Since mainly 180° domain reorientation occurs during the hysteresis loop only a slight variation would be expected in c_{11}, which is found to be the case for c^E_{11}. The dependence of c^D_{11} is essentially identical since the piezoelectric constant e_{31} has ·n measured and found to be nearly zero. The variation of c_{66} n polarization is then due mainly to c^E_{12} where $c^E_{12} \cong c^D_{12}$ for the reason mentioned above.

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* D. Berlincourt, to be published.

Session D - Thursday Afternoon, December 5, 2:00 PM
Invited Papers

D1. Nuclear Spin-phonon Interactions by User of Ultrasonic Techniques - D.I. Bolef, Washington University, St. Louis, Missouri

A brief review will be given of the theory and of the experimental techniques for observing acoustic spin-phonon absorption. The measured acoustic absorption coefficient and resonance line shapes will be discussed in their relation to nuclear electric quadruple interactions and exchange interactions in solids. Particular emphasis will be placed on spin-phonon interactions in metals and in III-V semiconductors and their relation to spin-lattice relaxation mechanisms.

The cw ultrasonic techniques used in the nuclear spin-phonon work enable one to measure changes of acoustic attenuation of parts per million. A description of the extension of these techniques to UHF frequencies spin-phonon interactions at low temperatures will be given.

D2. Comparison of Ultrasonic and Dielectric Relaxation in Liquids - T.A. Litovitz, Physics Dept., Catholic University of America, Washington, D. C.

The use of ultrasonic absorption and velocity measurements to investigate the dynamics of liquid structure will be considered. ·luded in this will be a discussion of the mechanism of molecular ·which determines the structural relaxation time obtained from the ultrasonic data. It will be shown how the dielectric relaxation time in a liquid is related to the ultrasonic relaxation time and how measurements of each of these phenomena lead to a better understanding of the other.

Session D - Thursday Afternoon, December 5, 2:00 PM
Contributed Papers

D3. Excitation and Propagation of Microwave Phonons in GaAs and InSb * - B. Abeles and K.R. Keller, RCA Labs., Princeton, N.J.

Sound waves at frequencies of 0.6, 3 and 10 Gc were propagated along the (110) direction in optically finished rods of semi-insulating GaAs and pure InSb. Direct surface excitation was used, or alternatively, the samples were bonded to quartz rods which were surface excited. The sound attenuation was measured in the temperature range 2° -300°K. A discussion of the results is given.

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*This research was sponsored in part by the Advanced Research Project Agency of the Department of Defense under Contract No. SD-182.

D4. Oscillation in CdS Ultrasonic Current Limiters - J.S. Crabbe Texas Instruments, Inc., Dallas, Texas

An idealized model of an ultrasonic current limiter predicts current saturation for fields which tend to cause electrons to drift faster than the piezoelectrically coupled ultrasonic wave. Data is presented which illustrates that the limiting field of 0.5 - 5.0 ohm cm CdS samples increases for decreasing sample thickness. ·ical values for field, current density and power at the limiting threshold are also presented.

Measurements of the current limiting properties of CdS samples at liquid nitrogen temperature have shown a sustained oscillation in the current flowing through the CdS sample upon application of fields in excess of those required to induce current limiting. The thickness of the current limiter sample corresponds closely to the half wavelength of the coupled ultrasonic wave at the oscillation frequency. Data is presented which shows the effect of applied drift field and terminating impedance on the oscillation frequency.

D5. Phonon Emission by Supersonic Electrons and Collective Phonon Propagations.- E.W. PROHOFSKY, Sperry Rand Res. Center, Sudbury, Mass.

The emission of piezoelectrically active phonons by electrons with drift velocity greater than the velocity of sound is studied in the quantum limit. This interaction is found to be very strong, as the electrons have a momentum space population inversion and are prone to undergo "Cerenkov-like" radiation. The most probable frequencies of emitted phonons are 10^{10} - 10^{11} CPS. In the presence of this stimulated emission, the crystal momentum losses for this band of phonons may be overcome, and collective propagations by the phonons become possible. The collective waves in the "phonon gas" are much like an ordinary sound wave in a molecular gas. A similar propagation among thermal phonons is thought to be the mechanism for second sound phenomena in superfluid liquid helium.

