

Surface oscillations in the crystals AlO_3 , LiNbO_3 , and $\text{Y}_3\text{Fe}_5\text{O}_{12}$

V. A. Yakovlev and G. N. Zhizhin

Spectroscopy Institute, USSR Academy of Sciences

(Submitted November 10, 1973; resubmitted December 18, 1973)

ZhETF Pis. Red. 19, 333-336 (March 20, 1974)

The method of disturbed total internal reflection was used to observe surface oscillations in the spectrum region $600\text{--}900\text{ cm}^{-1}$ corresponding to the strong reflection bands of sapphire, lithium niobate, and yttrium iron garnet crystals. The dependence of their frequency on the wave vector is traced.

Surface excitons, which are excitations that attenuate in the interior of a crystal and propagate only along its surface,^[1] have been attracting increased interest of late. Surface oscillations were experimentally observed in the IR band in a large number of crystals, both cubic and anisotropic.^[2-5] This shows that the existence of surface oscillations is not an exception but more readily the rule in crystals having strong reflection bands.

We have chosen the crystals $\alpha\text{-Al}_2\text{O}_3$ (sapphire), LiNbO_3 (lithium niobate), and $\text{Y}_3\text{Fe}_5\text{O}_{12}$ (yttrium iron garnet). We observed surface phonons in the $600\text{--}900\text{ cm}^{-1}$ spectral region corresponding to strong reflection bands of these crystals. To investigate these phonons and their interaction with light (surface polaritons), we used the procedure of disturbed total internal reflection. The investigated crystals were cut in the form of plates that were clamped to the KRS-5 semicylinder in the NPVO-1 attachment. The air gap between the crystal and the semicylinder could be adjusted with the aid of liners. The spectrum was recorded with an IKS-16 spectrophotometer. The measurements were made in light polarized parallel to the incidence plane (no surface oscillations are excited in perpendicularly polarized light). The polarizer was placed either ahead of the entrance slit of the monochromator, or behind the exist slit simultaneously in both beams.

For sapphire and lithium niobate, which are uniaxial crystals (unlike the cubic yttrium iron garnet crystals), the spectrum of the surface oscillations should depend on the direction of the optical axis.^[1,6] In the samples investigated by us, the optical axis was perpendicular to

the plane of the plate. By varying the light incidence angle θ in the attachment we were able to trace the dependence of the frequency of the surface polariton on the wave vector, which was determined^[2-5] from the formula

$$K_x = \frac{\omega}{c} n \sin \theta, \quad (1)$$

where n is the refractive index of KRS-5 glass.

Figures 1-3 show the measured dispersion curves for sapphire, lithium niobate, and yttrium iron garnet respectively. From the rather complete published data on the lattice dynamics of sapphire and lithium niobate and on the frequencies and oscillator strengths^[7,8] we were able to plot theoretical dispersion curves for these two crystals. We used for this purpose the formula^[4]

$$\epsilon_x = - \frac{\left[\frac{\epsilon_x}{\epsilon_z} (\kappa_x^2 - \epsilon_z) \right]^{1/2}}{(\kappa_x^2 - 1)^{1/2}} \quad \kappa_x = K_x \frac{c}{\omega}, \quad (2)$$

where the coordinate system, which coincides with the principal axes of the dielectric tensor, was chosen such that the z axis was perpendicular to the surface plane and the wave vector K_x was directed along the x axis. Figures 1 and 2 show the theoretical curves for the three orientations of the optical axis along the chosen coordinate axes. The experimental points lie somewhat lower than the dispersion curves for the corresponding cut, this being apparently due to anharmonicity.^[2] Figures 1 and 2 show no experimental points for κ_x

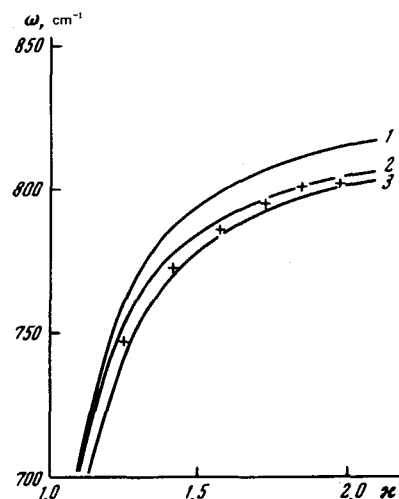


FIG. 1. Calculated dispersion curves for the cuts $C \parallel y$ (1), $C \parallel x$ (2), and $C \parallel z$ (3), and experimental results for the sapphire crystal with $C \parallel z$ (C is the optical axis).

