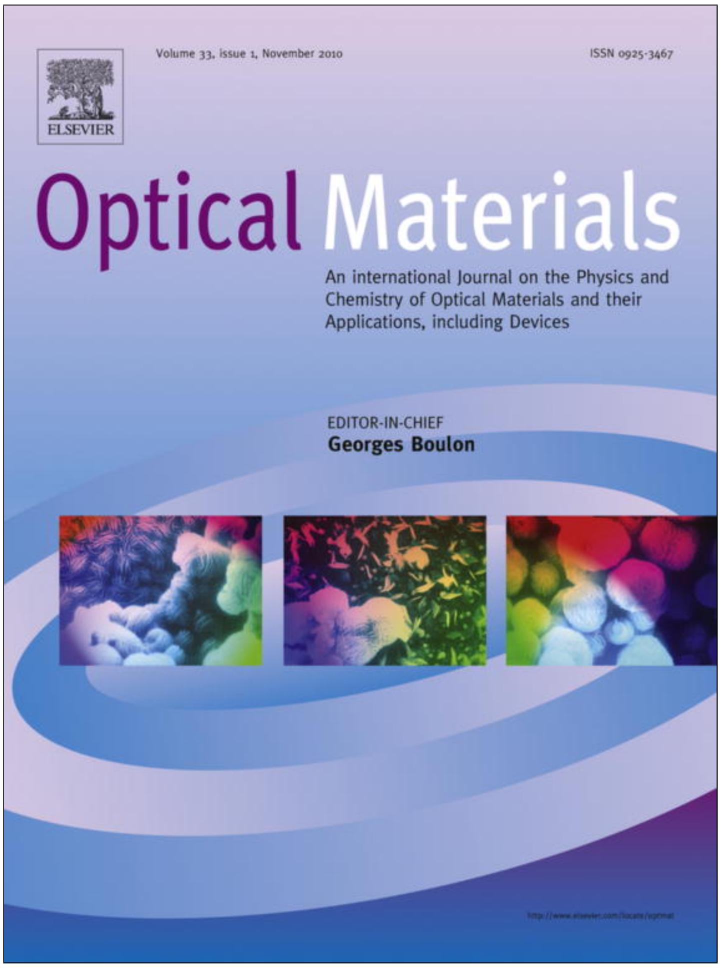
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Piezooptical coefficients of $La_3Ga_5SiO_{14}$ and $CaWO_4$ crystals: A combined optical interferometry and polarization-optical study

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ABSTRACT

Paper reports the piezooptical studies on langasit $La_3Ga_5SiO_{14}$ (LGS) and calcium tungstate $CaWO_4$ (CWO) crystals by means of the combined optical interferometry and polarization-optical techniques. Corresponding methodology is supplied by a set of derived equations suitable for the determination of the absolute piezooptical coefficients (POCs) in the crystals of trigonal or tetragonal symmetry. It is shown, that for the determination of all the eight absolute POCs π_{im} of trigonal LGS or tetragonal CWO crystals by means of polarization-optical technique one must perform additionally at least two optical interferometry measurements in certain experimental geometries. In most cases the combined study considerably improves an accuracy in the determination of the absolute POCs. Due to a large piezooptical effect revealed in CWO crystals they may be considered as quite perspective materials for eventual photoelastic or acoustooptical applications.

1. Introduction

The piezooptical effect and associated with it piezooptical coefficients (POCs) are usually studied in crystal materials by the optical interferometric technique [1–5]. Corresponding methods are rather time consuming and in the case of even slightly nonparallel crystal cuts are characterized by substantial errors in determination of the absolute POCs [6,7]. The number of experimental works devoted to such measurements is not large. Most of them are limited by determination of rotational-shear POCs of the cubic or tetragonal crystals [8–10]. An example is the absolute POC π_{66} determined indirectly as

