GENERAL PHYSICS

I. MICROWAVE SPECTROSCOPY*

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A. WORK COMPLETED

1. MEASUREMENT OF THE ELECTRONIC CONTRIBUTION TO ULTRASONIC ATTENUATION IN A TIN FILM AT 9 GHz

This work has been completed by Robert L. Woerner and submitted as a thesis to the Department of Physics, M. I. T., January 1970, in partial fulfillment of the requirements for the degree of Bachelor of Science. A summary of the thesis research follows.

Measurements of the attenuation of coherent phonons in a tin film (6.3 μ thick) at liquid Helium temperatures were made as the film was switched between the normal and superconducting states. The frequency of the phonons was varied between 9.1 GHz and 9.4 GHz. These relative attenuation measurements yielded a value for the electronic contribution to the attenuation of the phonons of 980 cm^{-1} $\pm$15%. This agrees with the theoretical formula for the attenuation given by Pippard if it is assumed that in tin four electrons per atom contribute to the attenuation. This is consistent with the valence of tin, which is 4.

M. W. P. Strandberg

B. METALLIC CONDUCTION

The equations given here form a complete set of transverse exponential solutions of Maxwell's equations and the Boltzmann equation in an infinite ideal metal in the semi-classical low-temperature limit (small signal, no x or y dependence, spherical Fermi surface, isotropic mean-free path, all excitations at the Fermi surface). They can be used to expand the field and momentum distribution of the anomalous skin effect with

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arbitrary surface reflection conditions.

$$\left.\begin{aligned} E_x &= E_o \exp j(\omega t \mp k_z z) \\ H_y &= \frac{\mp k_z}{\omega\mu} E_o \exp j(\omega t \mp k_z z) \\ f(\vec{p}) &= \frac{(2/h^3)\, e\tau(p_x/p_F)}{1 + j\omega t \mp jk_z \ell (p_z/p_F)} E_o \exp j(\omega t \mp k_z z) \end{aligned}\right\} \tag{1a}$$

Complex k_z is the solution of the transcendental equation $k_z^2 + j\omega\mu\, \sigma(k_z) = 0$.

$$\left.\begin{aligned} E_x &= E_o \exp j(\omega t - k_i z) \\ H_y &= \frac{\pm p_{zi}}{p_F \ell \omega\mu} E_o \exp j(\omega t - k_i z) \\ f(\vec{p}) &= \left[\frac{(2/h^3)\, e\tau(p_x/p_F)}{(1+j\omega t)(1 - p_z/p_{zi})} + A\tau\, \delta(1 - p_z/p_{zi})\right] (p_x/p_F)\, E \exp j(\omega t - k_i z) \end{aligned}\right\} \tag{1b}$$

where

$$jk_i \ell = (1+j\omega t) p_F/p_{zi}$$

p_{zi} runs from $-p_F$ to $+p_f$

$$\sigma(k_z) = \frac{3\sigma_o}{4(1+j\omega t)} \left[-\frac{2(1+j\omega t)^2}{(k_z \ell)^2} + j\frac{(1+j\omega t)}{k_z \ell}\left(1 + \frac{(1+j\omega t)^2}{(k_z \ell)^2}\right) \ln \left(\frac{1 - \frac{jk_z \ell}{1 + j\omega t}}{1 + \frac{jk_z \ell}{1 + j\omega t}}\right)\right]$$

and

$$A = -\frac{1}{\pi\left(p_F^2 - p_{zi}^2\right) e \ell} \left[\frac{(1+j\omega t)^2\, p_F^2}{j\omega\mu\, p_{zi}^2} + \sigma(k_{zi})\right].$$

Both forward- and backward-wave terms are included. Equations 1a are well known. Equations 1b do not seem to have been published. Although they offer a conceptually simple approach that may give insight into the anomalous skin-effect solutions, they are somewhat singular functions without obvious orthogonality properties. This may explain why there has been no stampede away from the conventional approach.

R. L. Kyhl

C. GEOMETRIC DISPERSION OF INCOHERENT PHONON PULSES IN QUARTZ

Bolometric observations of incoherent phonons in x-cut quartz by Andrews[1] included pulses associated with the usual archetypical longitudinal (L), fast transverse (FT), and slow transverse (ST) modes, as well as a remotely off-axis mode termed the oblique (O) mode. A plane wave in an anisotropic medium, characterized by a wave vector $\vec{k}$, and angular frequency ω may propagate in any direction with any of three phase velocities, v, given by the point on each of the three figured velocity surfaces corresponding to the direction of $\vec{k}$ (see Fig. I-1). In the nondispersive limit ($\omega \lesssim 10^{12}$ Hz), v is independent of the magnitude of $\vec{k}$. The acoustic power flow, or Poynting vector, $\vec{S}$, for a wave

