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DIGITAL HOLOGRAPHIC INTERFEROMETRY IN PHYSICAL MEASUREMENTS.

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Abstract. *Methods of using digital holographic interferograms are shown. Interferograms were obtained using laser radiation at different wavelengths, different durations and at different points in time. The registered phase inhomogeneity coincides with the calculated.*

Keywords: *digital holographic interferometry, interferogram, nonlinear optical and photorefractive crystals, phase distribution*

ЦИФРОВАЯ ГОЛОГРАФИЧЕСКАЯ ИНТЕРФЕРОМЕТРИЯ В ФИЗИЧЕСКИХ ИЗМЕРЕНИЯХ.

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Аннотация. *Показана возможность использования цифровых голографических интерферограмм. Интерферограммы полученны с использованием лазерного излучения на разных длинах волн и разной длительности в разные моменты времени, для реконструкции динамических фазовых изменений. Зарегистрированные фазовые неоднородности совпадают с расчетными.*

Ключевые слова: *цифровая голографическая интерферометрия, интерферограмма, нелинейная оптика и фоторефрактивный кристалл, фазовое распределение.*

1. Introduction

In digital holographic interferometry (DGI) "interfere" digital fields obtained from real fields using digital holography (DGI) methods [1,2]. These methods are based on the Huygens – Fresnel principles, the mathematical apparatus of the Fourier transform, numerical phase deployment algorithms, and digital image processing algorithms [3,4].

2. General Provisions

In contrast to conventional interferometry, in which two or more coherent phase fields are required to obtain a phase interferogram , the DGI can calculate the interference field of incoherent phase fields (for example, fields that existed at different times and really could not interfere with each other)) As a result of digital "interference" of such fields, a virtual interferogram . A prerequisite for the implementation of a single-wavelength DGI is the smallness of the difference in optical paths between adjacent pixels compared to half the radiation wavelength ($\Delta \leq \lambda/2$). If this condition is violated in the process of restoration (deployment) of the phase field, an uncertainty arises equal to 2 π in absolute. The condition $\Delta \leq \lambda/2$ places a severe restriction on the range of single-wavelength measurements in the DGI oscillator due to the natural spatial resolution of modern radiation detectors.

One way to eliminate this uncertainty is to use long-wave infrared radiation. However, the practical implementation of this method is limited due to the long-wavelength threshold of sensitivity of radiation detectors. Another method is the use of two waves of the visible range, differing in frequency [5-8]. Two-color DGI uses two data sets obtained at different wavelengths $\lambda_{1\ 1}$ and $\lambda_{2\ 2}$. Phase field reconstruction is performed at the equivalent wavelength $\Delta_{12} = \lambda_1 \lambda_2/|\lambda_1 - \lambda_2|$, longer wavelengths of the used real radiation of the visible range. Thus, the use of a two-color DGI substantially softens the requirements for the spatial resolution of radiation detectors, removes uncertainty in the process of reconstructing the phase field, and increases sensitivity. However, this increases noise due to the amplification effect. To find an acceptable compromise, various combinations of virtual and real wavelengths Δ_{12}, Λ_{12}, λ_1, λ_2 are used in the form of reference and object waves during reconstruction of the phase interferogram . Thus, the technologies developed to date for obtaining information on the interference of multicolored fields are aimed at solving the problem of uncertainty 2π inherent in all measuring interference methods that use the radiation wavelength as a real measure of measurement.

3. Results and discussion

In this work, we use the methods of digital two exposure interferometry - obtaining a differential phase surface that carries information about changes in the studied object over the time between exposures. In this case, holograms of the compared phase fronts were recorded at different wavelengths in pulses of different durations. In our studies of virtual interferograms, interferometers assembled according to the Mach – Zehnder and Michelson scheme were used. Primary digital holograms were recorded in laser radiation with a wavelength of 1.064 μm, 1.054 μm, 0.532 μm, 0.357 μm, in pulses of 30 ns, 50 ps , 200 fs duration and in the emission of a continuous He - Ne laser onto a TM-1020-15 digital camera CL with a pixel size of 9 x 9 microns.

