UDC 539.67:539.374

THE INFLUENCE OF X-RAY IRRADIATION ON DYNAMICAL AND STRUCTURAL CHARACTERISTICS OF STRAINED NaCl CRYSTALS

O.M. Petchenko, G.O. Petchenko, S.M. Boiko, A.V. Bezugly
O.M. Beketov Kharkiv National University of Urban Economy,
Kharkiv, Ukraine
E-mail: gdaeron@ukr.net

The influence of a preliminary deformation ε = 1,3% and X-ray irradiation to exposure doses 0…600 R on the frequency spectra of the dislocation ultrasonic absorption $\Delta_d(f)$ in NaCl crystals in the frequency interval 37,5…232,5 MHz and at room temperature has been studied using the pulsed technique. 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 dose of irradiation has been determined. The coefficient of dynamic viscosity *B* was found to be independent of the irradiation dose.

INTRODUCTION

This article is a continuation of [1–6], where we studied the effect of irradiation on the localization of the frequency spectra of the dislocation ultrasonic absorption $\Delta_d(f)$ in LiF single crystals. In this works the pulse-echo method has been used to thoroughly study the behavior of the parameters of the resonant maximum – the dislocation decrement Δ_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 the irradiation dose ξ. It has been found that the increasing of the irradiation dose in the examined crystals leads to the 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 [8–14], these shifts were so, that high frequency asymptote from the family of curves $\Delta_d(f)$ for different irradiation doses are practically identical to each other. The indicated effect of shifts, observed in LiF in [1–6], was similar to the previously observed one by the authors [7] at high purity copper. In [1–6] it has been possible to study the dependence of the viscosity coefficient *B* due to the dose of irradiation. It should also be also noted, that the works [1–6] additionally confirmed the effectiveness of ultrasonic methods of internal friction [15, 16] for reliable recording of the dislocations exposure of pinning points by the radiation origin.

The high efficiency of acoustic methods [15–23] has been stipulated by the fact that the attenuation of ultrasound α 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 [24–27], in which the dependence of the transmittance coefficient from the radiation wavelength, passing through the crystal is measured. Our studies [28, 29] of LiF crystals on the SF-26 spectrophotometer showed that 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 [1–6] and observe the dynamics the curves shift $\Delta_d(f)$, $L(\xi)$, and $B(\xi)$ in irradiated NaCl single crystals, which is the purpose of this paper.

MATERIALS AND EXPERIMENTAL TECHNIQUES

In this paper, by the pulse method in the frequency range 37.5…232.5 MHz and X-ray irradiation dose range 0…600 R, the frequency dependence of the dislocation losses of ultrasound in single crystals NaCl at the temperature T = 300 K has been studied. The single crystals with the magnitude of residual strain 1.3% were used in the experiments. Information about the features of samples preparation (gouging, grinding, polishing, annealing, pickling, deformation), as well as the acoustic features of the experiment presented below are minutely described in [1–6]. Irradiation of crystals NaCl to the dose of 600 R has been performed on the same unit URS-55 at the same operation mode as in [1–6]. The radiation dose rate was not changed and was 0.11 R/s.

RESULTS AND DISCUSSION

The results of the study of the frequency spectra of the dislocation ultrasonic absorption $\Delta_d(f)$ in X-irradiated NaCl single crystals for the doses in the range 0…600 R at room temperature are shown in Fig. 1 (curve 1–4).

As it can be seen, the flow of curves $\Delta_d(f)$ do not differ qualitatively from the corresponding dependences given in [1–6] for LiF single crystals. The experimental points as well as previously [1–6] are described by the theoretical frequency profiles [16, 30], calculated for the case of exponential distribution of dislocation loops along the lengths. It should be noted, that the binding of the theoretical curves [16] to the experimental data has been carried out with a focus on the points that lie on the descending branch of the experimental curve, and in the resonance area. 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.

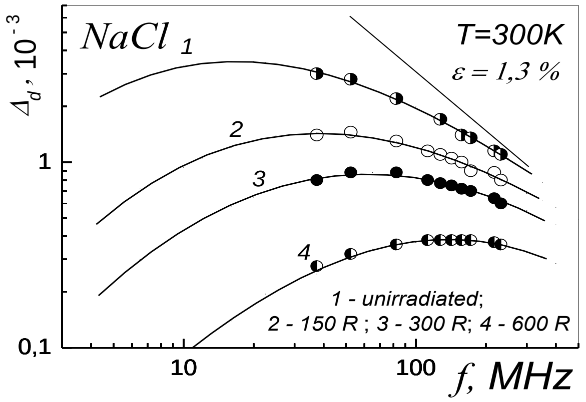

Fig. 1. Frequency spectra of the dislocation ultrasonic absorption $\Delta_d(f)$ in NaCl single crystals with different values of X-irradiation doses

The expressions for the resonance frequency f_m, the decrement in the maximum Δ_m and the average effective length of the dislocation loop L as a function of time t is taken in the form [15]:

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

where f_m^t, Δ_m^t, L_t are, 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 for the non-irradiated crystal; $\beta = \frac{P \cdot L_{t=0}}{\Lambda}$; P – the total number of blocking centers, which reach the dislocation net per time unit; Λ – the dislocation density (constant during the experiment).