D6. Experimental Observation of Collective Phonon Propagation in CdS - H. Kroger, Sperry Rand Res. Center, Sudbury, Mass.

Experimental observations of collective phonon waves in cadmium sulfide under acoustic gain (supersonic electron drift velocities) conditions are described. These include measurements of the velocity of collective waves in the 10-100 Mc/sec frequency band. The possible relation between collective phonon modes and nonohmic behavior of piezoelectric crystals under acoustic gain conditions is discussed. Two types of spontaneous current oscillations are described. The experimental arrangement was similar to that of Hutson, McPhee and White.[1] The period of one type of oscillation is exactly the transit time of piezoelectrically active sound wave across the crystal. The period of the other type of oscillation is not determined by the size of the crystal alone but also depends upon light intensity and voltage. Experiments are described which suggest that the latter mode of oscillation is related to the generation of collective electron-phonon waves.

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[1] A.R. Hutson, J.H. McPhee and D.L. White, Phys, Rev. Letters 7, 237 (1961)

Session E - Friday Morning, December 6, 9:00 AM
Invited Papers

E1. Magnon-Phonon Instabilities Associated with the Exchange Branch in Ferrimagnetic Crystals * - Frederic R. Morgenthaler, Dept. of EE and Lab. for Insulation Res., MIT, Cambridge, Mass

The spectra of the microwave and exchange magnons that are associated with a two sublattice ferrimagnetic crystal will be reviewed, and their modification due to magnetoelastic energy terms considered. It will be shown that the degree of magnon-phonon interaction for each of the magnon branches depends upon a different combination of sublattice components of the magnetoelastic energy. Measurements of the magnon-phonon splitting of both branches should allow one to decompose the usual magnetoelastic energy coefficients (such as b_2) into their sublattice components; this is not possible from the microwave measurements alone.

The possibilities and criteria for magnon-phonon instabilities involving the microwave branch will be reviewed and the theory extended to include the exchange branch. The instabilities will be considered as providing possible phonon sources and/or amplifiers, and as the basis of a nonlinear spectrometer used to measure a variety of fundamental properties of magnetoelastic systems.

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* This research was sponsored by the USAF under Contract AF 33(616) 8353

Session E - Friday Morning, December 6, 9:00 AM
Contributed Papers

E3. Coupling to Hypersonic Waves with Piezoelectric Insulators
C. F. Quate and W. H. Haydl, Stanford University, Stanford, Calif.

Piezoelectric discs can be used for efficient couplers for longitudinal waves in the microwave range if they are properly matched to the microwave circuit with acoustic impedance transformers.

We have considered insulating discs several odd half-wavelengths in thickness which are coupled to the acoustic transmission medium by "double layer" of quarter wave films. The quarter wave films are of alternately high and low impedance material and serve to transform the acoustic impedance of the acoustic medium to a value that is appropriate for matching to the electromagnetic circuit. This is in direct analogy to the use of "double layers" of quarter-wave films which are commonly used in optical devices.[1]

In this paper, the principles of such couplers together with the associated transformers are presented together with some initial results which lead to couplers with a power conversion efficiency of 10% and metallic band losses of less than 2 db over a narrow band at 600 Mc.

Such couplers are conveniently incorporated into acoustic wave amplifiers and the properties of such amplifiers using CdS as the active medium will be included in the discussion.

[1]M. Born and E. Wolf, Principles of Optics, Pergammon Press (1959), P. 65.

E4. A New Approach to High Frequency Delay Lines, Walter Strauss, Bell Tel. Labs., Inc., Murray Hill, N.J.

