Photo-ferroelectric noise effect. Observation and investigation

N. B. Luk'yanchikova, M. K. Sheĭnkman, and A. P. Lityuchiĭ

Semiconductors Institute, Ukrainian Academy of Sciences

(Submitted 15 January 1978; resubmitted 28 February 1978)
Pis'ma Zh. Eksp. Teor. Fiz. **27**, No. 7, 392–396 (5 April 1978)

A new photo-ferroelectric effect has been observed, and was named by us photo-ferroelectric noise. Its gist is that when a *c*-domain $BaTiO_3$ single crystal is illuminated, there appears on electrodes deposited on the (001) face a fluctuating voltage in a wide frequency range, greatly exceeding the thermal-noise level. Some singularities of the phenomenon are investigated and its possible mechanisms are considered.

PACS numbers: 78.20.Jq

The few existing studies of noise in ferroelectrics have been devoted to the development of a new noise-based research method and to the result of measurements of parameters of ferroelectrics in a linear and field-free regime, and unfortunately do not contain new data on the specifics and the mechanism of photo-ferroelectric processes (e.g.,[1,2]).

Yet it is known that a study of the fluctuation processes in semiconductors makes it possible in principle to obtain extensive information both on the nature of the different nonequilibrium processes that occur in them and on the parameters of the local centers in homogeneous crystals, on the mechanisms of current flow through inhomogeneous structures, contacts, *p-n* junctions, and heterostructures (e.g.,[3-5]). Pursuing similar aims, we have investigated electrical noise in $BaTiO_3$ single crystals in darkness and under illumination.

We describe below a new photo-ferroelectric noise effect, observed by us and connected with the photo-ferroelectric properties of $BaTiO_3$.

The investigations were carried out in the temperature interval $T=20$–$180\,^\circ\mathrm{C}$ on plate-like *c*-domain single crystals 100–300 μm thick, grown by the Remeika procedure and having a resistivity 10^8–10^{11} Ω-cm, and etched in H_3PO_4 at 130 °C before the measurements. Semitransparent electrodes were deposited on the (001) faces perpendicular to the ferroelectric axis, by evaporating gold in vacuum, and also by chemical deposition of silver. To measure the noise across such contacts, we used the installation and the procedure described in[6,7]. The crystal impedance $Z(f)$ was determined with a VM401E bridge. The samples were illuminated through the electrodes with polarized light from an incandescent lamp; a set of light filters passed light in the range $410<\lambda<460$ nm, corresponding to absorption. The sample temperature in the thermostat was measured with a chromel-alumel thermocouple placed in the immediate vicinity of the sample. Thermostabilization was accurate to ~0.01 °C in the temperature region 20–180 °C.

The results of the investigations reduced to the following.

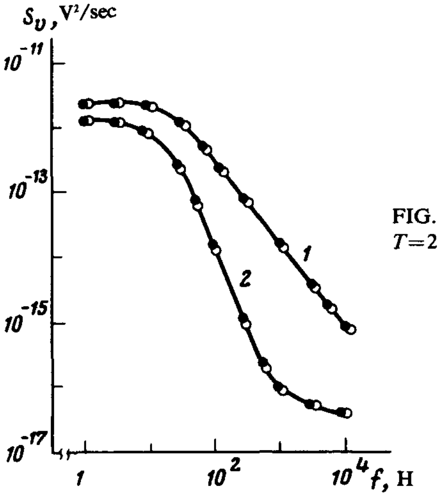

FIG. 1. Spectral density of noise: ●–in darkness, o–in light; 1–at $T=22.3$ °C, 2–at $T=118.8$ °C.

1. The equilibrium thermal noise voltage observed in darkness at temperatures below the phase transition ($T_c=118.5$ °C) is determined, as expected, from the Nyquist formula. The spectral density shown in Fig. 1 (curve 1) of the thermal noise measured in darkness and of the noise measured under the same condition but with the crystal illuminated are in full agreement in the entire frequency range $1-10^4$ GHz. The frequency dependences of the impedance $Z(f)$, measured in light and in darkness, are the same. This means that in the investigated temperature region the photoconductivity $\Delta\sigma_{\mathrm{ph}}$ was much lower than the dark conductivity σ_d, for example, as a result of the strong recombination of the photocarriers. Moreover, the equivalent noise resistance determined from the spectral noise density coincides with $\mathrm{Re}Z(f)$ of the crystal, thus demonstrating the absence of excess noise. This pattern is preserved in the ferroelectric region up to temperatures near the phase transition.

2. At temperatures close enough to T_c ($T=117.5$ to 118.2 °C), illumination of the *c*-domain single crystals through the semitransparent electrodes produces on the electrodes a fluctuating voltage in a wide frequency band, greatly exceeding the level of the thermal (Nyquist) noise (Fig. 2). The spectral density of this noise (curve 2) differs strongly from the spectrum of the thermal noise (curve 1), while the impedances of the crystal under illumination and in darkness remain the same in this temperature region.