$$\pi_{66} = \pi^*_{36}/n_1^3, \quad (1)$$

i.e. via the refractive index n_1 and the effective POC π^*_{36} being measured by polarization-optical method. Another prominent example is rochele salt [11]. Its crystal structure is characterized by the orthorombic symmetry (point group 222) thus POCs tensor contains neither pure rotational or shear components nor rotational-shear ones. Accordingly, 12 measurements should be performed in different sample geometries either on the direct cuts or on 45°-cuts, in order to determine 9 principal POCs π_{im} (i, m = 1, 2, 3) and 3 diagonal rotational-shear POCs π_{44}, π_{55} and π_{66}. While a set of relevant 12 equations is then solved the total error in determination of particular POCs rises significantly due to the reason that it accumulates the experimental errors resulted from many measurements corresponding to different sample geometries. The situation is especially crucial in regards to the POCs π_{44}, π_{55} and π_{66} where corresponding equations are expressed through complicated combinations of principal POCs as well as principal and non-principal elastic compliances. Thereby, the precision of the absolute piezooptical measurements usually is not high. Perhaps for this reason many authors frequently avoid the error analysis like e.g. in the work [11], discussed above, or in Refs. [12,13]. In particular, to prove a validity of the obtained data, authors [11] have determined six principal POCs by interferometric technique and consequently compared their ratios with the ones obtained by acoustooptical diffraction method.

In the present work we report the piezooptical studies on langasit $La_3Ga_5SiO_{14}$ (hereafter LGS) and calcium tungstate $CaWO_4$ (hereafter CWO) crystals by means of the combined optical interferometry (OI) and polarization-optical (PO) techniques. Structure of LGS and CWO crystals is characterized correspondingly by trigonal (point group 32) and tetragonal (point group $4/m$) symmetry. Regarding the crystallographic trigonal classes 32 and $3m$ it was developed in Ref. [14] the experimental method supplied with corresponding expressions being suitable for the determination of the absolute POCs. Such method is based on the PO technique,

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however: (i) it ignores the elastic deformation what rises an error in determination of POCs; (ii) it leads in several cases to rather complicate equations set providing again a substantial error in the determination of POCs and (iii) neither the sign of the piezooptical effect, retardation and/or birefringence nor the axes signs in relevant crystallophysical coordinate system are taken into account what may result to a completely wrong determination of POCs. One must be stressed that a solving of these questions appears to be obligatory for a correct and unambiguous determination of the absolute POCs in trigonal crystals. Actual work indeed consequently solves these problems. It will be shown that for the determination of all the eight POCs π_{im} of LGS crystals by the PO technique one must perform additionally at least two OI measurements. Likewise CWO crystals require also two OI measurements in order to determine all the principal POCs. Accordingly, we describe here corresponding methodology supplied by a set of derived equations suitable for the determination of POCs and give the error analysis relevant to it. In most cases the method offered here significantly improves an accuracy in the determination of the absolute POCs in the crystals.

2. Relationships between the absolute POCs π_{im} and the retardation piezooptic coefficients (RPOCs) π^o_{km}

First of all, in further analysis one should distinguish between the different types of the piezooptic coefficients, i.e. the absolute POCs π_{im}, the retardation piezooptic coefficients (hereafter RPOCs) π^o_{km} and the birefringent (effective) piezooptic coefficients (hereafter BPOCs) π^*_{km}. While the absolute POCs π_{im} are defined in conventional way as the stress (σ_m) derivatives of the optical polarization constants B_i:

$$\pi_{im} = dB_i/d\sigma_m, \tag{2}$$

the BPOCs π^*_{km} describes the piezoinduced changes of birefringence $\Delta n_k = n_j - n_i$:

$$\pi^*_{km} = -2d(\Delta n_k)/d\sigma_m \tag{3}$$

and expressed through the POCs π_{im} as [8]:

$$\pi^*_{km} = n_i^3\pi_{im} - n_j^3\pi_{jm}, \tag{4}$$

where k and m = 1–6 are the indices in the Voigt notation, n_i and n_j represent the principal refractive indices that correspond to the two orthogonally polarized waves traveling in k-direction. However, in practice we most often deal with the RPOCs defined as:

