LINEAR ELECTRO-OPTICAL TENSOR OF LITHIUM FORMATE SINGLE CRYSTAL. (LiHCOO. H_2O).

T. A. Ramadan
Department of Materials Science, Institute of Graduate Studies and Research,
Alexandria University, Alexandria, Egypt.

ABSTRACT

Lithium formate monohydrate (LFMH) single crystal has a point group mm2 and unit cell dimensions: a_1 = 6.46 A°, a_2 = 10.01 A°, and a_3 = 4.85 A°. The linear electro-optical tensor $[r_{ijk}]$ of LFMH has 8 independent components. Samples of 4 different orientations were prepared in a rectangular shape. A series of relative and absolute measurements in longitudinal and transverse directions were carried out using electrodynamic technique. The results show a great variety in values of tensor components which indicate anisotropic electro-optic property. The electro-optic effect of LFMH crystal is about one half of that of KH_2PO_4 crystal.

INTRODUCTION

Electro-optic effect in crystals has received a great attention in recent years due to its optical applications e.g. in light location devices, polarizing interference filters and high speed optical shutters.

The electro-optic effect was studied both in its linear and quadratic forms comparatively long ago. Pockels[1,2] reported the linear electro-optical behaviour as a direct influence of the electric field on the refractive indices of the crystal. Therefore, any physical external effect (e.g. electric, magnetic, mechanical) may induce a change in optical indicatrix, both in position and shape. Theoretical and experimental estimations of the electro-optical tensors were previously studied[3-8] for higher symmetric crystals.

The electron-optic effect is a linear tensorial form between the electric field and optical palarisation in addition to the existence of piezo-electric effect in such crystals. Studies on elastic, piezo-electric and piezo-optic properties of Lithium formate single crystal has been reported[9,10]. According to Neumann's principle[11] and the point group symmetry mm2, the linear electro-optic tensor $[r_{ijk}]$ of LFMH has only 8 independent components.

The aim of this work is to determine the 8 linear components of the electro-optical tensor $[r_{ijk}]$ of Lithium formate monohydrate single crystal based on the electrodynamic technique which provides high accuracy.

MATERIALS AND METHODS

Lithium formate monohydrate LFMH crystals exist in rhombic form of point group symmetry mm2 and space group $Rbn2_1$. It has unit cell dimensions[12] :

a_1 = 6.49 A°, a_2 = 10.01 A° and a_3 = 4.85 A°

Various samples of four orientation types Table (1) were prepared in the form of a rectangular shape. The main orientation (type 1) was obtained in which the 3-perpendicular edges of the prepared rectangular were coincidence with the axes of orthogonal lab. system. The other types of orientations were also prepared by inclination of 45° apart of each the main orthogonal axes (x, y & z).

Table 1.

Sample type	Sample Orientation
1	[100] [010] [001]
2	[100] [011] [011]
3	[101] [010] [101]
4	[110] [110] [001]

A series of relative and absolute measurements of the path difference changes ΔS in the longitudinal and transverse directions were carried out using the electrodynamic technique.[13] The optical systems which were used through this technique is shown in Figures. (1), (2). This technique applies to one of the three possible settings of specimen and to one of the possible directions of electric field E. Due to high sensitivity of measuring technique, experimental precautions were taken into considerations, to avoid any mechanical and thermal disturbances. e.g. the apparatus was set up on a table covered with a thick sheet of rubber in addition to the floor of lab. was also covered with a thick walled of rubber materials.

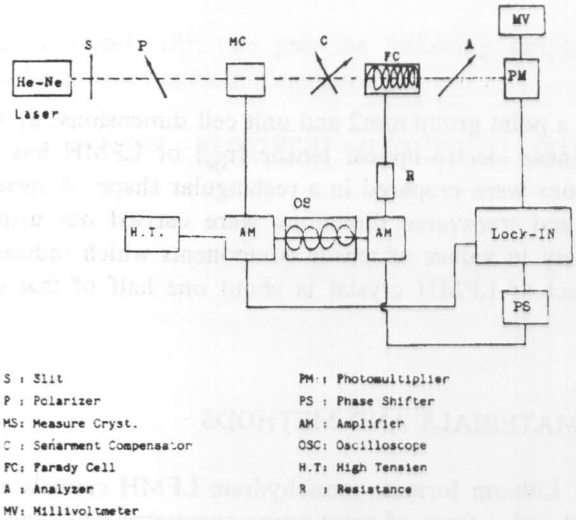

Figure 1. Block diagram of the apparatus for relative measurements.

