Effect of resonant suppression of the anomalous transmission of x rays by ultrasound

I. R. Éntin

Institute of Solid State Physics, USSR Academy of Sciences

(Submitted July 20, 1977)
Pis'ma Zh. Eksp. Teor. Fiz. **26**, No. 5, 392–395 (5 September 1977)

It has been observed that ultrasound of wavelength equal to the extinction length produces a resonant weakening of the anomalous transmission of x rays.

PACS numbers: 78.20.Hp

The short wavelengths of x radiation ($\sim 10^{-8}$ cm) might seem to preclude any resonant action on this radiation by an acoustic field of microscopic wavelength. In fact, the influence of ultrasound with wavelength $\lambda_s \sim 10^{-1}$ cm on the intensity of the Bragg diffraction, which has been demonstrated in a number of

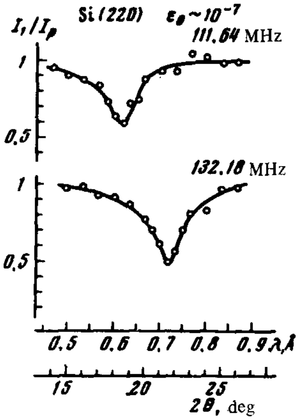

FIG. 1.

FIG. 1. Relative intensity of the (220) reflection vs. the x-ray wavelength. I_1 and I_0 are the reflection intensities with the sound generator turned on and off, respectively, 2θ is double the Bragg angle, and ϵ_0 is the strain amplitude.

studies,[1–3] manifests itself identically in a wide range of ultrasound frequencies, to the extent that the acoustic displacements cause deviations from the Bragg condition. It is shown in the present paper that, at a definite experimental geometry, resonant interaction is produced between an acoustic field ($\lambda_s \sim 10^{-2}$ cm) and the x-ray wave field in a perfect crystal.

It is known[4] that a new parameter—the extinction length τ—comes into play in diffraction by a perfect crystal. This parameter plays the role of the effective wavelength of the x-ray field, with

$$\tau = |\Delta \mathbf{k}|^{-1} \quad ,$$

where $\Delta\mathbf{k}$ is the difference of the quasiwave vectors of the Bloch waves of two branches of the dispersion surface (the equal-energy surface in the reciprocal-lattice space). Since the x rays interact weakly with the crystal (polarizability $\chi \sim 10^{-6}$—10^{-5}), the splitting of $\Delta\mathbf{k}$ is small, and τ has a macroscopic value 10^{-3}—10^{-2} cm. For the wave on the upper branch of the dispersion surface (field 1), modulated in such a way that the crystal atoms are located at the minima of the field, the effective absorption coefficient is $\mu_e \approx 0$, and the crystal is anomalously transparent (the Borrmann anomalous-transmission effect), whereas the field 2 on the lower branch is anomalously strongly absorbed ($\mu_e \approx 2\mu$, where μ is the linear coefficient of absorption). In a thick crystal ($\mu t \sim 10$, where t is the thickness) a noticeable amplitude far enough from the entrance surface is possessed on by the field 1.

It can be assumed that an ultrasound wave with wave vector $\mathbf{k}_s$, under the condition

$$\mathbf{k}_s = \Delta\mathbf{k} \qquad (\lambda_s = \tau) \quad , \tag{1}$$

causes scattering from the state 1 to the state 2 (the so called interbranch scattering)[1)] and a weakening of the anomalous transmission. Condition (1) for the resonant suppression of the Borrmann effect can be interpreted in the following manner. The phase difference $\Delta\phi$ of waves 2 excited on the neighboring spatial oscillations of the quasistatic displacement field, is equal to $2\pi(\lambda_s/\tau)$. At $\lambda_s = \tau$, the scattering into state 2 is enhanced by interference ($\Delta\phi = 2\pi$). The growth of the amplitude of the strongly absorbed field in the superposition of the wave field leads to an increase of μ_e and to a suppression of the anomalous transmission.

The geometry of the experiment was determined by the two conditions

$$\mathbf{k}_s \parallel \Delta \mathbf{k} \quad \text{and } (\mathbf{g}\,\mathbf{e}) \neq 0,$$

where **g** is the diffraction vector and **e** is the polarization vector of the acoustic wave. To introduce and register transverse ultrasonic oscillations, we attached to the end surfaces $(1\bar{1}0)$ of a perfect silicon crystal 7.85 mm thick quartz converters with a fundamental frequency ~10 MHz in such a way that the wave vector of the sound was in the reflecting plane perpendicular to the surface, and the polarization vector was directed along the (220) diffraction vector. The x rays from the continuous spectrum of the copper anode passed through mode converters, and was attenuated by each of them by not more than 20%. The measurements were performed at the frequencies of the mechanical resonance of the sample, which were located in the bands of the odd harmonics of the converter.

It is seen from the experimental curve (Fig. 1) that at definite x-ray wavelengths, depending on the ultrasound frequency, the intensity of the (220) reflection decreases. The positions of the minima correspond to equality of the extinction length (1) ($\tau \sim \lambda^{-1}$ far from the K absorption edge) to the sound wavelength $\lambda_s = c_s/\nu_s$ (the speed of sound is $c_s = 4.67 \times 10^5$ cm/sec,[7] and ν_s is the frequency). The atomic scattering factor $f(220) = 8.55 \pm 0.15$, calculated from the positions of the minima, agrees within the limits of errors with the known value.[4] The high sensitivity to weak acoustic strains $\epsilon \sim 10^{-7}$ disappears with deviation from the resonant wavelength.

The observed effects can serve as the basis for the development of methods of exact measurements of dynamic parameters of crystals in x-ray and neutron diffraction techniques, and to increase the sensitivity of topographic methods.

The author thanks Ya.M. Soifer and N.P. Kobelev, whose experimental assistance made the study possible, and V.I. Nikitenko and E.V. Suvorov for interest in the work and for useful discussions.

1)Interbranch scattering by dislocations and stacking faults is considered in[5,6].

1R.D. Mindlin and W.J. Spencer, J. Acoust. Soc. Am. **42**, 1268 (1967).
2T.F. Parkinson, E. Gürmen, S.K. Loyalka, and L.D. Muhlestein, J. Appl. Phys. **45**, 2021 (1974).
3A. Hauer and S.J. Burns, Appl. Phys. Lett. **27**, 524 (1975).
4Z.G. Pinsker, Dinamicheskoe rasseyanie rentgenovskikh lucheĭ v ideal'nykh kristallakh (Dynamic Scattering of X-Rays in Perfect Crystals), Nauka, 1974.
5A. Authier, Advances in X-Ray Analysis, Plenum Press, 1967, New York, vol. 10, p. 9.
6V.I. Al'shitz, V.L. Indenbom, and I.A. Rusakova, Abstracts of 4th Conf. on Dynamic Effects of X-Ray and Electron Scattering, Leningrad, 1976, p. 18.
7R. Truell *et al.*, Ultrasonic Methods in Solid State Physics, Academic, 1969.