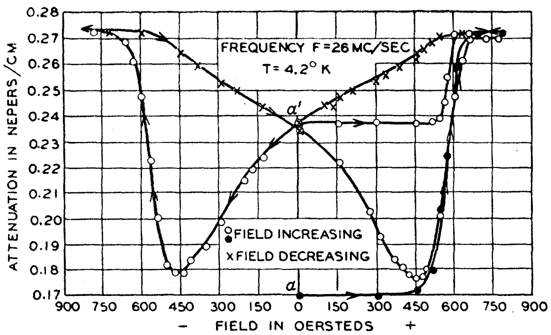

FIG. 3. Effect of "frozen in" field on attenuation in superconducting lead.

Figure 2 shows how the difference $\Delta\alpha$ in attenuation between the normal and superconducting states at 4.2°K changes with frequency, approximately a square law curve within the used frequency range. The ratio $\Delta\alpha/\alpha_n$ (α_n = total loss in normal conducting state at 4.2°K) changed from about 0.15 at 9 Mc/sec to 0.38 at 26.64 Mc/sec. These latter values must be regarded as minimum values since, for the reasons mentioned above, the actual values of α_n are probably smaller. For the same reason it has not yet been possible to make a statement about the actual value of the residual attenuation in the superconducting state which might be of great interest.

When superconducivity was destroyed by the magnetic field H and then re-established by turning off the field, the attenuation did not drop down to the original α, but (depending on the shape of the specimen and the speed of the field change) only to a 30–60 percent higher value α' (marked in Fig. 1 by the dotted line), indicating that a great part of the magnetic flux remained "frozen in." The attenuation as a function of H followed the curve given in Fig. 3. The form of this "magnetization curve" and the large hysteresis have not yet been fully explained and will be the subject of special investigation.

The curves in Fig. 1 look somewhat similar to the well known curves of thermal conduction as a function of temperature. This could suggest that a great part of the acoustic loss at low temperature might be due to loss from heat conduction, but since one gets the same effect with shear waves, this possibility seems to be ruled out.

Further experiments with better crystal samples, other elements, compounds, normal conducting materials, and a greater frequency range are in progress. The reported results might be a further support for the conception that superconductivity is mainly due to interactions between electrons and lattice vibrations, but it seems reasonable not to begin theoretical speculations about the observed effect before further experiments are carried out. Besides its theoretical interest, the effect might provide a very useful means for the study of superconducting properties, as, for example, observations in the intermediate state, etc.

The author wishes to express his gratitude to Mr. H. J. McSkimin for lending him his ultrasonic equipment and to Mr. T. B. Bateman for valuable help with the experiments.

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[3] D. Schoenberg, *Superconductivity* (Cambridge University Press, Cambridge, 1952), p. 74.

New Minority Carrier Phenomenon in Germanium

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IT is now well known that minority carriers can be injected into germanium by means of a point contact or P-N junction biased in the direction of easy flow of current carriers. An experiment reported by Haynes and Shockley[1] is considered a classical illustration of this phenomenon.

We have discovered that a P-N junction of indium alloyed to germanium and biased in the high-resistance direction can withdraw minority carriers from a bar of N-type germanium, and that the deficit can be propagated down the bar by means of an electrical field. The phenomenon is the exact inverse of the Haynes-Shockley effect and consequently we have named the withdrawal of minority carriers "minority carrier egression."

In Fig. 1, a bar of N-type germanium is provided with two indium alloyed P-N junctions labeled emitter and collector. In the Haynes-Shockley experiment, the emitter is biased positively by the proper position of switch S_2. The synchroverter switch S_1 opens and closes the emitter circuit with a repetition rate of 1000 cps and

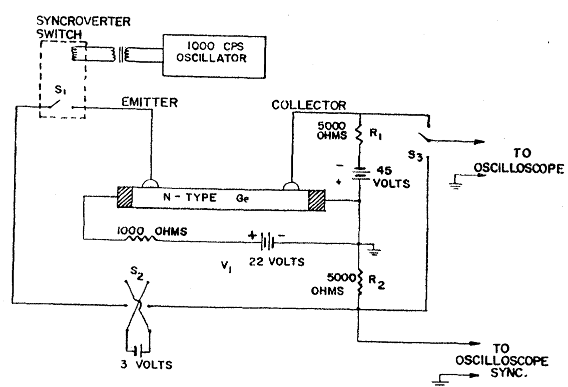

FIG. 1. Circuit used to compare minority carrier injection and egression.

