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FEATURES OF THE AMPLITUDE DEPENDENCE OF INTERNAL FRICTION IN SINGLE-CRYSTAL FERROELECTRICS

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It is known that, among the extensive variety of mechanisms of internal friction in solids, a number of mechanisms give rise to a dependence of internal friction on the amplitude of deformation ([1]). Moreover, for amplitude-dependent internal friction in ferromagnets and ferrites there is a specific mechanism caused by hysteretic reorientation of domains and often playing a determining role ([2]). It is natural to suppose that in ferroelectrics, in connection with the presence in them of a domain structure, the amplitude of deformation may also have a substantial influence on the magnitude of internal friction, and that this effect should depend strongly on the type of deformation, the constant electric field, the temperature, and the character of the domain structure. Unfortunately, up to the present these questions have been studied only briefly for some ceramic perovskite ferroelectrics ([3,4]) and have not been studied at all on single crystals.

Below we present the results of an experimental study of certain features of internal friction in single crystals of Rochelle salt and triglycine sulfate (TGS)—typical representatives of ferroelectrics with different types of domain structure ([5,6]).

The specimens were cut in the form of bars with dimensions of approximately $30 \times 4 \times 2$ mm. Electrodes of colloidal silver were applied to the main faces of the bars. Specimens with a symmetric, undistorted dielectric hysteresis loop were selected for study. The bar resonators were fastened by a point clamp at the nodes of vibration and placed in a thermostated glass flask with a desiccant. For the measurements we used a somewhat modified apparatus described earlier ([7,8]), on which the logarithmic decrement of damping δ of compression–extension vibrations of the specimens along their length was determined by the method of freely decaying oscillations. Piezoelectric excitation (at frequencies of 20-60 kHz) was produced by packets of sinusoids whose duration and repetition frequency could be varied over wide limits. Because of the large duty factor of the pulses, heating of the specimens was practically absent even at large vibration amplitudes.

Direct measurement of the deformation amplitude of the specimens is very difficult; therefore all experimental curves were plotted as functions of the current

Figure 1

Figure 1: Figure 1

through the crystal during mechanical resonant vibrations. The quantities entering into the coefficient at the deformation amplitude in the resonance term of the equation for the current through the crystal, $d'_{ij}\omega/s'_{ee}$ (d'_{ij} is the effective piezomodulus, s'_{ee} is the effective elastic compliance, $\omega = 2\pi f$ is the resonance frequency) ([9]), themselves depend on the deformation amplitude in the case of a ferroelectric resonator. However, as a first approximation, sufficient for a semiquantitative representation of the general picture of the phenomenon, the current through the crystal may be regarded as proportional to the deformation amplitude.

We studied the behavior of the logarithmic decrement of damping δ when the current through the specimen was varied by two orders of magnitude: from 0.02 to 2 mA. This corresponds to a change in the maximum deformation of approximately from 10^{-8} to 10^{-6}, from 10^{-7} to 10^{-5}, and from $5 \cdot 10^{-7}$ to $5 \cdot 10^{-5}$ for Rochelle-salt specimens of cuts $X45^{\circ}$,

Y 45° and Z 45°, respectively, and from 10^{-7} to 10^{-5} for Y-cut TGS specimens with length along the x axis (the x axis is parallel to the a axis in the Wood apparatus [(10)]).

The measurement results (the most characteristic of them are shown in Figs. 1 and 2) can be briefly summarized as follows.

1. For X 45°-cut Rochelle-salt bars, whose longitudinal vibrations in the ferroelectric phase are associated with ferroelectric polarization and can lead to reorientation of domains:

a) outside the ferroelectric temperature region, far from the Curie points, the internal friction is practically independent of the strain amplitude (for strains up to 10^{-6}) (Figs. 1, 4);

Fig. 1. Amplitude dependence of the logarithmic decrement of damping δ in single crystals of Rochelle salt (1-6) and triglycine sulfate (7-8).
1–X 45° cut, $t = 20^{\circ}$; 2–X 45° cut, $t = 24.1^{\circ}$; ($t_{\text{Curie}} = 24.4^{\circ}$); 3–$X$ 45° cut, $t = 27^{\circ}$; 4–X 45° cut, $t = -26^{\circ}$; 5–Y 45° cut, $t = 20.5^{\circ}$; 6–Z 45° cut, $t = 22^{\circ}$; 7 –$t = 45.8^{\circ}$; 8–$t = 24.5^{\circ}$.