$$\pi^o_{km} = -2\delta\Delta_k/(d_k\sigma_m), \tag{5}$$

where $\delta\Delta_k$ is piezoinduced retardation, d_k is the sample thickness. The RPOCs are usually measured by the half-wave stress method in which one determines the stress $\sigma^{\lambda/2}_{km}$ corresponding to the piezoinduced retardation of half optical wavelength ($\delta\Delta_k = \lambda/2$) thus $\pi^o_{km} = -\lambda/(d_k \cdot \sigma^{\lambda/2}_{km})$. On the other hand, the RPOCs are expressed via the BPOCs as:

$$\pi^o_{km} = -2\frac{\delta\Delta n_k}{\sigma_m} + 2\Delta n_k S_{km} = \pi^*_{km} - 2\Delta n_k S_{km}, \tag{6}$$

where $\delta\Delta n_k$ is the piezoinduced changes of the optical birefringence and S_{km} are the elastic compliancies. We apply this equation to determine the principal POCs π_{11}, π_{12}, π_{13}, π_{31} and π_{33} in trigonal classes of the symmetry 32 or 3m. The principal POCs π_{im} are determined from RPOCs which are measured on the direct cuts, i.e. on slabs being cut perpendicular to the principal crystallophysical axes X_1, X_2, and X_3. Corresponding equations read as:

$$\pi^o_{23} = \pi_{33}n_3^3 - \pi_{13}n_1^3 - 2\Delta n_2 S_{23}, \tag{7}$$

$$\pi^o_{21} = \pi_{31}n_3^3 - \pi_{11}n_1^3 - 2\Delta n_2 S_{21}, \tag{8}$$

$$\pi^o_{31} = (\pi_{21} - \pi_{11})n_1^3. \tag{9}$$

One must be noticed that the last equation does not contain the elastic term since the birefringence Δn_3 along the X_3-direction is equal 0. Obviously, the equation set (7)–(9) in fact appears to be not sufficient in order to obtain all the five POCs entering into it. Also eventual measurements on the 45°-cuts, as offered in [14], do not solve this problem since they lead to a set of dependent equations.

Thereby, an appropriate solution lies in combination of polarization-optical and interferometric measurements. Accordingly, the two principal POCs π_{11} and π_{33} have been measured by the OI technique, whereas the non-principal POCs π_{14}, π_{41} та π_{44} were calculated using the RPOCs π^o_{km} measured on X_1/45°-cut by means of PO technique, see Fig. 1. Accordingly, we explore here the way how to derive corresponding equations. First we obtain the equations suitable for determination of the POC π_{14}. We start from the Eq. (6) where instead of $\delta\Delta n_k$ and S_{km} one must substitute the expressions that corresponds to the experimental conditions relevant with measuring π^o_{14} and $\pi^o_{1\bar{4}}$. In particular, RPOC π^o_{14} is determined in the experimental geometry defined by k = 1 and m = 4. In this case the induced birefringence $\delta\Delta n_1 = \delta n_2(\sigma_m) - \delta n_3(\sigma_m)$ is caused by biaxial stress along 4-direction [$\sigma_m = \sigma(0, 1/2, 1/2, 1/2, 0, 0)$, σ is the stress magnitude]. The piezoinduced changes $\delta n_2(\sigma_m)$ and $\delta n_3(\sigma_m)$ may be evaluated as in Ref. [2] thus by substituting them into (6) one obtains the following two equations for the symmetry equivalent geometries with k = 1 and m = 4 or with k = 1 and $m = \bar{4}$:

$$\pi^o_{14} = \frac{1}{2}n_3^3(\pi_{33} + \pi_{31}) - \frac{1}{2}n_1^3(\pi_{11} + \pi_{13} - \pi_{14}) - \Delta n_2(S_{12} + S_{13} + S_{14}), \tag{10}$$

