Table. I. The structure factors of Si.

hkl	$\|F_g\|$
111	63.2_9, 63.4_3
220	67.2_8

Roughly speaking, the required accuracy in the geometrical setting must be to about 1° for attaining the accuracy of 0.1% in $|F_g|$. Another important correction should be performed properly for the lack of ideally perfect interferometer. In fact, several intrinsic fringes were recorded in the beams B_0 and B_g even when the specimen crystal was absent. The results mentioned above were obtained tentatively on the assumption that the intrinsic fringes were equally spaced. In principle, however, we can eliminate the error due to this assumption without difficulty.

The details of the principle, the apparatus used, and the refined results will be presented shortly elsewhere. The results obtained by the present method may give the knowledge on accurate charge distribution in crystals and make it possible to criticize the conventional method of determining the structure factors.

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MICROWAVE EMISSION FROM *n*-TYPE INDIUM ANTIMONIDE AT 4.2 AND 77°K *

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Indium antimonide emits microwave noise when it is subjected simultaneously to parallel dc electric and magnetic fields whose values exceed certain thresholds. Comparison of the emission characteristics at 77°K with those at 4.2°K shows two major differences: (a) The threshold magnetic field at 4.2°K is approximately half that at 77°K. (b) With increasing magnetic field the emission at 4.2°K is comprised of a background continuum upon which are superposed equally spaced resonant spikes; at 77°K the background continuum only is observed.

Larrabee[1] and Hicinbothem[2] were the first to observe microwave emission from *n*-type InSb when a sample was subjected simultaneously to dc magnetic and electric fields. The threshold values of B_0 and E_0 for onset of the emission were approximately 3000 G and 200 V/cm, respectively. At these high electric fields, electron-hole avalanche occurs, and Steele[3] attributes the microwave emission to photoconductive mixing of band-gap radiation.

Buchsbaum, Chynoweth, and Feldmann,[4] and others,[5-7] have found another regime of microwave emission at relatively low electric fields ($E_0 \approx 10$ V/cm), well below values of E_0 required for avalanche breakdown, where the sample exhibits nearly linear current-voltage characteristics. This report is concerned exclusively with this low-field regime.

It has been suggested[8,9] that the instability arises from phonons that are excited by the drifting electrons. The unstable longitudinal wave then couples to an electromagnetic wave at the boundary of the sample. If this is indeed the mechanism, the phonon lifetime plays a crucial role in the determination of the threshold magnetic and electric fields for onset of instability. Theory[8,9] indicates that the threshold in electric field requires that the electron drift velocity exceed the sound velocity, while the threshold in magnetic field decreases as the phonon lifetime increases. Since the phonon lifetime at 4.2°K is much longer[10] than at 77°K, the microwave emission at 4.2°K (if, in fact, it exists at this temperature) should set in at a lower value of B_0. To see this change in threshold was one of the motivations for the experiments described here.

A bar of InSb, $1\times1\times10$ mm^3, cut along the (110) crystal axis, was mounted near a shorted coaxial transmission line as shown in Fig. 1. All samples were cut from one block. For our block, the Hall mobility at 77 and 4.2°K was in the range $(2\text{-}5)\times10^5$ cm^2 V^{-1} sec^{-1}, and the carrier concentration was in the range $(1\text{-}2)\times10^{14}$ cm^{-3}. The surface of the sample was lapped and then etched in a bromine-ethanol solution. The coaxial line was tapered to allow for better rf impedance matching between the sample and a standard 50-Ω line. The entire assembly was immersed in liquid nitrogen or liquid helium kept at a constant level. The sample was bathed continuously by the coolant and good circulation of the liquid was insured by a number of holes drilled in the coaxial line. The axis of the sample and the dc current flow were parallel to the static magnetic field (with uncertainties in angle of less than ±2° of arc) in all the experiments reported here. The magnetic field was uniform to better than 0.5 % over the volume of the sample. Current pulses of 2.5-μsec duration were applied to the sample (at a repetition rate of 200 pulses/sec) through indium-soldered contacts. Tin solder was also used with no observable changes in the voltage-current or microwave-emission characteristics. It was also ascertained that no changes occurred when the pulse length was increased from 2.5 to 7 μsec, thereby indicating that no significant heating of the crystal occurred.

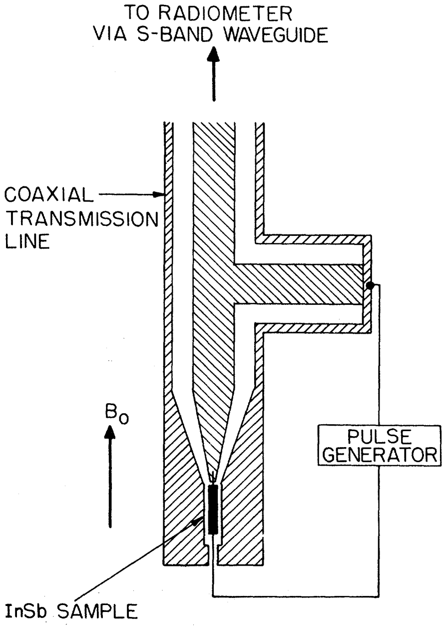

FIG. 1. Experimental arrangement.