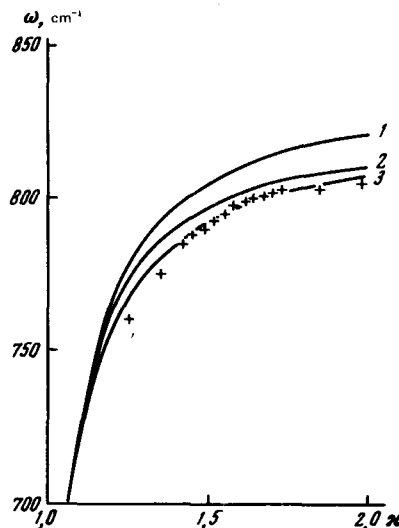


FIG. 2. The same as Fig. 1 but for the lithium niobate crystal.

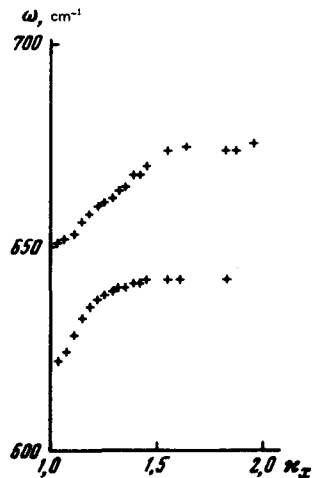


FIG. 3. Dispersion of the surface polaritons in yttrium iron garnet (experiment).

close to unity. The reason is that the divergence of the light beam in the NPVO element gives rise to a scatter [see formula (1)] in the values of the wave vector. At small K_x the slope of the dispersion curves increases to

very large values for sapphire and lithium niobate, and this leads to an abrupt broadening of the absorption peak and makes it difficult to measure its position. This phenomenon is not observed for yttrium iron garnet, for which, owing to the small slope, the dispersion curves of both surface polaritons observed by us could be traced all the way to $\kappa_x \approx 1$. It can be noted in conclusion that the spectrum of the surface polaritons of the yttrium iron garnet makes it possible to determine in the IR region optical constants that cannot be obtained by other methods.

¹V. M. Agranovich, *Teoriya eksitonov (Exciton Theory)*, Nauka, 1968, Chap. 8.

²V. V. Bryskin, Yu. M. Gerbshtein, and D. N. Mirlin, *Fiz. Tverd. Tela* **14**, 543 (1972) [*Sov. Phys. -Solid State* **14**, 453 (1972)]

³N. Marshall and B. Fisher, *Phys. Rev. Lett.* **28**, 811 (1972).

⁴V. V. Bryskin, D. N. Mirlin, and I. I. Reshina, *ZhETF Pis. Red.* **16**, 445 (1972) [*JETP Lett.* **16**, 315 (1972)]. *Fiz. Tverd. Tela* **15**, 1118 (1973) [*Sov. Phys. -Solid State* **15**, 760 (1973)].

⁵H. J. Falge and A. Otto, *Phys. stat. solidi (b)* **56**, 523 (1973).

⁶V. N. Lyubimov and D. G. Sannikov, *Fiz. Tverd. Tela* **14**, 675 (1972) [*Sov. Phys. Solid State* **14**, 575 (1972)].

⁷A. S. Barker, *Phys. Rev.* **132**, 1484 (1963).

⁸A. S. Barker and R. Loudon, *ibid.* **158**, 443 (1967).