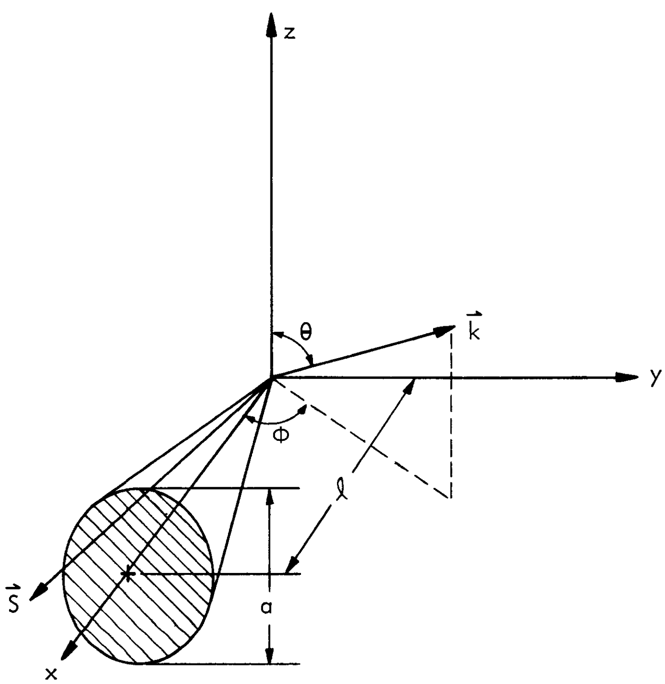

Fig. I-1. Coordinate geometry showing circular bolometer aperture of diameter a, located in yz-plane at distance ℓ from origin. The coordinate x axis is the crystallographic x axis of quartz. An example is given of detectable power, represented by the Poynting vector $\vec{S}$, with $\vec{k}$ outside the receiving cone.

of given $\vec{k}$ and v is in the direction of the gradient of that particular velocity surface at its intersection with $\vec{k}$. Consequently, as $\vec{k}$ moves over a particular locus, $\vec{S}$ moves over some other locus, whose relation to the first is quantitatively different for each velocity surface. As has been shown in the detailed analysis of Farnell,[2] waves having their wave vectors lying within an elliptical cone centered on the x axis contribute to

