Measurement of Hole Diffusion in n-Type Germanium

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A HOLE-ELECTRON pair is generated in a filament of n-type germanium for each photon of light absorbed, as previously discussed.[1] For densities of holes small in comparison with that of electrons only small electric fields are present and the holes move mainly under the influence of diffusion in a manner similar to that discussed in connection with carriers injected across the junction in a $p-n$ junction rectifier.[2] The presence of a hole density in excess of the equilibrium value can be detected by "the internal contact potential" developed at a rectifying point contact made with the surface.[3] This potential can be measured as a difference in potential between the contact point and another contact, such as one at the end of the filament, sufficiently far removed from the region of light absorption that the hole concentration in its neighborhood has substantially its equilibrium value. According to the theory, which is similar to that of the $p-n$ junction previously mentioned, the excess hole density produced by the light should decay as $\exp(-|x|/L)$, where $L=(D\tau)^{\frac{1}{2}}$ is the diffusion length, D the diffusion constant, and τ the hole lifetime in the filament. If then a small light spot is moved with respect to the rectifying contact or probe, the logarithm of the voltage response as a function of distance from the plane of the probe should plot as a straight line from the slope of which L can be calculated.

Figure 1 illustrates the essential features of our experimental set-up. The test specimen was a rectangular rod of n-type single-crystal germanium with electroplated end electrodes and of dimensions approximately $0.05\times 0.05\times 2.0$ cm. A potential probe P was brought into contact with one side of the rod in a fixed position about 1 cm from one electrode. A small light spot L in the focal plane of two crossed exit slits of a monochromator made normal incidence on the top surface at an adjustable distance x from the probe location. The light ($\lambda=1.5\mu$) was pulsed and the voltage V between the end electrode and the probe P was measured by means of a high impedance electronic voltmeter. A scan of the intensity of the light spot in the x-direction by means of a detector small in comparison with its width enables one to determine the extent of the region near p which was activated by light in the direct beam.

Figure 2 shows the results of our measurements. Curve A is semilogarithmic plot of V *vs* x for both positive and negative values of x. The straight line determined by the plotted points for values of x in excess of about 0.07 cm shows that on the average V falls off exponentially with distance from the plane of the probe. Curve B is a normalized response *vs* distance in the direction of x showing the variation of light intensity in the light spot from its maximum value for both positive and negative values of x. This shows a drop of intensity to one percent of its maximum value in a distance of about 0.05 cm. It is therefore reasonable to ascribe the exponential portion of curve A for distances in excess of 0.05 cm to the diffusion of holes.

From the slope of A, the diffusion distance L_D is 0.028 cm,

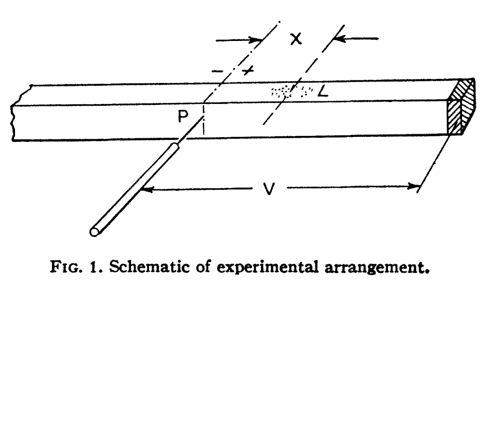

FIG. 1. Schematic of experimental arrangement.

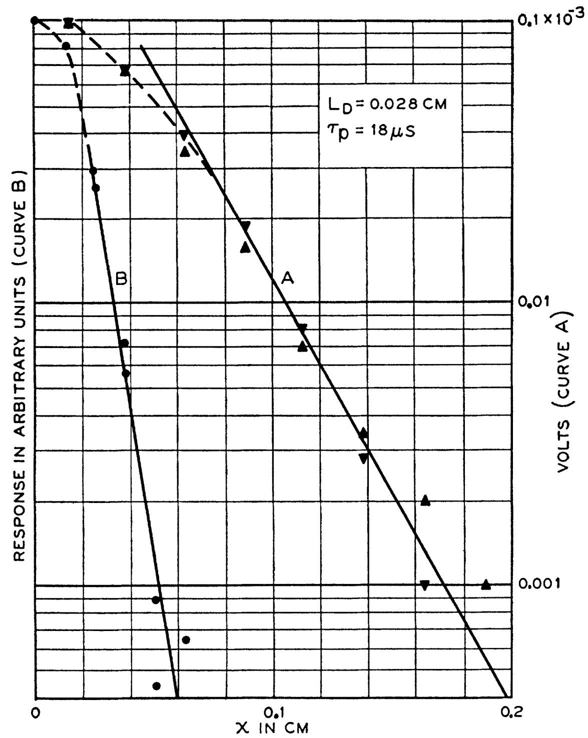

FIG. 2. Curve A—Photo-voltage V *vs* distance x (both positive and negative values). Curve B—Variation of light intensity in direction x measured from the center of the light spot L.

from which we can calculate a hole lifetime τ_p of 18 μsec, using the value 44 cm^2/sec for the diffusion constant D. This value is based on the most recent determination of the hole mobility,[4] μ_p, as 1700 cm^2/volt sec and the Einstein relationship.

That this is the correct interpretation was established by a direct measurement of mean lifetime[5] over the same portion of the specimen as that covered by the scanning curve A. A further check was also obtained by the photo-current method through the illumination of the same portion of the specimen with a known number of quanta, correction being made for reflection loss and unit quantum efficiency being assumed.[1] Each of these checks gave $\tau_p=18$ μsec within experimental error.

Thanks are due W. Shockley who suggested the experiment, to J. R. Haynes for the direct measurement of τ_p, and to H. B. Briggs for collaboration in making the optical measurements.

[1] F. S. Goucher, Phys. Rev. **78**, 816 (1950).
[2] W. Shockley, Bell System Tech. J. **28** (3), 435 (1949).
[3] See Shockley (reference 2) for $n-p$ junctions. The theory has been extended by J. Bardeen, Bell System Tech. J. **29** (4), 469 (1950).
[4] Pearson, Haynes, and Shockley, Phys. Rev. **78**, 295 (1950).
[5] Shockley, Pearson, and Haynes, Bell System Tech. J. **28** (3), 344 (1949).

The $Li^6(n, \alpha)H^3$ Reaction Spectrum

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A MEASUREMENT of the energy of the α and H^3 particles emitted in the $Li^6(n, \alpha)H^3$ nuclear reaction for slow neutrons is of considerable interest. Only measurements of the ranges of these particles[1] and evaluations of the energy released in the above reaction from known values of the Q's of other reactions[2] have been made thus far. A direct energy determination, if com-