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Abstract

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REPOLARIZATION JUMPS IN FERROELECTRIC CRYSTALS CAUSED BY APPLIED MECHANICAL STRESSES

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The Barkhausen effect in ferroelectric crystals has been studied by a number of authors (see, for example, ([1−5])). In all these works, repolarization jumps were observed arising in a specimen under the action of an electric field applied to it. As in ferromagnets ([6,7]), Barkhausen jumps in ferroelectrics are caused mainly by the formation of domain nuclei and by the jump-like motion and merging of domain boundaries during polarization or repolarization of the crystal under the influence of an external electric field.

It is known, however, that repolarization of some ferroelectrics can occur under the action not only of an electric field, but also of a homogeneous mechanical stress. It was natural to assume that in this case as well, along with smooth displacement of domain boundaries, their jump-like displacements should arise, leading to Barkhausen jumps. Consequently, one could expect that repolarization jumps in such ferroelectric crystals may occur even without the application of an electric field—under the action only of mechanical stresses.

All ferroelectric crystals that possess, in the paraelectric phase, piezoelectric properties (along the direction in which the spontaneous polarization P_s arises) ([8]) will belong to this type of ferroelectric. The spontaneous deformation in the ferroelectric phase of such crystals contains a shear that has opposite signs in domains with oppositely directed P_s vectors; therefore, by applying the corresponding external shear stress one can polarize (or repolarize) the crystal.

A typical ferroelectric of this type is Rochelle salt, in crystals of which we observed the expected effect.

The work used an apparatus consisting of a combination of the setups described in ([5,9]). Rochelle-salt specimens were used in the form of X 45°-cut plates with dimensions $10 \times 10 \times 2$ mm. The electrodes were applied by vacuum deposition of silver; the leads were attached with a special electrically conducting adhesive. To stabilize the temperature, the specimen was placed in a thermostat.

A load producing homogeneous mechanical compressive stresses, equivalent to the shear stress $Y_z(Z_y)$, could be applied to the side faces of the plate in mu-

Figure 1

Figure 1: Figure 1

tually perpendicular directions and varied stepwise. The repolarization jumps arising in the specimen led to the appearance of voltage pulses across a resistor connected in series with the specimen. These pulses were fed through an amplifier to a counting circuit for counting the number of jumps, and to an electronic oscilloscope for visual observation of the process.

As the experiments showed, under the action of homogeneous mechanical stresses in specimens, within the ferroelectric temperature interval, repolarization jumps arise that are analogous to the jumps caused—

by an electric field applied to the specimen along the X axis. This indicates that the jump-like processes of polarization (or repolarization) of Rochelle-salt crystals under the action of mechanical stresses and of an electric field proceed in the same way. For example, in both cases, at $t = 12.5^{\circ}$, the mean size of a jump corresponds to a change in electric moment $\Delta P = 10.5 \cdot 10^{-15}$ $\mathrm{C \cdot cm}$, i.e., to repolarization of a volume of the order of $3.0 \cdot 10^{-8}$ cm^3 (see (10)).

Fig. 1. Barkhausen jumps in an X 45°-cut specimen of a Rochelle-salt crystal, caused by an external homogeneous compressive stress. $1, 3$ —integral curves (n —number of jumps); $2, 4$ —differential curves. $t = 12.5^{\circ}$

Figure 1 shows curves of the distribution of the number of jumps as a function of the magnitude of the mechanical stress. These curves are analogous to the field-distribution curves for jumps caused by an electric field ([10]).

When the applied mechanical stress is reduced, and also when a compressive stress is imposed in the direction perpendicular to the initial one (which corresponds to a change in the sign of the equivalent shear stress), Barkhausen jumps of the opposite sign arise. If the number of jumps of one sign is taken as positive and of the opposite sign as negative, then the dependence of their algebraic sum on the applied mechanical stress will have the form of a hysteresis loop (Fig. 2).

It must be emphasized that the jumps investigated are caused precisely by the action of mechanical stresses that repolarize the specimen. Jumps due to the secondary action of the piezoelectric effect, as calculation and direct experimental verification show, play an insignificant role; they can introduce only small distortions into the distribution curves.

Let us now turn to ferroelectrics of another type, in which a homogeneous mechanical stress cannot directly cause displacement of the boundaries between domains with antiparallel orientation of P_s. This type of ferroelectric includes (with minor exceptions) all crystals that do not possess piezoelectric properties in the paraelectric phase (either in general or along the direction of occurrence of P_s) ([8]). If such a crystal has only one axis of spontaneous polarization

Figure 2

Figure 2: Figure 2

and, consequently, only 180° domain walls, then a homogeneous mechanical stress generally cannot cause any reorientation of domains in it. It is natural to assume that in such a crystal Barkhausen jumps will not arise upon application of mechanical stresses.

Fig. 2. Dependence of the algebraic sum of Barkhausen jumps in X 45°-cut specimens of a Rochelle-salt crystal on the mechanical stress during cyclic repolarization under the action of an external load. $t = 12.5^{\circ}$

A typical representative of such ferroelectrics is triglycine sulfate (TGS). Experiment has confirmed that if compressive stresses X_x or Z_z (the spontaneous strain in TGS includes x_x and z_z) are applied in increasing steps to the side faces of a ferroelectric plate of a Y-cut TGS crystal, then, in the case of a non-unipolar plate, no polarization-reversal jumps arise. If the plate is unipolar and, consequently, possesses piezoelectric properties, then only jumps arise that are due to the secondary action of the piezoelectric effect. Replacing the stress X_x by Z_z does not change the polarity of the jumps, in accordance with the fact that the piezomoduli d_{21} and d_{23} have the same sign. The magnitudes of these jumps are at least an order of magnitude smaller than the magnitudes of the jumps produced in the same specimen by an electric field, and they do not exhibit saturation even up to breaking loads.

The conclusion that the effect described above is present in Rochelle-salt crystals and absent in TGS crystals can apparently be extended also to all other ferroelectric crystals with a correspondingly analogous geometry of the domain structure.

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