In the construction of high frequency delay lines one usually encounters problems because of: (1) a need for optically flat and parallel surfaces, (2) high sonic loss at room temperature, and (3) poor electromechanical conversion efficiency. Recent observation of magnetoelastic waves by the author together with the work of Schloemann[1] and Eshbach[2] suggest that some of the above difficulties may be overcome. Magnetoelastic pulses propagating parallel to axis of a rod of yttrium iron garnet were observed at microwave frequencies. Input power was in the milliwatt range. The travel time of these pulses was varied by adjustment of the applied magnetic field. A proposed magnetoelastic delay line will have the feature of variable delay time. Since the magnetoelastic wave will be launched inside the sample, surface conditions should be only of secondary importance. Other characteristics and design problems of a magnetoelastic delay line will be discussed.

[1]E. Schloemann, Advances in Quantum Electronics, edited by J. R. Singer (Columbia University Press, New York, 1961), p. 444, Sec. 5

[2]J. R. Eshbach, J. Appl. Phys. 34, 1298 (1963)

E5. A Birefringent Scanner Concept - R. T. Babcock and G. C. Vorie, Computer Research Department, Cornell Aeronautical Lab., Buffalo, N. Y.

A concept under investigation at CAL for image dissection takes advantage of ultrasonically induced birefringence in photoelastic delay lines. The rotation of polarized light in the presence of a stress wave in two-orthogonal delay lines to use in conjunction with polarizing elements and optics to create an image dissector which may have camera and display application. From an electronics viewpoint, the advantages are that no vacuum tubes or high voltages are required and the device will probably not be limited by extreme environmental stresses of shock temperature, and nuclear radiation.

The paper describes the image dissector concept, together with results of a theoretical and experimental research program being conducted to investigate important questions concerning the technical feasibility of the scanner concept. Preliminary results of the resolution, sensitivity, and other characteristics of the birefringent scanner are presented, and the requirements of future research are indicated. These preliminary results indicate that this new scanning concept has the greatest potential application for displays.

E6. Orthogonal Ultrasonic Signals * - E. E. Henry, Institute of Science and Technology, The University of Michigan, Ann Arbor, Michigan

An ultrasonic light modulator is one good means of introducing an active signal into a beam of light for computing various logic functions such as Fourier transforms of the signal. A possible method of increasing the information capacity of the modulator is to introduce two signals perpendicularly, if the intermixing effect is negligible. To determine this effect, a water cell has been constructed with two quartz transducers mounted into two sides of the unit so as to produce two perpendicular ultrasonic wave trains with a common area of interaction. Each crystal is driven separately. They They are energized both singly and simultaneously with pure resonant frequency excitation and amplitude modulation as well. The cell isinserted into a collimated beam of light to form the diffraction pattern (or Fourier transform) of the signal. The effect of introducing various signals is found by studying the diffraction pattern of the composite signal. Studies to date of the optical effects indicate that the ultrasonic signals are orthogonal (that is, free from frequency mixing) when various modulations are used. This paper describes the equipment used and the results which have been achieved with this equipment.

*This work was conducted by Project MICHIGAN under Dept. of the Army Contract DA-36-039 SC-78801, administered by the U. S. Army Electronics Command.

E7. An L-Band Permanent Magnet Type Yttrium Iron Garnet Delay Line - R. A. Sparks and E. L. Higgins, RADCOM, Div. of Litton Systems, Inc., College Park, Md.

The results of using single crystal yttrium iron garnet as a delay line at ultra high frequencies have been previously reported by Eggers and Strauss.[1] In this paper the preliminary results of an investigation at L-band frequencies are presented also using YIG as the delay medium. The novel feature to be noted in these studies, in addition to extending the frequency range of operation, is the use of a permanent magnet biasing field to raise the polished and faces of the YIG bar into the neighborhood of ferromagnetic resonance. The (100) oriented crystals were first evaluated in a DC field provided by an electromagnet and then placed in the center of a cylindrical type permanent magnet. A special in-line coaxial crystal holder was constructed to maintain orientation concentric with the axial magnetic field. The r-f energy was coupled to the YIG using the nonresonant technique that has been described by Denton and Spencer[2]. Two areas of investigation have been examined for specific device applications. Maximum delays, corresponding to several round trip reflections in the medium, can be obtained by properly orienting the crystal with respect to the incident r-f magnetic field. Alternately, conditions can be established to suppress the multiple reflections and enhance the one way transmitted signal. A new configuration under development uses a C-type permanent magnet and a strip line matching section combined with the input and output coupling loops to provide a compact, light weight, low power device.

