Efficiency increasing of electro- and acousto-optical modulators as main component of optical communication network

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ABSTRACT

A new approach to the spatial anisotropy analysis of parametrical optical (electro-, piezo- and acousto-optical) effects in the low-symmetry crystal materials on basis of indicative surfaces for different components of tensor describing these effects has been proposed. Piezo- and elasto-optical effects as well as figure of merit were spatially analyzed by indicative surfaces construction for example of $LiNbO_3$:MgO and $La_3Ga_5SiO_{14}$ crystals. The obtained results provide increasing in several times of design efficiency for acousto-optical modulators based on these crystals.

Keywords: spatial anisotropy, indicative surfaces, figure of merit, electro- and acousto-optical modulators, optical communication network.

1. INTRODUCTION

As well-known [1], electro- and acoustooptical light modulators is the basic component of fiber-optical systems for information transmission with external modulation of input signal. State-of-the-art methods of development and manufacture of electro- and acousto-optical cells do not foreseen conducting of pre-optimization of interaction between light and applied external influence (electrical field or acoustical wave) in sensitive elements of corresponding cells, which are prepared as a rule from the anisotropic crystal materials. Unfortunately, until now there are not methods for the optimization of sample geometry regarding the low-symmetry anisotropic materials, especially in the case when parametrical optical effects are described by third- or higher order rank tensors, e.g. the electro-, piezo- or acousto-optical effects are being considered. From the one hand the problems are frequently related to incomplete data set (missing data about the all non-zero component for the electro-, piezo- or elasto-optical tensors), from the other hand they are related with the complexity of analytical description due to spatial anisotropy of such effects.

At first the problem solving of extreme values, started in respect to electro-optical effect in works [2,3] or effective photoelastic constant in works [4, 5], was connected to its finding only in plane of symmetry of tensor of electrooptical or photoelastical constants and only for trigonal symmetry. In our laboratory the works [6-14] according to problem solving on complete 3D analysis of spatial anisotropy for piezo-, [6-9] elasto- [10,11,12] and acousto-optical [12,13] effects were began for example of such crystals: $LiNbO_3$ [6,9], $(Ba_xSr_{1-x})Nb_2O_7$ [7], $LiTaO_3$ [8], β-BaB_2O_3 [10,12,14] and Cs_2HgCl_4 [11,13]. But the complete 3D-analysis problem concerning to the spatial anisotropy calculation for the electro- and acousto-optical effects remains actual, what is confirmed by recent publications (see e.g. [15-18]). Therefore the elaboration of technique for optimization conduction of electro- and acousto-optical interactions for anisotropic materials is scientifically justified and perspective with respect to practice. It will provide increasing of design efficiency of electro- and acousto-optical modulators and is the main purpose of this work.

The essence of our elaboration is new approach to the spatial anisotropy analysis of parametrical optical (electro-, piezo- and acousto-optical) effects in the low-symmetry crystal materials on the basis of indicative surfaces for different components of tensor describing these effects.

2. METHODOLOGY

The efficiency increasing of of electro- or acousto-optical modulators can be achieved accounting of spatial distribution of electro-optical coefficients r_{ij}^* on optical path [19] or well-known figure of merit M_2 [20], respectively. The construction of indicative surfaces [6-14,21,22] is the only way for the geometrical interpretation of physical effects anisotropy, which are described by third- or higher rank tensors.

Consider the acousto-optical interaction in anisotropic crystal materials. For acousto-optical effect in crystal the main parameter as figure of merit M_2 can be written by following way:

$$?\ _2 = \frac{n_m^3 n_n^3 p_{ef.}^2}{r V_q^3} \cos ß_\mu \cos ß_\nu \cos ? \tag{1}$$

where ρ is the crystal density; n_μ and $n_?$ are the refractive indices of the incident and diffracted light, respectively, V_q is sound velocity in anisotropic material, $ß_\mu$, $ß_?$, and ? are the walkoff angles between the propagation and wave front directions for the incident and diffracted light and the acoustic wave, respectively; $?_{ef}$ - the effective elasto-optical coefficient.

Taking into account the proposed by us approach the indicative surfaces for figure of merit can be constructed. This enables to determine the extreme value of the effect and choose the corresponding crystal cuts with aim of efficiency increasing during design of acousto-optical modulator.

