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Integral diagnostics of irreversible changes in power optical elements

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A novel processing technique has been proposed for crystal examination results obtained using complementary optical methods that provides an integral estimation of irreversible changes in the material caused by extreme external actions. A multifunctional optical diagnostic complex based on personal computer has been developed that makes it possible to check the irreversible changes in optical crystal elements at different stages of manufacturing, technological treatment, and operation thereof.

Предложена новая методика обработки результатов исследования кристаллов взаимодополняющими оптическими методами, позволяющая интегративно оценивать необратимые изменения в материале вследствие внешних экстремальных воздействий. На базе персонального компьютера разработан многофункциональный оптический диагностический комплекс, позволяющий эффективно осуществлять контроль необратимых изменений в кристаллических оптических элементах на разных этапах их изготовления, технологической обработки и эксплуатации.

A specific feature of optical elements (OE) made from crystalline ZnSe ingots consists in spatial inhomogeneity of elastic and electric fields. This due to considerable nonequilibrium in conditions of growing thereof from the melt under argon pressure by Bridgman technique. That is why even each of neighboring cuts of one crystalline ingot, and thus each crystalline element made thereof, is characterized by an individual stress-strained state (SSS). This is evidenced also by complex optical polarization and shadow images as well as piezoresonance spectra of the elements [1–5]. The purpose of this work is to develop a flexible measuring system and to search for the diagnostic data processing method providing the informational maintenance of power optical elements to estimate the quality thereof and predict the optical element life time.

A high-efficiency measuring system providing the comprehensive examinations is a diagnostic complex on the basis of a personal computer (PC) including a scanner, a printer, and original measuring modules (MM) that is in essence an universal optical device (Fig. 1). The realization of main functions within an integral measuring system makes it possible to use the whole potential of Windows graphic interfaces that provide a much more wide application range than a usual measuring instrument, to say nothing of potentialities offered by novel generation of software. The use of original measuring modules in the system allows to realize the main functionalities of a polariscope, interferometer, photometer, and other

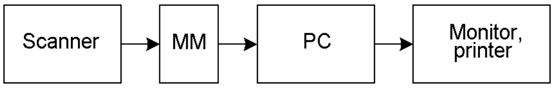


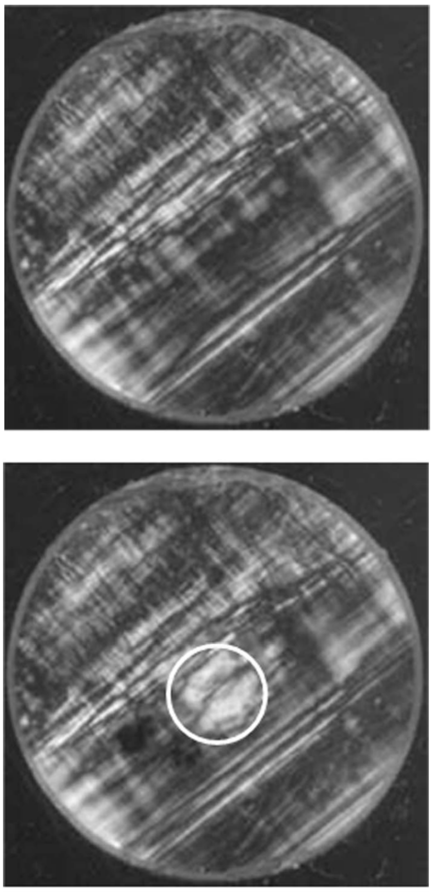
Fig. 1. PC-based diagnostic complex.

instruments. When the system is operated as any of the instruments on the PC basis (except for shadow module), the light emitted by the scanner slide extension passes through the corresponding MM with OE and hits the matrix scanning the image. The image is presented as a matrix of pixels with a $M \times N$ dimensionality where M is the number of rows and N is the number of pixels in a row. Each pixel with coordinates (x,y) is characterized by a certain brightness value $u = f(x,y)$. All the possible values of the image brightness can take G level values. The processing of digitized OE images using the known raster graphic programs makes it possible to determine the type of optical inhomogeneities, to establish the distribution character thereof (radial, elliptic, zonal, etc.) as well as to reveal the defects induced by growing and treatment. The use of digital effects (outline discrimination, correction, etc.) makes it possible not only to reveal the boundaries of optical, acoustic, and other inhomogeneities, but also to trace changes thereof in the course of the optical element operation (Fig. 2).

