Transition of a ferroelectric to a state with a magnetic moment in an external electromagnetic field

É. V. Bursian, Ya. G. Girshberg, V. A. Egorov, and R. Kh. Kalimullin
A. I. Gertsen Lenin State Pedagogical Institute

(Submitted 20 March 1983)
Pis'ma Zh. Eksp. Teor. Fiz. **37**, No. 11, 520–522 (5 June 1983)

Illumination generates a magnetic moment in the ferroelectric semiconductor GeTe. The moment disappears upon a phase transition to a paraelectric state. The effect is interpreted as either a consequence of an anomalous photovoltaic effect which forms ring currents or a transition to a ferromagnetic state in the external electromagnetic field.

PACS numbers: 78.20.Ls, 77.80.Bh

It has been found that illumination causes a sharp change in the orientation of a GeTe crystal suspended in a magnetic field. The torque is not small: When the large face of crystal with dimensions of $6\times6\times3$ mm, suspended on a filament with an elastic constant $\sim10^{-8}$ N m/rad, is illuminated by slightly focused light from an incandescent projection lamp (~1 W/cm^2) at 20 °C the crystal rotates 10° or more in a field ~1 kG. This torque is significantly greater than that which acts on a sample in the same field by virtue of the diamagnetism of the sample. Furthermore, and in contrast with diamagnetism, the effect is of odd parity in the magnetic field (Fig. 1). This means that a spontaneous magnetic moment $\mathbf{M}_s$ arises in the crystal when it is illuminated ("spontaneous" in the sense that it is not caused by a conjugate magnetic field; the external field is used simply as a measuring field). Under these conditions the value of M_s is of order 10^{-5}–10^{-4} A cm^2. When the sample is rotated 180° around the wave vector of the light, $\mathbf{Q}=Q\mathbf{k}$ (Fig. 1), the sign of the deviation $\Delta\varphi$ changes; in other words, the orientation of $\mathbf{M}_s$ is determined by some polar direction in the sample (more precisely, in the illuminated surface layer, since the light used in these experiments penetrates only a short distance into the crystal).

The deviation $\Delta\varphi$ (or the magnetic moment $\mathbf{M}_s$) during the illumination contains a dynamic part (the initial motion) and a static part. When the light is turned off, there

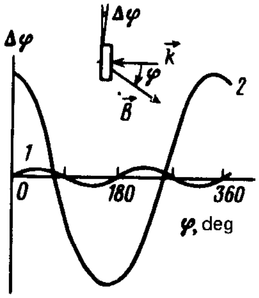

FIG. 1. Rotation of the sample as a function of the orientation of the external field **B**. 1—In darkness (a consequence of the diamagnetism); 2—the photoinduced increment, $T=20$ °C.

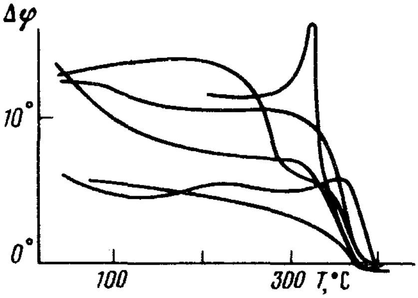

FIG. 2. Examples of the temperature dependence of the photo-induced increment in the rotation of the crystal in a magnetic field. $\varphi = 45°$.

is a brief motion in the direction opposite the original motion. The effect depends linearly on the light intensity.

The temperature dependence $M_s(T)$ is complex and unique to each crystal (Fig. 2), but the most important circumstance is that at about 400 °C there is a sharp decrease in both the dynamic and static parts of M_s; the decrease is to zero or at least to values difficult to measure (Fig. 2). Near this temperature we know that GeTe undergoes a phase transition from a ferroelectric to a paraelectric phase.