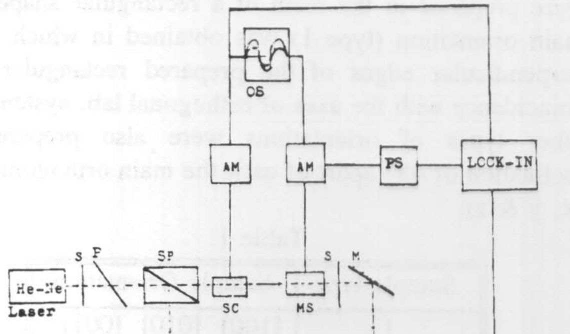

Figure 2. Block diagram of the apparatus for absolute measurement.

RESULTS AND DISCUSSION

When an electric field E is applied to an anisotropic crystal, an increment of polarization Δa_{ij} may be induced. and may be expressed in tensorial form:

$$\Delta a_{ij} = r_{ijk} E_k$$

where r_{ijk} is the electro-optic 3rd order tensor. Consequently a change of path difference ΔS of the incident beam may be detected. These variables can be expressed in a physical relation as follows:

$$S = \frac{L}{\lambda}(n_i - n_j) \qquad (1)$$

where S is the optical path difference between the two polarized light waves at right angle, L is the optical path, λ is the wavelength of the incident laser beam, n_i and n_j are the refractive indices for each plane wave in the direction of the optical indicatrix axes Figure (3).

The change in the path difference ΔS, due to the effect of electric field,can be estimated by differentiating equation (1) as follows:

$$\Delta S = \frac{L}{\lambda}(\Delta n_i - \Delta n_j) + \frac{\Delta L}{\lambda}(n_i - n_j) \qquad (2)$$

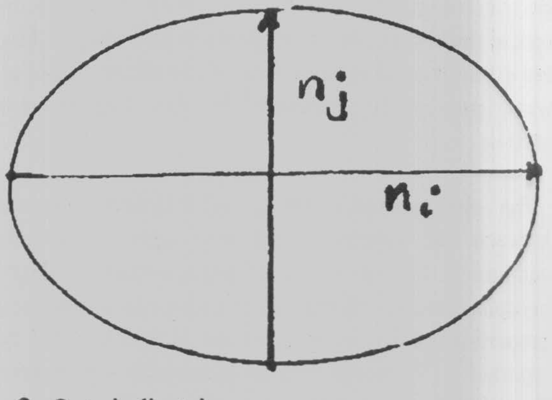

Figure 3. Opt. indicatrix.

Δn_i and Δn_j are the changes in refractive indices, and the term (n_i-n_j) refers to birefringence. A series of mathematical derivations were used to obtain the final experimental equations:[14]

$$\Delta S^{i} = \frac{-L}{\lambda}(n_i^3 \alpha_{ik} \alpha_{il} r_{klm}) - 2d_{mmk}(n_i - 1)] E_m \quad (3)$$

$$\Delta S^{j} = \frac{-L}{\lambda}(n_i^3 \alpha_{ik} \alpha_{il} r_{klm}) - 2d_{mmk}(n_j - 1)] E_m \quad (4)$$

α_{ik} and α_{il} are matrix-transformation, where d_{mmk} is the piezo-electric constant which was previously measured [9]. Equation (3), or (4), refers only to the effect of an electric field component E_m upon one direction in the sample. Each sample type Table (1) has 3 possibilities of orientation measurements. Relative and absolute measurements of changes in path difference ΔS as a function of electric fields, E show a linear relationship, Figures (4, 5, & 6).

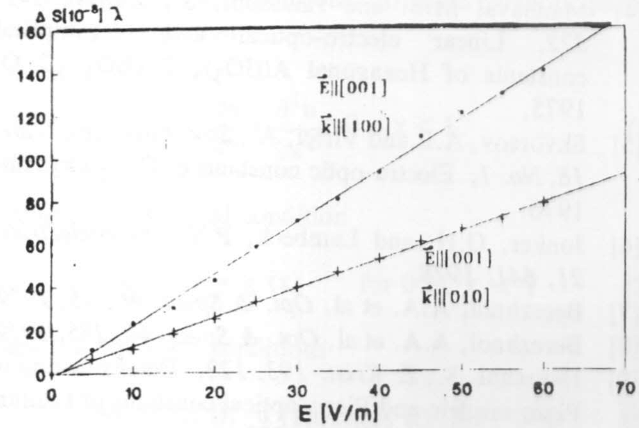

Figure 4. Relation between field E and the change of path difference ΔS (relative-longitudinal).

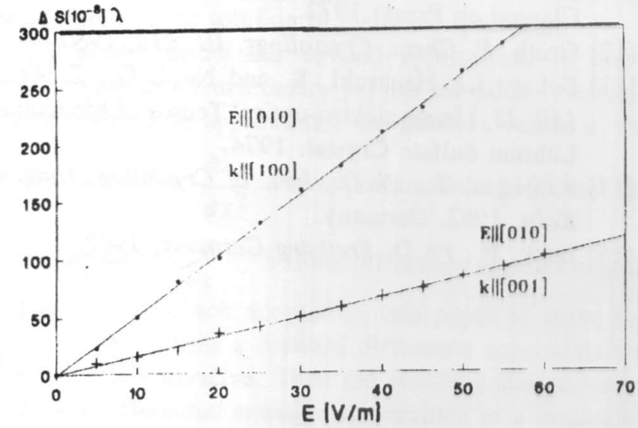

Figure 5. Relation between electric field E and change of path difference ΔS (relative-transverse).

