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Measurement of the Lifetime of Minority Carriers in Germanium

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Some basic aspects of recombination properties of high purity n-type germanium are studied by the photoconductive decay method, with a view to ascertaining the efficacy of accepted procedure of detecting radiation damage.

A cryostat entirely different from conventional types in its inverted set up was used.

§ 1. Introduction

In the studies of semiconductor, the recombination of holes and electrons plays an important role. It has been found that the lifetime of minority carriers in germanium depends on a structure-sensitive property of the material. The recombination process takes place through the medium of imperfectibilities of some sort in the crystal. The statistics of the recombination of holes and electrons in semiconductors was analyzed on the basis of a model in which the recombination occurs through the mechanism of trapping[1].

The basic aspects of the recombination of excess carriers in germanium and silicon are now familiar and have been recently treated in a number of review articles[2]. The minority carrier lifetime measurement to detect the radiation damage being a delicate process, the effect of irradiation on lifetime has been studied by several investigators[3]. The studies on the annealing of defects produced by irradiation were discussed in our previous papers [4]–[7]. We are also going to set about studying minority carrier lifetime of the semiconductor affected by irradiation. In this paper the basic aspects of the recombination of minority carriers in n-type germanium are treated

§ 2. Experimental Procedure

The measurements herein reported were obtained from observation of the decay of excessive conductivity following an injection pulse. We used the measurement of minority carrier lifetime in germanium on the method of photoconductive decay approved by the IRE Committee [8]. Observations have been made on single crystals of high resistivity n-type germanium which were cut along the longitudinal axis in ⟨111⟩ direction. The surfaces of the specimens were so etched as to minimize surface recombination effects. Xenon flash tube was used as the light source. The use of this type of pulsed light

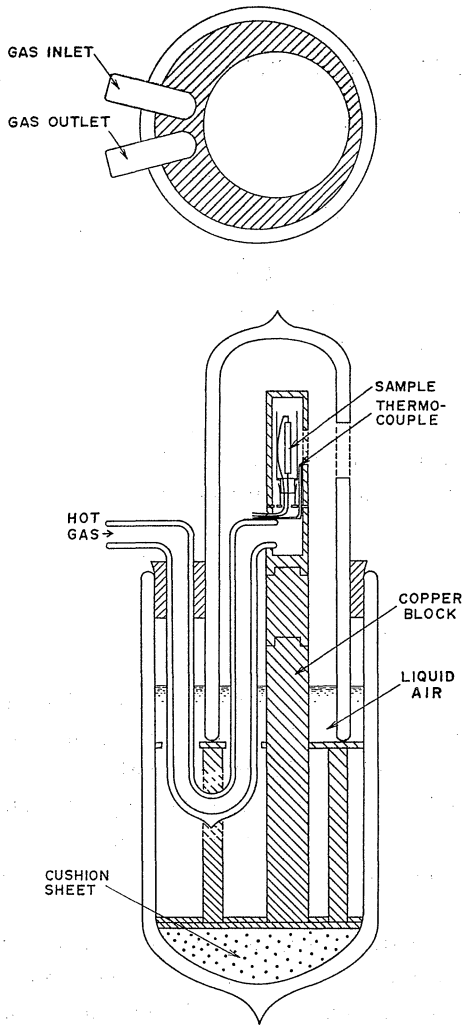

Fig. 1. Diagram of cryostat and sample mounting.

source was a success. The illuminating system (Ushio Kogyo Co. Ltd., UXP-1000LS) can deliver pulse of light with a very short turn-off time, 0.5μsec. This is short compared with the lifetime of specimens. These electrodes and all connections between parts of the system were shielded electrically. The syncroscope (Iwasaki Tsushinki, 5302) has adeqate characteristics to observe the decay curve. Contacts regions were shielded from light, while the central half of the sample was exposed.

Our cryostat had a few new features. It was so constructed, using two Dewars (see Fig. 1) 62 and 115 mm in diameter, that the smaller Dewar was inserted upside down into the other, thus facilitating the sample changing. Further, the upper Dewar was furnished with a region pervious to pulsed light. The sample was mounted on the copper-block heat-conductor encased in a copper cap, 30 mm in diameter. The Dewar was filled with liquid air 2/3 of its capacity. One of the two U-type tubes, thermally shielded, was used for injecting hot gas, the other for exhausting, in order to effect the temperature control of the sample. Lead wires were bound outside these tubes. The lifetime measurement was controlled within the temperature range of about 90°K through 300°K by the injection of hot nitrogen gas. For temperature measurement was used a copper-constantan thermocouple.

