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Analysis of the Frequency Spectra Behavior of Dislocation Ultrasound Absorption in Irradiated LiF Samples with Different Dislocation Structure

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The classical work of Stern and Granato studied the frequency spectra of the dislocation absorption of ultrasound $\Delta_d(f)$ for samples of high-purity copper. These authors recorded a non-standard feature in the behavior of the curves $\Delta_d(f)$ in experiments with irradiated crystals – their high-frequency asymptotes are superimposed on one another, which is fundamentally different from those obtained in experiments where similar characteristics are studied under conditions of change in temperature and density of samples' dislocations. In view of the absence of this experimental fact interpretation in special literature and as there were no physical description of dislocation absorption of ultrasound process in irradiated crystals, this paper was intended to analyze the latest studies' results in this area and give an explanation of this particular feature that was observed in the experiment. There are recommendations that can be useful in conducting acoustic exploration of crystals with impurities and pinning centers of magnetic nature.

Keywords: Phonon braking, Dislocation decrement, Deformation, Irradiation, Dislocation, Coefficient of dynamic damping, Average effective length of dislocation segment, Elastic modules.

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1. INTRODUCTION

In the paper [1] Stern and Granato pulsed method in the range of 5-100 MHz, the impaired dislocation resonance on crystals of high-purity copper was studied. This work was performed to test the efficiency of the newest at that time Granato-Lucke's theory [2], which most accurately described the experimental results in the amplitude-independent region of the dislocation losses of ultrasound energy and provided a single opportunity for a correct determination of the damping constant of dislocations B required as to describe and predict the process of plastic deformation of crystals, and to establish a hierarchy of mechanisms responsible for dynamic dislocation losses in real crystals [3].

The authors [1] obtained a number of fundamentally new results concerning the level of B in the crystals studied by them, that's closely connected with the spectra localization of the dislocation absorption of ultrasound $\Delta_d(f)$ in samples and the theoretical description of an interrelation between the irradiation time change and the resonant maximum parameters of the curves $\Delta_d(f)$ (the resonant frequency f_m and the decrement in the maximum Δ_m) and the mean effective length of the dislocation segment L:

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

where f_m^t, Δ_m^t, L_t – respectively, the resonance frequency, the decrement in the maximum Δ_m and the average effective length of the dislocation loop for the crystal irradiated over a time interval t, $f_m^{t=0}$, $\Delta_m^{t=0}$, $L_{t=0}$ – the same parameters are for non-irradiated one, $\beta = P \cdot L_{t=0}/\Lambda$, where P – the total number of blocking points suitable for the dislocation grid per time unit, Λ – is the density of dislocations.

The authors [1] claim, that the concentration $c(t) = \beta \cdot t$ of the pinning centers which are added to the loop of the length $L_{t=0}$ in the time of irradiation, which, speaking strictly, is not a linear function, and the relation (1) is valid only in the first approximation, that the authors also denote [6], and propose using a more precise, in their opinion, function $c(t) = \beta \cdot t^{2/3}$.

The earlier investigators [1] also fixed such an experimental feature, which, according to their words, is characteristic only for acoustic testing of irradiated crystals. All the spectral measurements by the authors of the dislocation absorption of ultrasound for crystals with different radiation doses and with constant values of Λ and fixed temperatures T converged with their decreasing branches under a single high-frequency asymptote. The authors themselves did not explain this experimental fact. Unfortunately there were no other works in this area.

Studying [4] the influence of X-ray irradiation on the behavior of the dynamic and structural characteristics of LiF crystals, the authors recorded a similar [1] effect of the high-frequency asymptotes' coincidence of the curves $\Delta_d(f)$, but now for the ionic crystals.

This behavior of the curves $\Delta_d(f)$ was radically different from all the data we obtained earlier in studies of the deformation and temperature influence on the acoustic, dynamic and structural characteristics of KBr [5], KCl [6] and LiF non-irradiated crystals.

The high-frequency asymptotes in experiments [5, 6] never merged with each other and represented a system of parallel lines.

In view of the above, in this paper we were aimed to understand the non-standard behavior of high-frequency asymptotes and find out its causes.

2. EXPERIMENTS, RESULTS AND DISCUSSION

The techniques for preparing samples to perform measurements and tests, methods and equipment used to obtain the data presented below are minutely described in [4]. Here we present the measurements' results: frequency dependences of dislocation decrement of ultrasonic attenuation in lithium fluoride crystals irradiated to various doses of X-ray irradiation. We used crystals with different values of the previous deformation ε as we can see in Fig. 1 and in Fig. 2. For a comparison, similar dependences for non-irradiated LiF and KCl crystals were given at $T = 300$ K with different ε.

