# LIGHT SCATTERING BY SURFACE PHONONS IN CRYSTALS

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Abstract

A theory of inelastic light scattering by surface acoustic phonons in homogeneous crystals is presented. The Green functions are determined by the use of a classical linear response method and used to evaluate the Brillouin cross section. The acoustic modes are found from solutions to the acoustical-wave equation and boundary conditions appropriated. Two light-scattering mechanisms, namely the surface corrugation and bulk elasto-optic effect are analyzed by deriving optical fields which satisfy both the acousto-optically driven wave equation and the electromagnetic boundary conditions. No restrictions are imposed concerning the angle of incidence of the light. Some representative computed Brillouin lineshapes are also presented and their features discussed.

## 1. Introduction

Two different techniques of inelastic light scattering spectroscopy have been developed for the study of acoustic phonons at the surface of opaque and transparent materials. The first one, backscattering of light from thermally excited phonons, gives information about both bulk and surface displacements: the coupling mechanism between light and phonons may be due either to the elasto-optic effect [ 1-2 ] or to the presence of mechanical surface-ripples [ 3,4 ]. The second technique - Brillouin scattering of reflected light - has been used to study acousto-electrically amplified bulk phonons [ 5,6 ]. Here the mechanical surface grating is responsible for the scattering [ 5 ].

In this communication we focus our attention on the former technique in order to explore the use of Green functions in the problem.

We consider two isotropic media distinguished by sufixes M (for $Z > 0$) and M' (for $Z < 0$) and assumed to be in contact along an infinite xy plane ($Z = 0$). The acoustic wavevectores Z - components for waves of a given frequency W and identical wavevector X - component $Q^x$ are

$$q_L^z = \left[(W/V_L)^2 - Q^{x^2}\right]^{1/2}$$
$$q_T^z = \left[(W/V_T)^2 - Q^{x^2}\right]^{1/2} \qquad (1)$$

with similar expressions for medium M'. Here $V_L$ and $V_T$ are the longitudinal and transverse velocities of the acoustic wave in medium M.

## 2. Elasto-Optic Scattering

If the medium M' is fairly transparent, the light scattering cross section in dominated by the coupling to the light via the variation of the dielectric susceptibility. The polarization $\vec{P}_s$ produced by the interaction between the incident light and the crystal excitation in the medium is given by

$$P_s^i = - \varepsilon_0 \, n^4 p^{ijk\ell} \, E_I^j \, u^{k\ell} \qquad (2)$$

where n is the refractive index, p is the elasto-optic tensor, $E_I$ the electric vetor of the incident light and $u^{k\ell} = \partial u^k/\partial x^\ell$ is the gradient of the displacement $u^k$.

The power spectra or correlation functions for the displacement gradient are obtained by application of the generalised fluctuation-dissipation theorem [ 4 ]

$$\left\langle u^{ij}(Q^z)\, u^{k\ell}(Q'^z)^* \right\rangle_{Q^x,W} = (i\hbar/2\pi)\left[n(W) + 1\right] x$$
$$\left[ \ll u^{k\ell}(Q'^z);\, u^{ij}\,(Q^z)^* \gg^*_{Q^x,W} - \ll u^{ij}(Q^z);\, u^{k\ell}(Q'^z)^* \gg_{Q^x,W} \right] \qquad (3)$$

where $n(W) + 1 \simeq K_B T/\hbar W$ is the Bose-Einstein thermal factor. Here $\ll\ \gg$ is the quantum-mechanical Green function as defined by Zubarev [ 7 ].

The cross section is now obtained by the use of (3) together with its usual definition [ 8 ] in order to get the form of the Brillouin lineshapes as shown in figure 1.