For determining the electro-optical tensor $[r_{ijk}]$ components, at least 10 mathematical equations were proposed. Through a suitable computer programme, the proposed 10 equations could be solved and all components of the electro-optical tensor $[r_{ijk}]$ were calculated and their values are presented in Table (2).

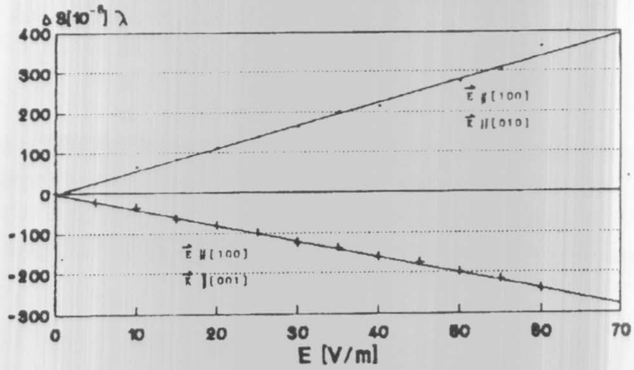

Figure 6. Relation between electric field E and change of path difference ΔS (relative-transverse).

Table 2. Values of the electro-optical constant.

r_{ijk}	Unit $[10^{-12}$ m/v)	St. Dev. %
r_{112}	2.88	4.1
r_{121}	2.90	3.0
r_{123}	-0.50	10.0
r_{132}	2.75	3.5
r_{222}	4.65	2.0
r_{231}	6.50	4.0
r_{233}	-0.20	11.0
r_{332}	2.10	4.0

The data show a great variety in the values of tensor components which indicates the anisotropy of the electro-optical property of LFMH crystal. The ratio between the maximum and minimum value of tensor component amounts to 32.0 times.

In order to evaluate the magnitude of electro-optic effect in LiHFM crystal, the obtained values of KH_2PO_4 crystal to that of $LiHCOO.H_2O$ crystal are compared. It is found to be two times as shown in Figure (7). According to Buck's observation[15], the ratio between piezo-electric tensor $[d_{kij}]$ and electro-optic tensor $[r_{ijk}]$ is equal to or greater than -1.

Since the electro-optic effect depends on the change in dielectric polarization with voltage, it is obvious that this effect can be used to produce very short pulses which may be of interest for optical applications, e.g. optical shutter, birefringence evaluation and light modulation (phase and amplitude).

Table 3. Ratio between piezo-electric and electro optic tensor components.

$[r_{ijk}]$	$[d_{kij}]$[9]	d_{kij}/r_{ijk}
r_{112} [2.88]	d_{211} [-3.43]	$\geq$ -1
r_{233} [0.20]	d_{332} [1.73]	$\geq$ -1
r_{231} [6.50]	d_{123} [7.60]	$\geq$ -1
r_{121} [2.90]	d_{112} [3.43]	$\geq$ -1

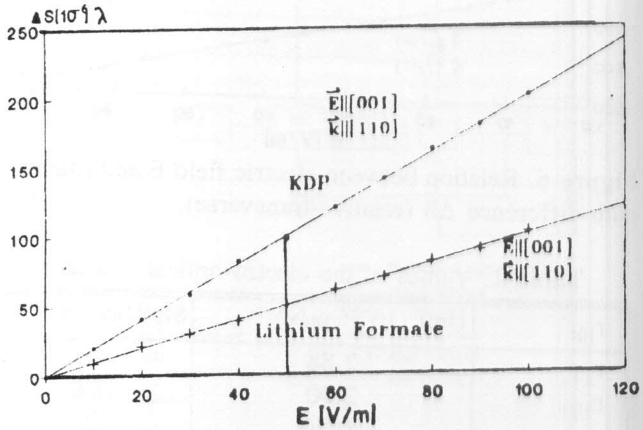

Figure 7. The electro-optical effects of KH_2 PO_4 and LiHCOO-H_20.

CONCLUSION

The linear electro-optic tensor $[r_{ijk}]$ calculations of Lithium formate monohydrate single crystal confirm its asymmetric behaviour. The electro-optic effect of LiHCOO.H_2O was found to be about half the value of that in KH_2PO_4. This indicates that Lithium formate monohydrate is one of the polar group crystals and may have potential optical applications. The ratio between piezo-electric tensor $[d_{kij}]$ and electro-optic tensor of LFMH obeys also Buck's observation.

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