But such construction of the indicative surfaces demands knowledge of all the parameters from equation (1). Particularly it refer to finding of all the p_{in} elasto-optical tensor components, at that within accurate of their magnitude and sign. It can be realized carrying out the measurements of all the π_{im} piezo-optical tensor components, and then finding the values of p_{in} based on known relationship: $p_{in}=\pi_{im}C_{mn}$ (where C_{mn} are components of elastic coefficients tensor). The measuring of all parameters necessary for optimization conduction of acousto-optical interaction in crystals of all symmetry classes can be carried out using the equipments created in our laboratory:

1. acoustical equipment for measuring of longitudinal and transverse acoustical wave velocities in anisotropic crystals of different symmetry classes by dynamical echo-pulse method with following calculation of elastic coefficients;
2. interferometric (on basis of Mach-Zehnder interferometer) and polarization-optical equipments for determination of all components of piezo-optical effect tensor in low-symmetric crystals;
3. automated equipment and corresponding software for precise measuring of refractive indices of plane-parallel samples with isotropic and anisotropic materials on basis of Michelson interferometer;
4. equipment for experimental determination of figure of merit M_2 in crystal materials by Dixon-Cohen method;
5. interferometric equipment (on basis of Michelson interferometer) for measuring of absolute electro-optical coefficients in crystals of different symmetry classes (for electro-optical modulators design);
6. equipments for investigation of work parameters of electro- and acousto-optical modulators of light.

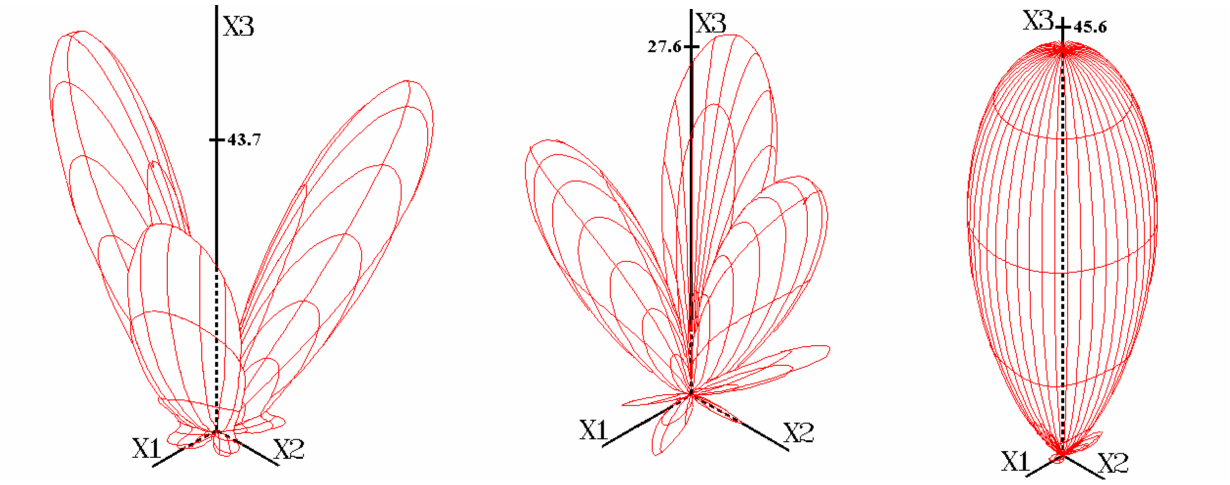
Therefore, conducting the necessary measurements of refractive indexes, sound velocities and having filled matrix of piezo-optical coefficients π_{im} we can calculate all values of elasto-optical coefficients p_{in} for these crystals (the necessary values of elastic coefficients C_{mn} can be determined from measurements of acoustical wave velocities on the same experimental samples). Then the spatial distribution calculation for figure of merit in crystals can be carried out. It allows to optimize the interaction geometry between light and acoustical wave for investigated crystals.

Given elaboration enables us to increase an application efficiency for existing and new anisotropic materials as sensitive elements of devices and their components operating on principles of electro-, piezo- and acousto-optical modulation of light.

3. EXPERIMENTAL RESULTS

Demonstrate an opportunities of the proposed approach on example of investigation of prospective piezoelectric [23] langasite ($La_3Ga_5SiO_{14}$) and modeling lithium niobate ($LiNbO_3$:MgO) crystals. It is worthy to note that electro-optical and dielectric properties of langasite crystals have been measured in [24]. However, piezo- and elasto-optical coefficients of $La_3Ga_5SiO_{14}$ crystals are so far unknown. Pure crystals of $LiNbO_3$ are studied well [25] for many parameters including of piezo-optic properties [6,9], but as we know the piezo-optic effect for crystal $LiNbO_3$:MgO is not investigated.

