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Dynamic damping of dislocations with phonons in KBr single crystals

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The damped dislocation resonance in KBr crystals has been studied using the pulse echo method in the frequency range 7.5 to 217.5 MHz and temperature range 77–300 K. In samples with pre-deformation 0.23 and 0.5 % the difference in dislocation density has been found to do not influence the temperature course of the damping constant B.

Импульсным эхо-методом в области частот 7,5–217,5 МГц и интервале температур 77–300 К исследован задемпфированный дислокационный резонанс в кристаллах KBr. Установлено, что в образцах с остаточной деформацией 0,23 и 0,5 % различие в плотностях дислокаций не влияет на температурный ход константы демпфирования B.

This work is a continuation of investigations [1, 2] considering the phonon-dislocation interaction in crystals using the high-frequency internal friction. The consideration of experimental data [1, 2] within the frame of theory of dislocation braking by phonons [3] has shown that both the dislocation damping coefficient B value at room temperature and its temperature dependence $B(T)$ within 77–300 K range is controlled by two mechanisms, namely, by the phonon wind and the relaxation of "slow" phonons. To reveal the possible braking due to the dislocation-dislocation interaction that is predicted by theory [4], the latter of those works has considered also the effect of dislocation density Λ on the damping constant B. The experiments were done under variation of the pre-strain ε from 0.23 to 1.5 % at room temperature. It has been found in the experiments that within said strain range, the dynamic braking coefficient B is independent of the dislocation density Λ. According to [2], the constancy of B at varying dislocation density evidences a negligible contribution of the additive caused by the mechanism [4] to the dislocation braking. The experiments aimed at establishing of the $B(\Lambda)$ functional dependence seem to be of extreme importance and should be performed in the whole temperature range where the $B(T)$ relationship is studied. This will make it possible not only to reveal the dislocation density effect on the temperature-induced $B(T)$ variations but also to trace the $B(\Lambda)$ behavior at low temperatures at which the part player by the "slow" phonons in the dislocation braking becomes predominant [3]. The purpose of this work is to study the damped dislocation resonance in KBr single crystals at residual strain $\varepsilon = 0.5$ % in 77–300 K temperature range using longitudinal waves in the frequency range of 7.5 to 217.5 MHz.

The high-accuracy measurements of the ultrasound damping and speed were carried out using the pulsed echo method on KBr single crystals oriented along the <100> crystallographic direction belonging to the same set of samples that those used in [2]. The sample preparation technology, the low-temperature acoustic-mechanical experiment procedure, the original experimental setup as well the methods of the data obtaining and processing are described in detail in [1, 2, 5–7].

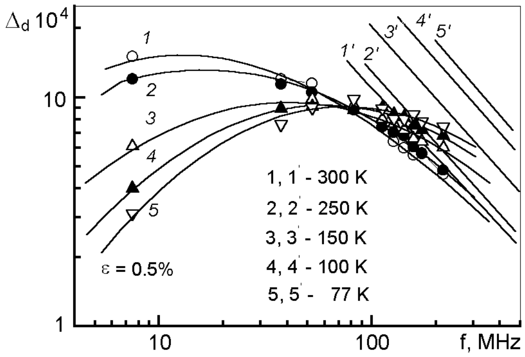

Fig. 1. Frequency dependences of dislocation decrement at various temperatures: theoretical curves (*1–5*) [9] and high-frequency asymptotes thereof (*1'–5'*).

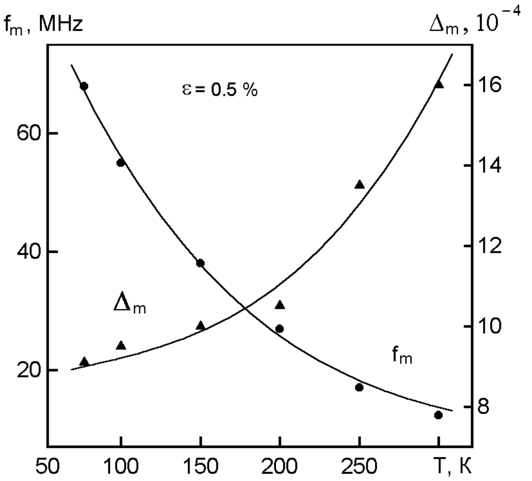

Fig. 2. Temperature dependences of resonance frequency f_m and the decrement maximum value Δ_m.

Fig. 1 shows the experimental data on the temperature effect on the frequency spectra of ultrasound absorption by dislocations $\Delta_d(f)$ at 77–300 K for the samples prestrained by compression up to $\varepsilon = 0.5$ %. Comparing these dependences with the corresponding curves for $\varepsilon = 0.23$ % obtained in [1], it is easy to conclude that the qualitative character of the $\Delta_d(f)$ dependences remains unchanged. The experimental points are described well enough by theoretical frequency profile obtained for exponential distribution of dislocation loops in lengths [8]. The trend to the frequency spectrum shift towards higher frequencies and lower dislocation decrement values at lowering temperatures is also retained. The effect of resonance parameter shift is more pronounced in Fig. 2 where presented are the temperature shifts of the resonance frequency $f_m(T)$ and of the dislocation decrement amplitude value $\Delta_m(T)$ in the maximum.

