Coordinate dependence of the photo-response in metal – lithium niobate – metal sandwich structure

Y Perkov and V Ivanov
Department of Physics and Theoretical Mechanics, Far Eastern State Transport University, Khabarovsk, Russia
E-mail: tmeh@festu.khv.ru

Abstract. The light induced current in doped lithium niobate crystals with two electrodes of different metals (sandwich system) includes the photovoltaic and the thermoinduced effects. The anomalous coordinate dependences of the light response are revealed and investigated experimentally.

1. Introduction
The photo-induced effects are well known phenomena for the ferroelectric crystals [1]. A series of nonequilibrium phenomena in ferroelectrics, which do not have a definite theoretical description, has appeared recently. In paper [2], the thermovoltaic effect deals with the initiation of the electric voltage between the opposite faces of the semiconductive sample of samarium sulphide (SmS) at heating to 400–500 K is described. The effect has appeared in the presence of the donor impurity concentration gradient directed towards these faces [3].

In this paper the results obtained in experimental studies of the light induced currents in the thin-layer metal-lithium niobate-metal (MLM) structure are presented. The coordinate dependences of the light response were revealed and investigated experimentally. This effect is similar to photovoltaic effect, but it includes the thermal contribution [4]. The possible models of the investigated phenomena are discussed. The results obtained can be used for investigating the properties of the sandwiched ferroelectric structures [5-9], as well as for developing new types of the coordinate photo-detectors [10-15]. This type of detector does not require the modulation of radiation unlike to the classical pyroelectric coordinate detector [6].

2. Light induced currents in ferroelectrics
It is well known the photovoltaic effect (PVE) in lithium niobate with iron impurities. It has been established that the density of steady-state current J is proportional to the laser intensity \( \Phi(t) \):

\[ J_{\phi t} = \alpha K_G \Phi(t), \]

where \( K_G \) is the Glass constant dependent on the nature of absorbing centers and wavelength of radiation, \( \alpha \) is the absorption factor [4].

In our work [5], the thermally-stimulated quasi-stationary current arising only in the highly-alloyed with iron crystal of lithium niobate with the evaporated electrodes from a pair of different metals was described. A sign of the thermo-electro-moving force (thermo-EMF) is determined by location of
electrodes applied by vacuum evaporation on the opposite faces of crystal and does not depend on orientation of the crystallographic axes of the sample in reference to electrodes.

In contrast with the classic pyroelectric effect, the value of observed thermal response is proportional to the crystal temperature increase and does not depend on the rate of its change. It was experimentally measured the coefficient characterizing the thermoinduced electro-moving force (EMF) value in the mode of voltage $U_n$ measurement:

$$P_{el} = (R_n S)^{-1} \Delta U_n / \Delta T, \text{ (A/K-sm^2)},$$

where $S$ is the area of crystal surface covered with sputtered (evaporated) electrode; $\Delta U_n$ is the change of voltage across load impedance $R_n$ when the sample temperature changes by $\Delta T$; $\Delta T$ is the difference between the initial and final temperatures of sample [5].

The study of the effect was performed using the slow modulation of the crystal temperature under the conditions of thermostat and the thermo-EMF was recorded under the stationary conditions (relaxation was not observed for observation time $\tau \sim 10^5$ s). The measurements showed that the thermovoltaic effect has approximately equivalent values in the Y- and Z-cut crystals. Because the sufficiently high rates of heating [about 0.1 K/s] were used in the installation, the pyroelectric current for the polar Z-cut crystals reached the considerable value. Therefore, the principal measurements were performed for the Y-cut lithium niobate crystals where the thermal response could be observed in pure form.

The known contact phenomena in the sandwiched structures with ferroelectrics do not explain the observed quasi-stationary currents [5-8]. The presence of initial voltage $U_n^0$ across the sample allows us to suggest the non-equilibrium nature of the thermally stimulated current.

