

PHYSICAL ACOUSTICS

Principles and Methods

VOLUME V

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Edited by WARREN P. MASON

DEPARTMENT OF CIVIL ENGINEERING
COLUMBIA UNIVERSITY
NEW YORK, NEW YORK

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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 treatise, 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 be the limiting value due to the requirement of parallelism necessary for coherent wave propagations. 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 propagation 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

CONTENTS OF VOLUME I—PART A

Wave Propagation in Fluids and Normal Solids

R. N. THURSTON

Guided Wave Propagation in Elongated Cylinders and Plates

T. R. MEEKER AND A. H. MEITZLER

Piezoelectric and Piezomagnetic Materials and Their Function in Transducers

DON A. BERLINCOURT, DANIEL R. CURRAN, AND HANS JAFFE

Ultrasonic Methods for Measuring the Mechanical Properties of Liquids and Solids

H. J. McSKIMIN

Use of Piezoelectric Crystals and Mechanical Resonators in Filters and Oscillators

WARREN P. MASON

Guided Wave Ultrasonic Delay Lines

JOHN E. MAY, JR.

Multiple Reflection Ultrasonic Delay Lines

WARREN P. MASON

CONTENTS OF VOLUME I—PART B

The Use of High- and Low-Amplitude Ultrasonic Waves for Inspection and Processing

BENSON CARLIN

Physics of Acoustic Cavitation in Liquids

H. G. FLYNN

Semiconductor Transducers—General Considerations

WARREN P. MASON

Use of Semiconductor Transducers in Measuring Strains, Accelerations, and Displacements

R. N. THURSTON

Use of p-n Junction Semiconductor Transducers in Pressure and Strain Measurements*

M. E. SIKORSKI

The Depletion Layer and Other High-Frequency Transducers Using Fundamental Modes

D. L. WHITE

The Design of Resonant Vibrators

EDWARD EISNER

CONTENTS OF VOLUME II—PART A

Transmission of Sound Waves in Gases at Very Low Pressures

MARTIN GREENSPAN

Phenomenological Theory of the Relaxation Phenomena in Gases

H. J. BAUER

Relaxation Processes in Gases

H. O. KNESER

Thermal Relaxation in Liquids

JOHN LAMB

Structural and Shear Relaxation in Liquids

T. A. LITOVITZ AND C. M. DAVIS

The Propagation of Ultrasonic Waves in Electrolytic Solutions

JOHN STUEHR and ERNEST YEAGER

CONTENTS OF VOLUME II—PART B

Relaxations in Polymer Solutions, Liquids, and Gels

W. PHILIPPOFF

Relaxation Spectra and Relaxation Processes in Solid Polymers and Glasses

I. L. HOPKINS and C. R. KURKJIAN

Volume Relaxations in Amorphous Polymers

ROBERT S. MARVIN and JOHN E. MCKINNEY

Nonlinear Acoustics

ROBERT T. BEYER

Acoustic Streaming

WESLEY LE MARS NYBORG

Use of Light Diffraction in Measuring the Parameter of Nonlinearity of Liquids and the Photoelastic Constants of Solids

L. E. HARGROVE and K. ACHYUTHAN

CONTENTS OF VOLUME III—PART A

Anelasticity and Internal Friction Due to Point Defects in Crystals

B. S. BERRY and A. S. NOWICK

Determination of the Diffusion Coefficient of Impurities by Anelastic Methods

CHARLES WERT

Bordoni Peak in Face-Centered Cubic Metals

D. H. NIBLETT

Dislocation Relaxations in Face-Centered Cubic Transition Metals

R. H. CHAMBERS

Ultrasonic Methods in the Study of Plastic Deformation

ROHN TRUELL, CHARLES ELBAUM, and AKIRA HIKATA

Internal Friction and Basic Fatigue Mechanisms in Body-Centered Cubic Metals, Mainly Iron and Carbon Steels

W. J. BRATINA

Use of Anelasticity in Investigating Radiation Damage and the Diffusion of Point Defects

DONALD O. THOMPSON and VICTOR K. PARE

Kinks in Dislocation Lines and Their Effects on the Internal Friction in Crystals

ALFRED SEEGER and PETER SCHILLER

CONTENTS OF VOLUME III—PART B

**Use of Sound Velocity Measurements in Determining the Debye
Temperature of Solids**

GEORGE A. ALERS

**Determination and Some Uses of Isotropic Elastic Constants
of Polycrystalline Aggregates Using Single-Crystal Data**

O. L. ANDERSON

The Effect of Light on Alkali Halide Crystals

ROBERT B. GORDON

Magnetoelastic Interactions in Ferromagnetic Insulators

R. C. LeCRAW and R. L. COMSTOCK

Effect of Thermal and Phonon Processes on Ultrasonic Attenuation

P. G. KLEMENS

**Effects of Impurities and Phonon Processes on the Ultrasonic
Attenuation of Germanium, Crystal Quartz, and Silicon**

WARREN P. MASON

Attenuation of Elastic Waves in the Earth

L. KNOPOFF

CONTENTS OF VOLUME IV—PART A

Transmission and Amplification of Acoustic Waves in Piezoelectric
Semiconductors

J. H. McFEE

Paramagnetic Spin-Phonon Interaction in Crystals

EDMUND B. TUCKER

Interaction of Acoustic Waves with Nuclear Spins in Solids

D. I. BOLEF

Resonance Absorption

LEONARD N. LIEBERMANN

Fabrication of Vapor-Deposited Thin Film Piezoelectric Transducers for the
Study of Phonon Behavior in Dielectric Materials at Microwave
Frequencies