Using the experimental $\Delta_d(f)$ curves measured at $\varepsilon = 0.5$ % at 77–300 K as well as theoretical formulas [9], the $B(T)$ dependence can be calculated. The theory [9] provides the relationships (1) and (2) below that make it possible to calculate the dynamic braking coefficient of dislocation, B, using both the high-frequency asymptote of the frequency function of dislocation decrement $\Delta_d(f)$ and the parameters of resonance maximum thereof, respectively, namely,

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

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

where b is the Buergers vector module; Λ, dislocation density; Δ_∞, decrement value at frequencies $f >> f_m$; Δ_m and f_m, dislocation decrement and frequency values at resonance, respectively; Ω, orientation factor; G, shear modulus in the active gliding system. It is seen from (1) and (2), to calculate the $B(T)$ dependence, it is necessary to know the dislocation density, the family of resonance curves $\Delta_d(f)$ at various test temperatures, as well as temperature-induced variations of other physical characteristics: $\Omega(T)$, $G(T)$, $b(T)$. The density of mobile dislocations in KBr samples was determined by selective etching and amounted $4.5 \cdot 10^9$ m^{-2}. The $\Omega(T)$, $G(T)$, and $b(T)$ dependences have been taken from [1].

It is to note that to obtain the most correct B values, the Eq.(1) is used most often where Δ_∞ is independent of the average effective length of dislocation segment, L. In this work, we attempted to calculate B in two manners, both from the descendent branch and from resonance. It was of importance to establish how different the calculated values will be. The interest in this problem is due to the following circumstances. It was revealed in [2], starting from the $\varepsilon \sim 0.8$ %, the increase in the crystal pre-straining results in a shift of the $\Delta_d(f)$ dependence towards higher frequencies. On the other hand, the same resonance maximum shifting effect is due to the cooling of a crystal having a fixed dislocation density (see [2] as well as Figs. 1, 2 in this work). Thus, when studying the $B(T)$ dependences in a strongly strained crystal, superposition of those two factors might be expected, resulting in the fact that the descendent branch of $\Delta_d(f)$ curve will overstep in part the limits of the measurement frequency range (7.5 to 217.5 MHz). In this case, the only possible path would consist in calculation of the B parameter using the formula (2).

The values of braking coefficient B in the 77–300 K temperature range calculated using Eqs.(1) and (2) are presented in Fig. 3. The $B(T)$ dependences obtained in different manners are seen to be essentially coincident. Thus, when crystals with different densities of mobile dislocations are studied, the $B(T)$ can be calculated using any of said methods, however under condition [5–7] that the theoretical frequency profile is fitted mainly using the points lying in the resonance region and after it.

In Fig. 3, presented are also data taken from [1] obtained for KBr crystals at $\varepsilon = 0.23$ %. The increase of pre-strain from 0.23 % to 0.5 % is seen to not influence essentially the $B(T)$ temperature trend. The result, although being still a preliminary one, evidences that the conclusion on the B independence of the mobile dislocation density [2] might be valid not only at 300 K but could be generalized for lower temperatures. However, further $B(T)$ studies in a broader pre-strain range are necessary to establish finally the functional relationship $B(\Lambda)$ in the 77–300 K range.

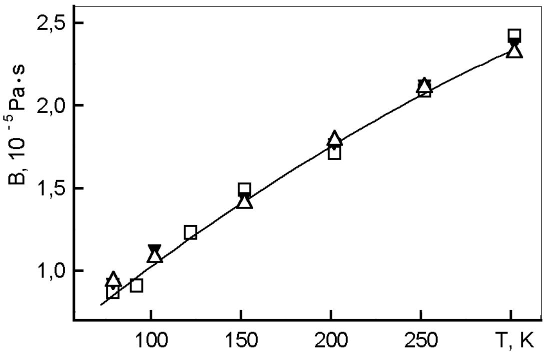

Fig. 3. Temperature dependence of dynamic dislocation braking coefficient, B: data from [1] for $\varepsilon = 0.23$ % (squares); data from this work obtained from descendent branches (dark triangles) and resonance regions (open triangles) of frequency spectra $\Delta_d(f)$ at various temperatures.

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Динамічне демпфування дислокацій фононами у монокристалах KBr

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Імпульсним луна-методом у області частот 7,5–217,5 МГц і інтервалі температур 77–300 К досліджено задемпфований дислокаційний резонанс у кристалах KBr. Встановлено, що в зразках із залишковою деформацією 0,23 і 0,5 % відмінність у густині дислокацій не впливає на температурний хід константи демпфування B.