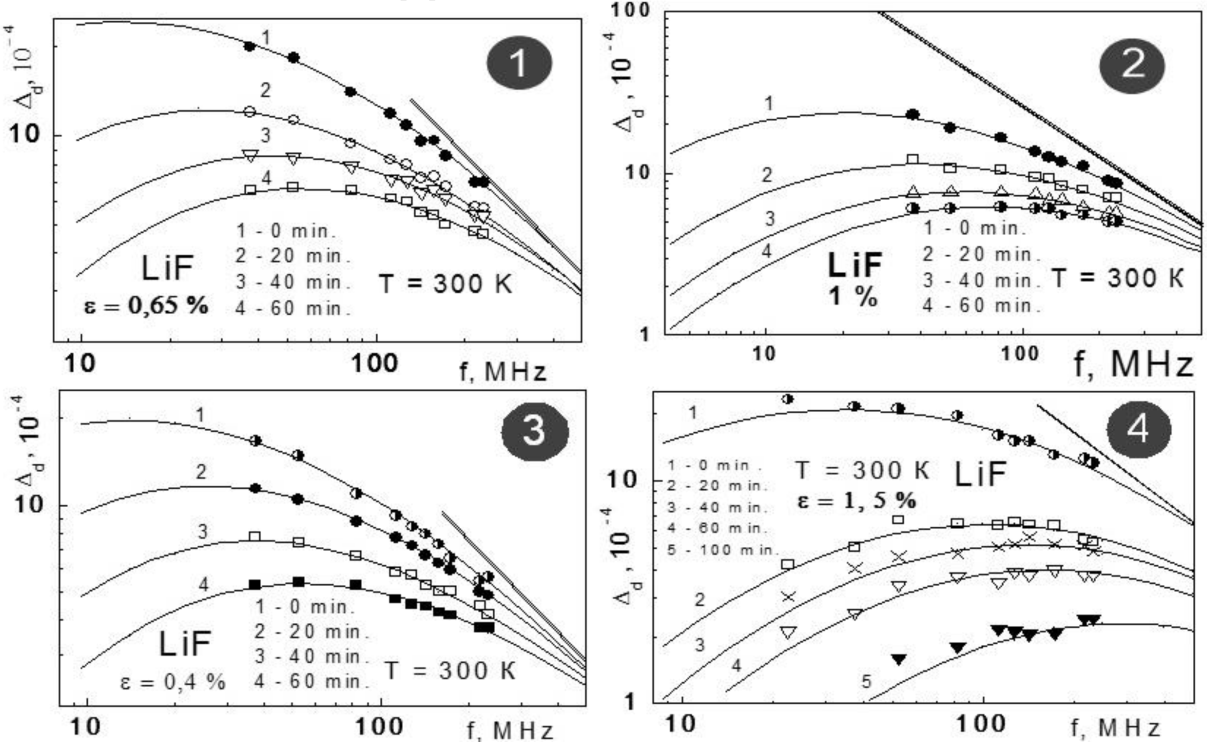

Fig. 1 – 1, 2, 3, 4 – Frequency dependences of the dislocation decrement of ultrasonic attenuation in irradiated LiF crystals with different values of the previous deformation at room temperature

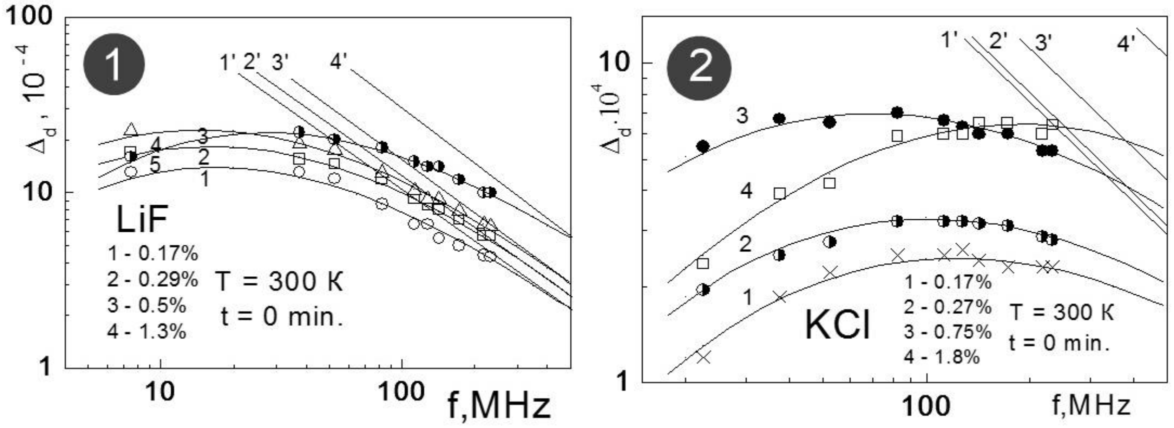

Fig. 2 – 1, 2 – Frequency dependences of the dislocation decrement of ultrasonic attenuation in non-irradiated LiF and KCl crystals with different values of the previous deformation at room temperature

