Table I. Calculated and observed frequencies and some observed Q's of two InSb plates.

p-n junction plate	p-type plate	
calc. freq's., Mc/sec	calc. freq's., Mc/sec	
1.92 ± 0.06	2.74 ± 0.06	
5.76 ± 0.18	8.22 ± 0.18	
obs. freq's., Mc/sec	obs. freq's., Mc/sec	Q in units of 10^4
1.949	2.764	0.57
1.962	2.796	1.7 to 2.4
1.973	2.857	1.0
1.988	2.869	1.4
1.995		
	8.380	
5.857	8.403	
5.874	8.419	
	8.440	

around the thickness mode. This is what was observed – resonances being found in the p-type plate from 2.60 Mc/sec to 2.87 Mc/sec, and from 8.38 Mc/sec to 8.44 Mc/sec. A similar situation existed in the p-n junction plate. The strongest of these modes for the fundamental and third harmonic are tabulated in Table I. The frequencies of the fundamental and third harmonic were calculated using elastic constants and density extrapolated to liquid helium temperature. The elastic constants used were means between the values given by McSkimin et al.[6] and Potter.[7] The latter's work was used for the extrapolation to liquid helium temperature. For the p-type plate, the Q's of several of the more prominent modes were measured and these results are also shown in Table I.

A quantitative evaluation of d_{14} is difficult since the contact impedance is large (~14 times the ohmic resistance of the sample). This contact impedance appears to decrease at piezoelectric resonance. The reason for this is not known at present. Further experiments are planned in order to overcome this difficulty.

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EXCITATION OF VERY-HIGH-FREQUENCY SOUND IN QUARTZ

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Recently Baranskii[1] reported the generation of longitudinal ultrasonic waves along the x axis of a 1.5-cm-thick quartz plate in the frequency range from 10^8 to 2×10^9 cps, using standard optical diffraction methods for detection.[2]

We have performed a series of further experiments at 10^9 to 2.5×10^9 cps as part of a program to extend research with ultrasonic waves into the microwave frequency range:

(1) A 9-mm quartz cube with optically flat surfaces was placed in the electric field of a coaxial cavity which had two opposite slots for optical observation. By orienting either the x or y axis of the cube parallel to the field, longitudinal or transverse waves could be generated, distinguished by their different diffraction angles for light. Figure 1 shows an example for longitudinal waves.

FIG. 1. Photograph of longitudinal sound beam in quartz cube. Frequency ν = 1000 Mc/sec. In the picture on the right, the HF Power was turned off.

(2) A rectangular rod 4×1×0.5 cm, with the x axis along its length, was placed with one end in the electric field of the cavity, parallel to the x axis [see Fig. 2(a)]. In this way it was possible to observe the traveling sound waves in the sections l_1 inside the cavity as well as l_2 outside. From the intensity of the diffracted light at different points of the rod, the sound attenuation at 1000 Mc/sec was estimated to be of the order of 2 to 4 db/cm.

(3) The direction of sound propagation depends on the angle between the end face f and the x axis [see Fig. 2(b)]. An angle of 10° caused, under otherwise identical conditions, a change in the direction of propagation of about 25° to 30°, as can be explained by the elastic properties of quartz.

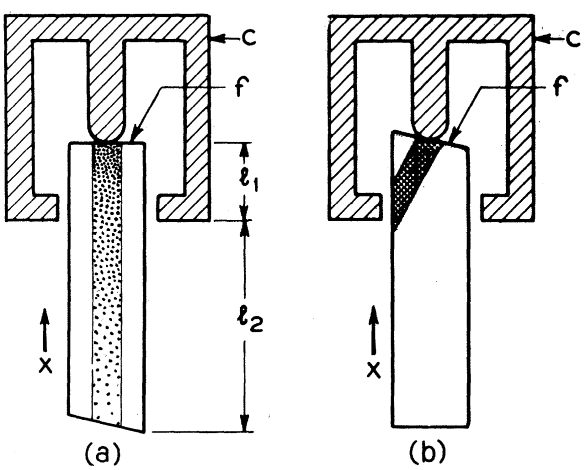

FIG. 2. Sound propagation in rectangular quartz rod extending out of coaxial cavity c. (a) End face perpendicular to x axis. (b) End face under angle of 10° to x axis.

(4) A cylindrical x-cut quartz rod 2.5 cm long and 0.3 cm in diameter, with optically flat and parallel end faces, was placed between two identical cavities, one of which served as a transmitter and the other as a receiver. This arrangement showed the reconversion of acoustical into electromagnetic energy: at 1500 and 2.5 Mc/sec, pulses of 1 microsecond duration fed into the transmitter cavity were received about 5 microseconds later in the second cavity, corresponding to the acoustic delay in the rod. The ratio of electrical input to output power was slightly greater than 10^7. There was no comparable electrical leakage between both cavities.

Our observations, in particular the one mentioned under 3, suggest that even for homogeneous electric fields these ultrasonic waves are excited at the surface of the quartz crystals. This is understandable, because it is only here that under the influence of the uniform piezoelectric stress a displacement can be initiated. This displacement then propagates as a traveling wave into the interior.

