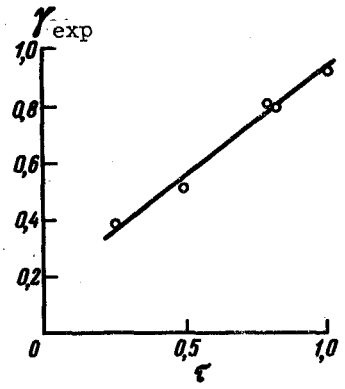

Fig. 3

values 0.027° (1), 0.013° (2), and 0.008° (3). We see that γ_{exp} increases with decreasing ΔT at fixed ρ_{12}, and the minimum of the curves shifts towards larger scattering angles (larger ρ_{12}). Such a behavior of γ_{exp} as a function of ρ_{12} coincides qualitatively with the predictions of [1], but calculations with allowance for the conditions of the given experiments are needed to obtain quantitative data.

Figure 3 demonstrates the increase of γ_{exp} with increasing optical thickness τ of the sample, at a fixed layer thickness, i.e., with increasing multiple scattering, for ρ_{12} = 3.8 mm. Such a dependence of γ_{exp} on τ can be attributed to the increase of the fluctuation correlation when the critical point is approached [1] and qualitatively contradicts the $\gamma(\tau)$ dependence in small-angle scattering of light by a system of independent scatterers [3].

In conclusion, we consider it our pleasant duty to thank D.M. Kaminker for support, V.A. Stepanov for a fruitful participation in the preparation of the last part of the investigation, G.V. Rozenberg, Yu.V. Petrov, and L.V. Popov for useful discussions, M.I. Trukhin for help and consultation on sensitometric measurements, and T.G. Braginskaya, A.D. Seledtsov, and T. Smirnov for help with the measurements and with the reduction of the experimental data.

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EFFECT OF IMPURITIES ON THE DAMPING OF HYPERSONIC WAVES IN CRYSTALS

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Point defects in crystals (impurities, vacancies, inclusions) cannot scatter hypersonic elastic waves directly, because the dimensions of such defects are smaller by several orders of magnitude than the wavelength of the elastic waves (the wavelength is about 10^{-4} cm at 1000 MHz). Point defects, nonetheless, can influence the damping of the elastic waves indirectly, via thermal phonons.

According to Akhiezer's theory [1], elastic-wave damping connected with their interaction with thermal phonons is given by [1 - 3]:

$$A = \gamma^2 \frac{CT\omega^2\tau}{2\rho v^3(1+\omega^2\tau^2)} \qquad (1)$$

Here γ is the anharmonicity constant, T the temperature, C the specific heat, ρ the density, v and ω the velocity and frequency of the elastic waves, and τ the relaxation time, proportional to the relaxation time τ_{ph} of the thermal

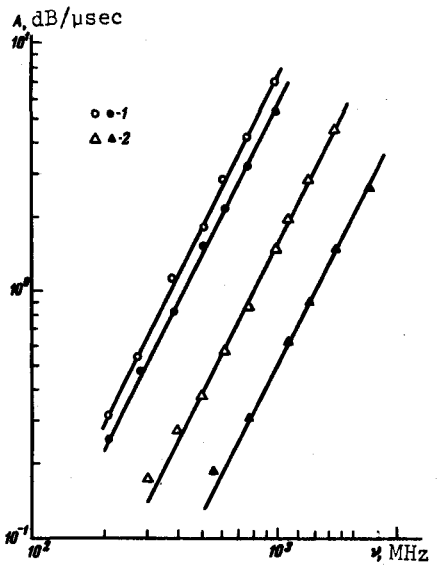

Fig. 1. Frequency dependence of the damping of longitudinal (1) and transverse (2) elastic waves at 300°K: o, Δ - pure silicon, •, ▲ - silicon with 4.4 at.% germanium. The straight lines were drawn assuming a quadratic frequency dependence of the damping.

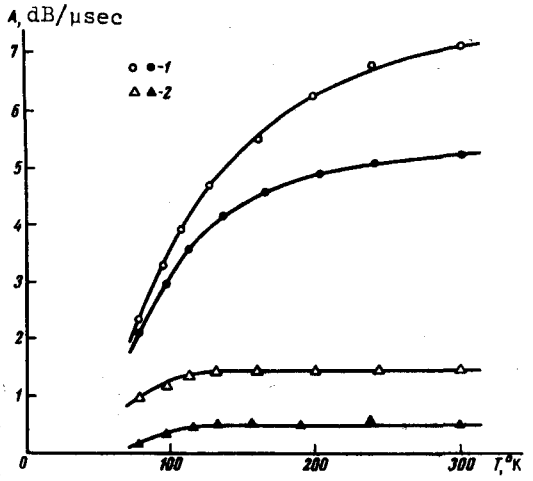

Fig. 2. Temperature dependence of elastic-wave damping at 1000 MHz. The notation is the same as in Fig. 1.

phonons. The latter is determined from the expression for the heat conduction

$$\kappa = \frac{1}{3} C\bar{v}^2\tau_{ph}.$$

Akhiezer's theory was developed for the case when $\omega\tau < 1$. This relation holds for many crystals at temperatures above that of liquid nitrogen. In this case (1) reduces to

$$A = \gamma^2 \frac{CT\omega^2\tau}{2\rho v^3} = \gamma^2 \frac{3\kappa T\omega^2\tau/\tau_{ph}}{2\rho v^3 \bar{v}^2}. \quad (2)$$

Thus, according to Akhiezer's theory, the damping of elastic waves in crystals is proportional to the thermal conductivity.

Impurities in crystals, causing the scattering of the thermal phonons, decrease the relaxation time of the latter and lead to a lowering of the thermal conductivity. According to (2), this should cause a decrease in the damping of the elastic waves, i.e., the damping should be lower in a crystal with impurities than in a pure crystal.

