EFFECT OF THE ELECTROSTATIC FIELD ON THE TRANSLATIONAL MOTION OF DISLOCATIONS ATTENDANT TO HIGH-FREQUENCY VIBRATION OF ALKALI-HALIDE CRYSTALS

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The effect of an electrostatic field on the translational motion of dislocations attendant to ultrasonic vibration is investigated. Moving dislocations were produced in an KCl crystal by indentation and were detected by repeated etching. It follows from the experiments that the combined effect of the electrical and acoustic fields is not equivalent to the effect due to separate application of these fields. Upon combined application of both fields the number of moving dislocations and the mean length of rim rays in the dislocation rosettes is greater than upon application of only the ultrasonic field. Analysis of results shows that the electrical field increases path length and number of the moved dislocations, but has little effect on the starting stresses of translational motion of dislocations.

1. **Introduction.** As was previously communicated [1-3], high-frequency vibration of alkali-halide crystals produces translational motion of dislocations in them. It is of interest to investigate in more detail the features of this motion of dislocations and the effect of the electrostatic field on the parameters of the translational motion, since dislocations in alkali-halide crystals have an effective electric charge.

When a crystal is subjected to alternating-sign stresses, the dislocations perform induced vibrations; the parameters describing the vibrational motion of the dislocations are investigated by internal-friction methods and from measurements of the effective modulus of elasticity [4-6]. Translational motion of dislocations due to high-frequency vibrations, and the causes underlining it is a phenomenon which has not yet been investigated. In the meantime, the clarification of this problem is of importance in understanding the plastification of materials by ultrasound, which is extensively used in the industry.

Study of the effect of the electric field on the motion of dislocations attendant to high-frequency vibration is of interest in estimating the role of electrostatic interaction between charged dislocations and point defects.

2. **Experimental Technique.** The study was performed on KCl crystals, grown under plant conditions by the Kyropoulus technique. The static yield strength and the density of dislocations were, respectively, 180 gramF/mm^2 and 10^4 cm^{-2}. The cation impurity concentration in the KCl crystals under study did not exceed

$10^{-2}\%$ by weight; strontium was responsible for the bulk of the impurity. Rod-shaped specimens were sliced out along the crystal's cleavage planes. The specimen dimensions were determined by conditions of resonance excitation of a standing ultrasonic wave.

The ultrasonic field was applied by the two-component oscillator technique [7]. This produced in the specimens a standing ultrasonic wave with longitudinal distribution of stresses:

$$\sigma_{yy} = \varepsilon^0_{\max} M \sin\frac{\pi y}{L} = \sigma^0_{\max} \sin\frac{\pi y}{L}, \qquad (1)$$

where $\varepsilon^0_{\max}$ and $\sigma^0_{\max}$ are the strain and stress amplitudes in the standing-wave antinode; M is Young's modulus, L is the specimen length, and y is a coordinate, measured from the point of cementing the specimen to the quartz. A single specimen suffices for following the variation in the dislocation structure at different stress amplitudes.

The electric field was obtained between the plates of a plane-parallel capacitor, which was suppied from a VS-23 stabilized rectifier.

3. **Experimental Results and Their Analysis.** The structure of dislocation rosettes and its variation due to uniform mechanical compression was investigated extensively by many workers [8,9]. Figure 1b depicts schematically the dislocation rosette described by Predvoditelev with his coworkers [10] and Boyarskaya [11]. Rays 1 through 8 correspond to emergence of edge dislocations, sliding in planes {110}, these are termed "rim rays." According to Predvoditelev with his coworkers [10] and Boyarskaya [11], each pair (1-2, 3-4, 5-6, 7-8) of rim rays consists of emergences of edge dislocations of opposite mechanical sign. Upon uniform compression in the <010> direction the dislocations, situated at the rim rays adjoining the direction of compression should move from the center of the rosette, whereas the dislocations in the other four rays should move to the center. In real rosettes this motion of dislocations does not rigorously follow this model.

Ultrasound moved the dislocations in the rim rays of dislocation rosettes primarily away from the center; here the elongation of rays 2, 3, 6, 7 was more perceptible than that of rays 1, 4, 5, 8 (Fig. 1b). This suggests that elongation straining is more effective for the motion of dislocations in rosette rays. In experiments with simultaneous application of the ultrasonic and electrical fields particular attention was paid to the change in length of rays 2, 3, 6, 7.

The distributions of the mean length of dislocation rays along the specimen are shown in Fig. 2. Curve 1 in this figure corresponds to the distribution of lengths of rim rays (2, 3, 6, 7) of dislocation rosettes for the starting state of two specimens with mirror-image cleavage planes. According to Shaskol'skaya and Dobrzhanskii [12], the length of rays of dislocation rosettes characterizes the impurity distribution. It can be concluded from curve 1 that the impurity is distributed rather uniformly in the central part of the specimens, and is approximately the same in both specimens. One of them was subjected to an electric field. The points characterizing the distribution of the mean ray length along the specimen following the application of only the electrostatic field, also fit in curve 1.

