Functional Materials 14, No.4 (2007)

Features of resonance absorption of longitudinal ultrasound in strained crystals KBr at temperature variations

A.M.Petchenko, G.A.Petchenko

Kharkiv National Academy of Municipal Economy, 12 Revolutsii St.,
61002 Kharkiv, Ukraine

Received June 8, 2007

The frequency dependence of a dislocation damping decrement of ultrasound in KBr single crystals preliminary strained up to 1 % in the temperature range 77–300 K and frequency range 7.5–217.5 MHz has been investigated. The temperature course of the phonon viscosity coefficient B was determined, which is agreed both with the theory and experimental literature data. The effect of temperature-induced changes in the dislocation segment length on parameters of the resonance maximum and dynamic drag of dislocations by phonons has been revealed and considered.

Исследована частотная зависимость дислокационного декремента затухания ультразвука в монокристаллах KBr, предварительно продеформированных до 1 %, в интервале температур 77–300 К и области частот 7,5–217,5 МГц. Определен температурный ход коэффициента фононной вязкости B, который хорошо согласуется как с теорией, так и экспериментальными литературными данными. Обнаружено и проанализировано влияние температурных изменений длины дислокационного сегмента на параметры резонансного максимума и динамическое торможение дислокаций фононами.

The informative and very reliable pulse echo method of high frequency (MHz) range is used most often in experimental studies of phonon dislocation drag mechanisms in crystals [1, 2]. The dislocation damping coefficient B is determined from the parameters of damped dislocation resonance, the localization of the latter being dependent substantially on the sample pre-strain value and temperature [3]. Basing on experiments on some ionic crystals, it was established that the temperature lowering [4–8] results always in a shift of the resonance maximum towards higher frequencies, and a continuous increase of strain at room temperature [9] displaces the resonance parameters (frequency and decrement in a maximum) in a nonmonotonic way, according to the type of a curve having a maximum. That is, under small strains, when only the primary slip planes in a crystal are involved, the resonance curves increasing in amplitude shift towards lower frequencies.

Under high loadings, when dislocations of "forest" arise in a crystal, the resonance maximum starts to reduce in height and shift towards higher frequencies. In this connection, it is of interest to study the influence of differences in preliminary sample straining on the temperature-induced shift of the resonance maximum. Such information is of a large importance, first of all, for the solution of actual scientific problems bound with the dependence of the dislocation damping coefficient B by phonons on temperature T and dislocation density Λ. The preliminary researches of that kind have already been conducted in a recent work [10] on KBr crystals with permanent strain of 0.5 %. The indicated strain was selected according to [9] to be of such a value providing the resonance maximum shift to the range of lower frequencies at room temperature. The purpose of this work is to consider the resonance maximum behavior in KBr samples with permanent deformation $\varepsilon = 1$ %, which in contrast to [9], exerts at $T = 300$ K an inverse influence on localization of the resonance parameters, reducing its amplitude value and shifts the resonance towards higher frequencies.

The damped dislocation resonance was studied on potassium bromide single crystals by a pulse echo method using longitudinal waves in the frequency range of 7.5–217.5 MHz and temperature range 77–300 K. The crystals of the same set as in [8, 9] were used in the experiments. To introduce fresh dislocations, the sample was previously deformed until $\varepsilon = 1$ % along the <100> crystallographic direction. The ultrasound was passed through the sample along the same direction. The samples preparation technology, including cleaving, thin grinding, optical polishing, temperature anneal as well as the chemical etching techniques and metallographic studies of their surfaces are described in detail in [8, 9]. The discrimination procedure of the dislocation contribution out of measured ultrasound absorption and the low-temperature experimental technique are described there, too.

The frequency dependence of the dislocation decrement $\Delta_d(f)$ was studied using an original precision apparatus providing the measurements of propagation speed and absorption of ultrasound with simultaneous recording the sample loading curve. To measure the mentioned acoustic properties, the pulse interference and calibrated exponent methods were used, respectively.

