 

# Dynamic damping of dislocations in the irradiated LiF crystals

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To study the nature of the mechanisms that limit the viscous motion of dislocations, the dampfed dislocation resonance in LiF crystals at room temperature in the range of radiation doses of 0–1000 R has been scrutinized by the impulse echo method in the frequency range 37.5–232.5 MHz. From the frequency curves, taken from crystals with different doses of radiation, the dependencies of the viscosity coefficient $B$ and the average effective length of the dislocation segment $L$ from the time of irradiation has been determined. On the basis of the carried out measurements, calculations and analysis it has been concluded that the dynamic damping of dislocations in the given object, and given experimental conditions is determined only by the phonon spectrum of the crystal.

С целью изучения природы механизмов, лимитирующих вязкое движение дислока-аций, импульсным эхо-методом в частотном диапазоне 37.5–232.5 МГц исследован задемпфированный дислокационный резонанс в кристаллах LiF при комнатной температуре в интервале доз облучения 0–1000 Р. Из частотных кривых, снятых для кристаллов с разными дозами облучения, определены зависимости коэффициента вязкости $B$ и средней эффективной длины дислокационного сегмента $L$ от времени облучения. На основании проделанных измерений, расчетов и их анализа сделан вывод о том, что динамическое торможение дислокаций в данном объекте и в данных экспериментальных условиях определяется только фононным спектром кристалла.

## *1. Introduction*

This article is a continuation of [1], where we studied the effect of low doses irradiation (0–400 R) on localization of the frequency spectra of the dislocational ultrasonic absorption $\Delta_d(f)$ in monocrystals of LiF. These crystals are of practical interest for X-ray spectroscopy [2], laser technology [3], radiobiology [4]. In addition, due to their high Debye temperature [5] they can be used at $T$ = 300 K in pure form to study the effects of dislocations consolidation by the radiation defects, since relaxation processes at this temperature do not occur.

In research [1], impulse-echo method had been used to thoroughly study the behavior of the resonant maximum parameters — the dislocation damping rate $\Delta_m$ in resonance and the resonance frequency $f_m$, and the average effective length of the dislocation segment $L$ and the coefficient of dynamic damping of dislocations $B$ due to irradiation time $t$. It had been found that increasing of the irradiation dose in the examined crystals leads to shift of the curves $\Delta_d(f)$ to higher frequencies and lower values of the decrement. The analysis of the data has revealed that in contrast to the experiments with temperature changes and strain [6, 7], these shifts were so, that high frequency asymptote from the family of curves $\Delta_d(f)$ for different irradiation doses were practically identical to each other. The indicated effect of shifts, observed in LiF in [1], was similar to the previously observed one by the authors [8] at high purity copper in the measurements of the attenuation by the impulse method in the range of 5–100 MHz.

In [1] it had been possible to study dependence of the viscosity coefficient $B$ on the time of irradiation, which had helped to clarify the results of work [9], in which there was an increase of parameter $B$ from the innitial values of $1.7 \cdot 10^{-4}$ to $2.5 \cdot 10^{-4}$ Pa·s due to the irradiation dose of ~ $10^3$ R on monocrystals. It should be also noted, that the work [1] additionally confirmed the effectiveness of ultrasonic methods of internal friction [10] for reliable recording of the dislocations exposure of pinning points by the radiation origin. The high efficiency of acoustic methods [8, 10] has been stipulated by the fact that the attenuation of ultrasound $\alpha$ is very sensitive to minor changes (including those due to irradiation) of the average effective length $L$ of the dislocation segment under the law $\alpha \sim L^4$. For registration of radiation-induced defects optical methods are often used, in which the dependence of the transmittance coefficient from the radiation wavelength, passing through the crystal is measured. However, indicated methods despite their major advantages do not allow on early stages to mark the accumulation of defects caused by radiation. According to the works of various authors, doses more than $10^3$ R are required to registrate the color centers.

Our preliminary studies of LiF crystals on SF-26 spectrophotometer showed that at the irradiation time 2 h 40 min (dose slightly higher $10^3$ R, taking into account the power of the radiation source 0.11 R/s) color centers can be actually observed in the examined samples.

Taking into consideration the above mentioned facts, it is interesting to continue the research which was begun in [1] and observe the dynamics the curves shift $\Delta_d(f)$, $L(t)$ and $B(t)$ in the range of irradiation doses 0–1000 R, under which the formation of color centers develops in the examined crystals, that became the purpose of the current study.