The following objects were used as survey objects: a plate made of a nonlinear optical $LiNbO_3$ crystal and a plate made of a photorefractive $LiNbO_3$: Fe crystal (0.01%). Using the recorded multi-colored holograms, two interferometric digital exposure interferometry methods [9] were used to obtain digital interferograms of various stages of relaxation of the phase inhomogeneity recorded in the volume of the photorefractive $LiNbO_3$: Fe crystal , as well as the nonlinear optical $LiNbO_3$ crystal . Based on the obtained interferograms, phase fronts, carrying quantitative information about the samples under study, were reconstructed. The information obtained is compared — the angle of inclination, the change in the refractive index, the amplitude and length of the surface acoustic waves, in various combinations of multi-colored primary phase fronts.

Figure 1 shows the recording scheme of phase holograms. The radiation of a neodymium laser (λ_1 = 1.06 μm) with a duration of 30 ns and 50 ps using a mirror (1) was directed to nonlinear optical crystals (2,3), in which the second and third harmonics of laser radiation with wavelengths were generated λ_2=0,532 μm and λ_3 = 0.357 μm

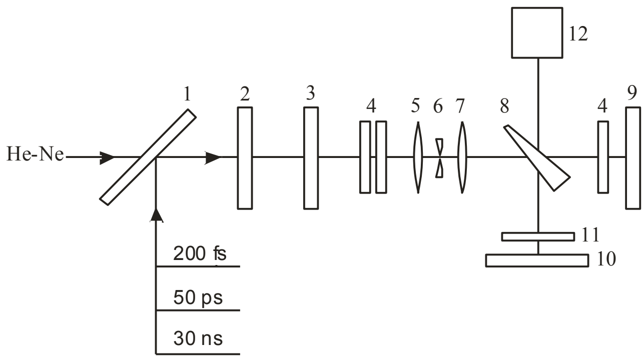
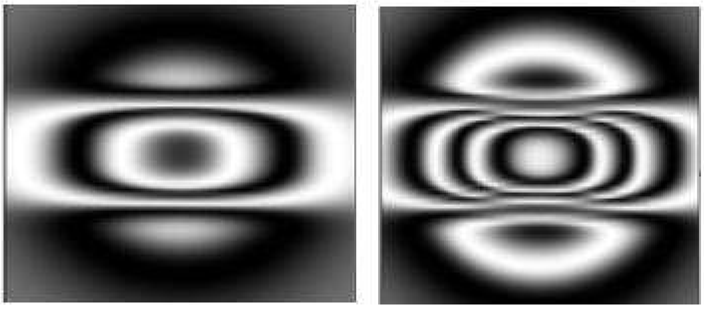


Figure 1: Scheme for recording phase holograms. 1 mirror. 2,3 - nonlinear frequency multiplication crystals. 4- light filters. 5.7- lens. 6 -spatial filter. 8 -optical wedge. 9-10 - mirror. 11 - test sample. 12-CCD camera.

Emission of radiation at a specific wavelength and a change in the radiation intensity was carried out using light filters (4). The radiation from He - Ne and femtosecond lasers did not convert in frequency. The spatial filtering of radiation was carried out by a spatial filter formed by lenses (5,7) and a diaphragm (6). At the output of the spatial filter, the phase front of the radiation was close to flat. Then, the radiation was directed to an interferometer formed by an optical wedge (8) and mirrors (9, 10). A sample was located in one of the arms of the interferometer (10). Holograms were recorded using a CCD camera (12) connected to a personal computer. Based on the processing of the obtained holograms, interferograms were constructed.

The phase inhomogeneity that arises in the laser field in a photorefractive crystal is determined by the laser radiation intensity *I(t)*, exposure time τ, photoreactive sensitivity of the material K, and absorption coefficient α. Figure 2 shows the calculated images of the phase inhomogeneity in the photorefractive $LiNbO_3$:Fe crystal at various exposure times corresponding to the interference pattern in digital format.

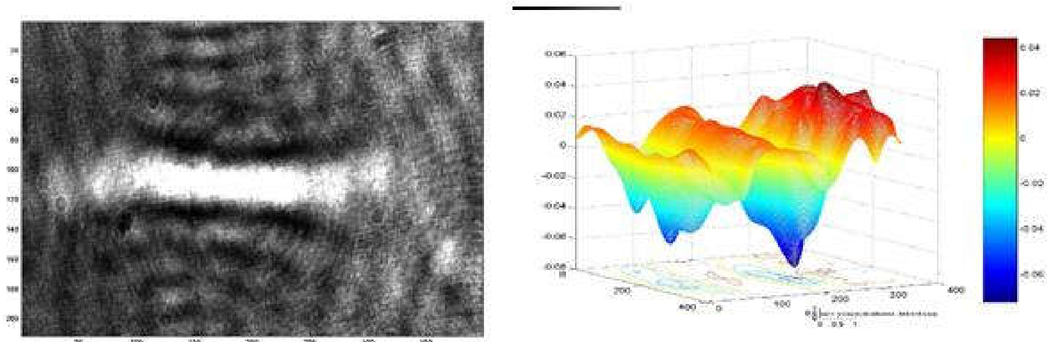


a b

Figure 2: Calculation of the photorefractive structure in a LiNbO 3: Fe crystal .