Using the data of the present work, shown in Fig. 1, and the results of calculations (1), we were able to compare the experimental points for $\Delta_m(\xi)$ and $f_m(\xi)$ with the theoretical curves (Fig. 2).

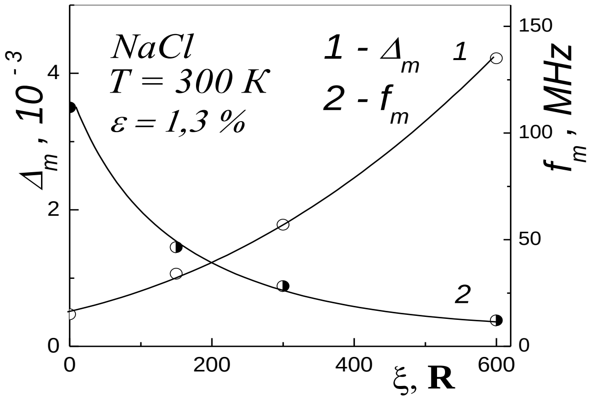

Fig. 2. Irradiation dependences of the resonance parameters Δ_m and f_m in NaCl single crystals

Fig. 2 shows that the experimental points are well described by the theoretical curves calculated by the Stern and Granato theory [15]. It also shows that the increase in irradiation time leads to the decrease of the dislocation decrement Δ_m and increase of the resonance frequency f_m.

To get information on the dependences due to the irradiation time in the range 0…600 R of the average effective length of the dislocation segment L and the coefficient of dynamic of dislocations damping B, we have processed the data shown in Figs. 1, 2, in the framework of the Granato-Lucke theory [16]:

$$\Delta_m = 2.2\Omega\Delta_0 \Lambda L^2 ; \quad f_m = \frac{0.084\pi C}{2BL^2} ;$$
$$\Delta_\infty = \frac{4\Omega G b^2 \Lambda}{\pi^2 B f} , \tag{2}$$

where Δ_∞ is the value of the decrement for frequencies $f >> f_m$; $\Omega = 0.365$ is the orientation factor; L – average effective length of the dislocation segment; $\Delta_0 = (8Gb^2)/(\pi^3 C)$, $C = 2 \cdot Gb^2/\pi(1-\nu)$ is the effective tension of a curved dislocation; $\Lambda = 16.5 \cdot 10^9\ m^{-2}$ is the dislocations density; $\nu = 0.212$ is the Poisson's ratio; $G = 1.78 \cdot 10^{10}$ Pa is shear module of the active slip systems; $b = 3.99 \cdot 10^{-10}$ m is the magnitude of the Burgers' vector.

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

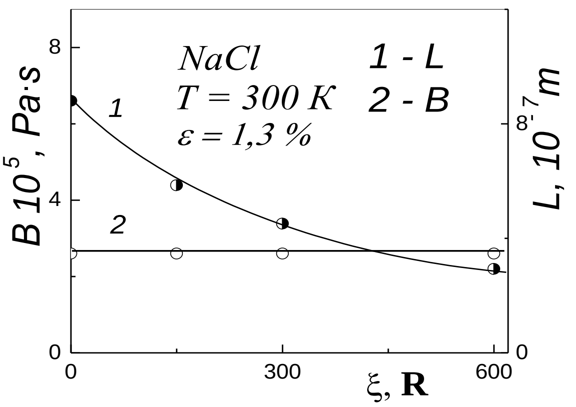

Fig. 3. Dependencies of the average effective length of the dislocation segment L (1) and the coefficient of dynamic damping of dislocations B (2) on the irradiation dose ξ. Curve 1 – the theoretical calculation of L in the framework of Stern and Granato model [29], points – the calculations in the framework of Granato-Lucke's theory[30]. Curve 2 – the calculation of B in the calculations in the framework of [30]

It can be seen (see Fig. 3, curve 1) that the experimental points, obtained by calculating $L(\xi)$ in the framework of Granato-Lucke's theory [16] fit the theoretical curve $L_t = L_{t=0}/(1+\beta t)$. As in papers [1–6], it may be noted that the behavior of the curve $L(\xi)$ fully explains all of the dependencies presented in Figs. 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 (see Figs. 1, 2) to higher frequencies areas and lower values of the dislocation decrement.