## 2. Experimental

In this paper, by impulse method in the frequency range of 37.5–232.5 MHz and X-ray irradiation dose range of 0–1000 R the frequency dependence of the dislocation losses of ultrasound in monocrystals LiF at the temperature $T = 300$ K was studied. The monocrystals [1] with the magnitude of residual strain 0.4 % were used in the experiments. Information about the purity of the samples, their size, features of preparation (gouging, grinding, polishing, annealing, pickling, deformation), as well as the acoustic features of the experiment has been given in [1]. Additional irradiation of LiF crystals to the total dose of about ~$10^3$ R was performed on the same unit URS-55 at the same operation mode as in [1]. The radiation dose rate was not changed and was 0.11 R/s. The total exposure time of crystals was 2 h and 40 min.

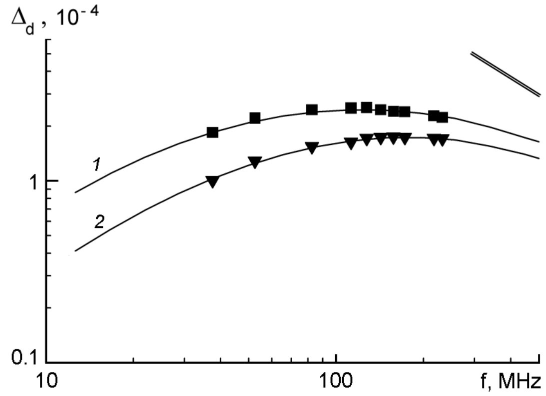


Fig. 1. Frequency dependences of the ultrasound dislocation damping rate at different periods of irradiation: the theoretical curves *1* (120 min) and *2* (160 min) [11] and their high-frequency asymptotes.

## 3. Results and discussion

The results of the study of frequency dependence of the ultrasound dislocation damping rate $\Delta_d(f)$ in LiF crystals for the total exposure time of 120 min and 160 min at room temperature are shown in Fig. 1 (curve *1* and *2*, respectively).

As it can be seen, the flow of curves $\Delta_d(f)$ do not differ qualitatively from the corresponding dependences given in [1] for low-dose irradiation. The experimental points as well as previously [1] are described by the theoretical frequency profiles [11], calculated for the case of exponential distribution of dislocation loops along the lengths. You can also see that under irradiation the resonance curves shift monotonically to higher frequencies areas and lower values of the decrement, and their high-frequency asymptotes are almost superimposed on each other. The expressions for the resonance frequency $f_m$, the decrement in the maximum $\Delta_m$ and the average effective length of the dislocation loop $L$ as a function of time $t$ is taken in the form [8]:

$$f_m = f_m^{t=0}(1+\beta t)^2; \qquad (1)$$
$$\Delta_m = \frac{\Delta_m^{t=0}}{(1+\beta t)^2};$$
$$L = L_{t=0}/(1+\beta t),$$

where $f_m^{t=0}$, $\Delta_m^{t=0}$, $L_{t=0}$ — the same parameters for the non-irradiated crystal, $\beta = P \cdot L_{t=0}/\Lambda$, $P$ — the total number of blocking centers, which reach the dislocation net per time unit, $\Lambda$ — the dislocation density (constant during the experiment).

In [10, 12] the above mentioned formulae have been also used, however it has been noted that the concentration of pinning centers $c(t) = \beta \cdot t$, which are added during the exposure time to the loop length $L_{t=0}$, in general, are not strictly linear function of time, and the above mentioned calculations can be used only as the first approach.

Thus, using the data of the present work, shown in Fig. 1, and the results of [1] and formulae (1), we were able to compare the experimental points for $\Delta_m(t)$ and $f_m(t)$ with the theoretical curves (Fig. 2).

Fig. 2 shows that the experimental points are well described by the theoretical curves calculated by the model [8]. It also shows that the increase in irradiation time leads to the decrease of the dislocation decrement $\Delta_m$ and increase of the resonance frequency $f_m$.

To get information on the dependences due to the irradiation time in the range of 0–1000 R of average effective length of the dislocation segment and the coefficient of dynamic of dislocations damping $B$, taking into account the cumulative effect of all the damping forces influencing on the dislocation, we have processed the data shown in Fig. 1,2, as in [1], in the framework of Granato-Lucke theory [13] using the equations describing the position of the resonance peak and the descending branch of the dependence of $\Delta_d(f)$:

$$\Delta_m = 2.2\Omega\Delta_0\Lambda L^2; \qquad (2)$$

$$f_m = \frac{0.084\pi C}{2BL^2}; \qquad (3)$$

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

where $\Delta_\infty$ — the value of the decrement for frequencies $f >> f_m$; $\Omega = 0.311$ [1] — the orientation