Experiments showed that an electrostatic field with strength of up to 5 kV/cm does not at all induce motion of dislocations in the dislocation rosettes of the KCl specimens under study.

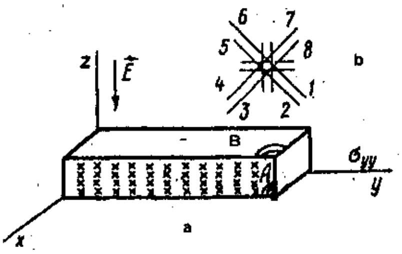

Fig. 1

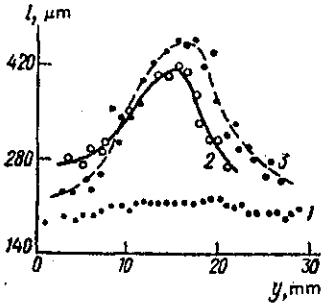

Fig. 2

Fig. 1. Schematic of the arrangement of dislocation rosettes on the KCl specimen under study. σ_{yy} is a component of the ultrasonic stress, E is the electric field intensity (a). Schematic of rays of the dislocation rosette at (100) (b).

Fig. 2. Distribution of the mean length of the rim rays of rosettes along the specimen. 1) At the initial state and upon application of the electrostatic field (E = 5 kV/cm); 2) after application of the ultrasonic field, σ^0_{max} = 270 gramF/mm^2, f_p = 73 kHz; 3) after simultaneous application of the electrostatic and ultrasonic fields; l is the mean length of the rim rays (2, 3, 6, 7) of the dislocation rosette.

Unlike the electrostatic field, the application of the acoustic field, produces a translational motion of the dislocations. Curve 2 in Fig. 2 characterizes the distribution of lengths of rim rays (2, 3, 6, 7) in a specimen which was first subjected to an electric and then to an ultrasonic field. The dislocations were set into motion and the rosette rays elongated. The distribution of the lengths of rim rays in dislocation rosettes subjected to an ultrasonic field is in agreement with the stress distribution in a standing ultrasonic wave, i.e., Eq. (1).

The number of displaced dislocations and the mean length of rim rays in dislocation rosettes upon simultaneous application of the electric and acoustic fields is greater than upon the application of the ultrasonic field alone. Curve 3 in Fig. 2 corresponds to the distribution of lengths of rim rays [2, 3, 6, 7) for a specimen subjected simultaneously to an acoustic and electrical field. It is seen by comparing curves 2 and 3 that the ray length in the stress antinode of the ultrasonic wave upon application of both fields increases by 17%.

For a constant amplitude of ultrasonic strain of $6 \cdot 10^{-5}$ the effect of the electrical field can be detected starting with a field strength of E > 1 kV/cm; it can be regarded as the threshold value for the KCl crystals under study, which agrees with the values found for LiF and NaCl crystals [5].

Equation (1) was used for constructing curves of the relative number of displaced dislocations $n_i/\Sigma n_i$* as a function of the cleaving stress at a given σ^0_{max}, i.e., the integral distribution of the relative number of displaced dislocations relative to the amplitudes of cleavage stress τ^0_{cl}. Curve 1 in Fig. 3 corresponds

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*n_i is the number of dislocations which are displaced at a given cleavage stress.

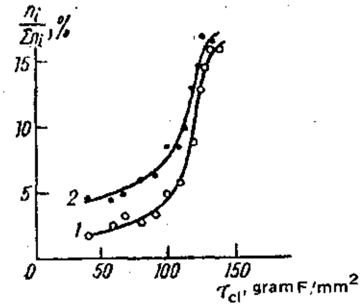

Fig. 3

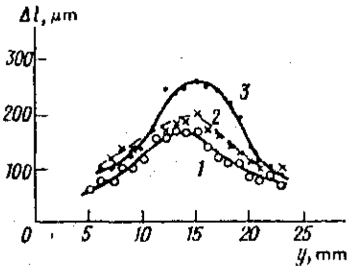

Fig. 4

Fig. 3. Integral distribution of the number of displaced dislocations vs. the amplitude of cleavage stress τ^0_{cl}. 1) Upon application of an acoustic field; 2) upon simultaneous application of the acoustic and electrical fields.

Fig. 4. Effect of the electric field on the path length of the leading dislocation in rim rays at σ^0_{max} = 270 gramF/mm², f_p = 73 kHz; 2) E = 0; 1 and 3) at E = 3 kV for rosettes applied respectively on edges B and A (see the schematic in Fig. 1).