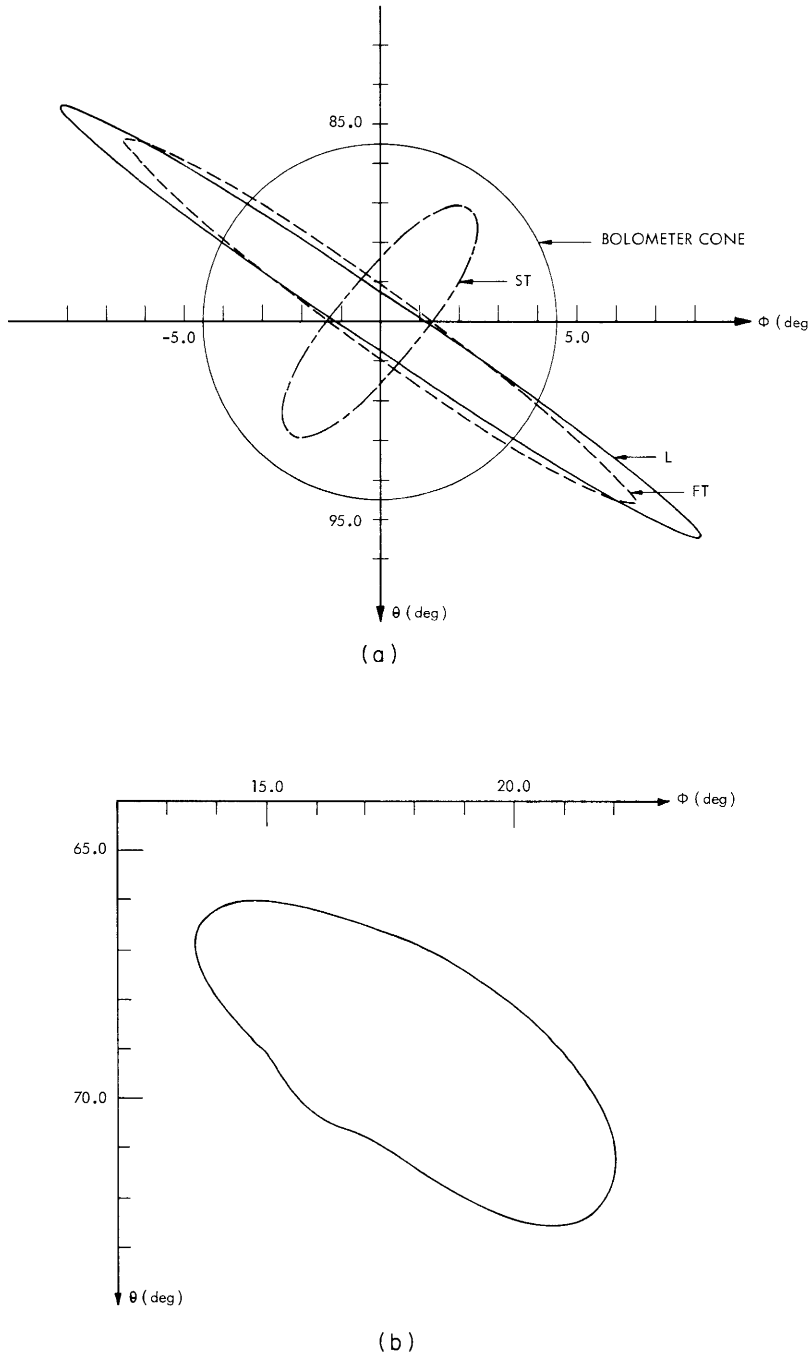

Fig. I-2. (a) Angular limits of the $\vec{k}$ excursion for the three near-axial modes of the three velocity surfaces. The designations L, FT, and ST refer to the type of polarization of the three exactly axial modes. The x axis corresponds to $\theta = 90°$; $\phi = 0°$.
(b) One lobe of the region corresponding to the oblique (O) mode. The other lobe is located, by symmetry, by rotation through 180° about the x axis.

power flow inside a coaxial circular cone of different angular dimensions. In Fig. I-2a, we show the results of calculations mapping out the region of $\vec{k}$ excursion of the three archetypical L, FT, and ST modes for power flow within a circular cone of half-angle 4.5° corresponding to the bolometer cone in Andrews' experiments (see Fig. I-1). In Fig. I-2b we give one lobe of another angular region, located on the same velocity surface that corresponds to the FT region in Fig. I-2a. This also gives rise to detectable power within the bolometer cone, and corresponds to the observed "oblique" mode. This region (both parts – the other lobe corresponds to a figure rotation of 180° about the x axis) has a relatively large total angular size compared with those in Fig. I-2a.

Following Andrews' assumption that a (temperature) pulsed hot-film source of incoherent phonons gives rise to black-body thermal "spikes" propagating in all directions, independently of polarization,[3] we have calculated the power delivered through the aperture of the bolometer as a function of time. This was done by calculating the delivery time of the detectable acoustic power corresponding to points on the unit sphere in $\vec{k}$ space on a 0.1° mesh. The "active" points were then tabulated against time with a v^{-3} density of states and $\sin\theta$ geometrical weighting. A histogram of the power delivery was then constructed by interpreting the density of the weighted, tabulated points per unit time interval as the power detected at the bolometer. Figure I-3 shows the broadening of instantaneous thermal spikes caused by the allowed excursion of $\vec{k}$ over each of the regions in Fig. I-2. Comparison with Andrews' discussion[3] of elastic

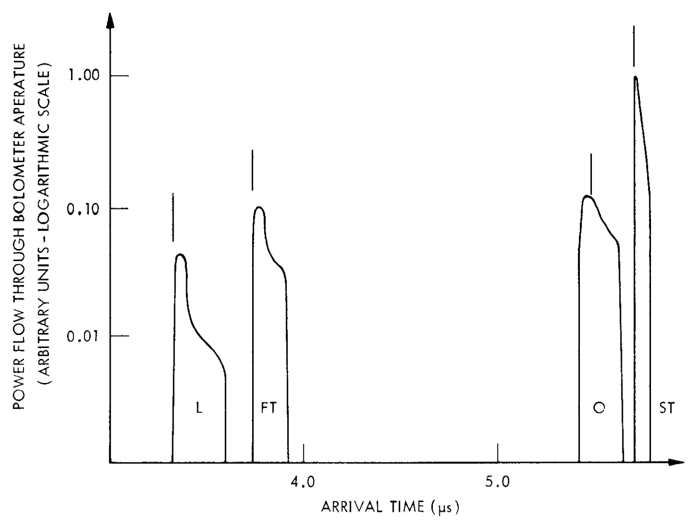

Fig. I-3. Power pulses corresponding to a hot-point source of infinitesimal duration, being delivered through a bolometer aperture a = 3 mm, situated at ℓ = 19 mm from the origin (see Fig. I-1). Vertical bars denote arrival times associated with the average velocity in each $\vec{k}$ region.

dispersion indicates that at generating temperatures below about 5°K, the geometric dispersion for the usual experimental arrangement is dominant, being in the range 0.1-0.3 μs. The relative pulse heights are in qualitative agreement with those observed by Andrews.

L. R. Fox

References

1. J. M. Andrews, Jr., "Observations of Incoherent Phonon Propagation in X-cut Quartz," Quarterly Progress Report No. 77, Research Laboratory of Electronics, M.I.T., April 15, 1965, pp. 7-15.
2. G. W. Farnell, Canad. J. Phys. 39, 79 (1961).
3. J. M. Andrews, Jr., "Incoherent Phonon Propagation in a Born-Karman Lattice," Quarterly Progress Report No. 79, Research Laboratory of Electronics, M.I.T., October 15, 1965, pp. 7-14.