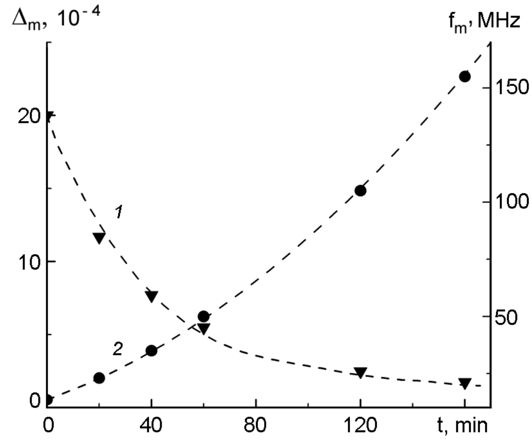


Fig. 2. Dependences of the parameters of the resonance peak $\Delta_m$ (*1*) and $f_m$ (*2*) from the time of irradiation, dotted lines — theoretical curves [8].

factor, which takes into account that provided reduced shear stress in the slip plane is less than the applied stress; $L$ — average effective length of the dislocation segment; $\Delta_0 = (8Gb^2)/(\pi^3 C)$, $C$ — effective tension of a curved dislocation ($C = 2\cdot Gb^2/\pi(1-\nu)$); $\Lambda = 14.5\cdot 10^9$ m$^{-2}$ [1] – the dislocation density; $\nu = 0.27$ [1] – Poisson's ratio; $G = 3.533\cdot 10^{10}$ Pa [1] — shear module of the active slip systems; $b = 2.85\cdot 10^{-10}$ m [1] — the magnitude of Burgers' vector, $Gb^2 = 28.7\cdot 10^{-10}$ Pa·m$^2$.

The results of calculations by formulae (1)–(4) of the dependences of the average effective length of the dislocation segment $L$ and the absolute values $B$ from the time of irradiation are shown in Fig. 3 by curves *1* and *2*, respectively.

It can be seen (Fig. 3, curve *1*) that the experimental points, obtained by calculating $L(t)$ by formulae (2) and (3) match well with each other and fit the theoretical curve $L_t = L_{t=0}/(1+\beta t)$. According to the research data [1], under the influence of X-irradiation dose of 400 R the average length of dislocation segment has decreased from the value $8.1\cdot 10^{-7}$ m (for non-irradiated crystal) to a value of $4.3\cdot 10^{-7}$ m, obtained after irradiation time of 1 h. Taking into consideration the results of this work, it is possible to state that the additional irradiation of the samples to a total dose of 1000 R, corresponding to the total exposure time of 2 h and 40 min, resulted in an additional reduction of $L$ to the value of

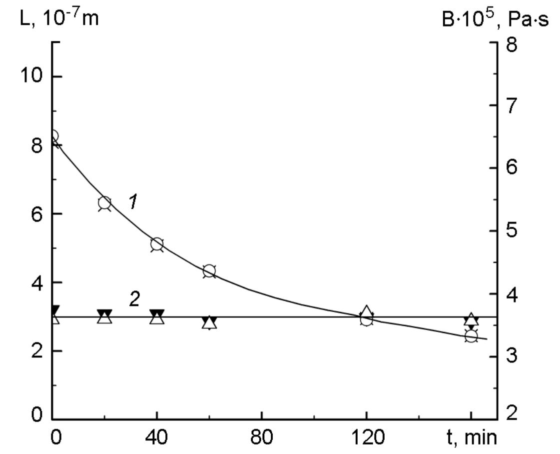


Fig. 3. Dependences of the average effective length of the dislocation segment $L$ (*1*) and the coefficient of dynamic damping of dislocations $B$ (*2*) from the irradiation time. Curve *1* — theoretical calculation of $L$ in the framework of [8] by the last expression (1), points — calculations in the framework of the theory [13]: × — calculation of $L$ by $B$ and $f_m$ (*3*), ○ — $L$ calculation by the resonance (2), ▼ — calculation of $B$ in the descending branch (*4*), Δ — calculation of the resonance (*3*) and (*2*).

$2.44 \cdot 10^{-7}$ m, i.e., the tendency of $L$ shortening by irradiation has been preserved, but the pace of decline has slowed. As in [1], it may be noted that the behavior of the curve $L(t)$ fully explains all of the dependences presented in Fig. 1 and 2. Irradiation leads to the reduction of the average effective length of the dislocation loops, vibrating in the ultrasonic wave, which is reflected in the shift of the resonance maximum (Fig. 1, 2) to higher frequencies areas and lower values of the dislocation decrement.

Calculations of the coefficient of the dynamic damping of dislocations $B$ (Fig. 3, curve *2*) have been also performed by two independent sources of information: according to the position of the resonance peak (Formula 3) and along the descending branch (Formula 4). It is seen that the results of the calculations are practically identical.

According to the research results [1], the average value of the parameter $B$ was $3.65 \cdot 10^{-5}$ Pa·s. After completing, in this paper the similar calculation in the range of exposure area 2.5 times larger than in [1], and having calculated the same value according to other data, we state that its average value remained virtually unchanged ($3.62 \cdot 10^{-5}$ Pa·s).

