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Acoustic emission caused by mechanical stress relaxation at oscillations of piezo-dielectric plates

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Time correlation of 3rd and 2nd oscillation harmonics for piezo-dielectric plates with $LiNbO_3$ as well as the acoustic emission (AE) parameters as functions of the strain amplitude have been studied. The threshold increase and a hysteresis have been revealed in dependences of the harmonic intensity that correlate with the threshold increase in the AE intensity. This correlation is related to the relaxation (quenching) of mechanical stresses near to the AE source in the course of the dislocation line tearing-off and fixation, that results in changes in the local elasticity moduli.

Исследованы временные корреляция величины 3-й и 2-й гармоник колебаний пьезоэлектрических пластин с $LiNbO_3$ и параметров акустической эмиссии (АЭ) от амплитуды деформации. Зарегистрированное пороговое увеличение и гистерезис в зависимостях величины гармоник, которые коррелируют с пороговым возрастанием интенсивности АЭ. Данная корреляция связывается с релаксацией (срывом) механических напряжений вблизи источника АЭ в процессах отрыва и закрепления дислокационных линий, которые приводят к изменению локальных модулей упругости.

The calculation of the piezoelectric element oscillations is restricted as a rule by the state equations for a piezoelectric medium that have the following form under isothermal conditions:

$$\begin{gathered} S_i = s^E_{ij}T_j + d_{mi}E_m + f_S(T_j \cdot T_i, E_m \cdot E_k, T_i(0)), \\ D_m = d_{mi}T_i + \varepsilon^T_{mk}E_k + \\ + f_D(T_j \cdot T_i, E_m \cdot E_k, T_i(0)), \\ i,j = 1\ldots6, m,k = 1\ldots3, \end{gathered} \quad (1)$$

where S_i and T_j are the mechanical strain and stress tensors, respectively; E_m and D_m, the electric field strength and induction; s^E_{ij}, ε^T_{mk}, and d_{mi}, tensors of elastic, dielectric, and piezoelectric constants, respectively [1]; the functions f_S and f_D take into account the crystal physical and geometric nonlinearity, the piezoeffect nonlinearity, and the residual mechanical stresses $T_i(0)$. In the simplified equation form (linear approximation), these functions are equal to zero. Due to those simplifications and small values of f_S and f_D, the $S(T)$ measurements do not allow to trace the development dynamics of structure defects. At the same time, f_S and f_D direct measurements are required to take into account the non-ideality of real piezoelectric single crystals and the change of residual mechanical stresses in time.

Some high quality piezoelectric single crystals, e.g., $LiNbO_3$ plates, show block structure. Therefore, in the region of electromechanical resonance (anti-resonance) where the local mechanical stresses (strains) in some local areas exceed the elastic limit σ_E (even the yield limit $\sigma_{0.2}$), not only manifestations of the hysteresis or relaxation type internal friction can be expected, but also a change in the material nonlinear properties as well as the acoustic emission (AE) appearance, i.e., emission of the stress pulse waves due to quenching of local mechanical stresses and the material structure