It is obviously shown by Fig. 1 that with increasing irradiation time, the resonance curves $\Delta_d(f)$, along with the decreasing in height, become steadily deflected toward higher frequencies. Experimental points are well described by the theoretical frequency profile [2], calculated for the exponential distribution of dislocation loops in lengths. It is also seen that the high-frequency asymptotes for the above-mentioned theoretical profiles almost coincide. It should be noted separately that the most noticeable shift in the $\Delta_d(f)$ curve is observed at the initial stage of exposure, for 20-40 minutes (the radiation dose rate is ~ 0.11 R/s).

Subsequently, as the dose of radiation increases, displacement of the dislocation resonance becomes less noticeable. Note that the binding of the theoretical curves [2] to experimental data was carried out with orientation to the points from the lower branches of the curves $\Delta_d(f)$ and from the resonance area.

In Fig. 2 the typical experimental curves of the dislocation decrement dependence on the frequency $\Delta_d = \Delta_d(f)$ for preformed LiF and KCl crystals are given. One can see that when the deformation changes, the inverse effect is observed in the behavior of frequency spectra. With the onset of deformation, the resonance curves increase in height, shifting to the region of low frequencies. In the case of further deformation, the resonance displacement process is slowing down, and then, after stopping, it begins to flow in the opposite direction. From Fig. 2 it can be seen that the measured dislocation losses, depending on the frequency $\Delta_d = \Delta_d(f)$ a characterized as the damped-out dislocation resonance [2]. It is also clear that for non-irradiated crystals LiF and KCl under conditions of a variable dislocation structure of samples, no merging of high-frequency asymptotes in one straight line could be described.

A similar picture is observed for KBr samples (Fig. 3), for which, in experiments with a variable dislocation structure and sample temperature, the nature of the curves' behavior $\Delta_d(f)$ differs from the characteristics of the irradiated samples LiF at T, Λ = constant (Fig. 1).