The dynamic part of the effect can be attributed to a change in the spontaneous polarization $\mathbf{P}_s$ during illumination (the pyrolytic effect, effects of a screening of $\mathbf{P}_s$ by nonequilibrium carriers, optical detection, etc.[1]). As a result, ring currents form in the illuminated part of the crystal in a direction specified by the direction of $\mathbf{P}_s$ in this part of the crystal. The loads closing the circuit play a role in the parts of the crystal which are not illuminated. It turns out that P_s is not small in GeTe in this case; according to rough estimates, it ranges from 10 to 100 μC/cm^2. We note that this would be the first evidence for the existence of $\mathbf{P}_s$ in a narrow-gap ferroelectric and the first method for studying its temperature dependence. Dielectric measurements in highly conducting ferroelectrics have previously yielded only the value of ε_0.

The static part of the effect (the steady-state deviation $\Delta\varphi$) can also be explained on the basis of macroscopic currents.[1)] Below the transition the illumination may give rise to ring currents by virtue of an anomalous photovoltaic effect.[2,3] If so, then the large value of the so-called Glass constant K is very interesting. In order to explain these values of M_s the ring current would have to be on the order of 100 μA, which would correspond to $K \sim 10^{-6}$ A cm/W. This value is three orders of magnitude larger than in narrow-gap ferroelectrics, in accordance with the predicted[2] strong dependence of K on the electron spectrum.

Another possible reason for the appearance of $\mathbf{M}_s$, in this case a microscopic mechanism not involving currents, might be a slight ferromagnetism induced by the external electromagnetic field. The present experiments were in fact carried out in a search for this effect. Like the appearance of an anomalous-photovoltaic-effect current, the appearance of $\mathbf{M}_s$ in an external field $\mathbf{E} = E_0\mathbf{e} \exp i[\mathbf{Qr} - \omega_L t]$ stems from the particular nature of the scattering of nonequilibrium carriers, in connection with the appearance of an electronic order parameter $\vec{\Phi} = \Phi \mathbf{c}$ below the transition. The corresponding calculations are qualitatively similar to those in Ref. 2 and reduce to finding the field corrections to the off-diagonal elements of the density matrix $\rho_{\alpha\beta}(p)$ [or the off-diagonal Green's functions $\widetilde{G}_{\alpha\beta}(p, \omega)$]. In the present case, however, transitions accompanied by a change in spin must be taken into account along with the ordinary dipole interaction. A specific calculation yields

$$M_s \simeq (\Phi/\omega_L)(\lambda_0/\omega_L)^2(m\,\omega_L)^{3/2}[(\omega_L - E_g)/\omega_L][Q^2/(m\omega_L)]^{1/2}\mu_B\,,$$

where E_g is the gap width in the original spectrum, and the notation is otherwise the same as in Refs. 2 and 3. Like the anomalous-photovoltaic-effect current, this effect can occur only in the presence of real transitions (i.e., only if $\omega_L > E_g$), and it does not have any characteristic relaxation times.

Just how important these proposed mechanisms are in giving rise to M_s requires further study, but there can be no doubt regarding the occurrence of the effect itself.

[1)] Ring currents in defective crystals may not be related to $\mathbf{P}_s$ and may result from a photo-emf at *p-n* junctions, a thermal-emf at composition inhomogeneities, etc. In samples with a surface that is not clean one can clearly observe pronounced "thermocurrents." In these cases shifting the light spot from one end of the crystal to the other changes the sign of $\mathbf{M}_s$; this effect may correspond to the heating of some "thermocouple junction." The same thermal effect, however, appears and vanishes when the sample is heated for a few seconds (or tens of seconds). In homogeneous samples with a clean surface, this effect actually disappears. These factors are apparently significant in certain cases, but unless supported by some rather arbitrary additional assumptions they cannot explain the disappearance of $\mathbf{M}_s$ upon the ferroelectric phase transition, and we will not discuss them further.

---

[1] V. M. Fridkin, Fotosegnetoélektriki (Photoferroelectrics), Nauka, Moscow, 1979.
[2] É. V. Bursian, Ya. G. Girshberg, and N. N. Trunov, Zh. Eksp. Teor. Fiz. **82**, 1170 (1982) [Sov. Phys. JETP **55**, 681 (1982)].
[3] Ya. G. Girshberg, N. N. Trunov, and E. V. Bursian, Ferroelectrics **43**, 143 (1982).

Translated by Dave Parsons
Edited by S. J. Amoretty