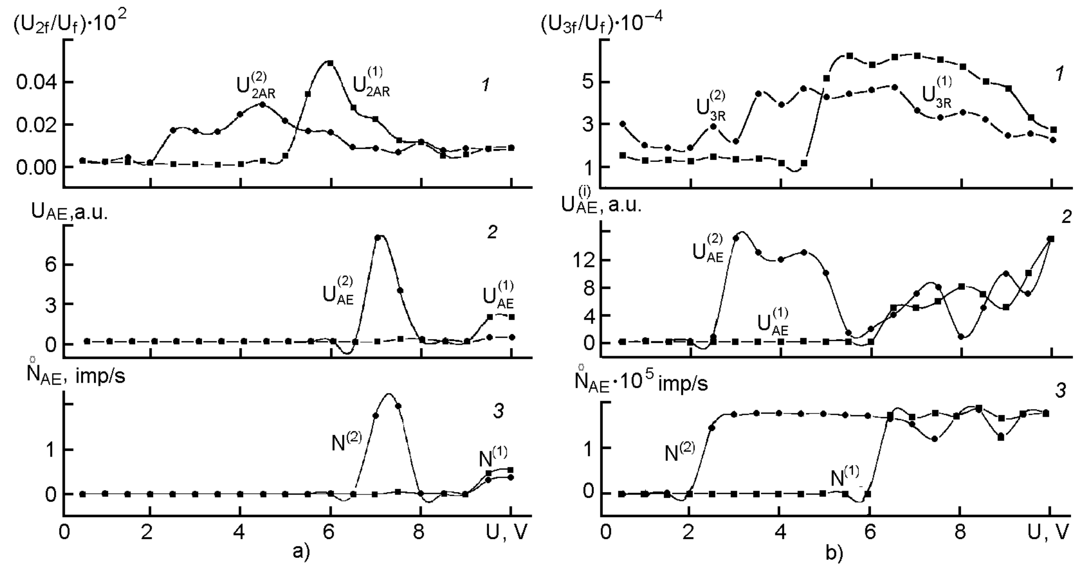

Fig. Harmonic dependences for: 2nd harmonics at the anti-resonance frequency (b); 3rd harmonics at the ground resonance frequency; AE amplitude and intensity (a).

rearrangement [2]. In this work, the time correlations of the change in nonlinear properties of $LiNbO_3$ resonators (dependences of 3rd and 2nd oscillation harmonic intensity) and parameters of acoustic emission as functions of strain amplitude.

The plates of different thickness and orientations with the ground resonance frequency in thickness of 1 to 4 MHz. To record the AE, an additional sensor and an acousto-emissive instrument AF-15 were used. The electric voltages of the ground and combination harmonics were determined using a S4-74 spectrum analyzer. Since the AE parameters become changed considerably during the measurement, the correlations of those parameters with 2nd and 3rd harmonics changes were measured separately. Figure presents for comparison three groups of typical dependences. Those are: dependence of U_{2f}/U_f and U_{3f}/U_f on the generator electric voltage U that, in linear approximation, is in proportion to the plate strain S, $U = 10$ V answering to $S \approx 10^{-4}$ (Group 1); dependence of continuous AE amplitude on U (Group 2); dependence of the AE intensity on U (Group 3). Index (1) denotes the measurements made at increasing U; index (2), those made at the reverse U run. Each set of curves in Fig. 1 having index (1) or (2) was measured during 15 to 20 min.

A threshold increase and hysteresis are observed in U_{2f}/U_f, U_{3f}/U_f, and AE intensity dependences on U. A typical feature of those curves is the irreproducibility thereof at repeated U increase/decrease. Since the AE phenomenon is related to irreversibility and irreproducibility of the processes occurring in the material [2], this agrees well with the behavior of dependences of the AE signal amplitudes having the maxima mostly shifted as compared to U_{2f}/U_f maxima towards larger strains. The AE results from release a certain energy amount in the system, associated with the mechanical stress relaxation in the AE source environment. Thus, it is probable that it is just the increased damping of sound waves and, respectively, a decrease in U_{2f}/U_f and U_{3f}/U_f that answers to the increased AE. The threshold increase of AE intensity, i.e., the number of active AE sources per unit time and the constancy of its value as the strain increases indicate slight differences in the parameters of AE sources. For dislocation mechanisms, each AE source is 10^3 to 10^4 dislocation segments that change their state simultaneously [2].

The reduction of continuous AE amplitude in time (the strain amplitude remaining unchanged) means a reducing number of active AE sources (those activated by the mechanic stresses present in the system). That is, at the certain time moment, only two dislocation states may exist in the crystal, namely, those fixed at excessively powerful stoppers and those separated from the stoppers and oscillating. During the AE, the competing processes of the dislocation line tearing-off and fixation, the tear-off being associated with local areas where maximum (threshold) strains are generated, while the fixation, with the minimum strain areas where the mechanical stresses are lower than the fixation threshold ones. The non-relaxed state of the defect structure means fluctuations in f_S and f_D functions in the Eq.(1), thus causing the correlation dependences described above.

The amplitude reduction of ultrasound straining results in increased probability of complex processes of repeated dislocation line fixation, thus, the fixation process becomes predominating. Since the repeated fixation takes place at mechanic stresses lower than the tear-off ones and may proceed according to another law than that occurring at increasing stresses, a hysteresis is observed in U_{2f}/U_f dependences on U.

References

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Акустична емісія, що зумовлена релаксацією механічних напруг при коливаннях п'єзодіелектричних пластин

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Досліджено часові кореляції величини 3-ї та 2-ї гармонік коливань п'єзодіелектричних пластин з $LiNbO_3$ та параметрів акустичної емісії (АЕ) від амплітуди деформації. Зареєстровано порогове збільшення та гістерезіс у залежностях величини гармонік, яке корелює з пороговим зростанням інтенсивності АЕ. Дана кореляція пов'язується з релаксацією (зривом) механічних напруг в околі джерела АЕ у процесах відриву та закріплення дислокаційних ліній, що призводять до зміни локальних модулів пружності.