Polarization-insensitive adaptive interferometer based on 3D-orthogonal three-wave mixing in photorefractive crystal

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The novel geometry of three-wave mixing in photorefractive crystal (PRC) is proposed and studied. In this geometry a single phase-modulated object wave interacts with two elliptically polarized reference waves. All three waves are mutually orthogonal and propagate in PRC of cubic symmetry along its principal axes [100], [010] and [001]. It is shown that each of two holograms recorded by pair of object and reference waves produces a demodulation signal which is related with one of two polarization components of the object wave. The total demodulation signal is result of incoherent superposition of two signals from two holograms. As a result the 3D-orthogonal geometry of waves mixing opens possibility of developing an adaptive interferometer completely insensitive to a polarization state of an object wave: such an interferometer can operate with object wave having arbitrary polarization state, including unstable or totally depolarized.

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It is known that an interferometer is very sensitive tool which allow detecting ultra-small physical quantities. Application of dynamic holography principle to interferometer measurement systems makes them adaptive to slow temporal changes of environment and allows use of interacting waves with completely different wave fronts, which can be also rather complex, e.g. speckled. Such adaptive interferometers based on wave mixing after diffraction from dynamic holograms which are continuously recorded in photorefractive materials [1] make possible to perform such a detection not only in a laboratory but also in real-life environment (e.g. in space, in vehicle, on production line, etc.), which is typically quite unstable. At the same time the waves mixed in PRC must be properly polarized in order to get efficient wave coupling in the most of known techniques based on PRC. However, in many practical cases, the object wave has often arbitrary polarization or even totally depolarized. Therefore, an object wave must be transmitted through a polarization filter in order to meet requirements of wave coupling [1, 2]. However, such a filtering as a rule causes significant optical losses (which usually exceed 50%) and as a sequence leads to worsening of the interferometer's sensitivity [2]. Moreover, the polarization filtering can become a reason of additional noise in an interferometer [3]. These reasons lead to significant reduction of SNR, and make difficult or even impossible a detection of ultra-small physical quantities.

Recently we proposed the scheme of adaptive interferometer which can operate in linear regime of phase demodulation in diffusion mode of dynamic hologram recording in PRC even when the object wave is totally depolarized [4]. Key feature of this scheme is vectorial wave mixing in the orthogonal geometry in which the interacting waves (object and reference) propagate in mutually orthogonal directions inside PRC. However dc-term in object beam intensity detected by photodetector is only which became free of polarization noise in orthogonal scheme while ac-term is still dependent on signal beam's polarization state due to polarization selectivity of orthogonal hologram, which results in appearance of instabilities in demodulation signal. Note that these instabilities are natural for any adaptive interferometers with PRC.

In this paper we propose novel scheme of adaptive interferometer based on three-wave interaction in 3D orthogonal geometry. Light with arbitrary polarization (linear, elliptical or completely depolarized) can be used as an object wave in this scheme. It is shown that instabilities in polarization state of the object wave do not produce the noise neither in dc- nor in ac-term of demodulation signal or this noise is significantly suppressed.

Key peculiarity of orthogonal geometry is that only parallel polarization components of mixed waves record the dynamic hologram; the rest two components are mutually orthogonal and do not interfere. As a result the dynamic hologram recorded in orthogonal geometry operates as a polarization-selective element. This allows one to provide a processing completely depolarized object wave without using any additional polarization filtering. However the wave coupling disappears if the object wave is linearly polarized in plane which contains interacting waves.

In three-wave mixing geometry (Fig.1) a single object wave (A_1) is mixed in a photorefractive crystal of cubic symmetry with two coherent reference waves (A_2 and A_3). All waves are mutually orthogonal and propagate along crystal's principal axes [001], [100] and [010], respectively. Waves interfere pairwise, and each pair records its own dynamic hologram. Due to the orthogonal geometry the reference wave A_2 interacts only with *y*-polarization component of the object wave, while wave A_3 – with *x*-polarization component of the object wave (see Fig.1). Thus, two orthogonal holograms operate independently and mutually complementary.

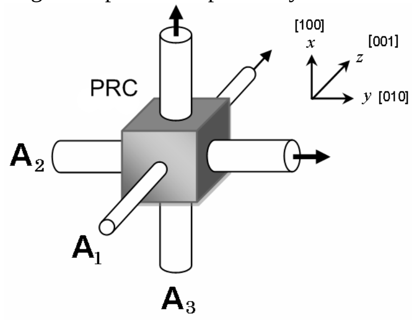

Fig. 1 3D-geometry of three-wave-mixing in PRC

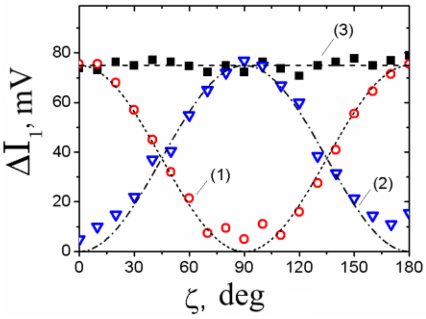

Fig. 2 Polarization dependency of demodulation signal in orthogonal geometry of two-wave (1, 2) and 3D-three-wave (3) mixing

