DIGITAL RECORDING AND ANALYSIS OF OPTICAL-POLARIZATION IMAGES OF A DOMAIN STRUCTURE

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A description is given of a differential two-channel system for digitally recording and analyzing images of the domain structure of ordered media - ferroelectrics, ferroelastics, ferromagnets, and ferrimagnets. The algorithms used for the analysis involve segmentation of the images based on an index of the state of polarization of light transmitted or reflected by the specimen.

Polarized light is widely used as a research tool in materials science. In a number of cases, it offers unique possibilities for observing the domain structure of ordered media (ferroelectrics, ferroelastics, ferromagnets, and ferrimagnets) and structural features of single crystals and polycrystals with natural and induced optical anisotropy [1, 2]. However, the optical-polarization contrast of the structural elements being studied often proves inadequate for direct visual observations, which is impeding the use of the method. Several techniques have been described in the literature that make it possible to increase the contrast of images in observations made in a polarization microscope. In particular, a differential photographic method of analysis was proposed in [3] to determine the domain structure of ferromagnetic materials by using the Kerr effect. In this method, the image of the noise background (the picture of a one-domain specimen in the state of saturation) is subtracted from the image of the same section of the surface of the specimen in the many-domain state. Thus, the authors of [3] were able to detect a very low-contrast (contrast less than 0.01–0.02) magnetic domain structure that could not be directly observed visually. The study being discussed here furthers develops the differential method in [3] and expands its capabilities by using modern computer-based techniques of recording and analyzing images.

Experimental Method. To conduct the study, we created the two-channel optical-polarization unit depicted in Fig. 1. Standard video cameras based on CCD-matrices (CCD - charge-coupled devices) with 768 × 576 elements were connected to a microcomputer via a video card. The optical part of the unit was built on the basis of horizontal metallographic (reflecting) microscope MIM-8, with an attachment for observations of transparent specimens in transmitted light.

The method is based on the use of optical effects that change the state of polarization of reflected or transmitted light during its interaction with the specimen (birefringence, the Faraday and Kerr effects, photoelasticity, etc.) [1, 2]. The transmission circuits in each channel differ in their transfer functions, which were chosen so that the difference output signal formed an image that was segmented based on a certain criterion. The transfer function of each channel is controlled by analyzers 1 and 2 (see Fig. 1).

Results and Discussion. 1. We will examine the possibilities of using the phenomenon of birefringence in the system that was developed to record and analyze images. It is known [1, 2] that the intensity of light \( I_i \) that passes through a "polarizer - birefringent plate - analyzer" system is determined by the expression

\[
I_i = I_0 \left( \cos^2 \chi - \sin 2\varphi \sin 2(\varphi - \chi) \sin^2 \frac{\delta}{2} \right),
\]

where \( I_0 \) is the intensity of the light after passage through the polarizer; \( \varphi \) is the angle between the transmission axis of the polarizer and the plane containing the optical axis and the light beam; \( \chi \) is the angle between the transmission axes of the polar-
izer and the analyzer; \( \delta = 2\pi \Delta n d/\lambda \) is the phase shift between the ordinary ray and the extraordinary ray at the input of the analyzer.

In the special case when the unit is parallel to the polarizer and the analyzer \((\chi = 0)\), it follows that

\[
I_{||} = E^2 \left( 1 - \sin^2 2\phi \sin^2 \frac{\delta}{2} \right),
\]

(2)

while for a perpendicular orientation \((\chi = \pi/2)\)

\[
I_{\perp} = E^2 \sin^2 2\phi \sin^2 \frac{\delta}{2}.
\]

It is evident from these formulas that (3) describes interference effects which are complementary in relation to the effects described by (2). This fact can be used to obtain two complementary colors for a pair of images formed of a birefringent object in crossed and parallel polarizers. A computer algorithm can easily be developed to analyze such a pair of images if we consider that the operation of inverting a color image in the color computer standard RGB (Red, Green, Blue) is essentially the operation of replacing all of the colors by the complementary colors. Thus, programmed subtraction of the above-described images leads to summation of the colors due to birefringence in the crystal. At the same time, the images of optically passive elements of the microstructure will compensate for one another. Such an algorithm is particularly useful for color images. It should be emphasized that in this case a color image means an image whose color was created as a result of interference of polarized radiation. None of the above remarks apply in the case of frequency dispersion of polarization-invariant absorption, scattering, or reflection of light.

The algorithm discussed above is convenient for analyzing images of ferroelectric domains, when the optical contrast of the domains is created by misorientation of their indicatrix [4]. As an example, Fig. 2 shows images, obtained by the above-described method, of the domain structure of a single crystal of gadolinium molybdate. Such algorithms for obtaining and analyzing images also turn out to be very useful in studies conducted by the methods of photoelasticity, particularly when observations are being made of the elastic fields of dislocations.

2. The use of rotation of the plane of polarization as an indicator can be demonstrated by considering the example of the recording of a magnetic domain structure detected by using the electrooptical Kerr effect. The contrast of the domain structure undergoes an inversion when the orientation of the analyzer and the polarizer shift from the angle \(+\Delta \alpha\) to the angle \(-\Delta \alpha\) (the angles are reckoned relative to the position in which the analyzer crosses the polarizer) [5]. Here, the intensity of the light