)

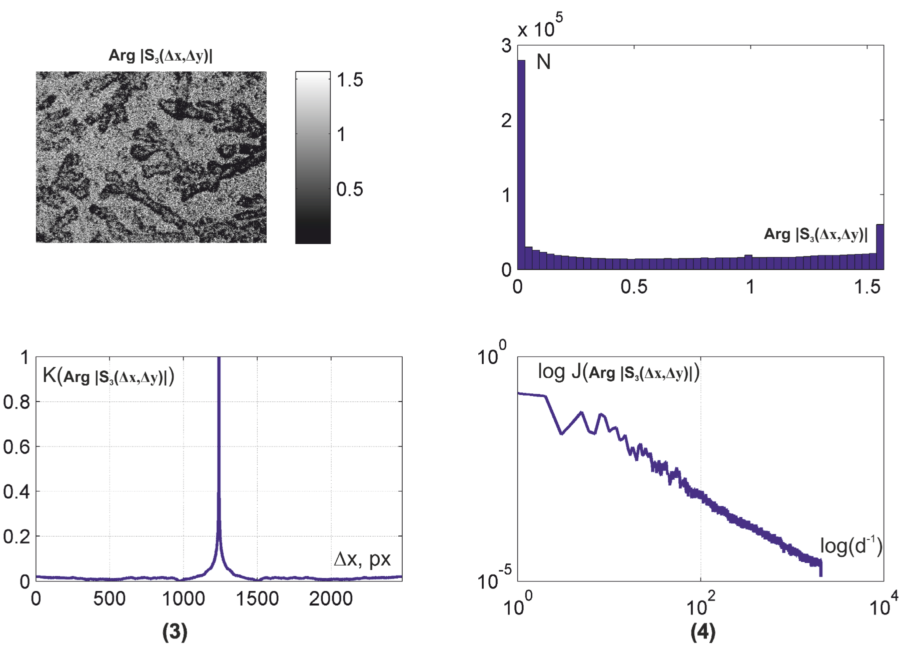

Figure 2. Maps (coordinate distributions (1), histograms (2), autocorrelation functions (3), logarithmic dependences of power spectra (4) of SCP phase $Arg(S_{i=3}(\Delta x;\Delta y))$ of polarization-inhomogeneous images of histological sections of biopsy tissues of FRS (prolapse)

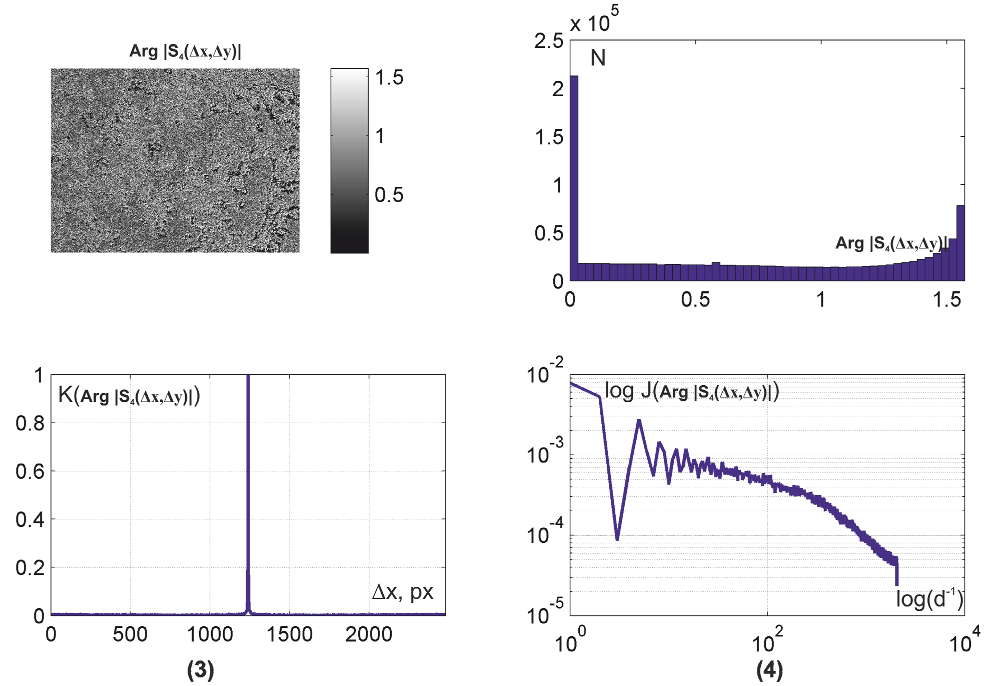

Figure 3. Maps (coordinate distributions (1), histograms (2), autocorrelation functions (3), logarithmic dependences of power spectra (4) of SCP phase $Arg\left(S_{i=4}\left(\Delta x;\Delta y\right)\right)$ of polarization-inhomogeneous images of histological sections of biopsy tissues of FRS (normal)