The absolute piezooptic coefficients π_{im} of the investigated crystals have been determined at room temperature by two-fold measurements method using laser interferometer (λ=0,6328 μm) [14]. Basing on the obtained piezooptic effect coefficients π_{im}, we have calculated all of the elastooptic coefficients p_{in} for these crystals, according to well-known relation $p_{in}=\pi_{im}C_{mn}$ (necessary components of the elastic constant C_{mn} were calculated from acoustical measurements of ultrasonic waves velocities in these crystals and some elastic constant C_{mn} were controlled by two-fold measurement method [14]).



a) b) c)

Fig1. The indicative surfaces for the figures of merit M_2 for the case of isotropic diffraction of light by the transverse acoustic wave with the lower (q=1 - a), the higher velocity (q=2 - b) and the longitudinal acoustic wave (q=3 - c) in $La_3Ga_5SiO_{14}$ crystals. Numerical data for M_2 are presented in units of 10^{-15} s^3/kg

Table 1. Extreme values of figure of merit M_2 for $La_3Ga_5SiO_{14}$ crystals[1]

The indicative surfaces M_2 for acoustic wave	Optic wave						Acoustic wave						$?_{ef}$	? 2, 10^{-15} s^3/kg
	i$_\mu$, deg.			**i**$_?$, deg.			**a**, deg.		**f**, deg.		?, deg.	V_q m/c		
	$?_\mu$	φ_μ	$ß_\mu$	??	$\varphi?$	$ß_v$	$?_a$	φ_a	$?_f$	φ_f				
q=1	28	30	0.3	28	30	0.3	28	30	110	30	9.3	914	0.074	60
q=2	25	210	0.3	25	210	0.3	25	210	67	30	3.7	1056	0.061	26
q=3	0	-	0	0	-	0	0	-	0	-	0	2049	0.21	44

On the basis of filled matrix of π_{im} and p_{in} the indicative surfaces for longitudinal or transverse piezo- and elasto-optical effects and their stereografic projections were constructed for $LiNbO_3$ and $La_3Ga_5SiO_{14}$ crystals using the developed software [7-10]. Besides, the spatial anisotropy of effective elasto-optical coefficient p_{ef} and well-known figure of merit M_2 were analyzed and their extreme values for different forms of light diffraction by acoustic wave for both crystals were calculated (for example of $La_3Ga_5SiO_{14}$ crystal see Fig. 1 and Table 1). In Fig.1 the indicative surfaces for isotropic diffraction by two transverse (a,b) and longitudinal (c) acoustic waves are shown. In Table 1 the extreme values for these surfaces and their spherical angular co-ordinates ? and φ are listed. The most value of figure of merit has been found to be $60\cdot10^{-15}$ s^3/kg for isotropic diffraction on transverse acoustic wave of lower velocity, when the light wave polarization is parallel to propagation direction **a** of acoustic wave. Such large value of figure of merit demonstrates that the investigated langasite crystals are also prospective acousto-optical material.

4. CONCLUSIONS

In the present paper new approach for spatial anisotropy analysis of parametrical optical (electro-, piezo- and acousto-optical) effects in the low-symmetry crystal materials on the basis of indicative surfaces is formulated. It has been shown

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[1] In the Table the interacting acousto-optical components **i**$_\mu$ and **i**$_?$ are the unit vectors along the polarization directions of the incident and diffracted light waves, respectively, **a** and **f** are the unit vectors pointing out the propagation and polarisation directions of the acoustic wave, respectively; V_q is the velocity of the acoustic wave; the index q defines which of three polarisation of the acoustic wave is examined: the case q = 1 corresponds to a transverse wave with lower velocity, q = 2 to a transverse wave with higher velocity and q = 3 to a longitudinal acoustic wave; $ß_\mu$, $ß_v$ and ? are the walkoff angles between the propagation and wave front directions for the incident and diffracted light and the acoustic wave, respectively; $?_{ef.}$ - the effective elasto-optical coefficient; ? and φ - the angles of the spherical coordinate system with respect to the axes X_1, X_2, X_3 of the principal crystallophysical coordinate systems for each of the vectors **i**$_\mu$, **i**$_?$, **a** and **f**.

that construction of indicative surfaces is the only way for accounting of spatial distribution of anisotropic materials, especially when parametrical optical effect is described by tensor of third- or forth rank.

The method has been applied for lithium niobate $LiNbO_3$:MgO and langasite $La_3Ga_5SiO_{14}$ crystals. The corresponding indicative surfaces for these crystals have been constructed for piezo- and elastooptic effects as well as for figure of merit. Taking into account the results of these investigations one can propose such geometry of interaction between light ray and acoustical wave, for which value of figure of merit for $LiNbO_3$:MgO and $La_3Ga_5SiO_{14}$ crystals will be maximal. It will provide increasing in several times of design efficiency of electro- and acousto-optical modulators based on these crystals.

Besides the scientific effect and practical application, this work has a social effect, too. Such elaboration of piezo-, electro- and acoustooptical devices on new or already existing anisotropic materials will ensure both the economy of valuable raw crystal materials with the use of smaller size samples with the extreme value of effect, and the economy of power resource due to its reduction for reaching the same electro- or acoustooptical cell efficiency using the same anisotropic material.

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