$$\pi^o_{1\bar{4}} = \frac{1}{2}n_3^3(\pi_{33} + \pi_{31}) - \frac{1}{2}n_1^3(\pi_{11} + \pi_{13} + \pi_{14}) - \Delta n_2(S_{12} + S_{13} - S_{14}), \tag{11}$$

where the combinations of the elastic compliances that enters into this equations describe the sample deformation along the 4 or $\bar{4}$ directions. The way how to get it is described in Ref. [2]. By subtracting (11) from (10) one obtains:

$$\pi^o_{14} - \pi^o_{1\bar{4}} = n_1^3\pi_{14} - 2\Delta n_1 S_{14}. \tag{12}$$

Similarly, the equation for the POC π_{14} can be obtained under the experimental conditions relevant with measurements of π^o_{41} and $\pi^o_{\bar{4}1}$. In this case we deal with the two experimental geometries, i.e. defined as k = 4 and m = 1 or $k = \bar{4}$ and m = 1. Evaluating then the birefringence changes $\delta\Delta n_4 = \delta n_{\bar{4}} - \delta n_1$ and $\delta\Delta n_{\bar{4}} = \delta n_4 - \delta n_1$ under the action of the uniaxial stress $\sigma_1 = \sigma$ and finding the elastic contribution likewise in Ref. [2] one gets again the two symmetry equivalent equations:

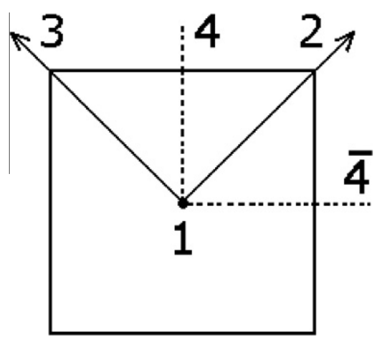

Fig. 1. Sample orientation as required for the determination of the POCs π_{14}, π_{41} та π_{44}.

$$\pi^o_{41} = \frac{1}{2} n_{\bar{4}}^3 (\pi_{12} + \pi_{31} - 2\pi_{41}) - n_1^3 \pi_{11} - \Delta n_4 (S_{12} + S_{13} + S_{14}), \quad (13)$$

$$\pi^o_{\bar{4}1} = \frac{1}{2} n_{\bar{4}}^3 (\pi_{12} + \pi_{31} + 2\pi_{41}) - n_1^3 \pi_{11} - \Delta n_4 (S_{12} + S_{13} - S_{14}), \quad (14)$$

where $n_4 = n_{\bar{4}} = \sqrt{2} n_1 n_3 / \sqrt{n_1^2 + n_3^2}$ are the refractive indices for the light waves polarized along 4 or $\bar{4}$ directions (see Fig. 1), respectively. The difference (13) and (14) leads to a simple relation:

$$\pi^o_{\bar{4}1} - \pi^o_{41} = 2 n_4^3 \pi_{41} + 2 \Delta n_4 S_{14}. \quad (15)$$

Finally, we can write similar relations for RPOCs $\pi^o_{4\bar{4}}$ and $\pi^o_{\bar{4}4}$ which correspond to the experimental geometries with $k = 4$ and $m = \bar{4}$ or with $k = \bar{4}$ and $m = 4$, respectively. They are associated with birefringence changes $\delta\Delta n_4 = \delta n_{\bar{4}} - \delta n_1$ $(m = \bar{4})$ or $\delta\Delta n_{\bar{4}} = \delta n_4 - \delta n_1$ $(m = 4)$ which lead to the two equations:

$$\pi^o_{4\bar{4}} = \frac{1}{4} n_4^3 (\pi_{11} + \pi_{13} + \pi_{14} + \pi_{31} + \pi_{33} + 2\pi_{41} + 2\pi_{44}) - \frac{1}{2} n_1^3 (\pi_{12} + \pi_{13} - \pi_{14}) - \frac{1}{2} \Delta n_4 (S_{11} + 2S_{13} + S_{33} - S_{44}), \quad (16)$$

$$\pi^o_{\bar{4}4} = \frac{1}{4} n_4^3 (\pi_{11} + \pi_{13} - \pi_{14} + \pi_{31} + \pi_{33} - 2\pi_{41} + 2\pi_{44}) - \frac{1}{2} n_1^3 (\pi_{12} + \pi_{13} + \pi_{14}) - \frac{1}{2} \Delta n_4 (S_{11} + 2S_{13} + S_{33} - S_{44}). \quad (17)$$

