The study of the dislocation resonance in LiF crystals under the influence of the low-dose X-irradiation

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The frequency spectra of dislocation losses of ultrasound in LiF single crystals irradiated with 0 - 400 roentgen doses and preliminarily strained at $\varepsilon = 0.3$ % are investigated at room temperature in 22.5 - 232 MHz frequency range. It is found that the rise of X-ray irradiation doses is accompanied with clearly observed effect of dislocation resonance quenching which manifests itself in monotonous shift of the dislocation resonance maximum towards higher frequencies and lower amplitudes. The dependences of the coefficient of dynamic viscosity B and the average effective length of the dislocation segment L on the irradiation time ranging from 0 to 60 min are established and analyzed.

Исследованы частотные спектры дислокационных потерь ультразвука в частотном диапазоне 22,5–232,5 Мгц для облученных в интервале доз облучений 0–400 рентген монокристаллов LiF с величиной предварительной деформации $\varepsilon = 0{,}3$ % при комнатной температуре. Установлено, что при увеличении дозы рентгеновского облучения в указанном интервале четко наблюдается эффект гашения дислокационного резонанса, выражающийся в монотонном смещении дислокационного резонансного максимума в сторону больших частот и меньших амплитуд. Установлены и проанализированы зависимости константы демпфирования B и средней эффективной длины дислокационного сегмента L от времени облучения в интервале 0–60 мин.

1. Introduction

It is known that radiation damage in ionic crystals leads to changes in mechanical [1–2], electrical [3] and optical [4, 5] properties. The efficient method [6] which allows to separate inputs to the restriction of dislocation mobility of various types of stoppers is based on the usage of the irradiation effect on the dislocations mobility in a magnetic field. To study the radiation-induced defects of these crystals, high doses of radiation have been used. However, considering that the beginning of the qualitative changes is formed in the very early stages of exposure, the information on changes beginning and their dynamics is very important in both applied and theoretical aspects. In particular, this information may be useful for the solution of the engineering problems associated with the usage of ionic crystals in acousto-optics, as well as the theoretical estimation of the radiation exposure effects [1]. To study the effect of low dose irradiation on the dislocation mobility, the method of amplitude-independent internal friction, which has a high sensitivity to weak stopper has been used. Earlier mentioned method has been used in the study dispersion of high-frequency ultrasound in NaCl [7].

The aim of this paper is a detailed study of the weak X-ray irradiation effect on the parameters of damped dislocation resonance and on the absolute value of the viscosity coefficient in a single crystal LiF.

2. Experimental

The frequency dependence of the dislocation losses of ultrasound in the acoustic LiF crystals with a residual deformation 0.3 % (in the unirradiated and then in the irradiated states) in the frequency range 22.5–232.5 MHz and temperature T = 300 K has been investigated. The LiF crystals of purity 10^{-4} wt.% and the dimensions of $17\times17\times25$ mm^3, obtained by the puncturing along the slip planes <100> have been used for the experiments. Later, the cleaved samples were fine polished and received the subsequent optical polishing, so that non-parallelism of the working end of the sample was approximately ±1 μm/sm. To insert into the crystal "fresh" dislocations, and thus avoid the appearance of slip bands, according to [8], a sample has been pre-deformed by the compression along <100> direction on the testing machine type "Instron", the strain rate of 10^{-5} s^{-1}. Under such loading conditions, the crystal surface is uniformly covered with the figures of etching, which facilitates their calculation.

The measurement of the longitudinal ultrasound absorption has been performed by the application of the calibrated exponential. The ultrasonic wave has been passed along the long axis of the crystal in a direction in which its preliminary deformation has been carried out.

The irradiation of the crystals LiF has been performed on an aggregate URS-55 (Cu, 40 kV, 10 mA). The irradiation dose rate, determined with a dosimeter KID-2 at the location of the crystals under consideration was 0.11 roentgen/sec. In order to avoid irregularities caused by the action of internal stresses, each of the 4 side faces parallel to the long axis of the crystal has been irradiated for 15 min, which corresponded to a total dose of 400 roentgen.

3. Results and discussion

Figure 1 shows the results of the frequency dependence study of dislocation decrement for the samples with LiF residual deformation ε = 0.3 % before the X-ray irradiation (curve 1) and after it (curves *2–5*).