b) in the immediate vicinity of the Curie points (in the region of sharp temperature peaks of internal friction), both inside and outside the ferroelectric region, the internal friction–caused mainly by the influence of dynamic stresses on the degree of ordering of the disordered structure [(5)]–is independent of the strain amplitude up to strains of the order of 10^{-7}, and then increases relatively weakly (Figs. 1, 2, 3)*;

c) within the ferroelectric region, where the domain mechanism of internal friction plays the principal role [8], two sections can be clearly distinguished on the curve of the dependence of δ on strain amplitude: up to strains of $\sim 10^{-7}$, the internal friction is independent of the strain amplitude, and then it increases strongly (reversibly) with increasing strain, increasing almost by an order of magnitude at strains of $\sim 10^{-6}$ (Fig. 1, 1);

d) in the ferroelectric region, both at small and especially at large strains, the internal friction is strongly affected by the application of a large constant electric field along the ferroelectric axis and by irradiation with small doses of γ-radiation, which sharply reduce the value of δ and almost completely eliminate the dependence on amplitude (Fig. 2, 1, 2, 3, 4; see also [7]);

e) like other physical properties (see, for example, [11,12]), the amplitude-independent and amplitude-dependent internal friction depend substantially on the shape of the dielectric hysteresis loop of the specimen and on its prehistory (previous heat treatments, conditioning in an alternating field, etc.), i.e., on the state of its domain structure.

2. For Rochelle-salt bars of Y 45° and Z 45° cuts, whose longitudinal deformation cannot lead to reorientation of domains, the amplitude dependence of internal friction has an entirely different character: both in the ferroelectric phase and outside it, only a weak dependence of δ on amplitude is observed, even at strains substantially larger than for the X 45° cut (Fig. 1, 5, 6).

3. For Y-cut TGS bars, whose longitudinal deformation is also associated with ferroelectric polarization but cannot lead

* In the region of the lower Curie point, the behavior of δ is qualitatively analogous, although it has some differences.

for domain reorientation, the dependence of internal friction on the deformation amplitude has a fundamentally different character than in Rochelle-salt bars of the X 45° cut. In them, in the ferroelectric phase, both near and far from the Curie point, a substantially smaller increase in δ is observed when the deformation amplitude is varied over still wider limits (up to $\sim 10^{-5}$) (Figs. 1, 7, 8).

From the results presented, two basic conclusions may be drawn.

1. The exceptionally large internal friction in Rochelle-salt bars of the X 45° cut within the ferroelectric temperature region, both at small and at large deformation amplitudes, is due to domain processes, but apparently different ones. It is possible that at small deformation amplitudes the internal friction is associated only with oscillations of domain walls in potential wells, whereas at large amplitudes displacement of domain boundaries takes place, accompanied by volume deformations, which leads to a change in the character of the internal friction. (We note that, as measurements

Fig. 2

Figure 2: Fig. 2

show, the magnitude of the deformations at which the internal friction becomes amplitude-dependent also corresponds to the onset of a substantial dependence of the specimen elasticity on the deformation amplitude.)

Fig. 2. Effect of an external constant electric field and γ-irradiation on the amplitude dependence of the logarithmic decrement of damping δ for Rochelle-salt specimens of the $X\,45^\circ$ cut.
1—$E_= = 60$ V/cm, $t = 21.7^\circ$;
2—$E_= = 0.5$ kV/cm, $t = 21.7^\circ$;
3—γ-irradiation dose 10^5 r ($t_{\mathrm{irr}} = 19^\circ$), $t = 21^\circ$;
4—γ-irradiation dose 10^6 r ($t_{\mathrm{irr}} = 19^\circ$), $t = 20^\circ$.

2. It may be supposed that a sharp amplitude dependence of internal friction at relatively small deformations will be observed in the ferroelectric region, for certain modes of oscillation of suitably oriented specimens of any ferroelectric crystals in which domain reorientation can occur under the action of homogeneous mechanical stresses, and is accompanied by deformation of the crystal volume (Rochelle salt, potassium dihydrogen phosphate, perovskite ferroelectrics in the presence not only of 180° domain walls, etc.). On the other hand, for ferroelectric crystals with another type of geometry of the domain structure, in which domain reorientation cannot occur under the influence of homogeneous mechanical stresses and, moreover, is not accompanied by volume deformations (TGS, guanidinium aluminum sulfate, etc.) ([5]), such a dependence will not be observed.

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Note: Figure translations are in progress. See original paper for figures.