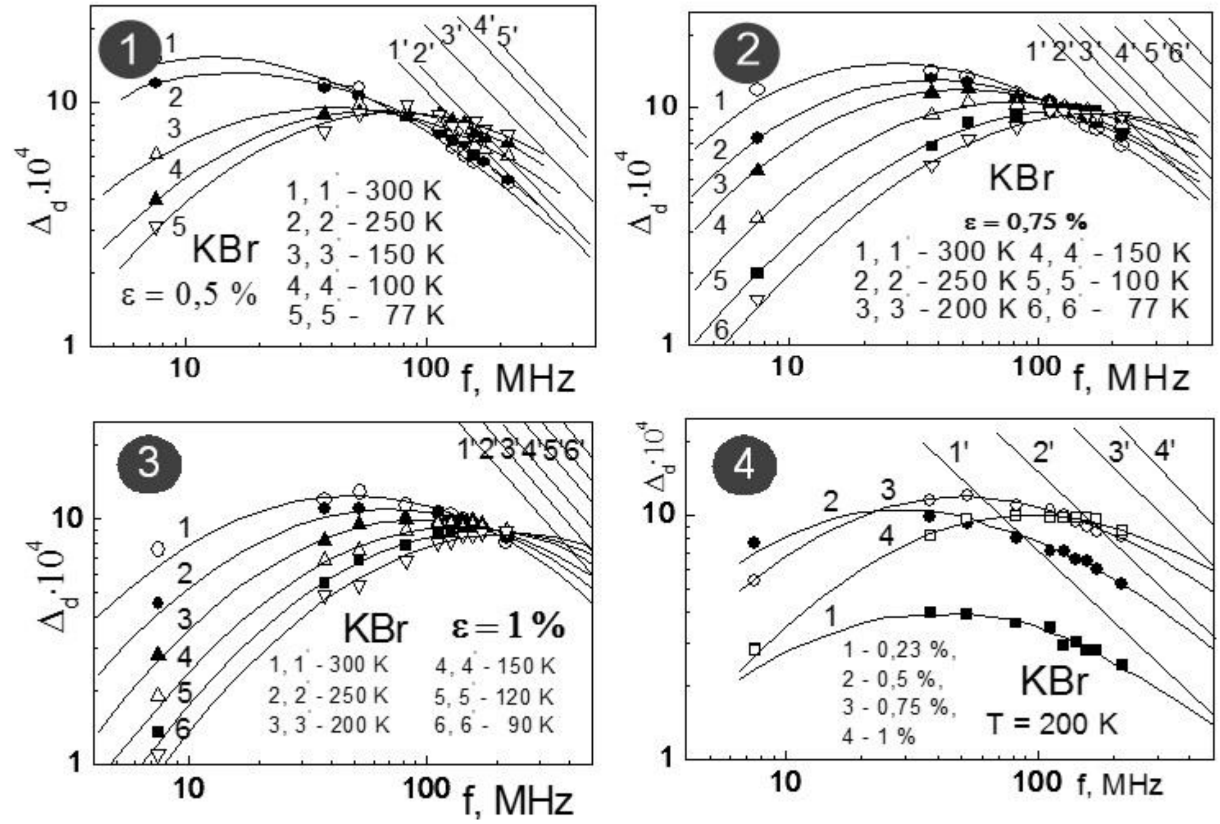

Fig. 3 – 1, 2, 3 – Frequency dependences of the dislocation decrement of the ultrasonic attenuation in LiF crystals with different magnitude of the previous deformation in the temperature range 77-300 K; 4 – The curves $\Delta_d(f)$ at T = 200 K and the variable value ε

Our checking the correlations (1) stated by Stern and Granato, showed that the approximation used by them is quite sufficient to describe the experimental data shown in Fig. 1. We regard the note of Siverstson [1] as to the expediency of using the function $c(t) = \beta \cdot t^{2/3}$ in the Stern and Granato model as a groundless.

To establish the cause of the non-standard behavior of the curves $\Delta_d(f)$ observed in Fig. 1, we consider the Granato-Lucke's ratio [2] used for further processing of the following experimental data:

$$\Delta_m = 2,2\Omega\Delta_0\Lambda L^2; f_m = \frac{0,084\pi C}{2BL^2}; \Delta_\infty = \frac{4\Omega G b^2\Lambda}{\pi^2 B f} \quad (2)$$

where Δ_∞ – the value of the decrement for frequencies $f \gg f_m$; Ω – the orientation 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; $\Delta_0 = (8\,Gb^2)\,/\,(\pi^3 C)$, C – effective tension of a curved dislocation ($C = 2\,Gb^2/\pi(1-\nu)$); Λ – the dislocation density; ν – the Poisson's ratio; G – shear module of the active slip systems; b – the magnitude of the Burgers' vector [2, 4-6].

By the author [3] the assumption was made that the coefficient of dynamic inhibition of crystal dislocations is determined only by dislocations' interaction with the gas of elementary excitations of the crystal and does not depend on its mechanical state. Our work [4-6] fully confirmed this view. Granato-Lucke's theory operates with two types of lock pins at dislocations: strong stopper-nodes of the dislocation grid (Mott's stoppers) and weaker centers of fixing (Friedel's stoppers). In our work the pinning centers of the dislocation are mainly of radiation origin. In [4], we have proved the independence of B from both strong and weak stoppers. Assuming that the independence of $B(\Lambda)$ and $B(t)$ is a proven fact, we decided to analyze the correlation (2) in details. Here we consider the experiments with the variable Λ and T = constant. Thou, it is clear that for fixing B = constant the combination of parameters $\Lambda/f\cdot\Delta_\infty$ must remain unchanged. All other parameters included in (2) and expressed through the elastic modules of the crystal, depend only on its temperature, and their values are always assumed to be in accordance with the condition of the low dislocation density crystal (annealed) in accordance with the conditions and constraints that form the model [2]. At the same time, in experiments on irradiation at varying time of exposure t and at T, Λ = constant the combination of parameters $1/f\cdot\Delta_\infty$ should remain unchanged to keep B at a constant level. When the radiation dose is accumulated by a crystal, its dislocation segment decreases due to the blocking by the Friedel type pinning centers, which causes a decrease in the dislocation damping losses in the sample [2]. At the same time, the reduction of the dislocation segment leads to an increase in the frequency of its resonant response to the ultrasonic attenuation of the crystal. Our experiments have shown that the decrement and frequency change synchronously, but in the opposite directions, compensating each other for the indicated changes. Therefore, the magnitude of the X-ray crystal exposure may increase, but the combination of parameters $1/f\cdot\Delta_\infty$ remains unchanged. This is the answer to why high-frequency asymptotes for curves $\Delta_d(f)$, corresponding to different doses of crystals' irradiation coincide in one straight line. With a change in the degree of the samples' deformation, the more complex combination of parameters $\Lambda/f\cdot\Delta_\infty$ takes effect, so high-frequency asymptotes are eroded in a band of a certain width. In experiments with Λ = constant and variable T the combination of parameters $\Omega Gb^2/f\cdot\Delta_\infty$ plays a decisive role, which is also the reason for the difference in high-frequency asymptotes.