One of main advantages of the PC-based diagnostic complex as compared to the conventional optical instruments consists in the possibility to obtain the optical polarization image as well as shadow and interference ones of the OE under study in the on-line regime, to compare these images obtained prior to and after a power action as well as to store the data obtained. The digital format of the data allows to make use of both standard and original software and algorithms. So, to trace the irreversible changes in optical elements, a statistical data processing is found to be effective, namely, the construction and analysis of histograms reflecting the relative appearance frequency of specified brightness and color levels in the images. The relative frequency of the g-th brightness level for a pixel is defined as

$$P_f(g) = n_g/(MN) \; at \; g = 0,1,\ldots,G-1,$$

where n_g is the number of the image elements with the level g.



a

b

Fig. 2. Optical polarization images for a laser window made from a ZnSe crystal prior to (a) and after a treatment (b) (the most changed crystal zone is shown by circle).

The distribution statistics of half-tints and thus the half-tint distribution histograms in the optical polarization images of a laser window prior to (Fig. 3, curve 1) and after a special treatment (Fig. 3, curve 2) resulting in irreversible changes of its SSS illustrate clearly the character of those changes. To analyze these data, let entropy H be used that can serve to estimate the average information content of any OE image:

$$H = \sum_{g=0}^{G-1} P_f(g) \log_2 P_f(g).$$

To estimate the irreversible changes in a crystal, the entropy difference between two images obtained after and prior to an intense influence thereon. The entropy changes due to irradiation related to the its duration characterize the irreversible process rate and thus the OE radiation resistance. To evaluate the entropy change, a

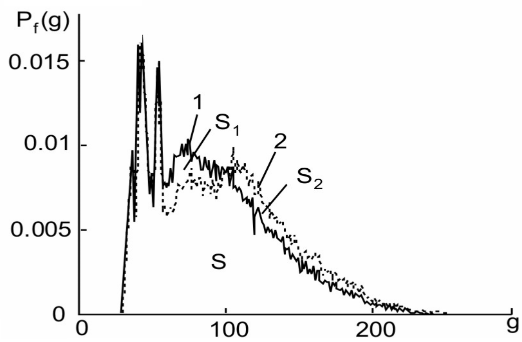


Fig. 3. Histograms of relative appearance frequency for brightness levels in images of the ZnSe optical element prior to (curve *1*) and after a treatment (curve *2*).

suitable procedure is to be selected for processing of any image. A number of parameters can be proposed to reflect integrally the irreversible changes in optical elements during the manufacturing and/or operation thereof. So, in the course of OE preparation, treatment, or operation, the SSS thereof, the impurity distribution therein, and other characteristics undergo changes due to mechanical, heat, and electromagnetic influences. As a result, the OE becomes transformed into a new metastable state the is characterized uniquely by a changed set of responses to a power action. Discrimination of subsets of pixels differing in the brightness level, contrast, or color allows to operate with those subsets (summarize, multiply, subtract, etc.) thus forming new subsets. Different relationships of the new subsets are parameters reflecting integrally various aspects of irreversible changes in the crystal. In spite of that the intense influences are reflected in the brightness and color changes of pixels within the same image, the relative changes in the cardinality and number of subsets in various images are interrelated, since those are referred to one and the same OE.

As an example, let the influence of a special treatment on the SSS of an OE be considered. The treatment caused irreversible changes in the sample and thus in the histogram 2 (Fig. 3). Not only the distribution of pixel brightness levels in the optical polarization image is seen to be changes but also the area under the histogram. It characterizes the cardinality of the pixel subsets reflecting all the features of the laser window SSS after the treatment. The initial state of the window is characterized by the area under the histogram 1. In Fig. 3, the area S reflects the number of general states; S_1, the number of states disappeared after the treatment; S_2, that of the treatment-induced ones. Then, $S_1 + S_2$ is the number of changed states. This allows to determine the integral parameter of irreversibility as $K = (S_1 + S_2)/S$. The analysis of the change rate of K under extreme operation conditions makes it possible to predict the crystal resistance against intense influences. Other relationships are also possible between the areas of histograms as parameters reflecting other aspects of changes in OE. Those offer wide possibilities for computerized analysis of quantitative and qualitative changes in a crystal under power action or under treatment as well as to compare and classify the state of various samples from the same ingot.

Thus, the use of information technologies offers new possibilities for application of known optical methods to solve the diagnostic problems of irreversible changes in power optics elements. In the same time, realization of some optical methods on the basis of PC allows to provide a diagnostic complex solving not only problems of diagnostic data obtaining and processing but also the systemic analysis thereof.

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Інтегральна діагностика необоротних змін в елементах силової оптики

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Запропоновано нову методику обробки результатів дослідження кристалів взаємодоповнюючими оптичними методами, яка дозволяє інтегративно оцінювати необоротні зміни у матеріалі внаслідок зовнішніх екстремальних впливів. На базі персонального комп'ютера розроблено багатофункціональний оптичний діагностичний комплекс, що дозволяє ефективно здійснювати контроль незворотних змін у кристалічних оптичних елементах на різних етапах їх виготовлення, технологічної обробки й експлуатації.