Measurement of Lifetime in Ge from Noise

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The lifetime of the minority carrier can be obtained from a noise measurement whose method consists of liberating hole-electron pairs by light. A convenient experimental arrangement is suggested and a typical plot of the experimental results are shown. The curves of the results are compared with the calculated curves.

THE lifetime of the minority carriers is measured using the current noise at 1.6 megacycle/sec. Our method for measuring the lifetime involves the measurement of the mean life path, $L=\tau v$, where τ is the lifetime of the minority carriers and v is the drift velocity. The physical model is shown in Fig. 1. The dimensions of the filament were $0.06\times0.11\times1.5$ cm³. Essentially the method consists of liberating hole-electron pairs by light on the surface of a germanium single-crystal filament, moving the illuminated rectangle of light slowly along the filament from left to right and at the same time measuring the noise power as a function of the distance X from the ohmic contact terminal to the left edge of the illuminated area. The light source was a tungsten filament at a color temperature of about 3200°K, and the illuminated rectangle was 0.11×0.4 cm² in area, on which a luminous intensity of about 0.028 lumen was incident. It must be assumed that the density of the minority carriers liberated by the illumination is constant at the left edge of the illuminated rectangle in the direction of the field as in Fig. 1 if the length of the area is longer than the mean life path, practically 0.4 cm. If the surface recombination is assumed to be negligible, the measured lifetime will be the volume lifetime.

A typical plot of the experimental results is shown in Fig. 2. When the direction of the field is changed oppositely, these phenomena arise at the opposite terminal. From these we see two characteristics: (1) Although the dc current through the sample with the field and the light present is almost constant as the illuminated rectangle is moved along the filament, the noise power increases with the distance X. (2) As the distance X is increased, a certain value of the noise power is reached, above which a further increase of the distance brings about no further increase of the noise power.

If we assume that the noise power is directly proportional to the number of the minority carriers which recombine in this distance X,[1,2] then we get

$$\langle i^2(X)\rangle = kn_0\int_0^X \frac{1}{\tau v}\exp\left(-\frac{x}{\tau v}\right)dx = kn_0\left[1-\exp\left(-\frac{X}{\tau v}\right)\right], \quad (1)$$

and

$$v=\mu E,$$

where k is the proportional constant, n_0 is the number of the injected minority carriers at the left edge of the illuminated rectangle, μ is the mobility, and E is the applied field strength.

The experimental results indicated by circles are compared with the calculated curves indicated by solid lines in Fig. 2. In this figure the ordinate is the root mean square noise power which is represented by the current of the square law detector, and the original point means that the thermal noise power is zero. The abscissa is the distance from the right edge of the left terminal to the left edge of the illuminated rectangle.

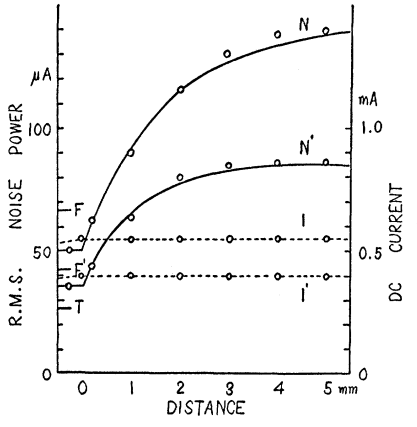

FIG. 2. Experimental results and calculated curves in N-type Ge. Excess noise power at the field strength 3.3 v/cm and 2.7 v/cm with the luminous intensity 0.028 lumen which is illuminated on the surface area 0.11×0.4 cm² is shown by N and N', respectively. Noise power with the field only present is indicated by lines F and F', respectively. The line T indicates the level of the thermal noise power. Each dc current with the field and the light present for N and N' is indicated by I and I'.

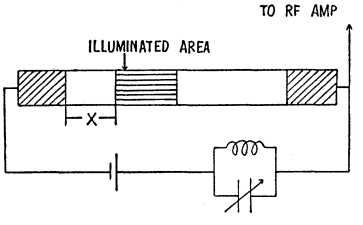

FIG. 1. Physical model. Sample dimension is $0.06\times0.11\times1.5$ cm³.