Mean Path of Leading Dislocation in Rim Rays

Ray number, i	Δl_i, μm	Ray number, i	Δl_i μm
1	71	6	144
2	117	5	85
3	134	8	144
4	81	7	102
$\sum_{i=1}^{4} \frac{\Delta l_i}{4}$	101	$\sum_{i=5}^{8} \frac{\Delta l_i}{4}$	119

to experiments without the electric field whereas curve 2 was obtained upon simultaneous application of the acoustic and electric fields. The effect of the electrostatic field was found to be greater at lower stresses.

It was assumed in the first approximation that distribution of the number of displaced dislocations vs. the cleavage stress is normal, which is usually done in analyzing the results of static loading. The variances of normal distributions for experiments with and without the electric field were found undistinguishable with 0.95% confidence. According to Strunin [13], the standard deviation characterizes the amplitude of internal stresses, the value of which for the experiments described here was about 13 gramF/mm². This is in agreement with data obtained in analogous experiments with rosettes, but for static loading [8]. The starting stresses for these distributions were found to be about 120 gramF/mm², which exceeds significantly data for static loading. The effect of the electric field reduces to an insignificant change (about 5-10 gramF/mm²) of the starting stresses.

A more detailed analysis of the location of experimental points on probability charts showed that the assumption of a normal distribution is not an exact approximation. The distribution is asymmetric; a significant deviation is observed in the direction of high starting stresses. This suggests that the distribution of the number of displaced dislocations vs. starting stresses is closer to the Maxwellian which, according to Li [14], characterizes the distribution of dislocation segments relative to lengths.

The ray length in the initial state of the rosettes may depend significantly on the local conditions; hence, in order to estimate the effect of the electric field on the elongation of various rim rays it is best to analyze the change Δl_i of ray length, corresponding to the travel path of the leading dislocation. It is seen from Fig. 1b that the component of the vector of field E for rays 1-4 and 5-8 is oriented differently relative to the direction of motion of dislocations in elongation of rays. Values of $<\Delta l_i>$ averaged over all the rosettes are listed in the table, from which it is seen that $<\Delta l_i>$ for rays 5-8 is by 18 μm greater than for rays 1-4, for a standard deviation of Δl_i of 4 μm. This asymmetry in the effect of the electric field allows the conclusion that a contribution to the increase in Δl_i is made by interaction of the electric field with the dislocation as with a charged wire, and that the excess sign of the charge at the dislocation is negative. The latter is in agreement with data on the sign of the dislocation charge in NaCl crystals containing two-valent impurity cations [15,16].

Two mechanisms of the effect of the electric field on the motion of dislocations is possible: direct effect of the electric field on the dislocation as a charged wire, and an indirect effect, when the electric field changes the orientation or state of the centers interacting with the dislocation. It is extremely difficult to determine the contribution of each of these.

An attempt was made to detect the manifestation of these mechanisms, for which a specimen, the dislocation rosettes of which were drawn on two adjoining specimen surfaces (sides A and B in Fig. 1a), was subjected simultaneously to an electrical and acoustic field. For rosettes on face B $\mathbf{E}_{\parallel} \parallel \mathbf{u}$ ($\mathbf{u}$ is the directional vector of the edge dislocation components), and the electric field should not act directly on the charged dislocation. But, according to Paperno and Galustoshvili [17,18], field E should exert an orienting effect on charged dipole pinning centers, arranging them parallel to the edge components of dislocations in planes $(1\bar{1}0)$ and $(\bar{1}10)$ and thus reducing the mobility of dislocations in these planes. For rosettes on face A the electric-field component $E_{\parallel} \parallel u$ is smaller than in the preceding case, and there appears the component $E_{\perp} \perp u$, which acts on the dislocation as on a charged wire. As a result, the mean path of leading dislocations in rays of rosettes drawn on face A should be greater. In fact, these effects were actually observed, as can be seen in Fig. 4, which shows the distributions of $<\Delta l_B>$ and $<\Delta l_A>$ along the specimen (curves 1 and 3, respectively). Curve 2 is the distribution of $<\Delta l_{A'}>$ for a specimen, face A' of which was a mirror-image cleavage of A, with the specimen subjected only to the ultrasonic field.

4. **Conclusions.** The effect due to simultaneous application of an electric and acoustical field on a specimen is not equivalent to that of their successive application.

The high value of starting stresses, which significantly exceeds the values of starting stresses in static tests, indicates that the factor responsible for the translational motion of dislocations is the stress field in the standing ultrasonic wave.

The electrostatic field increases the path length of dislocations and of the number of displaced dislocations, but has little effect on the starting stresses of the translational motion of dislocations. The electrostatic field affects both charged centers, pinning the dislocations, and the charged dislocations directly.

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