Role of the dislocation mechanism in the polarization-echo phenomenon

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(Submitted July 14, 1976; resubmitted January 3, 1977)
Pis'ma Zh. Eksp. Teor. Fiz. **25**, No. 3, 165–167 (5 February 1977)

It is shown that the long-lived echo in a piezoelectric powder is preserved after the sample is thoroughly stirred. The mechanism of dislocation nonlinearity of the elastic properties of the particles is used as an explanation.

PACS numbers: 77.60.+v, 77.30.+d, 81.40.Jj

A new explanation was recently proposed for the anomalously long relaxation times of the polarization (electroacoustic) echo in piezoelectric powders.[1,2] The nonlinear behavior of the system of oscillators, which is mandatory in principle for echo formation,[3] is attributed in[1,2] to the effect of the orientation of the piezoelectric axis of the powder particle relative to the direction of the exciting electric field. According to this model, which we shall call the orientational model, information on the frequency, phase, and waveform of the sequence of the exciting pulses is carried only by the states of the spatial orientation of the powder particles, while the internal structure of the particles remains unchanged. To verify this theory, we have performed an experiment under the following experimental conditions: the apparatus was of the type described earlier,[4] the sample was $KBrO_3$ powder sifted through a $135 \pm 15\ \mu$ sieve, with sample weight 13.5 g, $t = 22\,°C$, pulse duration $\Delta t_{1,2,3} = 5$ sec, and pulse amplitude $E_{1,2,3} = 5$ kV/cm.

Prior to excitation of the sample by the pulse pair, a single "reading" pulse

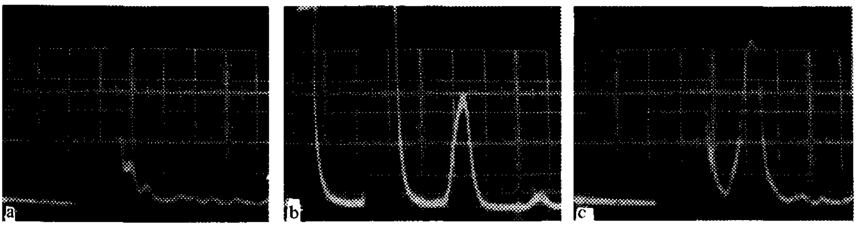

FIG. 1. Recorded signal of polarization echo that is produced by the orientation of the $KBrO_3$ powder particles in the electric field. Average particle dimension $d_{av} = 135\ \mu$, RF electric-field radiopulse frequency $f = 12.5$ MHz, sweep rate 10 μsec/cm. Receiver gain $K = 500$ (a, c) or $K = 50$ (b).

was applied with a repetition frequency $F = 50$ Hz. After repeated stirring of the powder particles, the same monotonic decrease was observed in all cases (Fig. 1a). The sample was then excited for one minute by pulse pairs with interval $\tau = 25$ μsec and pair repetition frequency $F = 500$ Hz. In this case, an intense two-pulse echo signal was observed (Fig. 1b). After this recording cycle, the sample was removed from the pickup, sifted three times through a sieve of 200 μ mesh, and placed in another pickup identical with the first. When only the single reading pulses with repetition frequency $F = 50$ Hz were applied, the previously recorded echo signal (see Fig. 1c) was observed. After the first sifting the signal was decreased by a factor of seven compared with the initial signal (prior to the sifting), while after the second and third siftings it remained unchanged.

The result demonstrates that the orientational model is inadequate for the following reasons:

1) Complete disruption of the initial orientation does not cause complete destruction of the information concerning the signal.

2) Each succeeding stirring (sifting) of the sample does not destroy the additional information.

The echo shown in Fig. 1c was not observed in other experiments, obviously as a result of interfering "ringing". We have chosen a sample with very large number of almost identical particles, making it possible to reduce to a minimum the masking "ringing" signals.[2]

To explain the echo signals which are not connected with the particle orientation, we propose here a mechanism based on the dislocation nonlinearity of the elastic properties. The prolonged recovery processes inherent in this mechanism (wherein the dislocations are pinned by point defects produced upon deformation) can explain the fixed internal particle state observed in the foregoing experiments. A detailed theory of the echo phenomenon in piezoelectrics, with allowance for this form of nonlinearity,[3] will be reported in a detailed article.

We investigated the influence of prior cold working on the relaxation characteristics T_2 and T_1 of the polarization echo (KDP sample, $t = 22\,°C$). We note that, as shown earlier,[4,5] the time T_2 is determined to a considerable degree by the damping of the sounds in the sample, while T_1 is the lifetime of the piezoelectric polarization induced by the exciting pulses. Three equal amounts (weight 1.3 g) from one KDP batch were sifted through equal sieves (135 ± 15 μ), but differed in the degree of cold working of the powder particle. Typical measurement results are summarized in Table I. Examination with an optical microscope has shown that the particles in samples 1, 2, and 3 (see Table I) have different transparencies: the most transparent are those of sample 1 (sifted without crushing), and the least transparent are in sample 3 (the most intense crushing). This confirms the increase of the dislocation density from the first to the third sample, since the presence of dislocations influences strongly the scattering of light in transparent crystals (of the KDP type).[6] (We had no other means of directly estimating the dislocation density in crystals with dimensions on the order of 100 μ).

The recorded (see Table I) difference between the parameters T_2 of samples having different dislocation densities can be explained within the framework of

TABLE I.

Samples	T_2, μsec	T_1, sec
1	185	0.3
2	130	2×10^3
3	175	10

the dislocation mechanism. In sample 1, with low dislocation density, the damping of the sound is minimal (T_2 is maximal). The small difference between the sound damping in samples 3 and 1 is due to the "rigid" dislocation grids introduced into the crystal by the intense cold working; the sound interacts weakly in this case with the dislocations.[7] The decrease of T_2 in sample 2 corresponds to a strong interaction of the sound with the dislocations, and the simultaneous very appreciable increase of T_1 may signify that it is precisely this interaction which causes the longevity of the echo picture. The polarization echo relaxation parameter T_2 is in this case a reflection of the dislocation losses, while T_1 characterizes the process of the recovery of the residual deformation (polarization) of the piezoelectric, brought about by the unpinning and multiplication of the dislocations.

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