Visualization of volumetric defects and dynamic processes in crystals by digital IR holography

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Abstract: In this work, the method of IR digital holography intended for detection of volumetric defects in $ZnGeP_2$ single crystals has been tested. A method of visualization of the process of optical damage of a $ZnGeP_2$ single crystal using digital holography is suggested.

The production of single crystal multicomponent optical materials is characterized by inevitable formation of local composition variations resulting in internal volumetric defects that affect the properties of crystals, especially the crystals for photonics. Therefore, the observation and study of these defects and their occurrence is necessary to determine the qualitative characteristics, optical properties of a material and to diagnose its manufacturing procedures. In this case, it is quite relevant to characterize the defects in order to ensure their further identification. This requires measuring the geometrical parameters, shape and location of defects.

This study used the digital holography [1] to characterize the defects of a $ZnGeP_2$ single crystal. DHC technology (DHC – Digital Holographic Camera) includes the registration of a digital hologram of the studied material, level-by-level numerical restoration of images of the volume cross section, detection of focused restored images of defects, definition of their geometrical parameters [2,3]. The $ZnGeP_2$ single crystal is non-transparent in the visible range, so the holograms were recorded in the near IR range.

The obtained information is necessary when the single crystal material is cut into elements for subsequent production of devices for photonics. Besides, the level-by-level restoration of the material volume image and 3D mapping of defects allows an operator, using a priori technological information, classifying the defect, assuming the most probable reasons of its formation and proposing technological process adjustments. The study presents the main ZnGeP2 defects, their holographic images and unique characteristics.

In the production of optical nonlinear crystals, it is important to increase the optical resistance of nonlinear elements. In order to improve the technology thus increasing the damage threshold of a material, it is necessary to study the temporal and spatial characteristics of the damage. This work illustrates the use of the digital holography for visualization of the optical damage in the $ZnGeP_2$ single crystal.

Ho:YAG-laser with pulse repetition frequency of ~ 10 kHz, pulse duration of ~ 25 ns, average power changing in the range from 500 mW to 9 W and a wavelength of 2.097 μm served the source of acting (power) laser radiation. Radiation was focused onto the input face of a $ZnGeP_2$ single crystal with a 40 mm short-focus lens and the exposure time amounting to 30 s. The medium response was recorded by DHC through the side polished surfaces of the single crystal. The DHC technology was used to record a time sequence of digital holograms, from which the images of the crystal cross section in the acting radiation propagation plane were restored, following which these images were used to create a video. Figure 1 shows the time lapse of changes within the crystal synthesized from the reconstructed image sequence. This times lapse can be used to estimate the size of the damage luminescence cloud, its velocity, dynamics, etc. For example, it can be seen that the propagation direction of the optical damage is opposite to the propagation direction of the acting radiation.

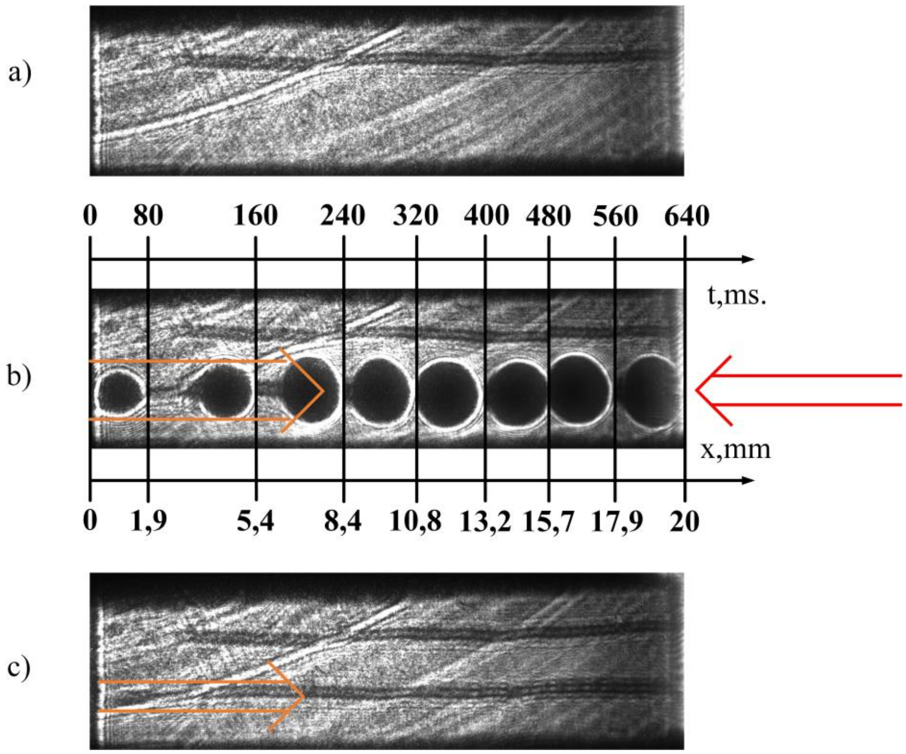

Fig. 1. Results of digital hologram processing at optical damage of the $ZnGeP_2$ single crystal using laser radiation at energy density of ~ 1.3 J/cm^2. a – sample before optical damage, b – gluing together frames thus visualizing the movement of a “luminescent cloud”, c – sample with optical damage tracks.

The research shows the possibilities of digital holography used to study and characterize the structural defects of optical single crystals, as well as to analyze the behavior of materials exposed to optical loads. Besides, the study defines the damage characteristics of the ZnGeP2 single crystal, namely, the speed and time of damage development, dependence of the track speed and diameter on the structure of optical inhomogeneities, local temperature, and effect of inclusions on the efficiency of nonlinear materials.

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