Fig. 3 (curve 2) shows that the parameter *B* does not depend on the irradiation dose in the range 0…600 R. This result, together with the results of papers [1–6] confirms the validity of the authors' views [14, 17] 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.

CONCLUSIONS

The effect of X-ray irradiation in the range 0…600 R on the frequency spectra of the dislocation ultrasonic absorption in NaCl single crystals with a residual deformation of 1.3%, was studied in the frequency range from 37.5 to 232.5 MHz and at $T = 300$ K. 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 $\Delta_m(\xi)$ and $f_m(\xi)$ have been studied. The dependence of the length dislocation segment *L* from the irradiation dose ξ has been calculated. The independence of the coefficient of dynamic damping of dislocations *B* from the irradiation dose ξ in the examined dose range has been proved.

REFERENCES

1. G.A. Petchenko, A.M. Petchenko. The study of the dislocation resonance in LiF crystals under the influence of the low-dose X-irradiation // *Functional Materials*. 2010, v. 17, N 4, p. 421-424.
2. G.O. Petchenko. Acoustic studies of the effect of X-ray irradiation on the dynamic drag of dislocations in LiF crystals // *Ukrainian Journal of Physics*. 2011, v. 56, N 4, p. 339-343.
3. G.A. Petchenko. The investigation of the dislocations resonant losses of ultrasonic sound in irradiated LiF single crystals in the interval of irradiation doses 0…400 R // *Problems of Atomic Science and Technology*. 2012, N 2(78), p. 36-39.
4. G.A. Petchenko. Dynamic damping of dislocations in the irradiated LiF crystals // *Functional Materials*. 2012, v. 19, N 4, p. 473-477.
5. G.A. Petchenko. The study of the dynamic and structure characteristics in irradiated LiF crystals // *Problems of Atomic Science and Technology*. 2013, N 2(84), p. 55-59.
6. G.O. Petchenko, O.M. Petchenko. Research of the elastic wave velocity dispersion in X-ray irradiated LiF crystals // *Ukrainian Journal of Physics*. 2013, v. 58, N 10, p. 974-979.
7. T. Suzuki, A. Ikushima, M. Aoki. Acoustic attenuation studies of the frictional force on a fast moving dislocation // *Acta met*. 1964, v. 12, N 11, p. 123-1240.
8. O.M. Petchenko, G.O. Petchenko. Phonon drag of dislocations in KCl crystals with various dislocation structure states // *Ukrainian Journal of Physics*. 2010, v. 55, N 6, p. 716-721.
9. A.M. Petchenko, G.A. Petchenko. Features of resonance absorption of longitudinal ultrasound in strained crystals KBr at temperature variations // *Functional Materials*. 2007, v. 14, N 4, p. 475-479.
10. Kh.M. Khalilov, A.I. Agaev. Dislocation absorption of ultrasound in deformed KCl crystals // *FTT*. 1971, v. 9, N 9, p. 2729-2731.
11. I.V. Gectina, F.F. Lavrentiev, V.I. Startsev. Temperature dependence of the viscous drag coefficient of dislocations in zinc crystals // *Physics of Metals and Metallography*. 1974, v. 37, N 6, p. 1274-1277.
12. L.A. Yakovlev. Investigation of the frequency and amplitude dependences of the dislocation absorption of ultrasound in aluminum // *Acoustic Journal*. 1965, v. XI, N 2, p. 239-242.
13. L.G. Merculov, R.V. Kovalionok, E.V. Konovodchenko. Temperature dependence of the absorption of ultrasonic waves in NaCl crystals // *FTT*. 1971, v. 13, N 4, p. 1171-1177.
14. N.P. Kobelev, Ya.M. Soifer. Viscous drag of dislocations in alkali halide crystals // *FTT*. 1976, v. 18, N 4, p. 1073-1076.
15. R.M. Stern, A. Granato. Damped dislocation resonance in copper // *Internal friction and defects in metals*. M.: "Metallurgiya". 1965, p. 149-191.
16. A. Granato, K. Lücke. String model of dislocation and dislocation ultrasound absorption // *Physical Acoustic*, v. 4, p. A. M.: "Mir", 1969, v. 4, p. 261-321.
17. V.I. Alshits, V.L. Indenbom. Dynamic drag of dislocations // *Usp. Fiz. Nauk*. 1975, v.115, N 3, p. 3-39.
18. V.I. Startsev, V.Ya. Ilyichev, V.V. Pustovalov. *Plasticity and strength of metals and alloys at low temperatures*. M.: "Metallurgiya", 1975, 328 p.
19. R. Truell, Ch. Elbaum, B. Chik. *Ultrasound Methods in Solid State Physics*. M.: "Mir", 1972, 307 p.
20. S.P. Nikanorov, B.K. Kardashov, *Elasticity and Dislocation Inelasticity of Crystals*. M.: "Nauka", 1985, 256 p.
21. V. Naundorf, K. Lücke. *Mechanisms of Internal Friction in Solids.* M.: "Nauka", 1976, 91 p.
22. A.V. Granato, J. de Clerk, R. Truell. Dispersion of elastic waves in sodium chloride // *Phys. Rev*. 1957, v. 108, N 3, p. 89-896.
23. M.A. Krishtal, S.A. Golovin, I.V. Troitskij. Study of the parameters of the dislocation structure of copper by the ultra-sound pulse method // *Phys. Metals and Metal Science*. 1973, v. 35, N 3, p. 632-639.
24. A. Smakula. Uber Erregung und Entfarbung lichtelektrisch leitender Alkalihalogenide // *Z. Physik*. 1930, N 9-10(59), p. 603-614.
25. V.M. Lisitzyn. *Radiation solid state physics*. Tomsk: "Izdatelstvo Tomskogo Politekhnicheskogo Universiteta", 2008, 172 p. (in Russian).
26. M.V. Galustashvili, M.G. Abramishvili, D.G. Driaev, V.G. Kvachadze. Effect of magnetic field on the radiation hardening LiF crystals // *FTT*. 2011, N 53(7), p. 1340-1342.
27. T. Klempt, S. Schweiser, K. Schwartz, et al. Magnetic resonance unvestigation of the dynamics of F centers in LiF // *Solid State Communications*. 2001, N 119, p. 453-458.
28. G.A. Petchenko, S.S. Ovchinnikov. Effect of the preliminary deformation and irradiation on the optical absorption in LiF crystals // *Problems of Atomic Science and Technology*. *Series "Physics of Radiation*