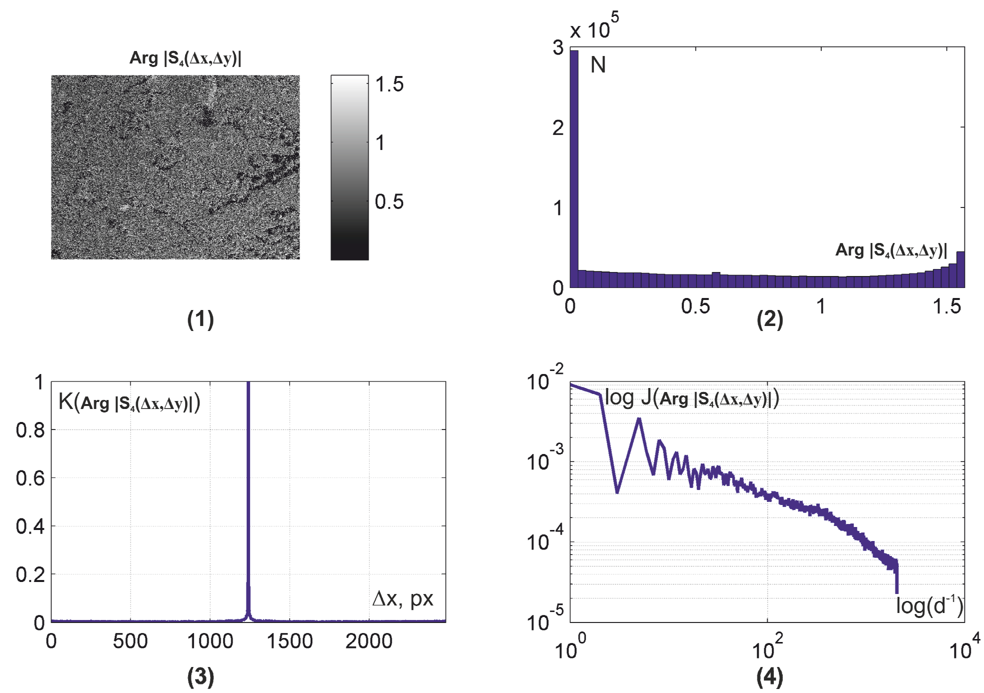

Figure 4. Maps (coordinate distributions (1), histograms (2), autocorrelation functions (3), logarithmic dependences of power spectra (4) of SCP phase $Arg\left(S_{i=4}\left(\Delta x;\Delta y\right)\right)$ of polarization-inhomogeneous images of histological sections of biopsy tissues of FRS (prolapse)

The potentiality of Stokes-correlometry differentiation of the two groups of FRS samples is quantitatively illustrated by the data presented in Table 1

Table 1 Statistical, correlation and fractal parameters of SCP phase maps of polarization-inhomogeneous images of histological sections histological sections of biopsy tissues of FRS

Parameters	$Arg(S_{i=3}(\Delta x;\Delta y))$		$Arg(S_{i=4}(\Delta x;\Delta y))$	
Condition	Normal $(n=39)$	Prolapse $(n=39)$	Normal $(n=39)$	Prolapse $(n=39)$
Z_1	$0{,}016 \pm 0{,}0011$	$0{,}013 \pm 0{,}0012$	$0{,}93 \pm 0{,}054$	$0{,}17 \pm 0{,}014$
Z_2	$0{,}14 \pm 0{,}016$	$0{,}041 \pm 0{,}0037$	$0{,}16 \pm 0{,}017$	$0{,}071 \pm 0{,}0043$
Z_3	$0{,}68 \pm 0{,}055$	$1{,}91 \pm 0{,}16$	$0{,}59 \pm 0{,}046$	$1{,}72 \pm 0{,}15$
Z_4	$0{,}79 \pm 0{,}066$	$4{,}29 \pm 0{,}37$	$0{,}76 \pm 0{,}058$	$3{,}12 \pm 0{,}29$
Z_2^k	$0{,}065 \pm 0{,}005$	$0{,}13 \pm 0{,}009$	$0{,}07 \pm 0{,}006$	$0{,}09 \pm 0{,}008$
Z_4^k	$3{,}36 \pm 0{,}26$	$1{,}54 \pm 0{,}077$	$4{,}46 \pm 0{,}32$	$2{,}53 \pm 0{,}056$
D^f	$0{,}21 \pm 0{,}018$	$0{,}17 \pm 0{,}014$	$0{,}26 \pm 0{,}022$	$0{,}16 \pm 0{,}013$

These data were obtained for the SCP phase distributions:

- ΔZ_1 = 1.45 – 6.11 times; ΔZ_2 = 2.15 – 2.56 times; ΔZ_3 = 3.01 – 3.17 times; ΔZ_4 = 4.89 – 5.14 times;
- ΔZ_2^k = 1.41– 1.63 times; ΔZ_4^k = 1.79 – 2.24 times;
- ΔD^f = 1.43 – 1.56 times.

The complex study found significantly greater accuracy of the methods of Stokes-correlometry in the differentiation of weak changes in optical anisotropy of histological sections of the structured ($94\% \le \max Ac \le 98\%$)biological tissues histological sections histological sections of biopsy tissues of FRS.

CONCLUSION

A new method of Stokes-correlometry – determination of the coordinate distributions of the phase of "two-point" Stokes-vector parameters of polarization-inhomogeneous images of histological sections of biological tissues of different morphological structure and physiological state – is suggested and analytically substantiated.
Within the statistical, correlation and fractal analysis the objective criteria characterizing the SCP-maps of polarization-inhomogeneous microscopic images of two groups (normal-prolapse) of samples of biological tissues are determined.
The comparative analysis of the objective statistical, correlation and fractal analysis of distributions of polarization "single-point" azimuth and ellipticity and "two-point" Stokes-vector parameters of polarization-inhomogeneous images of histological sections under study demonstrated the excellent accuracy ($Ac \succ 90\%$) of differential diagnostics of changes in optical anisotropy of histological sections histological sections of biopsy tissues of FRS
by the Stokes-correlometry method.

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