[1]F. G. Eggers and W. Strauss, J. A. P., 34, pt. 2, 1180 (1963)

[2]R. T. Denton, and E. G. Spencer, NEREM Record, 44, (1962)

Session F - Friday Afternoon, December 6, 2:00 PM
Invited Papers

F1. Ultrasonic Wave Propagation in Pure and Doped Silicon and Germanium - Warren P. Mason and T. B. Bateman, Bell Tel. Labs. Inc., Murray Hill, N. J.

Ultrasonic attenuation and velocity measurements have been made in pure germanium and silicon (doping $< 10^{14}$ impurity atoms per cc) and in doped silicon and germanium having doping values of p-and n-type impurities in the range from 5×10^{17} up to 3×10^{19} doping atoms. The attenuation in pure material shows a continuous decrease as the temperature is decreased and an almost complete absence of attenuation below 20°K. These results indicate that the energy losses are accounted for entirely by phonon-phonon interactions. A calculation has been made of these losses using a model based on the Akheiser effect and incorporating the recently measured th order elastic moduli of silicon and germanium. For both matei the calculated values agree with the measured values within 50 percent for both shear and longitudinal waves.

The effect of doping silicon and germanium with p-and n-type impurities is to increase the attenuations and to decrease the velocities. The n-type material produces a constant loss independent of the temperature at low temperatures. This loss can be used to evaluate the intervalley relaxation time associated with the motion of electrons from one valley to another. The corresponding intersurface relaxation time measured for p-silicon doped with boron shows an activation energy effect which is believed to be caused by the capture of the hole by the boron atom. This energy disappears for high doping levels.

F2. Propagation of Microwave Phonons in Germanium *
M. Pomerantz, International Business Machines Corp.
Thomas J. Watson Res. Center, Yorktown Heights, N. Y.

The effect of various kinds of interactions on the propagation of 9 Gc/s microwave phonons in germanium have been studies experimentally. We will discuss phonon interactions (a) with conduction electrons in degenerate n-Ge, which produces attenuation of waves of specific polarization in particular directions of propagation, (b) with microwave phonons, which gives nonlinear effects, (c) with thermal phonons, which gives temperature dependent ultrasonic attenuation.

* This research has been supported in part by the U. S. Army Electronics Research & Development Lab., Fort Monmouth, N. J.

Session F - Friday Afternoon, December 6, 2:00 PM
Contributed Papers

F Simulation of Crystal Symmetries Through Working Poly-alline Metals: Ultrasonic Applications and Experiment on Tool Steel - Ammanuel P. Papadakis, Bell Tel. Lab., Inc., Allentown, Penna.

Plastic deformation of polycrystalline metals produces preferred orientation among the crystallites. The effect is to align certain crystallographic axes in the grains with the directions and planes in the specimen characterizing the mechanical working (e.g., drawing axis, rolling place and direction, etc.). The anisotropic elastic moduli of the grains impart to the finished specimen as elastic anisotropy characteristic of the metal and its deformation. Certain crystal symmetries such as hexagonal, orthorhombic, and tetragonal can be simulated in worked metals. The degree of anisotropy can be controlled through the degree of working and subsequent heat treatment. This simulation will be useful in ultrasonic wave propagation studies since diffraction, double refraction, conical refraction, wave surfaces, and other phenomena could be investigated in specimens fabricated to order. Ultrasonic devices may be devised to utilize anisotropic materials. Several experiments are suggested. An experiment was performed on rolled bars of tool steel both before and after hardening to study this hexagonal crystal facsimile. The five elastic moduleswere found from absolute measurements of the ultrasonic wave velocities while the velocity surfaces were investigated by twin-sample ultrasonic interferometry and ultrasonic double refraction. Surprisingly, hardening changed the anisotropy very little while lowering all the elastic module somewhat.