Sum of these equations read as:

$$\pi^o_{\bar{4}4} + \pi^o_{4\bar{4}} = \frac{1}{2} n_4^3 (\pi_{11} + \pi_{13} + \pi_{31} + \pi_{33} + 2\pi_{44}) - n_1^3 (\pi_{12} + \pi_{13}) - \Delta n_4 (S_{11} + 2S_{13} + S_{33} - S_{44}) \quad (18)$$

and may be used for the determination of the POC π_{44}. Their difference leads to a simple relation

$$\pi^o_{4\bar{4}} - \pi^o_{\bar{4}4} = \pi_{14} \left(n_1^3 + \frac{1}{2} n_4^3 \right) + \pi_{41} n_4^3, \quad (19)$$

which can be used for independent verification of the POCs π_{14} and π_{41} determined e.g. in other sample geometries.

3. Experimental technique

The LGS crystals were grown by Czochralski method using a platinum crucible in the atmosphere consisting of the mixture of N_2 (97%) and O_2 (3%). The seed crystal with a contact [0 0 0 1]-face was simultaneously rotated with a rotational speed 30–50 turns/min and pulled up with a speed of 3–5.5 mm/h. The grown LGS crystals were of yellow-brown color. Similarly, the CWO crystals were grown by the same technique using the iridium crucible and the Ar atmosphere instead. The seed crystal with a contact [0 0 1]-face was rotated (15–20 turns/min) and pulled slowly up with a speed of 3–5 mm/h. The grown CWO crystals were originally of milky gray color which consequently could be removed by their annealing in the oxygen atmosphere at 1250 °C during ~70 h.

All the grown crystals have been oriented by means of X-ray technique (the accuracy of about 0.05°) and consequently cut of into cube shape samples with the dimensions of $\sim 8 \times 8 \times 8\ mm^3$ and faces oriented perpendicular to the principal crystallophysical axes X_1, X_2 or X_3. The nonparallelity of consequently polished opposite faces did not exceed 0.02°.

The piezooptical measurements are based on the OI methods. Following the route described in the Section 2 several principal POCs, like e.g. π_{11} or π_{33}, have been measured by OI technique using the Mach–Zehnder interferometer. On the other hand, RPOCs π^o_{km} were determined by the modified polarization-optical method in the reflected optical light [15]. The optical setup is shown in Fig. 2. The polarized beam reflects from the backside of the sample and after a reflection from the semitransparent mirror is registered by the photodetector. Because the light passes this sample twice the half-wave stress is only a half of the magnitude determined by the conventional polarization-optical method. Due to such advantage this method is especially appropriate in the cases when eventual half-wave stresses are comparable with mechanical strength of the samples. In particular, this is the case of the RPOCs π^o_{31}, π^o_{32}, $\pi^o_{1\bar{4}}$, $\pi^o_{\bar{4}1}$, $\pi^o_{4\bar{4}}$, $\pi^o_{\bar{4}4}$ (LGS) and π^o_{13}, π^o_{23} (CWO). Large refractive indices of both LGS and CWO provides substantial reflection of the light (~10%) from the sample backside (see Fig. 2) thus in the case of these or similar crystal materials the mirror 7 may be omitted. Described technique may be used also for the electrooptic measurements.

