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Polychromatic two-wave mixing in a cubic photorefractive crystal

R.V. Romashko[a,b], M.A. Asalkhanova[b]*, Yu.N. Kulchin[a,b]

[a]*Federal Far-Eastern University, Suhanova St. 8, Vladivostok, 690950, Russia*
[b]*Institute of Automation and Control Processes far Eastern Branch of the Russian Academy of Sciences, Radio St. 5, Vladivostok, 690041, Russia*

Abstract

Model of polychromatic two-wave mixing in a cubic photorefractive crystal is proposed. The model is based on the coupled waves theory and allow simulate the hologram recording process in PRC. Based on proposed model the adaptive polychromatic interferometer could be designed.

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Keywords: polychromatic light; dynamic hologram; two-wave mixing; photorefractive crystal

1. Introduction

Today there a lot of tasks where the interferometric measuring systems are used. Generally such systems use monochromatic light sources (lasers).They are usually used to measure linear parameters of objects such as geometrical dimensions, vibrations and displacements in wide range with resolution of a few angstroms. However to conduct measurements in range more than the source wavelength monochromatic interferometers operate in a counting fringes mode. It brings uncertainty in estimation of results and complicates the process of data processing. Intense development in field of the polychromatic light sources (machines of white light, generators of supercontinuum, frequency-shifted feedback lasers) led to creation of new high-precision measuring systems including systems which use the polychromatic interference. In works (Pique J. P. (2013), Polhemus C. (1973)) some measuring system based on polychromatic interference and able to register distances up to 10 meters are

* Corresponding author. Tel.: +7-914-328-0694.
E-mail address: facir@dvo.ru, facir13@yandex.ru

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presented. However all interferometric measuring systems have one essential drawback – their performance becomes unstable under influence of external factors such as external noises, changes in temperature, pressure or humidity. Usually additional devices are used to stabilize operation of measuring system. But their applying may lead to increase in noises of system, decrease sensitivity or make scheme more complex. There is an alternative to classical interferometer scheme with active stabilization. It is an interferometer based on recording dynamic holograms (DH) in photorefractive crystals (PRC). Systems based on such holographic interferometer are adaptive to external influences which affect measurements. There are a lot of theoretical works (Stepanov S. I. (1991), Vinetskii,V. L. et al. (1983), Solymar L. et al. (1996)) including strict theoretical ones which describe a process of formation and reading dynamic holograms in PRC by monochromatic light. Moreover there are some practical works devoted to recording holograms by polychromatic light (Zhou Y. et al. (2006)). However there aren't any theoretical works devoted to creation of adaptive holographic systems operated with polychromatic light sources. In this paper we present a mathematical model of the polychromatic waves coupling in cubic PRC.

2. Description of the polychromatic model for two-wave mixing in PRC

We assume polychromatic light as a superposition of N monochromatic light waves with close frequencies and shift Δλ between consecutive components. All spectral components have the same amplitude and width much less than Δλ. Two identical polychromatic beams (signal and reference) came into crystal. In crystal the components of the reference and signal beams overlap but only the pair of components having the same frequencies would record the dynamic holograms in photorefractive media. As is known, there are two main mechanisms of recording dynamic holograms in photorefractive media: drift and diffusion. In this paper we consider only diffusion holograms because they don't require any external electrical fields applied to PRC and provide high cut-off frequency and better adaptive properties of holographic interferometer (Di Girolamo S. et al. (2007)). Then, the components of both beams diffract on recorded holograms. However, only components with frequencies equal to the correct one for recorded holograms obey the Bragg conditions. Other spectral components which violate the Bragg conditions will be of little influence the energy interchange between waves and value of this contribution would be dependent of the spectral shift Δλ. We assume the spectral components are equidistant. So there is limited number of spectral components with shift Δλ for which the influence the energy interchange would be minimal.

To describe a polychromatic two-wave interaction in PRC we have simulated processes of recording the diffusion holograms in transmissive scheme and processes of phase demodulation of modulated signal beam in crystals with cubic symmetry. Diffraction on holograms recorded in cubic crystals is anisotropic so we use the theory of vector wave coupling in cubic crystals proposed by B.I. Sturman (Sturman B. I. et al. (1999)). From this theory and from the coupled waves theory for the polychromatic two-wave interactions in the paraxial (Kogelnik H. (1969)) approximation we have the differential equations system of coupled waves for the vector wave amplitudes $\mathbf{A_1}$ and $\mathbf{A_2}$:

$$\begin{cases} \dfrac{\partial}{\partial z}\mathbf{A_1} = -m\kappa\mathbf{H}\mathbf{A_2} - \dfrac{(\alpha + i\cdot\vartheta)}{2}\cdot\mathbf{A_1} \\ \dfrac{\partial}{\partial z}\mathbf{A_2} = m\kappa^*\mathbf{H}\mathbf{A_1} - \dfrac{(\alpha + i\cdot\vartheta)}{2}\cdot\mathbf{A_2}, \end{cases} \tag{1}$$

where

$$\kappa = \frac{-\pi n_0^3 r_{41} E_{SC}}{\lambda\cdot\cos\theta}, \tag{2}$$

$$m = \frac{2\mathbf{A_1}\mathbf{A_2^*}}{|\mathbf{A_1}|^2 + |\mathbf{A_2}|^2}, \tag{3}$$