*Journal of Nano- and Electronic Physics*
Vol. **12** No 3, 03040(3pp) (2020)

*Журнал нано- та електронної фізики*
Том **12** № 3, 03040(3cc) (2020)

## Short Communication

# Analysis of the Dynamic and Structural Characteristics' Behavior in NaCl Single Crystals Pre-deformed and X-ray Irradiated

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(Received 01 November 2019; revised manuscript received 15 June 2020; published online 25 June 2020)

Pulse-echo method in the frequency range 37.5-232.5 MHz has been used to study the behavior of dislocation decrement $\Delta_d(f)$ on X-ray irradiated to doses 0-600 R NaCl single crystals with the residual strain value of 0.5 % at room temperature. It has been found out that with the increasing doses of radiation, the effect of amplitude damping of the dislocation resonance can be observed, which leads to a marked restoration of initial acoustic characteristics of the crystals. It also noted that high-frequency asymptote for these theoretical profiles are identical which is characteristic only for acoustic testing of irradiated crystals. 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 $L$ on the dose of irradiation $\xi$ have been determined in the framework of Granato-Lucke's string dislocation theory. In the framework of the Stern and Granato model, the behavior of $\Delta_m(\xi)$, $f_m(\xi)$ and $L(\xi)$ curves has been studied. The validity of the theoretical prognostications concerning increasing or decreasing with the exposure time according to the law $(1 + \beta t)^2$ parameters $\Delta_m$, $f_m$, and $L$ have been proved. A good match of the calculations' results with the theoretical curve $L(\xi)$ by Stern-Granato and Granato-Lucke theories has been noted. Obtained results show, that the parameter $B$ does not depend on the irradiation dose in the range 0-600 R. It confirms the validity of the views 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.

**Keywords:** Dislocation decrement, Deformation, Irradiation, Dislocation, Coefficient of dynamic damping, Average effective length of dislocation segment.

DOI: 10.21272/jnep.12(3).03040 PACS number: 43.35. + d

## 1. INTRODUCTION

This work is devoted to studying the influence of structural imperfections of crystals on the mobility of dislocations [1-10]. According to the Granato-Lucke string dislocation theory, there are two types of stoppers that have a fixing effect for dislocations. The first type of stoppers, Mott's stoppers, are the so-called strong stoppers, nodes of the dislocation grid. They are due to the presence of a sufficiently large value of preliminary deformation in the testing crystals. The second type of stoppers, Friedel's stoppers, are weaker in their fixing action. These are point defects: impurities, radiation defects, and so on. The main characteristic that determines the course of plastic deformation of crystals is the dynamic drag coefficient of dislocations $B$. At present, we have accumulated a rather large array of information on ionic crystals [8-10] regarding the fact that parameter $B$ is determined only by the interaction of mobile dislocations with the phonon subsystem of the crystal and independent of its dislocation structure. As regards the effect of radiation-induced defects on the dynamic drag of dislocations $B$ in crystals, it can be noted [9] that, apart from the experiments on LiF crystals that we performed, there is no other information. Summarizing the information already available, the following can be noted. In contrast to experiments with a change in temperature and the value of preliminary deformation of crystals, irradiation experiments have a peculiarity – the high-frequency asymptotes of the $\Delta_d(f)$ curves are not represented by a family of straight lines parallel to each other, but converge in a single line. In [9], we analyzed this fact in detail and presented its justification. The proof is based on the use of the Granato-Lucke string dislocation theory. In addition, it was noted that the damping coefficient $B$ does not depend on the dose of X-ray irradiation of the crystals. This result was obtained for the first time and is of great importance. Earlier in the literature, there was a heated discussion about the order of magnitude of $B$. Each research group used samples with different structural states and it was believed that it is impossible to compare the results of the works. Many researchers irradiated crystals with X-ray radiation, since it was noted long ago that the acoustic methods were sensitive to radiation damage to the crystal. It was believed that when assessing the level of dynamic drag of dislocations in crystals, unirradiated and irradiated samples could not be compared at all. Our work showed that preliminary X-ray processing of crystals does not have any effect on parameter $B$. In view of this circumstance, a deep analysis of a large array of experimental studies of the mobility of dislocations in crystals can be carried out. At the same time, it should be noted that this information was obtained only for LiF crystals. It is clear that similar studies should be carried out on other crystals in order to more substantively prove the validity of our conclusions [9].

Thus, the aim of the present work is to study the effect of X-ray irradiation of samples on the frequency spectra of ultrasonic dislocation absorption in NaCl crystals and to determine the dynamic and structural characteristics for samples with different radiation doses. First of all, the fact of convergence of high-frequency asymptotes in one line for the studied NaCl crystals is verified, and then the fulfillment of the condition for the independence of the dynamic drag coefficient of dislocations $B$ from the radiation dose of the crystals is monitored. Stern-Granato theory, which describes the behavior of the resonance characteristics of the $\Delta_d(f)$ curves as a function of the radiation dose of crystals, is also verified.