Fig. 3 shows that the parameter $B$ does not depend on the irradiation dose in the range of 0–1000 R. This result, together with the results of [6, 7] confirms the validity of the authors' views [14] that the coefficient of dynamic damping of dislocations $B$ is a fundamental characteristic of the crystal, depending only on the interaction of dislocations with the phonon subsystem of the crystal, and not depending on the parameters of its dislocation structure.

Summarizing the work, the following conclusions can be done. As it can be seen, ultrasound is a convenient way of probing the processes of radiation damage in crystals at an early stage, which importance has been emphasized by the authors of the research [5]. Using standard and proven optical techniques for the same samples, it is possible to draw conclusions not only about the presence of color centers in irradiated crystals, but also to determine their type and number [15] by the spectral dependence of the irradiation transmittance $\tau$ ($\lambda$). These problems, in our view, have significant prospects and could form the basis of our subsequent works.

## 4. Conclusions

1) The effect of X-ray irradiation in the range of 0–1000 R on the frequency spectra of ultrasound dislocation absorption in the frequency range of 37.5–232.5 MHz in LiF at $T$ = 300 K was investigated.

2) On the basis of the comparison of the obtained experimental data, with the performed in the framework of the model by Stern and Granato theoretical calculation, the flow of curves $\Delta_m(t)$ and $f_m(t)$ was studied over the entire range of radiation doses of 0–1000 R. The validity of the theoretical prognostications concerning increasing or decreasing with the exposure time according to the law $(1 + \beta t)^2$ parameters $\Delta_m$ and $f_m$ respectively have been proved.

3) On the basis of the performed and compared to each other calculations of the dynamic viscosity $B$ coefficient in the descending branches, and by the location of resonance on curves $\Delta_d(f)$, the independence $B$ from the irradiation dose in the examined dose range of 0–1000 R has been proved, which is consistent with the theory [14].

4) In the framework of the theory [13] the dependence of the length dislocation segment $L$ from the irradiation time was

calculated in two ways. A good match of these calculations' results with each other and with the theoretical curve $L(t)$ by Stern and Granato has been noted.

### *References*


1. G.A.Petchenko, *Probl. Atom. Sci. Techn.*, **2(99)**, 36 (2012).
2. M.I.Mazuritsky, X-ray Optics, Rostov State University, Rostov on Don (2005) [in Russian].
3. V.V.Antsiferov, *J.Techn. Phys.*, **68**, 74 (1998).
4. I.M.Neklyudov, A.K.Malik, A.A.Parkhomenko, A.V.Rudnitsky, *Problems of Atomic Science and Technology*, **2(93)**, 52 (2009).
5. A.A.Botaki, A.A.Vorobev, V.L.Ulyanov, Radiation Physics of Ionic Crystals, Atomizdat, Moscow (1980) [in Russian].
6. A.M.Petchenko, *Crystallography*, **37**, 458 (1992).
7. A.M.Petchenko, G.A.Petchenko, *Vistn.Khark. Nats.Univers.*, **865**, 39 (2009).
8. R.M.Shtern, A.V.Granato, in: Proc. Internal Friction and Defects in Metals: ed. by V.S.Postnikov, Metallurgy, Moscow (1965) [in Russian].
9. T.Suzuki, A.Ikushima, M.Aoki, *Acta Met.*, **11**, 1231 (1964).
10. R.Truell, C.Elbaum, B.Chik, Ultrasonic Methods in Solid State Physics, Mir, Moscow (1972) [in Russian].
11. O.S.Oen, D.K.Holmes, M.T.Robinson, US AEC Report NORNL-3017, 3 (1960).
12. J.M.Sievertsen, in: Proc. Internal Friction and Defects in Metals: ed. by V.S.Postnikov, Metallurgy, Moscow (1965) [in Russian].
13. A.Granato and K.Lucke, in: Proc. Physical Acoustics: ed. by U.Mezon, Mir, Moscow (1969) [in Russian].
14. V.I.Alshits, V.L.Indenbom, *Uspehi Fiz. Nauk*, **115**, 3 (1975).
15. A.Smaula, *Z.Physik*, **59**, 603 (1930).


# Динамічне гальмування дислокацій в опромінених кристалах LiF

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З метою вивчення природи механізмів, що лімітують в'язкий рух дислокацій, імпульсним луна-методом в частотному діапазоні 37,5–232,5 МГц досліджено задемпфований дислокаційний резонанс у кристалах LiF при кімнатній температурі в інтервалі доз опромінення 0–1000 Р. З частотних кривих, знятих для кристалів із різними дозами опромінення, визначено залежності коефіцієнта в'язкості $B$ і середньої ефективної довжини дислокаційного сегменту $L$ від часу опромінення. На підставі виконаних вимірювань, розрахунків та їх аналізу зроблено висновок про те, що динамічне гальмування дислокацій у даному об'єкті та в даних умовах експерименту визначається лише фононним спектром кристала.