3. The observed effect vanishes when the temperature is increased by 1–2 °C and the transition into the paraelectric phase takes place. Thus, the spectral density of the noise of the sample in darkness and under illumination, shown in Fig. 1, become equal (curve 2) already at $T=118.8$ °C. In the paraelectric phase, as in the ferroelectric phase, the equivalent noise resistance of the illuminated and non-illuminated crystal coincide with the $\mathrm{Re}Z(f)$ of the crystal.

4. When the crystal is illuminated with modulated light, a photo-emf is produced on its contants, but only in the narrow temperature interval in which the considered photo-noise effect is observed.

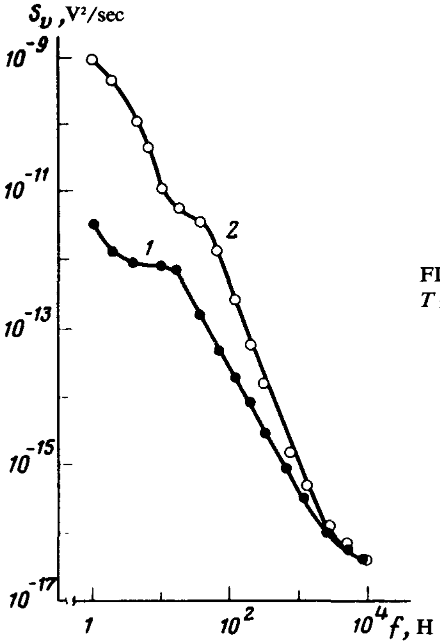

FIG. 2. Spectral density of the noise at the temperature $T \approx T = 118.5$ °C: 1–in darkness, 2–in light.

5. The effect is observed both on recovered and nonrecovered crystals, and on various contacts (gold, silver, aquadag, LiCl solution).

Thus, the photo-ferroelectric noise effect consists of fluctuations of the photovoltage (exceeding thermal noise) which are produced when the ferroelectric is illuminated in the region of the phase transition. One can consider several possible causes of this noise: a) The investigated fluctuations may accompany the onset of anomalously high photo-emfs in a homogeneous ferroelectric if it is uniformly illuminated (these were observed by Glass[8]). In this case, however, one should expect a wider temperature interval in which the effect is observed, in accordance with the larger temperature range where the anomalous emf is observed.[8] b) The noises in question are fluctuations of the ordinary photo-emf in an initially inhomogeneous ferroelectric. However, such an emf (and, accordingly, noise) should remain also in the paraelectric phase, where the inhomogeneities do not vanish, and this contradicts the results. c) The measured noise constitutes fluctuations of the photo-emf produced on inhomogeneities which are absent from the sample far from the phase transition, but appear in the region of the transition when the sample is illuminated, for example because of the appearance of interphase boundaries.[9,10] Taking into account the properties of such phase boundaries, namely stability at the temperature T_0, the presence of a structure that has the properties of a heterojunction and therefore leads to the appearance of noise,[4] we are inclined to think that it is precisely this cause of the observed photo-noise effect which is the most probable.

[1] J. Brophy and S.L. Webb, Phys. Rev. **128**, 584 (1962).
[2] L. Godefroy, J. Phys. (France) **33**, suppl. C-2, 44, 197.

[3] N.B. Lukyanchikova, N.P. Garbar, M.K. Sheinkman, and M.N. Zargarjante, Solid-St. El. **15**, 801 (1972).

[4] N.B. Luk'yanchikova, N.P. Garbar, M.K. Sheinkman, B.D. Solganik, and L.M. Panasyuk, in: Problemy fiziki soedinenii $A^{II}B^{VI}$ (Problems of Physics of II-VI Compounds), Part II, Vilnius, 1972, p. 137.

[5] N.B. Lukyanchikova, G.S. Pekar, N.N. Tkachenko, Hoang Mi Shin, and M.K. Sheinkman, Solid-St. Elektron **20**, 879 (1977).

[6] N.B. Luk'yanchikova and N.B. Grabar, Prib. Tekh. Éksp. No. 2, 178 (1966).

[7] N.B. Luk'yanchikova and M.K. Sheĭnkman, Fiz. Tekh. Poluprovodn. **1**, 345 (1967) [Sov. Phys. Semicond. **1**, 283 (1967)].

[8] A.M. Glass *et al.*, Appl. Phys. Lett. **25**, 233 (1974).

[9] J.C. Burfoot and T.L. Parker, Brit. J. Appl. Phys. **17**, 213 (1966).

[10] M. DiDomenico and S.K. Wemple, Phys. Rev. **155**, 539 (1967).