Fig. 1 the frequency dependences of the dislocation damping decrement $\Delta_d(f)$ of ultrasound in KBr crystals with preliminary strained to $\varepsilon = 1$ % are shown at 77–300 K. The comparison and analysis of these data with similar results obtained before for strain $\varepsilon = 0.5$ % [10] have shown that both the character of experimental frequency dependences $\Delta_d(f)$ and their rather good description by an theoretical frequency profile [11] as well as the change tendency of resonance maximum parameters with temperature are in a good qualitative agreement. As for frequency localization of experimental curves for the models with a various dislocation density, it differs notably. In the sample strained up to $\varepsilon = 1$ % at a room temperature (see curve *1*, Fig. 1), the resonance maximum is appeared at frequency $f = 43$ MHz, whereas the maximum in a similar curve for 0.5 % strain [10] was at $f = 12.3$ MHz.

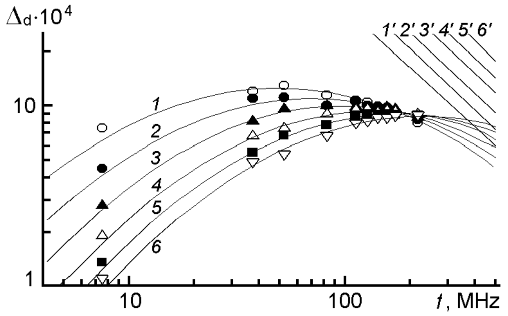

Fig. 1. Frequency dependence of dislocation ultrasound losses at various temperatures: theoretical curves (*1–6*) [11] and their high frequency asymptotes: *1, 1'* – 300K; *2, 2'* – 250K; *3, 3'* – 200K; *4, 4'* – 150K; *5, 5'* – 120K; *6, 6'* – 90K.

As the test temperature decreases, in this work, similar to [10], the resonance maximum shifts, as expected, to the high-frequency region, while reducing in amplitude. At the same time, the temperature shift of the frequency resonance found in this work is smaller than that established in [10]. As is seen from Fig. 1 (curve *6*), the resonance maximum at liquid nitrogen temperature is shifted towards higher frequencies, so that the descending branch of $\Delta_d(f)$ dependence has already partly left the limits of the effective measured frequency range 7.5–217.5 MHz. The behavior of frequency resonance parameters at the temperature variation is demonstrated in Fig. 2. It is seen that as the temperature drops, the dislocation decrement value Δ_m and the resonance frequency f_m in the maximum are changed monotonically in opposite directions. That is, the decreasing of Δ_m value at the temperature drop is accompanied by a fast increase of parameter f_m. The experiment confirms clearly the shift of resonance frequency curves, caused at first by the sample straining [9, 10] at a constant (room) temperature, and then, by its cooling up to nitrogen temperature [8–10]. At the crystal strains exceeding 1 %, the resonant maximum, monotonically reducing in amplitude, will be expected to leave the working range of measuring frequencies and its observation will become difficult.

When processing the obtained experimental results presented in Figs. 1 and 2 within the framework of the theory [3], it is possible to estimate the damping coefficient B for various temperatures. According to

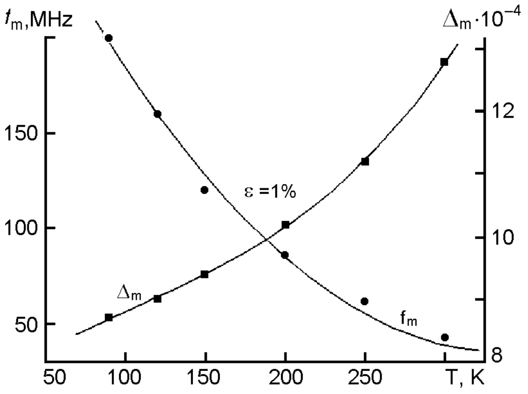

Fig. 2. Temperature changes of resonance frequency f_m and the decrement Δ_m value in the maximum of a resonance characteristic.

[3], the most preferable for that purpose is the equation (1), describing the descending branch of the resonance curve $\Delta_d(f)$, where the value Δ_∞ does not depend on the average effective length of the dislocation segment L

$$B = \frac{4\Omega G b^2 \Lambda}{\pi^2 \Delta_\infty f}, \qquad (1)$$

where b is the modulus of the Burgers vector; Λ, the dislocation density; G, the shear modulus in the active sliding system; Ω, the orientation factor; Δ_∞, the decrement value in the descending branch of the $\Delta_d(f)$ dependence. In the cases where it is possible to determine reliably the resonance Δ_m and f_m parameters, the values of coefficient B can also be found from equation (2) describing the resonance range [3]