J. DE KLERK

The Vibrating String Model of Dislocation Damping

A. V. GRANATO and K. LÜCKE

The Measurement of Very Small Sound Velocity Changes and Their Use
in the Study of Solids

G. A. ALERS

Acoustic Wave and Dislocation Damping in Normal and Superconducting
Metals and in Doped Semiconductors

WARREN P. MASON

Ultrasonics and the Fermi Surfaces of the Monovalent Metals

J. ROGER PEVERLEY

CONTENTS OF VOLUME IV—PART B

Oscillatory Magnetoacoustic Phenomena in Metals

B. W. ROBERTS

Transmission of Sound in Molten Metals

G. M. B. WEBBER and R. W. B. STEPHENS

Acoustic and Plasma Waves in Ionized Gases

G. M. SESSLER

Relaxation and Resonance of Markovian Systems

ROGER CERF

Magnetoelastic Properties of Yttrium-Iron Garnet

WALTER STRAUSS

Ultrasonic Attenuation Caused by Scattering in Polycrystalline Media

EMMANUEL P. PAPADAKIS

Sound Velocities in Rocks and Minerals: Experimental Methods, Extrapolations to Very High Pressures, and Results

ORSON L. ANDERSON and ROBERT C. LIEBERMANN

CONTENTS

CONTRIBUTORS	v
PREFACE	vii
CONTENTS OF PREVIOUS VOLUMES	xi

1

Acoustic Wave Propagation in High Magnetic Fields

Y. SHAPIRA

I. INTRODUCTION	1
II. LIQUID METALS	3
III. IMPURE SOLID METALS	6
IV. HIGH-FIELD SUPERCONDUCTORS	10
V. GIANT QUANTUM OSCILLATIONS	23
REFERENCES	56

2

Impurities and Anelasticity in Crystalline Quartz

DAVID B. FRASER

I. INTRODUCTION	59
II. ANELASTICITY: A REVIEW	64
III. ACOUSTIC LOSS MEASUREMENTS	66
IV. LOSS MECHANISMS	94
V. CONCLUSIONS	107
REFERENCES	108

3

Observation of Resonant Vibrations and Defect Structure in Single Crystals by X-Ray Diffraction Topography

W. J. SPENCER

I. INTRODUCTION	111
II. EXPERIMENTAL X-RAY TECHNIQUES	114
III. QUALITATIVE X-RAY THEORY	118
IV. OBSERVATION OF DEFECTS IN SINGLE CRYSTALS	128

V. OBSERVATION OF RESONANT VIBRATIONS IN SINGLE-CRYSTAL PLATES	135
REFERENCES	160

4

Wave Packet Propagation and Frequency-Dependent Internal Friction

M. ELICES AND F. GARCÍA-MOLINER

I. INTRODUCTION	163
II. THE PHYSICAL NATURE OF THE WAVES	166
III. THE PROPAGATION OF WAVE PACKETS: MORPHOLOGICAL ANALYSIS	170
IV. THE PROPAGATION OF WAVE PACKETS: ENERGETIC ANALYSIS	202
V. APPLICATION TO THE THEORY OF INTERNAL FRICTION	209
REFERENCES	217

5

Coherent Elastic Wave Propagation in Quartz at Ultramicrowave Frequencies

JOHN ILUKOR AND E. H. JACOBSEN

I. INTRODUCTION	221
II. CAVITY AND CRYSTAL GEOMETRY	221
III. APPARATUS FOR GENERATION AND DETECTION	223
IV. RESULTS	224
V. FUTURE RESEARCH	228
REFERENCES	230

6

Heat Pulse Transmission

R. J. VON GUTFELD

I. INTRODUCTION	233
II. PHONON ENERGY AND PHASE VELOCITIES	236
III. PHONON SCATTERING	252
IV. HEAT PULSES IN METALS	273
V. THERMAL RELAXATION TIMES AND INTERFACIAL BOUNDARY RESISTANCE	281
REFERENCES	289

AUTHOR INDEX	293
--------------	-----

SUBJECT INDEX	299
---------------	-----

Acoustic Wave Propagation in High Magnetic Fields

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I. Introduction	1
II. Liquid Metals	3
A. Theory	3
B. Experimental Results	5
III. Impure Solid Metals	6
A. Theory	6
B. Experimental Results	8
IV. High-Field Superconductors	10
A. Some Properties of HFS	10
B. Theory of Ultrasound Propagation in HFS	14
C. Experimental Results	19
V. Giant Quantum Oscillations	23
A. Theory	24
B. Experimental Results	45
References	56

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, and 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 commercial 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.