PHYSICAL ACOUSTICS

Principles and Methods

VOLUME V

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Principles and Methods

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PREFACE

High frequency sound waves in gases, liquids, and solids have proven to be powerful tools for analyzing the molecular, defect, domain wall, and other types of motions that can occur in these media. The first four volumes of this treastise, each composed of two separate books, were produced to provide a background for these applications. Outlines of these volumes can be found following the table of contents.

Starting with Volume V, the aim has been to apply some of the techniques and results discussed in previous volumes to more current investigations. Since the chapters are not limited to any one field but rather cover the whole of physical acoustics, Volume V has no subtitle; this policy will be extended to subsequent volumes as well.

The first chapter discusses a number of new effects that can occur when waves are propagated in solids subject to high magnetic fields, i.e., fields up to 150 kG. The subjects include attenuation and velocity changes in liquid and solid metals, transmission of sound waves in superconductors, and giant quantum oscillations at high magnetic fields.

The second chapter consists of the latest measurements and techniques used for investigating the effects of impurities on the anelastic properties of crystalline quartz. The results show that at room temperature the impurity that has the largest effect on the internal friction (Q^{-1}) of synthetic quartz is the adsorbed water molecule H_2O. The presence of this molecule also shows up in infrared measurements, and in fact a very good correlation is obtained between crystal Q and infrared absorption. This work won the author one of the C.B. Sawyer awards presented at the 1968 Signal Corps Symposium.

A related chapter presents the x-ray diffraction topological method for studying resonant vibrations and the defect structure of single crystal quartz. The modes of motion possible in a vibrating crystal quartz plate are numerous and it is difficult by ordinary means to identify the mode of vibrations. By using x-ray topographs together with a mathematical analysis of the motion, considerable clarification has been obtained for the modes of motion of quartz crystals.

The last three chapters deal with the transmission of hypersonic sound waves of frequencies as high as 800 GHz, i.e., 8×10^{11} cycles. These frequencies are approaching the limiting frequencies that can be transmitted by the crystal lattice and require special techniques to be employed. The two techniques employed are: coherent elastic wave propagation generated by piezoelectric film transducers, and transmission of thermal pulses at low temperatures. Both of these techniques raise questions about what conditions have to be met before such concepts as group velocity and energy velocity can be meaningful and a theoretical chapter is included which covers these conditions.

Elastic wave propagation has been carried to a frequency of 114 GHz. This appears to the limiting value due to the requirement of parallelism necessary for coherent wave propogations. It is suggested that quantum detectors may be substituted for piezoelectric films since quantum detectors are insensitive to all geometrical irregularities and higher frequencies may be obtained. The other technique of heat pulse transmission employs a superposition of a wide band of randomly placed frequencies approximately centered about the frequency kT/h. For sapphire, isolated heat pulses with the longitudinal and shear wave velocities could be observed at temperatures up to 38°K which corresponds to frequencies as high as 8×10^{11} cycles (800 GHz). This represents the highest frequency sound transmission yet obtained. Above that temperature phonon scattering is so large that the propogation is by normal heat conduction. This probably sets a limit on the frequency for which sound wave transmission can be carried out by thermal techniques.

Heat pulses have also been used to study sound transmission in metals and evidence is presented for the transmission of heat pulses with the Fermi electron velocity for gallium. Hence this technique is a powerful tool for ultrasonic waves and thermal heat pulses.

The editor owes a debt of gratitude to the many contributors who have made this volume possible and to the publishers for their unfailing help and advice. Starting with Volume VI, he would like to welcome as coeditor Dr. Robert N. Thurston of Bell Telephone Laboratories.

Warren P. Mason

July, 1968

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Acoustic Wave Propagation in High Magnetic Fields

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I. Introduction

In the last decade ultrasonic techniques have been used extensively in solid-state research. The impetus to this activity came from Bömmel's discoveries of (a) the dramatic decrease in the ultrasonic attenuation which occurs when a metal becomes superconducting (Bömmel, 1954) and (b) the oscillatory variation of the attenuation as a function of magnetic field which is observed in pure metals at low temperatures (Bömmel, 1955). The physical basis of these two important effects was already understood in the late fifties, and subsequently these phenomena were used as tools in studies of superconductivity and the Fermi surfaces of metals. During the last few years other types of ultrasonic phenomena were discovered in metals, paramagnets, ferrites, and high-field superconductors. Each of these discoveries opened a new avenue of research in the field of ultrasonics.

Magnetic fields play a key role in many ultrasonic studies of solids. For example, in the investigation of the ultrasonic attenuation in superconductors magnetic fields are often used to quench superconductivity. Furthermore, most ultrasonic studies of the Fermi surfaces of metals are based on phenomena which involve some oscillatory or some resonance type of behavior of the attenuation in a magnetic field.

Until the last five years or so the use of magnetic fields in ultrasonic work was confined to magnetic field intensities below ~30 kG. There are two basic reasons for this fact. First, prior to 1963 magnetic fields above ~30 kG were available only in a small number of laboratories. Second, magnetic field intensities exceeding a few kG were not required for the most popular types of ultrasonic studies. For example, superconductivity in ordinary (type-I) superconductors such as lead, tin, or indium can be quenched with fields of less than ~1 kG. Also, the geometric resonances [see Roberts (1968)], which are widely used in Fermi-surface studies, are observed only at relatively low magnetic fields but not at high fields, where the cyclotron orbit of the electron is small compared to the ultrasonic wavelength. In the last few years magnetic fields far in excess of 30 kG have become available and the use of such high fields in ultrasonic work became more widespread.

At present there are three standard ways of generating high magnetic fields:

a. Superconducting Magnets. The magnetic field in these magnets is produced by passing an electric current through a coil of a high-field superconducting material. The first generation of commerical superconducting magnets became available in 1963. These magnets were capable of producing a steady magnetic field up to ~60 kG. At present superconducting magnets which generate fields up to ~100 kG are commercially available. The use of superconducting magnets in solid-state research is increasing rapidly.

b. Bitter-Type Magnets. These magnets consist of a series of copper plates connected to form a helix. High magnetic fields are produced in the bore of the helix by passing high electric currents through the plates, which are cooled by a steady stream of water. Magnetic fields up to ~250 kG (the highest steady fields attained thus far) have been produced in such magnets. While Bitter-type magnets are very convenient for ultrasonic work at high fields, their use is limited by the fact that they are available only in a few installations around the world.

c. Pulse Magnets. High magnetic fields, approaching 700 kG, can be produced in a small fraction of a second by discharging a capacitor bank or a battery through a conducting coil. Because of the short time duration of the magnetic field, pulse magnets have not been used in ultrasonic work until 1966. Recently, however, Kazanskii and Korolyuk (1966) used a pulse magnet to investigate giant quantum oscillations in antimony.