$$B = \frac{7.48 \cdot 10^{-2} \Omega G b^2 \Lambda}{\Delta_m f_m}. \qquad (2)$$

In order to apply correctly the formulas (1) and (2), the theoretical frequency profile in this work was fitted to the experimental data extremely basing on data points lying in the resonance field and in descending branch $\Delta_d(f)$, as is recommended in [1, 2]. As is seen from the formulas (1) and (2), to calculate the relationship $B(T)$, it is necessary to know the dislocation density, the set of resonance characteristics $\Delta_d(f)$ for various temperatures, and temperature changes of other physical characteristics [$\Omega(T)$, $G(T)$, $b(T)$]. It is to note that the density of mobile dislocations in the KBr samples was determined by us in [9] before by selective etching and amounted $\Lambda = 13 \cdot 10^9$ m^{-2}. The temperature relations $\Omega(T)$, $G(T)$ and $b(T)$ were taken from [8].

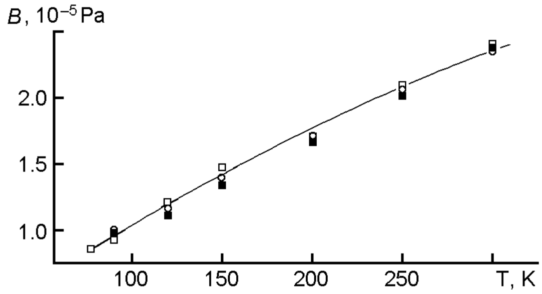

Fig. 3. A temperature course of the phonon drag factor of dislocations B: the data from [4] for $= 0.23$ % (light squares); the data from this work obtained on a descending branch (light circles) and parameters of a resonance (dark squares).

To check the comparability of results received under temperature displacement of resonance curves $\Delta_d(f)$, in this work the calculation of parameter B was made by two ways — and on a descending branch, and on a resonance. The calculation results of the coefficient B for the temperature 77–300 K are shown in Fig. 3. It is seen that the temperature dependences $B(T)$ obtained by various ways practically do not differ from each other. Within error limits of the experimental technique, those agree completely with the results of [8] obtained for KBr crystals with permanent strain $\varepsilon = 0.23$ %. The comparison of the above experimental data demonstrates that the increase of the KBr crystal preliminary strain from 0.23 up to 1 % considerably influences the ultrasound absorption level and the frequency localization of the damped dislocation resonance. At the same time, the account for its frequency and amplitude shift practically has not effected the absolute value and temperature course of the phonon dynamic dislocation drag $B(T)$. This result confirms the opinion [12] that the damping constant B is a fundamental characteristic of a crystal and is independent of its dislocation structure parameters (dislocation density Λ and length of segment L).

When considering the mentioned results, it was found that in a sample with permanent strain 0.5 % [10], the resonance frequency of the maximum f_m shifts from 12.3 up to 68 MHz, that is, increases by a factor of 5.53 as the temperature decreases from 300 to 77 K. At the same time, the similar characteristic for a sample strained up to 1 % increases only by a factor of 4.93. To elucidate the reasons for the decrease of the frequency spectrum shift, in this work the parameter L was estimated theoretically [3] using the formula

$$L = \sqrt{\frac{0.084 \cdot G \cdot b^2}{B \cdot f_m \cdot (1 - \nu)}}, \qquad (3)$$

where ν is Poisson factor.

Using the data for B and f_m shown in Figs. 2 and 3, and also taking from [8, 10] the values of remaining parameters included in (3), we have determined the average effective length of dislocation segment $L_{300} = 1.03 \cdot 10^{-6}$ m and $L_{77} = 0.76 \cdot 10^{-6}$ m for a sample with permanent strain 0.5 % at room and nitrogen temperature, respectively. For crystals with $\varepsilon = 1$ %, such estimations make $L_{300} = 0.55 \cdot 10^{-6}$ m and $L_{77} = 0.44 \cdot 10^{-6}$ m. When comparing those results, it is seen that the dislocation segment length L_{300} for the sample with 0.5 % strain is 1.86 times is more larger than that calculated for $\varepsilon = 1$ %. As a result, the dislocation resonance [3] at $T = 300$ K for crystals with $\varepsilon = 1$ % lies in higher frequency range, than that for a sample with $\varepsilon = 0.5$ %.