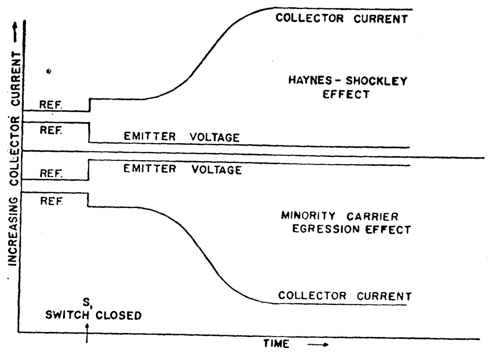

FIG. 2. Haynes-Shockley effect compared with minority carrier egression.

an oscilloscope sweep is synchronized with S_1 to give a repetitive presentation. The collector is biased negatively to attract positive holes. Positive holes in excess of the equilibrium density cause an increase in collector current which appears as an increased voltage across resistor R_1. This voltage is presented on the oscilloscope. A sweeping voltage V_1 causes positive holes to go from the emitter to the collector.

In Fig. 2, the upper trace is the Haynes-Shockley effect compared with the emitter voltage appearing across R_2 to show the switching instant. The lower trace appears when switch S_2 is reversed. In this case, the leakage current of the collector is decreased after a time delay for propagation of the effect and remains depressed as long as the emitter bias remains. It is to be noted that the sweeping voltage V_1 has the same polarity in both cases.

The phenomenon of electron egression has implications in the physical mechanism of the operation of transistor devices.

[1] J. R. Haynes and W. Shockley, Phys. Rev. **75**, 691 (1949).

Effective Masses of Electrons in Silicon*

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THE original cyclotron resonance experiments on germanium were made possible by virtue of rf ionization of carriers by the microwave electric field.[1] This technique could not be used on silicon because of the relatively large trapping energies for carriers. Recent experiments by the groups at Berkeley and at Lincoln Laboratory have used optical excitation of carriers.[2] We report here the independently obtained results of the two laboratories on the effective mass m^* of electrons in silicon. The principal values of m^* agree within the experimental error. The experiments were

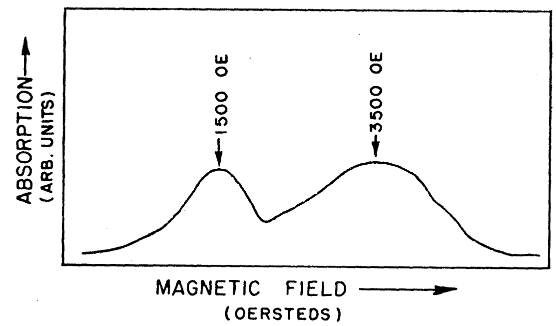

FIG. 1. Cyclotron resonance absorption of electrons in silicon as a function of magnetic field H when H is parallel to the [001] direction.

carried out on single crystals at liquid helium temperature. Microwave frequencies were in the 23-kMc/sec region.

The resonance peaks were observed when the magnetic field was parallel to the [001] and [110] directions and one peak was observed when the magnetic field was along the [111] axis. This suggests that the constant energy surfaces at the bottom of the conduction band in silicon can be represented by six ellipsoids of revolution along the cubic axes in the Brillouin zone, in agreement with the conclusions drawn from magnetoresistance[3] and piezoresistance[4] experiments.

The principal values of the mass tensor are conveniently obtained from the peak positions when the magnetic field is along the [001] direction. An absorption trace for this orientation is shown in Fig. 1; the peaks correspond to effective masses m_2 and $(m_1m_2)^{\frac{1}{2}}$. These data indicate a transverse mass $m_2=0.19\,m_0$ and a longitudinal mass $m_1=0.98\,m_0$, where m_0 is the free electron mass.[5] The average effective mass for these values is $\bar{m}^*=3\,m_1m_2/(2\,m_1+m_2)=0.26\,m_0$. The ratio $m_1/m_2=5.2$ is consistent with the value estimated from the magnetoresistance effect.[3] By using these values of m_1 and m_2, following Shockley,[6] two theoretical curves for m^*/m_0 as a function of θ were computed, where θ is

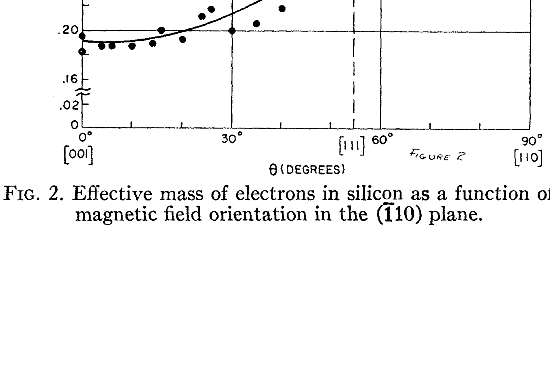

FIG. 2. Effective mass of electrons in silicon as a function of magnetic field orientation in the $(\bar{1}10)$ plane.