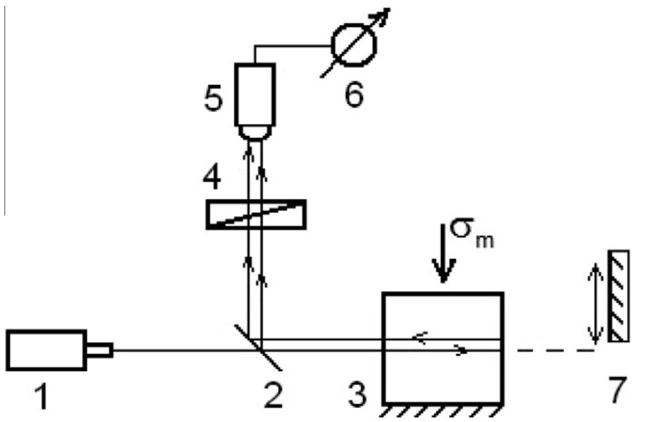

Fig. 2. Experimental setup for measurements of the RPOCs π^o_{km} in the reflected geometry: 1 – laser, 2 – semitransparent mirror, 3 – sample, 4 – analyzer, 5 – photodetector, 6 – registration system, 7 – mirror.

4. Results and discussion

Determination of the absolute POCs in LGS and CWO crystals is based on the equations, derived in Section 2, and associated with them optical interferometric and polarization-optical measurements. As important problem in the piezooptical studies is a correct determination of the signs associated with measured RPOCs π^o_{km} that enter into Eqs. (7)–(9), (12), (15), (18), and (19). One must be emphasized, that they are defined unambiguously by the sign of the piezoinduced birefringent retardation $\delta\Delta_k$ taking into account that the uniaxial compression corresponds to a minus sign. By definition $\delta\Delta_k = \Delta_k(\sigma) - \Delta_k(0)$ thereby for $\Delta_k(0) \neq 0$, what is the case when $k = 1, 2, 4$ or $\bar{4}$, the piezoinduced birefringent retardation $\delta\Delta_k$ is accepted to be positive if $\Delta_k(\sigma) > \Delta_k(0)$ and vice versa. Rising or decreasing of Δ_k vs. σ can be easily verified by means of Berek compensator or wedge quartz plate. However, the question remains still open for $k = 3$, i.e. when the laser beam propagates along the optical axis characterizing by a lack of the optical birefringence at $\sigma = 0$ [$\Delta_k(0) = 0$]. If this is the case, then one should determine the sign of $\Delta_k(\sigma) = \delta n_1(\sigma) - \delta n_2(\sigma)$. In particular, we have found that in LGS crystals $\delta n_2 > \delta n_1$ thus $\pi_{21} > \pi_{11}$ and the form of Eq. (9) remains unchanged. In CWO crystals $\delta n_1 > \delta n_2$ thereby the difference of POCs $\pi_{21} - \pi_{11}$ in Eq. (9) should be replaced by $\pi_{11} - \pi_{21}$. Certain ambigiouities occurs also in regards to the non-principal POCs π_{14}, π_{41} or π_{44} where their signs indeed depend on a choice of positive directions in the coordinate axes set. In the present work the positive direction of the axes X_1, X_2, X_3 are set according to the criteria that $\pi_{14} > 0$ as recommended in Ref. [2].

Determination of the absolute POCs by means of Eqs. (7)–(9), (12), (15), (18), and (19) requires the magnitudes of the elastic compliances S_{km} and the refractive indices n_i which for the LGS crystal have been taken from Refs. [16–18], correspondingly. Here are the magnitudes of S_{km} [in Brewsters (Br), 1 Br = 10^{-12} m^2/N]:

$$S_{11} = 8.76,\quad S_{12} = -4.03,\quad S_{13} = -1.85,$$
$$S_{33} = 5.59,\quad S_{14} = 3.59,\quad S_{44} = 21.0,$$

likewise the refractive indices and birefringence (λ = 633 nm):

$$n_1 = n_2 = n_o = 1.8993,\quad n_3 = n_o = 1.9107,$$
$$n_4 = n_{\bar{4}} = 1.9050,\quad \Delta n_1 = \Delta n_2 = 0.0114,$$
$$\Delta n_4 = \Delta n_{\bar{4}} = 0.0057,$$