We've got an impression that in any experiments which have unchanged Λ and T – for example, acoustic studies of crystals with different concentrations of impurities, or acoustic experiments with crystals that have undergone a magnetic processing [7-10], it will be the effect of high-frequency asymptotes' merging into a single straight line. That is, we predict that under the conditions of constant temperature and under the unchanging cell of the dislocation grid, the implantation of the Friedel type crystalline blocking points of any physical nature, will ensure the curves' $\Delta_d(f)$ decreasing branches' coincidence. To confirm our prognosis we need tests with a variable admixture of crystals or experiments with preliminary or in situ magnetic processing of samples, as suggested by authors [7-10].

3. CONCLUSION

The mode of changing the frequency spectra of dislocation ultrasonic absorption in LiF, KCl and KBr crystals with the use of temperature, plastic deformation and irradiation of samples was analyzed in our paper. Differences and common features are found in the characteristics that reflect different physical processes in crystals.

For the first time, the effects of various displacements of the curves $\Delta_d(f)$ observed during acoustic experiments and under the influence of temperature, deformation and irradiation, have been explained. The peculiarities of the curves' $\Delta_d(f)$ localization, that was marked in experiments on irradiation of crystals by Stern and Granato, were substantiated.

There was made a prediction for the features of the curves' $\Delta_d(f)$ localization for crystals with Friedel type dislocation stoppers of any physical nature.

Аналіз поведінки частотних спектрів дислокаційного поглинання ультразвуку в опромінених зразках LiF з різною дислокаційною структурою

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У класичній роботі Штерна і Гранато вивчались частотні спектри дислокаційного поглинання ультразвуку $\Delta_d(f)$ на зразках високочистої міді. Цими авторами було зафіксовано нестандартну особливість у поведінці кривих $\Delta_d(f)$ у дослідах з опроміненими кристалами – їх високочастотні асимптоти накладаються одна на одну, що докорінно відрізняється від тих результатів, що отримані у дослідах, де вивчається аналогічні характеристики в умовах зміни температури і густини дислокацій зразків. Зважаючи на відсутність у літературі будь-яких тлумачень цього експериментального факту і фізичного описання картини процесу дислокаційного поглинання ультразвуку в опромінених кристалах, у даній роботі було поставлено за мету проаналізувати новітні результати з вказаного напрямку і дати пояснення вказаній особливості, що спостерігається на експерименті. Надаються рекомендації, що можуть бути корисними при проведенні акустичних досліджень кристалів з домішками і центрами закріплення магнітної природи.

Ключові слова: Дислокаційний декремент, Деформація, Опромінення, Дислокації, Коефіцієнт динамічного гальмування, Середня ефективна довжина дислокаційного сегмента, Пружні модулі.

REFERENCES

1. R.M. Stern, A.V. Granato, *Int. Friction Defects Metals*: (Moskow: Metallurgy: 1965).
2. A. Granato, K. Lucke, *J. Appl. Phys*, **27**, 583 (1956).
3. V.I. Alschits, V.L. Indenbom, *UFN* **115**, 3 (1975).
4. G.A. Petchenko, *Func. Mater.* **20**, 315 (2013).
5. G.A. Petchenko, A.M. Petchenko, *Func. Mater.* **16**, 253 (2009).
6. O.M. Petchenko, G.O. Petchenko, *Ukr. J. Phys.* **55**, 716 (2010).
7. Yu.I. Golovin, *Phys. Solid State* **46**, 789 (2004).
8. V.I. Alshits, E.V. Darinskaya, M.V. Koldaeva, R.K. Kotowski, E.A. Petrzhik, P.K. Tronczyk, *Phys. Usp.* **60**, 305 (2017).
9. V.I. Alshits, E.V. Darinskaya, M.V. Koldaeva, E.A. Petrzhik, *J. Appl. Phys.* **105**, 063520 (2009).
10. V.I. Alshits, E.V. Darinskaya, M.V. Koldaeva, R.K. Kotowski, E.A. Petrzhik, P.K. Tronczyk, *Pol. J. Appl. Sci.* **2**, 21 (2016).