The spatial distribution of the laser radiation intensity was assumed to be Gaussian. Exposure time for the image shown in Fig. 2b , 3.5 times the exposure time for the image shown in Fig. 2, a. It can be seen from the figure that with an increase in the exposure time, the image of the phase inhomogeneity becomes more complex, an increase in the interference fringes appears.

Figure 3 shows an enlarged image of the volume phase inhomogeneity induced in the constriction of a focused laser beam, as well as a three-dimensional reconstruction of the phase inhomogeneity recorded in $LiNbO_3$: Fe by radiation with a wavelength of 532 nm .



a b

Figure 3: Interferogram and phase reconstruction of the photorefractive structure

This image was obtained in the field of nanosecond laser pulses. The polarization of the laser radiation was directed parallel to the main optical axis of the crystal. When the polarization was rotated through 90°, the picture did not change. From the analysis of the recorded phase inhomogeneity shown in this figure, it follows that its form qualitatively coincides with the calculated phase distribution. In this case, the main role was played by photorefractive heterogeneity.

In a picosecond laser field, a change in the resulting phase inhomogeneity is due to the influence of the Kerr nonlinearity. Kerr nonlinearities (and therefore a nonlinear addition to the refractive index) are a tensor quantity connecting the third-order polarization components and the corresponding components of the electromagnetic field strength. In the nonlinear optical $LiNbO_3$ crystal, in the absence of losses, the Kerr nonlinearities are generally determined by 4 components

[10]. In this case, a semi-empirical model was used to calculate the Kerr nonlinearities. This model is based on the contribution of one transition in the discrete spectrum.

In this approximation, the Kerr nonlinearity is expressed as a function of the refractive index and its second derivative with respect to the wavelength. The expression also includes the density of oscillators N, which was defined as the average density of atoms in a crystal. Figure 4 shows simulation values calculated dependences of the phase shift induced by the intensity of the spatial coordinates at an angle to the propagation of radiation of 72 principal crystal axis of the wavelength $\lambda = 532$ nm . The initial distribution of the laser radiation intensity was assumed to be Gaussian. In the calculations, the following relation between the components of nonlinearities $\chi_{12} : \chi_{14} : \chi_{23} : \chi_{33} = 1 : 0.1 : 0.2 : 6.0$ was used. Note that in this case the components χ_{14} and χ_{23} made only a small contribution. It can be seen from the presented figures that the induced nonlinearity has the form of an ellipse, which, as it approaches the beam axis, turns into a dumbbell-like structure elongated along the z axis of the crystal.

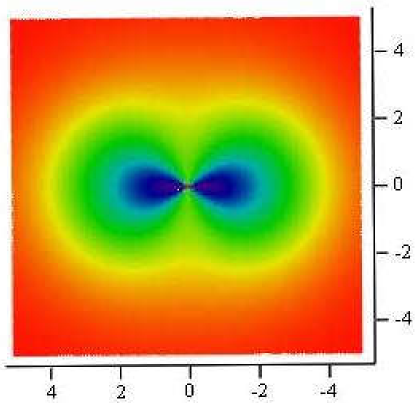


Figure 4: The calculated dependence of the phase difference shift in a crystal with a symmetry of 3 m, due to a change in the refractive index, depending on the intensity of laser radiation

4. Conclusion

Thus, the studies showed the possibility of using digital holographic interferograms obtained using laser radiation at different wavelengths and different durations at different points in time to reconstruct the dynamic phase changes that occur in the samples. The most promising practical application of multi-color DGI in the measurement of nanometer displacements (nanotechnology, digital microscopy) due to the possibility of using tunable femtosecond laser sources and making measurements with high time resolution or using cheap laser diodes in the spectral ranges available for digital cameras.

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