all given at room temperature (T = 20 °C). Originally, the elastic compliancy S_{14} is given in Ref. [16] with the minus sign, however, in Ref. [6] it was proved that S_{14} is indeed positive. The polarization-optical measurements give the following magnitudes of the RPOCs for LGS crystals [in Br units]:

$$\pi^o_{12} = 6.2;\quad \pi^o_{13} = -10.7;\quad \pi^o_{31} = 2.0;$$
$$\pi^o_{1\bar{4}} = -3.35;\quad \pi^o_{14} = -1.25;\quad \pi^o_{41} = 6.3;$$
$$\pi^o_{4\bar{1}} = 1.65;\quad \pi^o_{44} = -4.0;\quad \pi^o_{4\bar{4}} = 1.7.$$

One must be noticed, that the elastic contribution into the π^o_{km}, being calculated either according to Eq. (6), as for direct cuts, or by means of Eqs. (12), (15), and (18) as for X_1/45°-cut, is small and in each case does not exceed $0.03 \cdot \pi^o_{km}$. In fact, this is caused by small birefringence Δn_1 or Δn_4 in LGS crystals, respectively. Thus, up to the precision of the polarization-optical measurements, which in our case is about 5%, the piezooptical coefficients π^o_{km} and π^*_{km} in LGS crystals are nearly equal. Nevertheless, the calculations of the absolute POCs by means of Eqs. (7), (8), (12), (15), and (18) indeed take into account the elastic contributions. Table 1 lists the values of POCs π_{im} in LGS crystals being determined in the combined OI and PO measurements (upper row) which are compared with the previous pure interferometric measurements of Ref. [6] (lower row). The total error has been estimated in each case as mean square error of particular contributions that enter into a corresponding equations. As example, we present here the error evaluation for the absolute POC π_{13} which reads as:

$$\begin{aligned}\pi_{13} &= \pi_{33}n_3^3/n_1^3 - \pi^o_{23}/n_1^3 - 2\Delta n_2 S_{23}/n_1^3\\ &= (-1.26 \pm 0.07) \times 1.02 + (10.7 \pm 0.54) \times 0.146\\ &\quad + (1.85 \pm 0.09) \times 3.3 \cdot 10^{-3}\\ &= -1.28 \pm 0.07 + 1.56 \pm 0.08 + 0.01 \pm 0.0003\\ &= 0.29 \pm 0.11,\end{aligned} \tag{20}$$

where the errors $\Delta(\pi^o_{km})$ and $\Delta(S_{km})$ corresponding to the particular contributions are taken in each case as 5% from their actual magnitudes. From Table 1 it follows that the combined OI and PO measurements give in many cases much better precision compared to the one achieved in pure OI measurements, see e.g. Ref. [6] for comparison. We have also determined the value of the POC π_{41} using Eq. (19). Its magnitude [π_{41} = (0.34 ± 0.05) Br] well agrees with the one obtained by means of Eq. (15) which represent an additional verification of the developed here methodology. A certain remark should be made only regarding the discrepancy in the magnitude of the POC π_{44} measured by different methods. Its evaluation is accompanied by rather low accuracy because corresponding equations both in OI (see Ref. [6]) or PO [see Eq. (18)] methods represent rather complicated combinations of POCs and elastic compliances. Consequently, this leads to a large error (~50%) being accumulated while the POC π_{44} is determined.