It is seen, that the form of frequency curves $\Delta_d(f)$ for the dislocation decrement has the character of damped resonance. The obtained experimental points fall on the theoretical frequency profile, calculated for the case of exponential distribution of dislocation loops along its length. When comparing the measured curves $\Delta_d(f)$ with the theo-

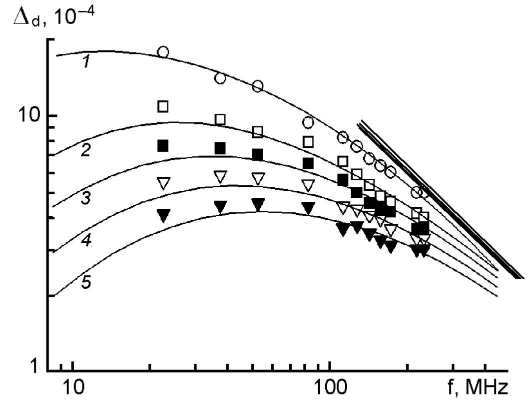

Fig. 1. Frequency dependence of the dislocation decrement for LiF samples with the value of deformation ε = 0.3 % at room temperature with the different irradiation time t: *1* — unirradiated, *2* — 15 min., *3* — 30 min., *4* — 45 min., *5* — 60 min. Solid lines *1*, *2*, *3*, *4*, *5* — theoretical curves and high frequency asymptotes.

retical profile, the binding of the latter was carried out primarily with a focus on those data points that lay on the descending branch of the experimental curve in the resonance area. As in [7–9], we have used the equations describing the position of the resonance peak and its descending branch:

$$\Delta_m = 2.2\Omega\Delta_0\Lambda L^2, \quad (1)$$

$$f_m = \frac{0.084\pi C}{2BL^2}, \quad (2)$$

$$\Delta_\infty = \frac{4\Omega G b^2\Lambda}{\pi^2 B f}, \quad (3)$$

where Δ_∞ — the value of the decrement for frequencies $f > f_m$, Ω — the orientation factor which takes into account that the reduced shear stress in the slip plane is less than the applied stress, L — an average effective length of dislocation segment, $\Delta_0 = (8Gb^2)/(\pi^3 C)$, C — the effective stress of the bent dislocation ($C = 2\cdot Gb^2/\pi(1-\nu)$), Λ — the density of dislocations, ν — Pausson's ratio, G — shear modulus of the current slip system, b — Burgers vector value. The equation (3) shows that the limiting value of the decrement Δ_∞ is mainly determined by the parameters Ω, Λ, B and does not depend on the length of the dislocation segment L and the nature of the loops distribution along its length, i.e., measuring

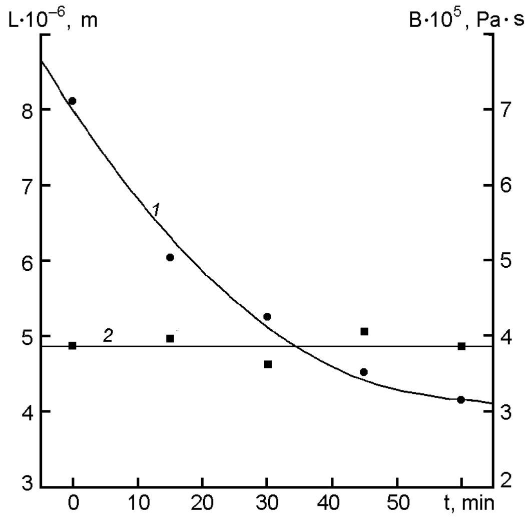

Fig. 2. Dependence of the irradiation time t of the average effective length dislocation segment L (*1*) and damping constants B (*2*) for the LiF crystals with the magnitude of previous deformation $\varepsilon = 0.3$ % at room temperature.

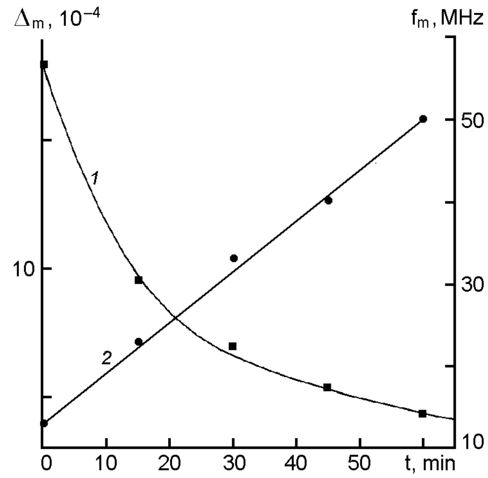

Fig. 3. Dependence of the irradiation time t values of the dislocation decrement at the maximum Δ_m (*1*) and the resonance frequency f_m (*2*) for the LiF crystals with the magnitude of deformation $\varepsilon = 0.3$ % at room temperature.

the resonance curves $\Delta_d(f)$ and using relation (3), we can easily determine the damping constant B, previously determining the amount of high-frequency asymptote value Δ_∞ and the dislocation density by the selective etching. To find the coefficient of the viscosity B the following values have been used in this study $G_{110} = 3.533 \cdot 10^{10}$ Pa, $\Omega = 0.311$ [9], $b = 2.85 \cdot 10^{-10}$ m, calculated by the formula $b = a/\sqrt{2}$ [10], where $a = 4.025 \cdot 10^{-10}$ m [11], $\Lambda = 1.23 \cdot 10^{10}$ m^{-2} obtained in this study by counting the etch pits. The dislocation density Λ in LiF before and after the exposure to X-ray beams of X-ray dose of 400 roentgen remains unchanged.