The cause of decreasing dislocation segment effective length L of a with temperature drop observed in this work and in [5–8, 10] associated with decreasing density of phonon gas. Due to increase of shear modulus G [8], the interaction energy of dislocation with impurity atoms increases, that makes potential stoppers (impurity atoms) the real points of pinning. As a result, the effective dislocation segment length L decreases, that becomes apparent in experiment as a shift of the resonance maximum both in amplitude and frequency (Figs.1, 2). Besides, due to the stated increase of G under temperature decrease, the linear tension force of dislocations increases (~ Gb^2). At a specified level of external stresses (in the amplitude-independent region), the curvature and amplitude of the dislocation segment decrease, that results in diminution of the area which is swept out by dislocation under its oscillatory motion. A consequence is the decrease of a dislocation damping decrement Δ_d at decreasing temperature (Fig. 1, 2). Note that all described processes are reversible. As the temperature rises from 77 up to 300 K, all the processes run in the opposite direction. Within the frame of the presented qualitative analysis, it is obviously possible to explain temperature-induced shifts of parameters f_m and L found in the present work, which are smaller than in samples, deformed up to $\varepsilon = 0.5$ % [10].

In a crystal pre-strained up to $\varepsilon = 1$ %, the dislocations of primary slip planes are intercepted by dislocations of "forest". In the interception points, appear strong pinning centers arise, resulting in a limited mobility of primary dislocations and linear shrinkage of their effective length. When temperature decreases from 300 to 77 K, the dislocation pinning effect by weak stopping centers also becomes apparent, though it is less pronounced in the presence of above-mentioned strong stoppers. As stated above, it is seen that while the ratio L_{300}/L_{77} for the samples strained up to 1 % makes 1.24, it is equal to 1.36 for crystals with 0.5 % strain.

Thus, in this work, we are managed to reveal the simultaneous influence of strong and gentle stoppers on the temperature-induced change of dislocation segment length L. Moreover, the influence of dislocation structure parameters on localization of frequency acoustic losses and on the temperature course of the of a dynamic dislocation drag constant B has been also studied. A rather good fitting to one $B(T)$ curve of the experimental data obtained for samples with various dislocation densities testifies that independence the $B(\Lambda)$ at $T = 300$ K established in [9], will perhaps be confirmed even at lower temperatures.

References

1. V.I.Alshits, A.M.Petchenko, Mechanisms of Internal Friction in Solids, Nauka, Moscow (1983) [in Russian].
2. V.I.Alshits, V.L.Indenbom, *Usp.Fiz.Nauk*, **115**, 3 (1975).
3. A.Granato, K.Lucke, *J.Appl.Phys.*, **27**, 583 (1956).
4. A.M.Petchenko, V.I.Mozgovoy, *Fiz.Tverd. Tela*, **30**, 2992 (1988).
5. A.M.Petchenko, *Kristallografia*, **37**, 458 (1992).
6. A.M.Petchenko, *Functional Materials*, **7**, 94 (2000).
7. A.M.Petchenko, D.L.Stroilova, A.A.Urusovskaya, *Fiz.Tverd.Tela*, **30**, 3455 (1988).
8. V.P.Matsokin, G.A.Petchenko, *Fiz.Nizk.Temper.*, **26**, 705 (2000).
9. G.A.Petchenko, *Functional Materials*, **7**, 785 (2000).
10. A.M.Petchenko, G.A.Petchenko, *Functional Materials*, **13**, 403 (2006).
11. O.S.Oen, D.K.Holmes, M.T.Robinson, US AEC Report NORNL-3017, 3 (1960).
12. N.P.Kobelev, Ya.M.Soyfer, V.I.Alshits, *Fiz. Tverd.Tela*, **21**, 1172 (1979).

Особливості резонансного поглинання повздовжнього ультразвуку у деформованих кристалах KBr при варіюванні температури

О.М.Петченко, Г.О.Петченко

Досліджено частотну залежність дислокаційного декремента згасання ультразвуку у монокристалах KBr, попередньо продеформованих до 1 %, в інтервалі температур 77–300 K та області частот 7,5–217,5 МГц. Визначено температурний хід коефіцієнта фононної в'язкості B, який добре узгоджується як з теорією, так і з експериментальними даними. Виявлено і проаналізовано вплив температурних змін довжини дислокаційного сегмента на параметри резонансного максимуму і динамічне гальмування дислокацій фононами.