The electrets model of the MLM structure was proposed in our work [9]. In this model the thermoinduced changing of the conductivity of the crystal leads to change in the stationary current on the load impedance.

3. Research methods
The samples of doped lithium niobate crystals (iron concentration is equal to 0.3 wt%) with different electrodes (aluminum (Al) – chromium (Cr)) were studied. The metal electrodes were applied through the vacuum evaporation with a thickness varying from 0.1 to 1 $\mu$m.

The study of the light induced effect was performed by using the slow modulation of the light with the power $P$ falling on the crystal (Figure 1).

![Figure 1. Experimental scheme.](image-url)
As the sufficiently high rates of heating [about 0.1 K/s] were registered during the experiments, the pyroelectric current for the polar Z-cut crystals reached the considerable value. Therefore, the principal measurements were performed for the Y-cut lithium niobate crystals where the pyroelectric response could be observed in pure form.

The coefficient characterizing the light induced response was experimentally measured:

\[ G = \frac{\Delta U_n}{P_n} \text{(V/W)}, \]  

where \( \Delta U_n \) is the change of voltage across load impedance \( R_n \) when the sample is illuminated by the light, \( P \) is the power of the radiation.

The \( \text{LiNbO}_3: \text{Fe} \) crystal (0.3 Wt.% Fe, Al−Cr, 2 × 2.5 × 0.13 mm\(^3\)) was used. The preamplifier coefficient is \( K=20 \). The crystal was installed in the coordinate table, which allows you to seamlessly move crystal in two directions. The light spot diameter in the focus lens was 340 µm.

4. Experimental results
In some experiments He-Ne laser (0.63 µm) was used as a source of radiation. The dependence of light induced response from the coordinates of the laser spot on the crystal top surface was revealed.

The value of the stationary light response versus \( X \) (along polar axis) and \( Y \)-coordinates is shown in Figure 2.

The coefficient \( G^* \) (\( G \) in arb. un.) reaches the greatest magnitude at the ends of the crystal and it takes different signs at the opposite ends of the sample (Figure 2a).

![Graph](image)

**Figure 2.** The coefficient \( G^* \) versus the coordinate \( X \) (a) and the coordinate \( Y \) (b) of the laser spot (lithium niobate crystal; 0.3 wt% of Fe; Al–Cr electrodes; 2 × 2.5 × 0.13 mm\(^3\)).
The coefficient $G^{*}$ versus $Y$-axis is changed monotonically (Figure 2b). This asymmetry can be associated with only one selected direction in crystal associated with the polar axis $X$.

Edge effects can be caused by the coordinate dependence of crystal temperature. These effects are confirmed experimentally by the thermographic registration (Figure 3). But these phenomena don’t explain change of the response sign and the X-Y asymmetry (Figure 2).

![Figure 3](image)

**Figure 3.** The temperature distribution on the surface of the lithium niobate crystal with He-Ne laser illumination: a) – the laser spot is on the sample edge, $T_{\text{max}} = 45.6 ^{\circ}C$ ; b) - the laser spot is on the sample mid, $T_{\text{max}} = 42.1 ^{\circ}C$.

The anomaly in the coordinate dependence can be explained by the existence of two response mechanisms (photovoltaic and thermovoltaic) with different signs. The photovoltaic response gives the contribution in the light induced current, because the electrodes are partially transparent. The coordinate dependence disappeared when the upper electrode was blackened. The detailed explanation of the describing experiments requires the further investigation.
5. Conclusions

The results obtained in experimental studies of the light induced currents in the thin-layer nonsymmetrical metal-lithium niobate-metal (MLM) structure are presented. In experiments with the local illumination of the LiNbO$_3$:Fe crystal the anomalous dependence of light induced response from the coordinates of the laser spot on the crystal top surface was revealed. The temperature coordinate dependence confirmed experimentally, but thermal model cannot explain the change of response sign. However, the alleged explanation of the coordinate anomaly should include the photovoltaic effect and the thermovoltaic contribution.

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