F4. A Novel Method of Measuring Elastic and Anelastic Properties of Solids - D. B. Fraser and R. C. LeCraw, Bell Tel. Labs., Inc., Murray Hill, N.J.

A technique has been devised whereby the elastic and anelastic perties of solids can be measured both as a function of frequency temperature. A small sphere, of the order of 5mm or less in diameter, is placed without bonding on a ceramic shear mode transducer. The transducer is pulsed at one of the sphere's resonant frequencies and the free decay of vibrations is observed by feeding the transducer signal to a receiver. From the decay of the vibrations the internal friction, Q^{-1}, may be determined. Various series of modes may be excited and from comparison with the calculated mode spectra of an isotropic solid, the Lame constants, and μ, and Poisson's ratio may be computed directly. Measurements have been made over a range of temperatures from 1.4°K to 400°K, the present upper limit being set by the solder connections to the transducer. Several materials have been tested and results for two single crystal garnet spheres will be given as representative of the capabilities of the technique for reasonably isotropic substances. The range of Q^{-1} that has been measured extends from 2.5×10^{-7} to 5×10^{-4}, and in this range the loss appears to be independent of the transducer.

F5. Methods of Measuring Mechanical Properties of Plastics with High Frequency Ultrasound - H. J. McSkimin and R. P. Chambers Bell Tel. Labs., Inc. Murray Hill, N. J.

Two methods are described for measuring ultrasonic wave velocities and attenuation in plastics. The first is a variation of the "water immersion" method, and involves measuring the differential loss and phase shift resulting from removal of the specimen from the ultrasonic beam. Longitudinal wave data can be obtained to about 100 Mc. For the second method, which is applicable to both shear and longitudinal waves, the specimen, is cemented between two solid rods of quartz, and the desired quantities are obtained from measurement of wave amplitudes as a function of frequency.

Preliminary results for polystyrene indicate that measurements for this low loss material can be made at frequencies as high as 500 Mc; however, special attention must be paid to precise mechanical alignment of component parts.

F6. Modes in Circular AT Quartz Plates - W. J. Spencer, Bell, Tel. Labs., Allentown, Penna.

A complete analysis of acoustic modes in an anisotropic disc is not presently available. To circumvent this problem and to provide a tool for mode analysis of circular AT cut quartz discs, a study of high frequency shear and flexure modes in these plates has been made by x-ray diffraction. The x-ray technique depends on the reduction of primary extinction in a Laue diffraction due to the lattice curvature associated with various acoustic modes. The curvature tensor $\underline{K}$ related to the strain tensor by $\underline{K} = \underline{\nabla} \times \underline{S}$ indicates from which planes the x-rays should be diffracted to obtain a maximum intensity. Diffraction patterns give a direct picture of the acoustic mode without resorting to analysis. Results may be used to determine the nature of spurious responses and coupled modes in AT quartz plates of any geometry whose fundamental frequency is above 800 kc. Generally, mode patterns in complete devices are obtainable.

F7. Attenuation of Longitudinal and Flexural Wave Motions in Strips G. A. Coquin, T. R. Moeker, and A. H. Meitzler, Bell Tel. Labs., Inc. ABSTRACT

The frequency variation of the attenuation per unit length for elastic waves travelling in strips has been observed experimentally to depend markedly upon the particular longitudinal or flexural mode of propagation involved. Experimental and theoretical studies have been carried out on the lowest three longitudinal and lowest three flexural modes in strips of polycrystalline aluminum. Although a medium of this form has many possible loss producing mechanisms, a theory for wave propagation in a plate of viscoelastic material provides a useful basis for interpreting a number of the details observed for loss measurements in the frequency range of 1 to 35 Mc. Applications of the results of this work to the design of ultrasonic strip delay lines will be discussed, with particular attention paid to the way in which the frequency dependent loss characteristics of the lowest longitudinal mode and the two lowest flexural modes affect the design of dispersive strip delay lines.