The microwave signal was led through the coaxial transmission line, past a double-stub tuner and S-band waveguide to a time-resolved radiometer[11] that operated at a fixed frequency of 3000 Mc/sec, with an i.f. bandwidth of 10 Mc/sec. The i.f. amplifier was gated with a 2-μsec gate so that the noise emission was received only during the central portion of the 2.5-μsec current pulse. The noise power from the sample was compared repetitively with the noise power emitted by a standard noise source that had an equivalent noise temperature of 18 500°K. Thus the absolute noise power from the sample could be measured.

Figure 2 is a plot of the threshold magnetic field as a function of the threshold electric field for measurements on a given sample at 4.2 and 77°K. Threshold is defined as that val-

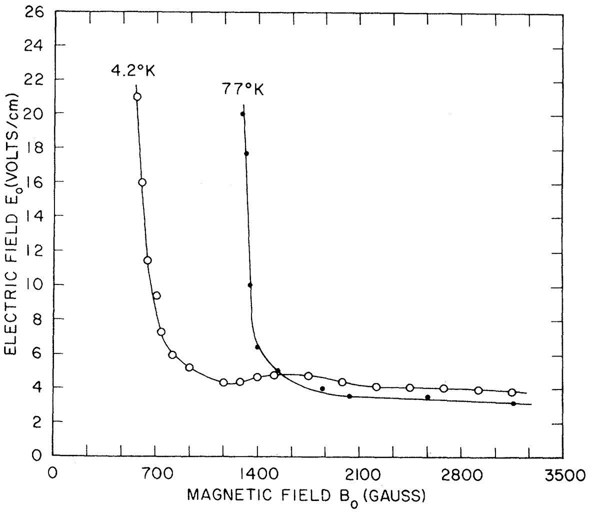

FIG. 2. Threshold electric field versus threshold magnetic field. Emission occurs above and to the right of each curve.

ue of B_0 and E_0 for which the emitted noise power had an equivalent temperature of 100°K. This value of temperature is near the limit of sensitivity of our radiometer. The results shown for 77°K agree qualitatively with observations of Musha, Lindvall, and Hagglund.[5] We see that the threshold magnetic field for onset of emission at 4.2°K is approximately half that at 77°K, whereas the threshold electric field is virtually unchanged.

The dependence of the radiation intensity on magnetic field (above threshold) is illustrated in Fig. 3 for different values of electric field. The measurements made at 77°K are qualitatively the same as those obtained by Buchsbaum, Chynoweth, and Feldmann.[4] However, measurements made at 4.2°K differ quite dramatically from those made at 77°K. We now see resonant spikes superposed on the monotonically increasing background emission.

We have labeled the spikes with a series of integers n from 1 to 11. As the electric field on the sample is decreased, a given spike moves to higher values of magnetic field. This increase in B_0 is very nearly the same as the corresponding increase in the threshold value of B_0 shown in Fig. 2 for the monotonic "continuum" radiation. Indeed, at some values of E_0, the first spike occurs precisely at the threshold of the "continuum" radiation (see spike $n=1$ of Fig. 3). These observations suggest that the "spikey" and "continuum" emission processes are coupled to one another. A given spike n is sometimes not excited or it is too small to be resolved. This is indicated in Fig. 3. For example, for $E_0=18$ V/cm, spikes 1, 2, 3, 5, 7 are missing. If we accept this possibility of missing spikes, we are led to the conclusion that the spikes are nearly equally spaced with a spacing of approximately 255 G. This fact is confirmed in Fig. 4, where the magnetic field value of a given spike n is plotted as a function of n.