Effect and Radiation Materials Science". 2014, N 2(90), p. 29-33.

29. G.A. Petchenko, A.M. Petchenko. Dependence of electronic color center concentration on the state of irradiated LiF crystal dislocation structure // *Problems of Atomic Science and Technology*. *Series "Physics of Radiation Effect and Radiation Materials Science".* 2015, N 2(96), p. 25-28.

30. O.S. Oen, D.K. Holmes, and M.T. Robinson: *US AEC Report ORNL-3017.* 1960, N 3.

Article received 10.02.2020

ВЛИЯНИЕ РЕНТГЕНОВСКОГО ОБЛУЧЕНИЯ НА ДИНАМИЧЕСКИЕ И СТРУКТУРНЫЕ ХАРАКТЕРИСТИКИ ПРОДЕФОРМИРОВАННЫХ КРИСТАЛЛОВ NaCl

А.М. Петченко, Г.А. Петченко, С.Н. Бойко, А.В. Безуглый

Импульсным методом в области частот 37,5…232,5 МГц при T = 300 К исследованы влияния предварительной деформации ε = 1,3% и облучения дозами 0…600 Р на ход частотных спектров дислокационного поглощения ультразвука $\Delta_d(f)$ в кристаллах NaCl. Из частотных кривых, снятых для кристаллов с разными дозами облучения, определены зависимости коэффициента вязкости B и средней эффективной длины дислокационного сегмента L от дозы облучения. Установлено, что коэффициент динамической вязкости B с увеличением дозы облучения остается неизвестным.

ВПЛИВ РЕНТГЕНІВСЬКОГО ОПРОМІНЕННЯ НА ДИНАМІЧНІ І СТРУКТУРНІ ХАРАКТЕРИСТИКИ ПРОДЕФОРМОВАНИХ КРИСТАЛІВ NaCl

О.М. Петченко, Г.О. Петченко, С.М. Бойко, А.В. Безуглий

Імпульсним методом в області частот 37,5…232,5 МГц при T = 300 К досліджено вплив попередньої деформації ε = 1,3% і опромінення дозами 0…600 Р на хід частотних спектрів дислокаційного поглинання ультразвуку $\Delta_d(f)$ в кристалах NaCl. З частотних кривих, знятих для кристалів із різними дозами опромінення, визначено залежності коефіцієнта в'язкості B і середньої ефективної довжини дислокаційного сегмента L від дози опромінення. Встановлено, що коефіцієнт динамічної в’язкості B зі зростанням дози опромінення залишається незмінним.

.