If one assumes that most of the electric field of the cavity is concentrated in a volume V of the quartz rod, an estimate shows that the acoustic power F_1 leaving the surface is

$$F_1 = [k^2(\lambda q/V)Q]P_i, \qquad (1)$$

where k = electromechanical coupling constant (for quartz about 10^{-1}), λ = acoustic wavelength, q = cross section of the rod, Q = quality factor of the cavity, and P_i = power input. This holds for critical coupling of the input lead into the cavity. The order of magnitude of F_1 agrees with a qualitative estimate from the observed intensity of light diffracted by the sound waves.

Relation (1) can also be shown to be reciprocal, i.e., the conversion at the receiving cavity from acoustic into electromagnetic energy takes place with the same efficiency:

$$P_{\text{out}} = [k^2(\lambda q/V)Q]F_2, \qquad (2)$$

where P_{out} = output of the receiving cavity, F_2 = incident sound energy flux. Therefore, neglecting sound absorption, the output from the second cavity should be smaller than the power input into the first cavity by a factor $[k^2(\lambda q/V)Q]^2$. Allowing for sound absorption, this agrees with the results reported under 4.

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INFRARED ABSORPTION OF PHOTO GENERATED FREE CARRIERS IN GERMANIUM

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The far infrared absorption in semiconductors due to free carriers, electrons or holes, has previously been used for the detection and measurement of injected carriers.[1] The same kind of investigation can also be used for photogenerated carriers.[2,3] This technique permits studies of diffusion, lifetimes, recombination and scattering mechanisms in semiconductors by purely optical means. The following note is an introductory report of an investigation performed according to these ideas.

A single crystal of pure germanium of dimensions 5×10×15 mm, optically polished and etched, was inserted in front of the entrance slit of a Perkin Elmer spectrophotometer equipped with a rock salt prism. By illuminating the crystal with a tungsten ribbon lamp using a large condenser lens, an appreciable increase in the absorption took place. The spectral distribution of the absorption increase showed the well-known structure of Fig. 1, which is ascribed to the transition of holes between the valence sub-bands.[4-6] It is known[4] that, in this wave-number region, the absorption cross section for holes is much greater than for electrons. Since every absorbed photon creates an electron-hole pair, we may suppose that the increase in the number of holes is of the same order of magnitude as (but not necessarily equal to) the increase in the number of electrons. Hence, the actual absorption is dominated by the holes. These measurements are being extended to longer wavelengths.

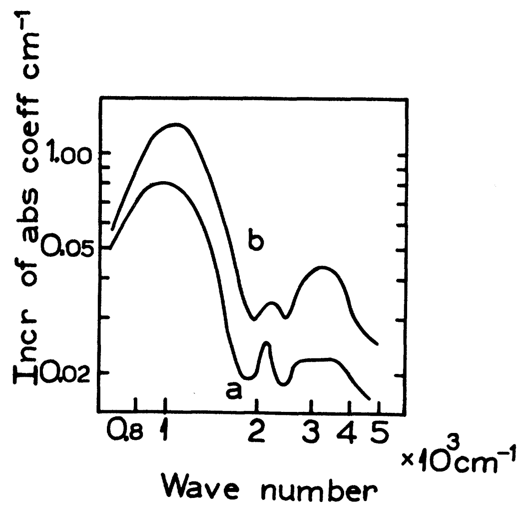

FIG. 1. Increase, due to illumination, of the absorption coefficient of germanium as a function of wave number. Curve a: intrinsic Ge (resistivity 50 ohm cm). Curve b: antimony-doped, *n*-type Ge (resistivity 20 ohm cm).

The increase in the hole concentration illustrated in Fig. 1 is due to the sum of the photoelectric effect and the heating effect caused by the illumination. The temperature increase resulting from steady ribbon lamp irradiation was determined by using the known shift of the main absorption edge[6,7] as a thermometer and was found to be about 30°C. This temperature increase should produce an absorption increase which is negligible compared with the observed level. By taking readings rapidly, thus avoiding this heat effect, we could extend the measurements in the short-wavelength direction. It was found that the free-hole absorption is still decreasing when passing into the main absorption band.

For studying the geometrical distribution of the hole concentration increase, a narrow pencil of the infrared beam penetrating the sample was isolated by means of auxiliary slits on each side of the sample. The exciting light from the ribbon lamp was incident perpendicularly to the test beam upon the rectangular surface of the crystal. The latter could be moved in a plane perpendicular to the infrared beam by means of two micrometers. For intrinsic Ge (50 ohm cm), a movement perpendicular to the ribbon lamp beam caused no alteration in the photoinduced absorption. Hence, we can conclude from this that, for this sample, surface recombination is unimportant. The distribution perpendicular to the illuminated surface is shown in Fig. 2 for different intensities of exciting light. Within the accuracy of measurements, the absorption increase, and hence the increase in the number of holes, was approximately proportional to the light intensity which was attenuated nonselec-

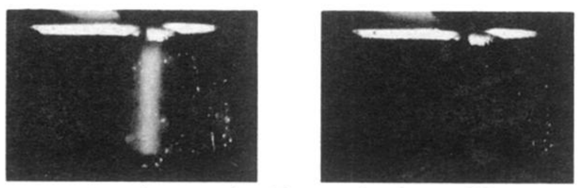

FIG. 1. Photograph of longitudinal sound beam in quartz cube. Frequency ν = 1000 Mc/sec. In the picture on the right,' the HF Power was turned off.