Considering the case when phase modulated object wave with arbitrary polarization is mixed in PRC with two elliptically polarized reference waves, we represent their amplitudes by Johns' vectors as following

$$\mathbf{A}_1 = \begin{pmatrix} a_x \\ a_y e^{i\alpha} \end{pmatrix} e^{i\varphi_t}; \qquad \mathbf{A}_2 = \begin{pmatrix} b_y \\ ib_z \end{pmatrix}; \qquad \mathbf{A}_3 = \begin{pmatrix} c_x \\ ic_z \end{pmatrix}, \tag{1}$$

where α is a phase shift between polarization orthogonal components of the object wave; φ_t is transient phase shift in the object wave.

Mixing of phase modulated object wave with reference waves in PRC leads to the intensity modulation (i.e. to appearance of the demodulation signal). One can show that intensity modulation, ΔI_1, of the arbitrary polarized object wave mixed with two elliptically polarized reference waves in optically non-active photorefractive crystal of cubic symmetry in 3D-geometry depicted in Fig.1 has two additive components ΔI_{12} and ΔI_{13} which represent contributions from two holograms recorded by pair of waves "A_1-A_2" and "A_1-A_3", respectively:

$$\Delta I_1(\varphi_t) = \Delta I_{12}(\varphi_t) + \Delta I_{13}(\varphi_t), \tag{2}$$

with $\Delta I_{12}(\varphi_t) = \eta_0[a_y^2 b_y b_z \sin\varphi_t + a_x a_y b_y^2 \cos(\varphi_t + \alpha)]$, $\Delta I_{13}(\varphi_t) = \eta_0[a_x^2 c_x c_z \sin\varphi_t + a_x a_y c_x^2 \cos(\varphi_t + \alpha)]$, where $\eta_0 = \sqrt{2}\kappa_D z I_0^{-1}$; κ_D is a wave-coupling constant which depends on material parameters of PRC and wavelength; I_0 is a total light intensity in PRC.

If polarization components of the reference waves amplitude fulfill the condition $|b_y/b_z| = |c_x/c_z| << 1$ the object wave intensity modulation becomes independent on its polarization state and is determined only by its intensity:

$$\Delta I_1(\varphi_t) \cong \eta_0 I_1 \sigma^2 \varphi_t, \qquad \text{where} \quad \sigma^2 = b_y b_z = c_x c_z. \tag{3}$$

Polarization dependencies of demodulation signal amplitude experimentally obtained for the crystal CdTe:V at λ =1064 nm for three cases of two- and three-wave mixing are presented in Fig.2. The first case: linearly polarized object wave interacts with reference wave A_2, while reference wave A_3 is blocked; the angle ζ corresponds to the object wave polarization plane orientation. The second case: the object wave interacts with reference wave A_3, while reference wave A_2 is blocked. Third case: the object wave interacts with both reference waves A_2 and A_3. As one can see, only in the last case, the demodulation signal magnitude does not depend on an orientation of the object wave polarization plane. Being in full agreement with Eq.(3) this experimental result confirms a realization of polarization-insensitive mode of adaptive interferometer.

Thus, in this work we proposed the novel geometry of wave mixing in photorefractive crystal. The geometry implies interaction of three waves which propagates in PRC of cubic symmetry in three mutually orthogonal directions. The geometry proposed opens possibility for development of polarization-insensitive adaptive interferometers.

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REFERENCES

1. Stepanov, S. I., "Adaptive Interferometry: A New Area of Applications of Photorefractive Crystals," in International Trends in Optics, J. Goodman, ed., Academic, Boston, 1991.

2. Kamshilin, A.A., Romashko, R.V. and Kulchin, Y.N., "Adaptive Interferometry with Photorefractive Crystals," J. Appl. Phys., Vol. 105, No. 3, pp. 031101, 2009.

3. Di Girolamo, S., Kamshilin, A.A., Romashko, R.V., Kulchin, Y.N. and Launay, J.-C., "Sensing of Multimode-Fiber Strain by a Dynamic Photorefractive Hologram," Opt. Lett., Vol. 32, No. 13, pp.1821-1823, 2007.

4. Di Girolamo, S., Romashko, R.V., Kulchin, Y.N. and Kamshilin, A.A., "Orthogonal Geometry of Wave Interaction in a Photorefractive Crystal for Linear Phase Demodulation," Opt. Commun., Vol. 283, No. 1, pp. 128-131, 2010.