Anomalous photovoltaic effect in $LiNbO_3$:Fe in polarized light

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Dependence of the photovoltaic current in the ferroelectric $LiNbO_3$:Fe on the direction of light polarization is obtained for the first time, and the components of the photovoltaic tensor k_{ijk} are determined. The longitudinal, photorefractive effect is observed.

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The anomalous photovoltaic effect (AP effect) in crystals without the symmetry center is described by the tensor of third order α_{ijk} [1]

$$J_i = \alpha_{ijk} E_j E_k , \tag{1}$$

where J_i is the photovoltaic current, and E_j and E_k are projections of the light polarization vector (for linearly polarized light). The AP effect in ferroelectric materials was observed for the first time in Refs. 2 and 3 in $LiNbO_3$:Fe and in barium and strontium niobate crystals. The dependence of J_z on the light polarization (z is the direction of spontaneous polarization) in ferroelectric materials was not observed in Refs. 2 and 3 or in the subsequent work,[4] and it was reported that $J_y = J_x = 0$. At the same time, the AP effect in a cubic piezoelectric $Bi_{12}SiO_{20}$ was observed only in the polarized light.[5] In this paper, we report for the first time the dependence of the photovoltaic current on light polarization in $LiNbO_3$:Fe, and we determine all the components of the photovoltaic tensor.

The measurements performed using an iron-doped lithium niobate single crystal in the shape of a parallelepiped with the (001), (010) and (100) faces and the corresponding linear dimensions $0.5 \times 0.35 \times 0.1$ cm. The crystal was illuminated with a linearly polarized light at $\lambda = 500$ nm, which corresponds to the edge of absorption band of Fe^{2+} in $LiNbO_3$:Fe.[6] A xenon lamp and ZMR monochromator were used as a source of light. The method described earlier[6] was used for measuring both the steady-state photovoltaic current J and the field induced by it $\widetilde{E} = J/\sigma$, where σ is the photoconductivity. All the measurements were conducted at a constant light intensity $I = 2.3 \times 10^{-3}$ W/cm^2 at room temperature.

The photovoltaic current was measured both in the direction of spontaneous polarization (z axis) and in the x and y directions for all possible orientations of light polarization plane. Figures 1 a, b, and c show the experimental dependence of the photovoltaic current J_z, J_y, and J_x on the angle β between the light polarization plane and the corresponding crystal axis. Allowing for the nontrivial value of the α_{ijk} tensor component for the point group $3m$ to which lithium niobate belongs, we write the expressions, in accordance with Eq. (1), for the photovoltaic current J_z, J_y, and J_x

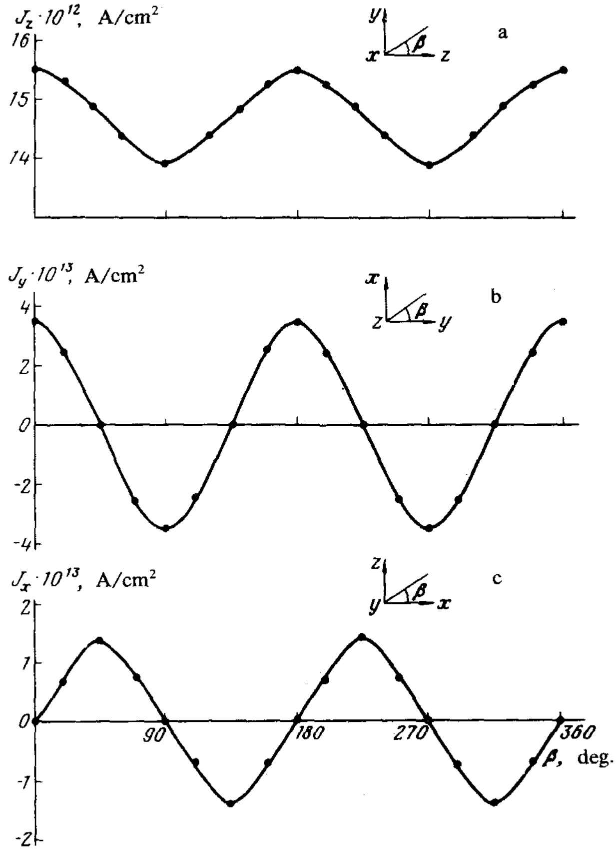

FIG. 1. Dependence of the photovoltaic currents J_z(a), J_y(b), and J_x(c) on the orientation of the plane of the light polarization in $LiNbO_3$:Fe. The direction of light propagation is indicated in the insets.

(the direction of propagation of the linearly polarized light is shown in Figs. 1a, b and c, respectively).

$$J_z = \alpha_{31} I + (\alpha_{33} - \alpha_{3}) I \cos^2\beta, \tag{2}$$

$$J_y = \alpha_{22} I (1 - \sin^2\beta), \tag{3}$$

$$J_x = \alpha_{15} I \sin 2\beta, \tag{4}$$

where I is the intensity of light. A comparison of the experimental orientational dependences in Figs. 1 a, b, and c, respectively, with Eqs. (2), (3), and (4) shows a good agreement. Although the currents J_x and J_y have nonzero values only for the polarized light and change their signs twice when the polarization plane is rotated by 360°, the current in the direction of spontaneous polarization has a component that is independent of the direction of the polarization of light. This possibly accounts for the fact that the effect of light polarization on the photovoltaic current J_z has not been observed earlier.[2-4] Two interesting cases are not shown in Fig. 1. If the light propagates along the x axis, then $J_x = 0$ for any value of β. When the light propagates along the z axis, the current $J_z = \alpha_{33} I$ is independent of the direction of light polarization. We note that the amplitudes of the currents J_y and J_x are smaller than J_z by more than an order of magnitude. Therefore, the induced field $\tilde{E}_y$, $\tilde{E}_x$ is by more than an order of magnitude lower than $\tilde{E}_z$ and does not exceed 200 V/cm. However, these fields were sufficient to observe the longitudinal, photorefractive effect in the direction of the z axis, $\delta(\Delta n) \approx 10^{-6}$, which at the light intensity shown above was more than an order of magnitude lower than the transverse photorefractive effect (in the direction of the y axis) determined earlier.[6]

We determined from a comparison of the curves in Figs. 1 a, b, and c with Eqs. (2)–(4) the numerical values of α_{ijk} or the photovoltaic coefficients $k_{ijk} = 1/\alpha^* \alpha_{ijk}$, where α^* is the absorption coefficient (in $LiNbO_3$:Fe $\alpha^* \approx 4.5$ cm^{-1} at $\lambda = 500$ nm; pleochroism can be disregarded). The following values were obtained: $k_{31} = 1.4 \times 10^{-9}$, $k_{33} \approx 1.5 \times 10^{-9}$, $k_{22} \approx 0.5 \times 10^{-10}$, and $k_{15} \approx 1.0 \times 10^{-11}$ A·cm/W. The values of k_{31} and k_{33} are close to the value of the photovoltaic coefficient obtained earlier for $LiNbO_3$:Fe in unpolarized light.[7]

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