To verify this interesting conclusion of Akhiezer's theory, we measured the damping of elastic waves with frequencies near 1000 MHz in silicon crystals with germanium impurities.

It is known that introduction of germanium in silicon decreases the thermal conductivity greatly [4]. Thus, in silicon crystals with 4 at.% of germanium, the thermal conductivity is about one-tenth that of pure silicon at room temperature, and 1/30-th at liquid-nitrogen temperature. Such a strong decrease of the thermal conductivity should, if formula (2) is valid, lead to an equal decrease in the elastic-wave damping.

The damping measurements were made by the usual pulsed method. The elastic waves were excited and registered with the aid of piezoelectric converters made of quartz and lithium niobate. The damping was measured for elastic waves propagating along the directions <100>, <110>, and <111>. The differences in the damping in different directions turned out to be negligible.

The measurement results are shown in Figs. 1, 2, and 3.

Figure 1 shows the frequency dependence of the damping of elastic waves for pure silicon and for silicon with germanium impurity. In either case the damping is proportional to the square of the frequency, as it should in accord with (2). We see that the germanium impurity indeed leads to a decrease of the damping.

Figure 2 shows the temperature dependence of the damping, and Fig. 3 shows the dependence of the relative decrease of the damping on the concentration of the germanium impurity.

It follows from the foregoing results that at a germanium concentration close to 4 at.% the damping of transverse elastic waves is one-third that in pure silicon at room temperature, and one-sixth at liquid-nitrogen temperature. For longitudinal waves a decrease in the damping is likewise observed, but it is insignificant, merely about 30% at room temperature and even less at nitrogen temperature.

The results thus confirm qualitatively the conclusion of Akhiezer's theory that the damping of elastic waves is lower in crystals with impurities. The decrease of the damping, however, is not as strong (especially for longitudinal waves) as it should be in accordance with formula (2) and the thermal-conductivity data [3].

The reason for the quantitative discrepancy between Akhiezer's theory and our experimental results lies apparently in the following.

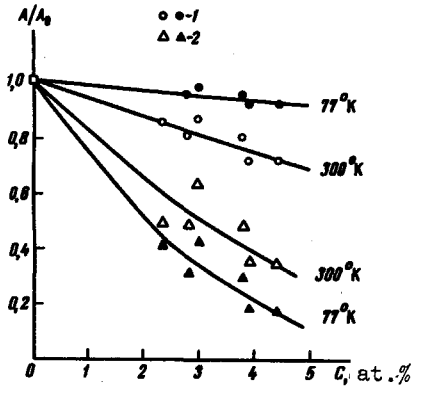

Fig. 3. Dependence of the relative decrease of elastic-wave damping in silicon on the germanium-impurity concentration: 1 - longitudinal waves, 2 - transverse waves.

X-ray diffraction topography data[1)] show that when germanium is introduced in silicon as an impurity, it becomes partially segregated, i.e., macrodefects of a sort are produced, and can scatter the elastic waves directly. In this case the increase of the elastic-wave damping in germanium-doped silicon, resulting from the scattering by the macrodefects, compensates to some degree for the decrease of the damping as a result of the decreased thermal conductivity of the crystals.

Allowance for this circumstance may reconcile the Akhiezer theory with the experimental results for the transverse elastic waves, but the discrepancy for longitudinal waves will still remain large.

The difference between the behavior of the longitudinal and transverse waves in crystals with impurities can apparently be explained as follows:

It was shown in [3] that the experimental results on the damping of elastic waves in pure

[1)]The authors are grateful to O.N. Efimov for reporting these data.

silicon and germanium crystals are well described by a formula of type (1) if it is assumed that for transverse waves the relaxation time τ is equal to the effective thermal-phonon relaxation time τ_{ph}, and is twice as large for longitudinal waves.

It has been proposed that this difference is due to the different character of the interaction between the longitudinal and transverse elastic waves with thermal phonons, as is the case when $\omega\tau > 1$. Indeed, from the energy and momentum conservation laws it follows that in the interaction between elastic waves and phonons the transverse waves can interact directly with the high-frequency thermal phonons, and the longitudinal waves only with thermal phonons having approximately the same frequencies; this should lead to relatively large relaxation times for the longitudinal waves.

If it is assumed that the germanium impurity in the silicon scatters thermal phonons in accordance with the Rayleigh law, a strong decrease of the relaxation can be expected for the high-frequency phonons, but the relaxation time of the low-frequency phonons is affected little. Accordingly, the relaxation time, and according to (2) also the damping, should decrease strongly in the case of transverse elastic waves interacting with high-frequency thermal phonons. The change in the damping is small for longitudinal waves interacting with the low-frequency phonons.

The rigorous explanation of the results requires, of course, a detailed theoretical analysis.

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FARADAY EFFECT IN YTTRIUM ORTHOFERRITE

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The transparency of orthoferrites in the visible and in the infrared has been known already for more than 10 years [1], but the Faraday effects in them has not been investigated to this day. Study of this effect in other transparent ferromagnets revealed magnetic susceptibility at optical frequencies [2] and a number of other phenomena. In all the magnetooptic investigations performed to date on orthoferrites, the light propagated along the weak-ferromagnetism axis [4]. The use of the Faraday procedure yielded in this case very small rotations of the polarization plane, on the order of one degree, and not proportional to the sample thickness. The reason, as shown in [4, 5], is that orthoferrites are birefringent crystals. Light propagating in them along directions that do not coincide with the optical axes produces not the Faraday effect, but elliptic birefringence. The major axis of the resultant ellipse rotates on emerging from the sample through an angle χ proportional to the ratio of the off-diagonal component ε' of the tensor $[\varepsilon]$ to the birefringence