In the case of CWO crystals we have determined the principal POCs only by means of Eqs. (7)–(9), see Table 2. Two POCs, namely π_{12} and π_{33} (marked by bold) have been determined directly by OI technique whereas the rest ones by PO method using measured RPOCs (in Br units):

$$\pi^o_{21} = -5.6,\quad \pi^o_{31} = 17.4,\quad \pi^o_{23} = -3.4.$$

In our evaluations we have used the magnitudes of the refractive indices n_i and the elastic compliances S_{km} taken from Refs. [19,20]:

$$n_1 = n_2 = 1.920,\quad n_3 = 1.936;\quad \Delta n_1 = \Delta n_2 = 0.016;$$
$$S_{12} = -5.1\ \text{Br},\quad S_{13} = -1.7\ \text{Br}.$$

On must be noticed, that for the determination of the POC π_{31} we substituted into Eq. (8) the magnitude of π_{11} being calculated by Eq. (9) whereas the POC π_{13} has been determined by means of Eq. (7). One can realize, that the errors corresponding to the absolute POCs π_{11}, π_{13} or π_{31}, which have been determined in the PO measurements, appear to be considerably smaller comparing to the ones obtained within the OI measurements. An advantage of the combined measurements seems to be again obvious.

The CWO crystals is found to exhibit quite large piezooptical effect which considerably exceeds the one in LGS crystals, likewise in other highly efficient photoelastic materials such as e.g. $LiNbO_3$ [7]. Four of the five POCs determined in CWO crystals, namely π_{11}, π_{13}, π_{31} and π_{33}, exceeds the magnitude of 1 Br. For comparison, all the POCs of $LiNbO_3$ are less than 1 Br [7]. This finding means that photoeleastic effect and associated with it the acoustooptical efficiency (i.e. the figure of merit) are expected to be large. Accordingly, the CWO crystals may be considered as quite perspective materials for eventual acoustooptical applications. Spatial anisotropy of the photoelastic and/or acoustoptical properties in these materials may be characterized in the term of the indicative surfaces as described in Refs. [21,22]. For this purpose a complete set of elastic constants (C_{mk} or S_{km}) is required. A standard route in this respect are former piezooptical studies of orthorombic Cs_2HgCl_4 crystals [23,24] combined with the ultrasonic measurements [25–27]. More

Table 1
The absolute POCs of LGS crystals (λ = 633 nm, T = 20 °C).

π_{im} (Br)	π_{11}	π_{12}	π_{13}	π_{31}	π_{33}	π_{14}	π_{41}	π_{44}
This work	−***0.15*** ± 0.04	0.14 ± 0.04	0.29 ± 0.11	0.72 ± 0.06	−***1.26*** ± 0.07	0.32 ± 0.03	0.34 ± 0.02	0.28 ± 0.15
Ref. [6]	−0.17 ± 0.04	0.10 ± 0.07	0.30 ± 0.08	0.70 ± 0.19	−1.25 ± 0.07	0.32 ± 0.15	0.33 ± 0.12	0.35 ± 0.16

Table 2
The principal POCs of CWO crystal (λ = 633 nm, T = 20 °C).

π_{im} (Br)	π_{11}	π_{12}	π_{13}	π_{31}	π_{33}
Polarization-optical (PO) technique	1.86 ± 0.12	−***0.60*** ± 0.03	1.52 ± 0.15	1.02 ± 0.12	***1.01*** ± 0.14
Optical interferometry (OI) technique	1.75 ± 0.27	−0.60 ± 0.03	1.49 ± 0.20	0.87 ± 0.23	1.01 ± 0.14

detailed characterization of CWO crystals requires also direct acoustooptical studies.

5. Conclusion

In conclusion, we have reported here the piezooptical studies on LGS and CWO crystals by means of the combined OI and PO techniques. Corresponding methodology is supplied by a set of derived equations suitable for the determination of the absolute POCs in the crystals of 32 or 3*m* symmetry. Present work proves a statement, that for the determination of all the eight absolute POCs π_{im} of trigonal LGS crystals by means of PO technique one must perform additionally at least two OI measurements in different experimental geometries. Two OI measurements are required also to determine all the principal POCs in tetragonal CWO crystals. In most cases the combined study significantly improves an accuracy in the determination of the absolute POCs. Due to a large piezooptical effect revealed in CWO crystals they may be considered as quite perspective materials for eventual photoelastic and acoustooptical applications.

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