[1] H. C. Montgomery, Bell System Tech. J. **31**, 950 (1952).
[2] J. E. Hill and K. M. Van Vliet, Physica **24**, 709 (1958).

TABLE I. Lifetime in the N-type Ge in which resistivity is 32 ohm-cm and mobility is 1700 cm²/v-sec.

Lifetime (μsec)	Mean life path (mm)	E(v/cm)
27	1.5	3.3
26	1.1	2.5

For instance, in the curve N the thermal noise power with the light and the field absent is 27 μa in the current of the square law detector, with the field present and the light absent 67 μa, and with the light and the field present is indicated by circles on the solid line. The noise power with the field only present is larger than the noise power with the field and the light both present at the right edge of the left terminal, in which the minority carriers enter. But these do not arrive at the right terminal without the direction of the field changing. Each dc current through the filament with the light and the field both present is indicated by dotted lines I and I'. In this case each dc current increased by light (whose luminous intensity is about 0.028 lumen) is 90 μa and 60 μa, respectively. From these curves the lifetime of the injected minority carriers is calculated according to the Eq. (1) and tabulated in Table I.

The frequency dependence of the noise by the narrow band measurements should exhibit an oscillatory behavior as in the results obtained by Hill and Van Vliet.[2] But the noise spectrum illuminated by light at the midpoint of the filament does not change in shape between the frequencies from 3 kc/sec to 10^4 kc/sec, while our measurements were made in steps of the large frequencies. When the length of the illuminated region varies, the noise power increases about proportional to the length. But the life path seems not to vary.

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Diffusion of Cadmium and Zinc in Gallium Arsenide†

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The diffusion of Cd and Zn in GaAs has been studied by using radioactive isotopes of these elements as tracers. The diffusion of Cd follows the correct solution to the diffusion equation and its temperature dependence is of the customary form, $D=D_0 \exp(-E/kT)$ where E, the activation energy, is 2.43 ev and D_0 is 0.05 cm²/sec. The diffusion of Zn from the vapor cannot, however, be described in terms of a single diffusion constant. The penetration curves decrease much more sharply than they theoretically should. Hall measurements indicate that all the Zn is substitutional and that it forms an impurity conduction band merging with the valence band. When Zn diffuses from a thin electroplated layer of radio-zinc, then the penetration profiles do correspond to the proper solution to the diffusion equation. The diffusion constants so determined have the usual temperature dependence given by $D=D_0 \exp(-E/kT)$, where D_0 is 15 cm²/sec and E is the same as that found for Cd. From the work reported here and that of others, it is suggested that the diffusion of Cd and Zn in GaAs proceeds via vacancy migration within the gallium sublattice.

I. INTRODUCTION

IN the course of a study of diffusion in compound semiconductors composed of elements from columns III and V of the periodic table, the diffusion of cadmium and zinc was studied in gallium arsenide. These elements have been found to be acceptors in GaAs,[1] and are presumed to enter the lattice substitutionally, replacing gallium atoms. The purpose of this work was to measure the important parameters of the diffusion, such as the diffusion coefficient and the activation energy, and also to determine as much as possible about the specific mechanism of the diffusion.

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[1] J. T. Edmond, Proc. Phys. Soc. (London) **73**, 622 (1959).

II. EXPERIMENTAL PROCEDURES AND RESULTS

A. Diffusion of Cadmium

The general experimental procedure was as follows: Single crystal wafers of GaAs, $\frac{3}{16}$ in. square and about 50 mils thick were cut, lapped flat to within 0.1 micron across their surfaces, and then polished to a mirror finish. The wafers were then placed on quartz flats and heated in evacuated quartz ampoules for appropriate times at temperatures ranging from 868°C to 1149°C in regulated furnaces. Pieces of pure Cd, which had been sent to the Oak Ridge National Laboratory for irradiation, producing radioactive Cd^{115} (43-day half-life), were included in the ampoule to produce the vapor source for the diffusion. An amount of arsenic was also included to produce a pressure sufficient to prevent dis-