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INFRARED ABSORPTION OF PHOTOGENERATED 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 $5 \times 10 \times 15$ 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 known⁴ 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.

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

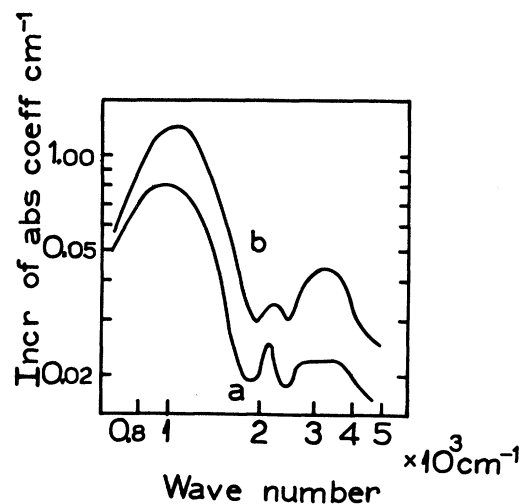


FIG. 1. Increase, due to illumination, of the absorption coefficient of germanium as a function of wave number. Curve a: intrinsic Ge (resistivity 50 ohm cm). Curve b: antimony-doped, *n*-type Ge (resistivity 20 ohm cm).

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-

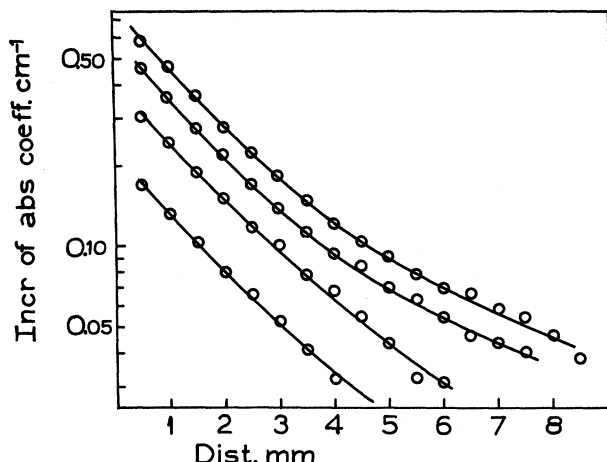


FIG. 2. Increase in absorption coefficient of Ge crystal (50 ohm cm) at wave number 850 cm^{-1} as a function of distance to illuminated surface for four different intensities of exciting light. The intensities were varied, from bottom to top, in the ratio 1:2:3:4.

tively.

The curves in Fig. 2 are, disregarding the absolute magnitude, independent of the wave number of the infrared radiation but not independent of the spectral composition of the exciting light. The latter fact is illustrated in Fig. 3, where the radiation from the tungsten ribbon lamp has been filtered through different media. The water jacket absorbs the radiation of wave number $<7000\text{ cm}^{-1}$. For the remaining light, the absorption coefficient in Ge is greater than

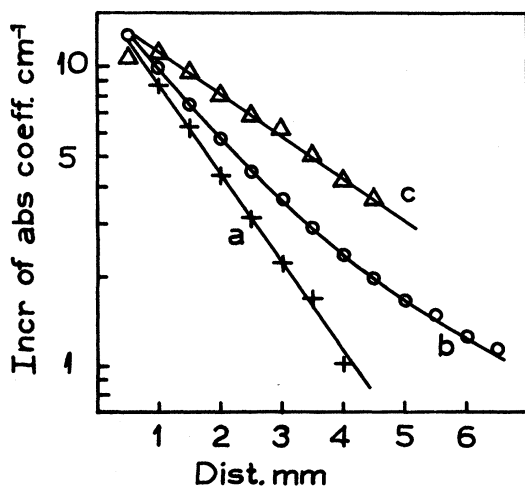


FIG. 3. Increase in absorption coefficient of Ge crystal (50 ohm cm) versus distance to illuminated surface for exciting light (a) filtered through 10-mm water, (b) unfiltered, (c) filtered through Ge plate, 1 mm thick.

10^3 cm^{-1} which means that the absorption and carrier generation takes place in a surface layer of thickness $\ll 1\text{ mm}$. Thus the curve (a) in Fig. 3 illustrates the diffusion of holes from the surface. On the other hand, a pure germanium plate, 1 mm thick, transmits radiation with absorption coefficient $\sim (\text{crystal length})^{-1}$ and accordingly, curve (c) represents the action of ionizing, penetrating radiation.

The "white light curves" in Fig. 2 and (b) in Fig. 3 may be considered to be a superposition of curves (a) and (c). In order to study hole diffusion, only nonpenetrating exciting radiation should be used, i.e., the light should be filtered through a water jacket. In such a case, every curve in the semilogarithmic representation will become a perfect straight line within the limits of error. In the sense of current recombination theories,⁸ our case should correspond to "high carrier density." The diffusion length for the intrinsic sample was found to be 0.14 cm. From $L_p = (D_p \tau_p)^{\frac{1}{2}} = (48\text{ cm}^2\text{ sec}^{-1} \times \tau_p)^{\frac{1}{2}}$, we obtain the mean hole lifetime $\tau_p = 400\text{ }\mu\text{sec}$.

For an *n*-type sample of 20 ohm cm, the surface recombination appeared to be more important than that for the intrinsic sample. The diffusion length was of about the same magnitude.

A direct determination of lifetimes by means of an optical method is being performed. Until this is completed, we postpone further discussions of the data observed and their interpretations.

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