The results of the calculations by the formula (3) of the absolute value B have been shown in curve *2* in Fig. 2. The coefficient of viscosity before and after irradiation at a constant temperature and density of dislocations is virtually identical. The average value of the parameter B, obtained according to Figure 2 is $3.87 \cdot 10^{-5}$ Pa·s. To elucidate the mechanism controlling the shift of the dislocation resonance on height and frequency in the present work, the behavior of the dislocation of the parameter L in LiF crystals under the influence of various doses of irradiation has been investigated. L values have been calculated by the formula (2), with the substitution of values for Pausson's coefficient $\nu = 0.27$, obtained from the relation $\nu = C_{12}/C_{11} + C_{12}$ [10] and value $C = 2.5 \cdot 10^9$ N, calculated taking into account the value $Gb^2 = 2.87 \cdot 10^{-10}$ Pa·m^2. In addition, the data for the resonance frequency f_m and the damping constant B, given in Fig. 3 and 2, have been used respectively. As a result of the generated calculations, the dependence of the dislocation segment length L from the irradiation time has been specified, which is represented with the curve *1* in Fig. 2. It is seen that with the increasing doses of the irradiation the length of the dislocation segment L decreases monotonically from the initial value of $8.11 \cdot 10^{-7}$ m (for the unirradiated crystal) to a value of $4.14 \cdot 10^{-7}$ m, obtained after the X radiation for 1 h.

The analysis of equations (1) and (2) shows that the reduction of the length of the arc L has to result in a shift of the resonance peak to higher frequencies and decrease its amplitude, as it is observed in Fig. 3. Moreover, a high frequency asymptote of the maximum in accordance with (3) should be the same for all stages of irradiation. This is due to the fact that in equation (3) the value Δ_∞ does not depend on the length of the dislocation loop L, but on the dislocation density Λ, which does not change at such doses. The experimental data presented in Fig. 1 clearly confirm these theoretical predictions.

4. Conclusions

It has been discovered that after the exposure to doses of X-ray irradiation equal to about 100 roentgen in LiF crystals the level of the resonant absorption of ultrasound is significantly reduced, and also its frequency localization is changed. With the further irradiation, the behavior of dislocation resonance remains the same. Resonance curves $\Delta_d(f)$, decreasing in amplitude, monotonically shift towards the high frequency areas.

It has been shown that after the exposure to X-ray irradiation the quantity of the dislocation decrement Δ_m at the maximum decreases sharply, and its resonant frequency f_m in this case increases about 4 times. With the application of the maximum dose of 400 roentgen in crystals the quenching effect of the dislocation resonance is observed, accompanied by a substantial reverse of subordinate acoustic characteristics of the crystal.

It has been proved that the density of dislocations Λ in LiF crystals before and after exposure to X-ray dose of 400 roentgen remains the same, and the independence of the coefficient of dynamic viscosity B from the radiation dose has been established. The average value of the parameter B is $3.87 \cdot 10^{-5}$ Pa·s.

The dependence of the dislocation segment length L on the irradiation time has been defined. It has been shown that with the increasing doses of the dislocation segment length L, due to its pinning with blocking centers, decreases monotonically from the initial value of $8.11 \cdot 10^{-7}$ m (for the unirradiated crystal) to a value of $4.14 \cdot 10^{-7}$ m, obtained after the X radiation for 1 h.

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Спостереження ефекту гасіння дислокаційного резонансу в кристалах LiF під впливом малих доз рентгенівського опромінення

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Досліджено частотні спектри дислокаційних втрат ультразвуку в частотному діапазоні 22,5–232,5 Мгц для опромінених в інтервалі доз опромінення 0–400 рентген монокристалів LiF з величиною попередньої деформації $\varepsilon = 0{,}3$ % при кімнатній температурі. Встановлено, що при збільшенні дози рентгенівського опромінення у вказаному інтервалі чітко простежується ефект гасіння дислокаційного резонансу, що виражається у монотонному зміщенні дислокаційного резонансного максимуму в бік більших частот і менших амплітуд. Встановлено та проаналізовано залежності константи демпфування B і середньої ефективної довжини дислокаційного сегменту L від часу опромінення в интервалі 0–60 хв.