## 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 [8-10]. Fig. 1 shows the results of the research of the frequency dependence of the dislocation decrement $\Delta_d(f)$ for NaCl samples with a residual deformation $\varepsilon = 0.5$ % measured before (curve 1) and after (curves 2-4) irradiation.

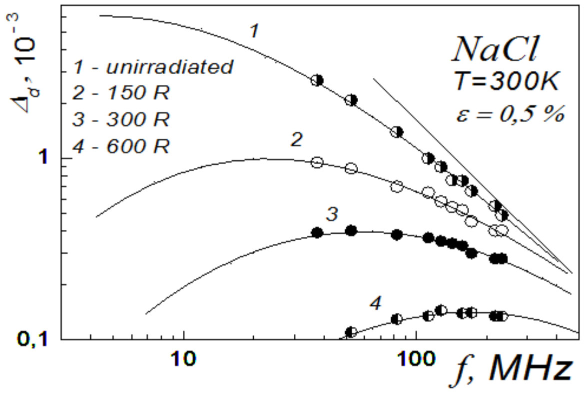

**Fig. 1** – Frequency dependences of the dislocation decrement of ultrasonic attenuation in irradiated NaCl crystals with different values of X-irradiation doses

It can be noted that with the increase of the irradiation dose, resonance curves $\Delta_d(f)$, decreasing in the height, monotonically shift toward higher frequencies. The experimental points are well described by the theoretical frequency profile calculated for the case of the exponential distribution of dislocation loops in length. It also shows that high-frequency asymptote for these theoretical profiles 1-4 is identical. It should be noted that the binding of the theoretical curves [8, 9] 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.

Fig. 2 demonstrates the shift effect [9] with irradiation of the parameters of the resonance peak in amplitude and frequency. The course of irradiation dose $\xi$ dependences $\Delta_m(\xi)$ and $f_m(\xi)$ shows that under conditions of the radiation dose rise up to 600 R, the magnitude of the dislocation decrement $\Delta_m$ in the maximum dramatically reduces, and its resonance frequency $f_m$ increases at that time.

According to Stern and Granato model [9], the 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 $\Delta_m$) and the mean effective length of the dislocation segment $L$:

$$\begin{aligned} f_m^t &= f_m^{t=0}(1+\beta t)^2; \\ \Delta_m^t &= \frac{\Delta_m^{t=0}}{(1+\beta t)^2}; \quad , \\ L_t &= L_{t=0}/(1+\beta t). \end{aligned} \qquad (1)$$

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

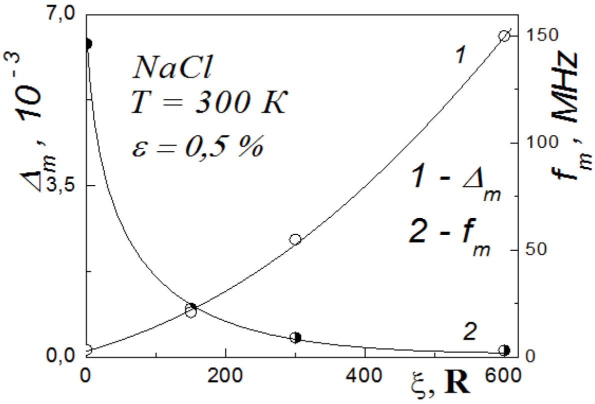

**Fig. 2** – Irradiation dependences of the resonance peak in amplitude $\Delta_m$ and frequency $f_m$ in NaCl single crystals

Granato-Lucke theory [8, 9] provides the relationships (2) describing the resonance peak and descending branch of the curve $\Delta_d(f)$:

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

where $\Delta_\infty$ is the decrement value at frequencies $f >> f_m$; $\Omega = 0.3655$ is the orientation factor, $G = 1.78 \cdot 10^{10}$ Pa is the shear modulus in the active gliding system; $b = 3.99 \cdot 10^{-10}$ m is the Burgers' vector module, $Gb^2 = 2.83 \cdot 10^{-9}$ Pa·m$^2$, $\nu = 0.212$ is the Poisson's coefficient, $C = 2 \cdot Gb^2/\pi(1-\nu) = 2.29 \cdot 10^{-9}$ N is the effective stretch of bent dislocation, $\Lambda = 7.3 \cdot 10^9$ m$^{-2}$ is the density of dislocations; $L$ is the average effective length of the dislocation loop, $\Delta_0 = (8Gb^2)/(\pi^3 C)$.

Using the curves (Fig. 1), the $B$ and $L$ values can be calculated from the relationships (2). The results of calculations of the dependences of these parameters on the irradiation dose $\xi$ are shown in Fig. 3. Experimental points $L(\xi)$ are well described by the theoretical Stern and Granato curves calculated by formula (1).

The damping coefficient $B$ is seen to be independent of irradiation dose in the range 0-600 R (Fig. 3, curve 2). This result is in good agreement with previous results [9].