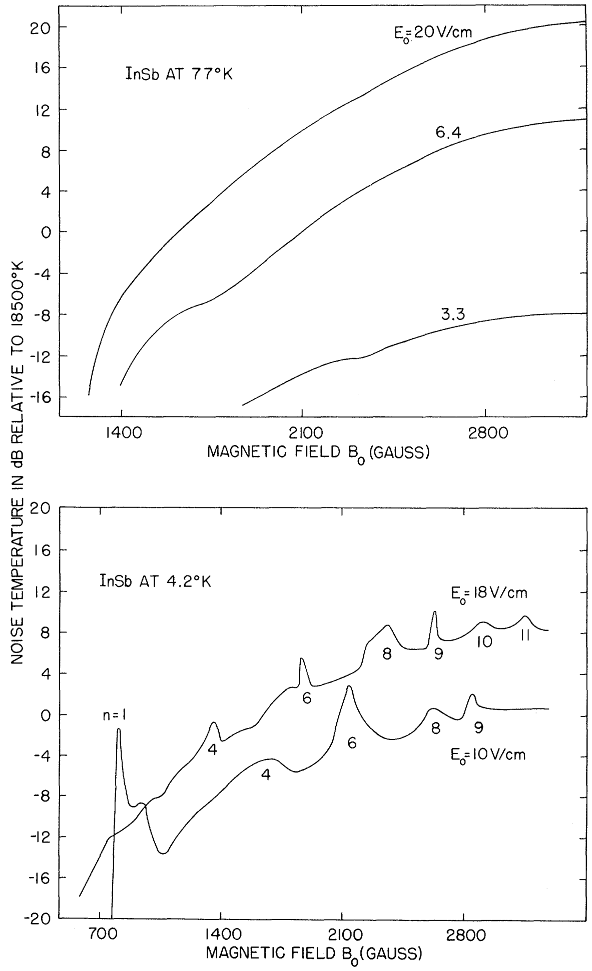

FIG. 3. Noise power output as a function of magnetic field for various values of applied electric field, at 77°K (above) and 4.2°K (below).

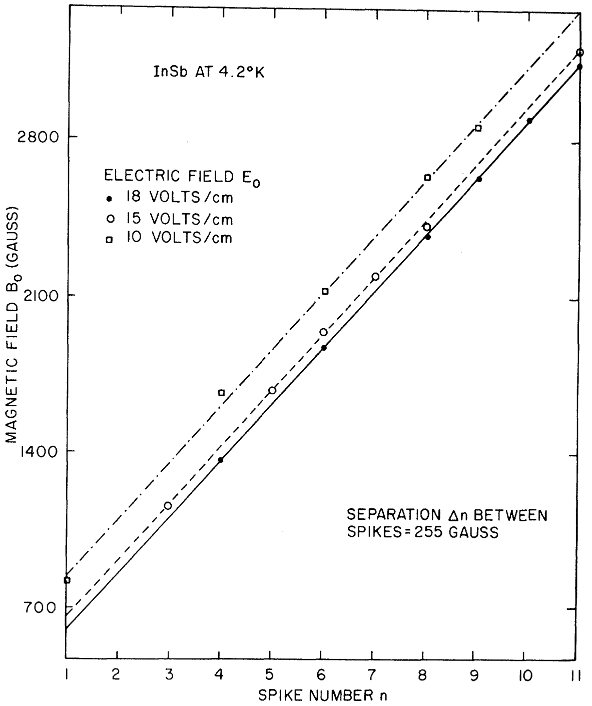

FIG. 4. Position in magnetic field of a given spike n as a function of n. The labeling of the spikes is as shown in Fig. 3. Note that whether or not a spike is missing appears to be a random event.

All of the observations above refer to measurements made on the same sample of InSb and for one polarity of the applied electric field. When the polarity was reversed, the only significant change was in the over-all power level of the continuum radiation. Changes as high as 5 dB were noted. Different samples exhibited variations of power level by as much as 8 dB. The separation between spikes from sample to sample varied, however, less than 5%.

Threshold characteristics similar to those shown in Fig. 2 can be deduced[12,13] from linear instability theory based on the model that the observed emission comes from the excitation of longitudinal phonons by electrons drifting along $\vec{B}_0$. We assume that there is both deformation potential and piezoelectric coupling between the electron and phonon systems.[10] The associated electric field excites transverse electromagnetic waves at the surface of the sample. Since the magnitude of the phonon propagation constant $\vec{q}$ is much greater than that of the electromagnetic wave (ω/c), the observed fields must be mainly due to phonons that travel almost perpendicular to $\vec{B}_0$. In the range of experimental parameters E_0, B_0, and ω, the principal mechanism for generation of phonons propagating almost across $\vec{B}_0$ is found to be inverse Landau damping (Landau growth). We point out, however, that the resonant spikes observed at 4.2°K (Fig. 3) are at present unexplained.

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MEASUREMENT OF RECOMBINATION LIFETIMES IN SUPERCONDUCTORS

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It is shown that the experimentally measured quasiparticle recombination lifetime in a superconductor is not the same as the previously calculated theoretical lifetime. A simple expression relating the two is derived.

Over the past few years, several experiments have been carried out to measure the quasiparticle recombination lifetime in a superconductor,[1-3] i.e., the time τ_R required for a quasiparticle at the gap edge to recombine with a thermally excited quasiparticle, thereby forming a Cooper pair and becoming part of the superfluid.[4] In each of these experiments, a double-tunnel-junction structure was arranged so that one junction could be used to inject quasiparticles into a superconducting film and the second junction could be used to detect the resulting increase in the density of quasiparticles in the film (see Fig. 1). In calculating τ_R from the experimental data, it is assumed that the steady-state density of injected quasiparticles ΔN is small compared with N_T, the thermal number present, and that the phonons