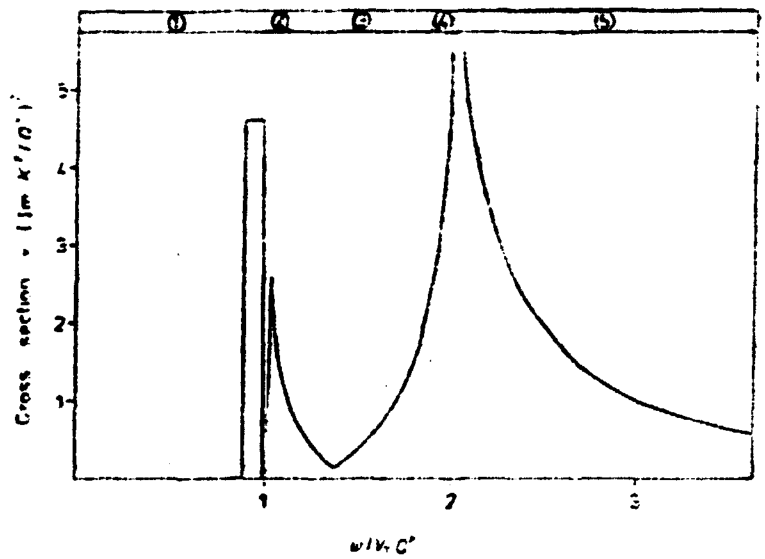

Figure 1 - Light scattering cross section, elasto-optic mechanism. The rectangle shows the integrated area of the surface peak of the Stoneley type.

3. Surface - Ripple Scattering

For highly absorbing materials M'(metals for example) the cross section is due to the surface - ripples induced by the displacement component normal to the surface. The surface - ripple amplitude is a statistical quantity whose mean - square value is calculated by use of the fluctuation - dissipation theorem

$$< | u^z(0) |^2 >_{Q^x_, W} = \frac{\hbar}{\pi} [ n(W)+1 ] I_m << u^z(0); u^z(0)^* >>_{Q^x_, W} \quad (4)$$

The shape of the spectrum for this case is determined by (4) and this is plotted as a function of the dimensionless parameter $W/V_T Q^x$ in figure 2.

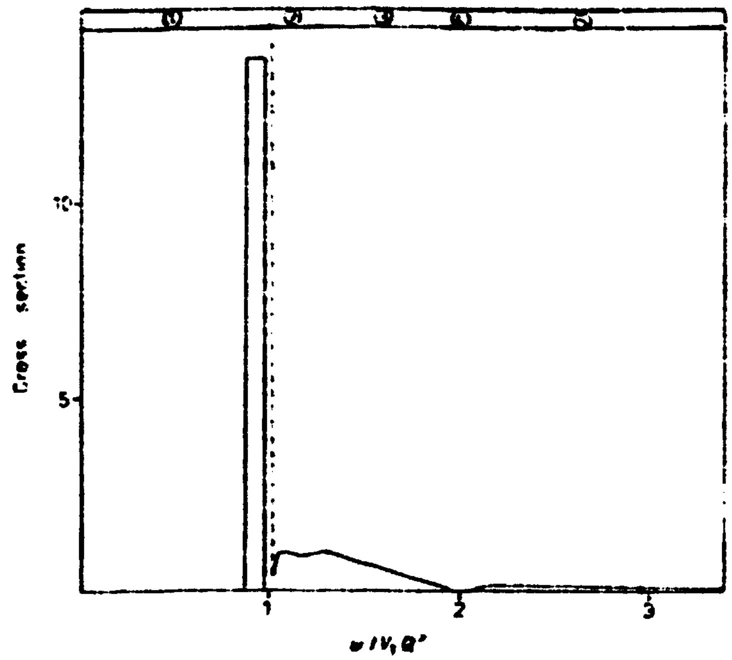


Figure 2 - Light scattering cross section, surface - ripple mechanism.

## 4. Conclusion

We have presented in a summarized way, a theory of light scattering from two media with elastic isotropy. The theory takes into account the elasto - optic and surface - ripple mechanism in the cross section but interference term between these two scattering processes is not considered here [ 9 ]. Unfortunatelly there are so far no experimental measurements by light scattering spectroscopy that can be compared with our theoretical predictions.

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