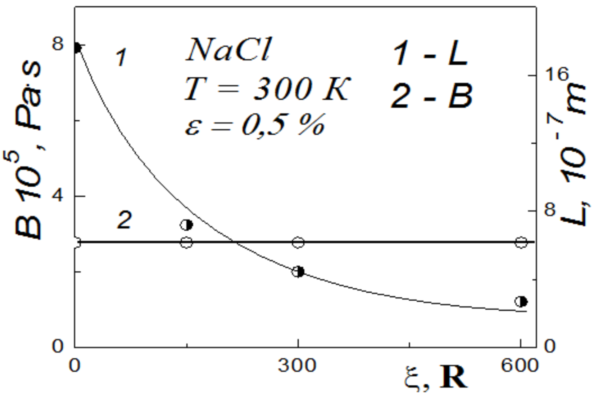

**Fig. 3** – Dependences of the damping constant $B$ and the average effective length of the dislocation loop $L$ on the irradiation dose $\xi$

## 3. CONCLUSIONS

1. The effect of X-ray irradiation in the range 0-600 R on the frequency dependence of the dislocation attenuation decrement in NaCl crystals with a residual strain of 0.5 % at room temperature was studied.
2. Irradiation dependences of the resonance peak in amplitude $\Delta_m$ and frequency $f_m$ in NaCl single crystals were obtained. The results obtained are well described in the framework of the Stern and Granato model.
3. In the framework of the Granato-Lucke theory, the dynamic viscosity coefficient and average effective dislocation loop length were calculated for different doses of X-ray irradiation of crystals. The length of the dislocation segment decreases with increasing dose of X-ray irradiation, and parameter $B$ remains unchanged which is in good agreement with the results obtained on other crystals.

## REFERENCES

1. I.M. Neklyudov, A.K. Malik, A.A. Parkhomenko, A.V. Rudnitsky, *Probl. At. Sci. Techn.* 93, 52 (2009).
2. V.I. Alshits, M.V. Koldaeva, E.A. Petrzhik, A.Yu. Belov, E.V. Darinskaya, *JETP Lett.* **99**, 82 (2014).
3. V.I. Alshits, E.V. Darinskaya, M.V. Koldaeva, E.A. Petrzhik, *JETP Lett.* **88**, 428 (2008).
4. V.I. Alshits, E.V. Darinskaya, M.V. Koldaeva, E.A. Petrzhik, *J. Appl. Phys.* **105**, 063520 (2009).
5. V.I. Alshits, E.V. Darinskaya, M.V. Koldaeva, E.A. Petrzhik, *JETP Lett.* **104**, 353 (2016).
6. Yu.I. Golovin, *Phys. Solid State* **46** No 5, 789 (2004).
7. M.V. Galustashvili, M.G. Abramishvili, D.G. Driaev, V.G. Kvachadze, *FSS* **53**, 1412 (2011).
8. O.M. Petchenko, G.O. Petchenko, S.M. Boiko, *J. Nano-Electron. Phys* **10**, 05022 (2018).
9. O.M. Petchenko, G.O. Petchenko, S.M. Boiko, *J. Nano-Electron. Phys.* **10**, 06010 (2018).
10. G.O. Petchenko, O.M. Petchenko, *Ukr. J. Phys.* **58**, 974 (2013).

# Аналіз поведінки динамічних і структурних характеристик у попередньо продеформованих та опромінених Х-променями монокристалах NaCl

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Імпульсним ехо-методом у діапазоні частот 37,5-232,5 МГц на монокристалах NaCl із величиною залишкової деформації 0,5 % при кімнатній температурі вивчено поведінку дислокаційного декремента $\Delta_d(f)$ в умовах варіювання дози Х-опромінення зразків в інтервалі 0-600 Р. Встановлено, що із зростанням дози опромінення спостерігається ефект гасіння амплітуди дислокаційного резонансу, що призводить до помітного відновлення вихідних акустичних характеристик кристалів. Також відзначається, що високочастотні асимптоти вказаних характеристик збігаються в суцільну лінію, що є характерною особливістю акустичного експерименту з опроміненими кристалами. З частотних кривих, знятих для кристалів з різними дозами опромінення, в рамках струнної дислокаційної теорії Гранато-Люкке визначено залежності коефіцієнта в'язкості $B$ і середньої ефективної довжини дислокаційного сегменту $L$ від дози Х-опромінення $\xi$. У рамках моделі Штерна і Гранато було вивчено хід експериментальних залежностей $\Delta_m(\xi)$, $f_m(\xi)$ і $L(\xi)$. Виконано перевірку теоретичних передбачень моделі стосовно зростання чи спаду вказаних характеристик з часом Х-опромінення $t$ за законом $(1 + \beta t)^2$. Спостерігається добра відповідність поміж собою залежностей $L(\xi)$, одержаних в рамках розрахунку за теоріями Гранато-Люкке і Штерна-Гранато. Одержані результати демонструють той факт, що коефіцієнт динамічного гальмування дислокацій $B$ не залежить від дози Х-опромінення у вивченому інтервалі доз 0-600 Р. Це підтверджує уявлення щодо того, що коефіцієнт демпфування $B$ є фундаментальною характеристикою кристала, що залежить лише від взаємодії дислокацій з його фононною підсистемою і не залежить від параметрів дислокаційної структури кристалів.

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