§ 3. Experimental Results and Discussion

Temperature variations of lifetime seems to be one of the best tools for studying the recombination process. Fig. 2 shows the dependence of lifetimes and resistivities on temperature for samples D4−1 and C1−9, and the resistivities *vs* typical temperatures (0°C, dry ice temp. and liquid air temp.) have been plotted. Samples D4−1 and C1-9 have room-temperature lifetimes of 56.5 μsec and 51.0 μsec, and these two samples have resistivities of 24.4 ohm-cm and 38.0 ohm-cm at 0°C, respectively. As shown in the Fig. 2 the basic similarity between the temperature behavior of lifetime and that of resistivity was recognized. According to the recombination theory of Roosbroeck[9], minority carrier

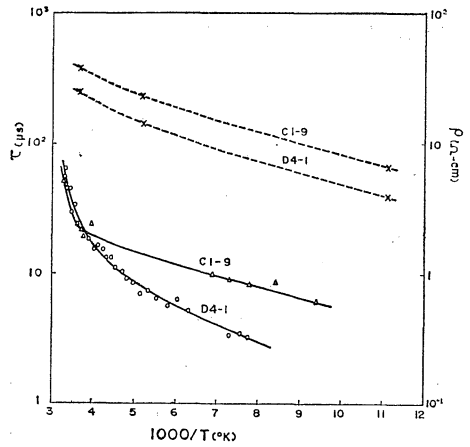

Fig. 2. Minority carrier lifetime, τ, and resistivity, ρ, (dotted line) *vs* reciprocal temperature, 1/T, for sample C1−9 and D4−1.

lifetime decreases as the concentration of electrons increases, if the density of traps is constant. The similarity pattern between lifetime and resistivity seemed to support Roosbroeck's theory. The logarithm of minority carrier lifetime *vs* reciprocal temperature for sample D4−1 is plotted in Fig. 3. The dependence of lifetime on temperature was so remarkable that the recombination level (ΔW) indicated by the slope of ln τ *vs* 1/T curve was 0.26 eV. Fig. 4 shows the temperature dependence for sample C1−9. The upper lifetime curve, obtained at temperatures below 200°K, indicated the occurence of trapping phenomenon with fairly large time constant τ_∞. The trapping level 0.26 eV was determined from our analysis of the slope of ln τ_∞/τ_r *vs* 1/T curve. The plot of recombination lifetime showed a strangely behaving curve in the region from 173°K to 260°K, interpreted to have been influenced by the trapping time constant τ_∞. This corresponds to our assumption that the trapping time constant τ_∞ must be swallowed in recombination lifetime τ_r at high temperature[10]. It is assumed by us that the recombination lifetime

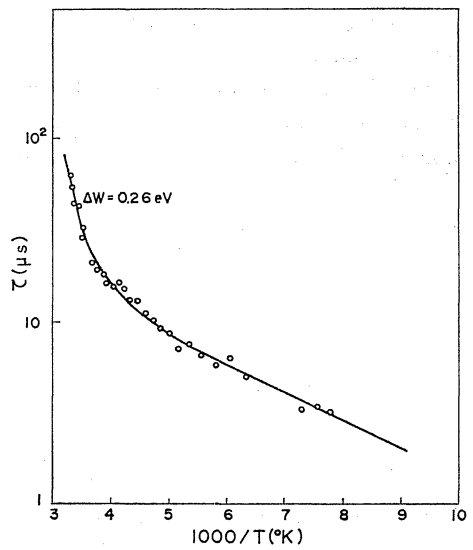

Fig. 3. Minority carrier lifetime, τ, *vs* reciprocal temperature, 1/T, for sample D4−1.

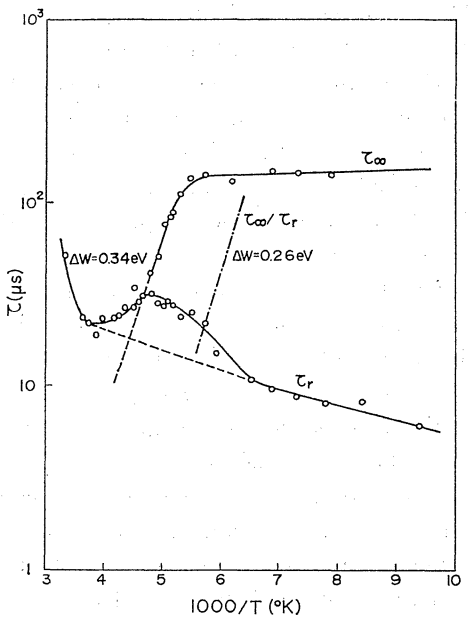

Fig. 4. Minority carrier lifetime, τ, *vs* reciprocal temperature, 1/T, for sample C1−9.

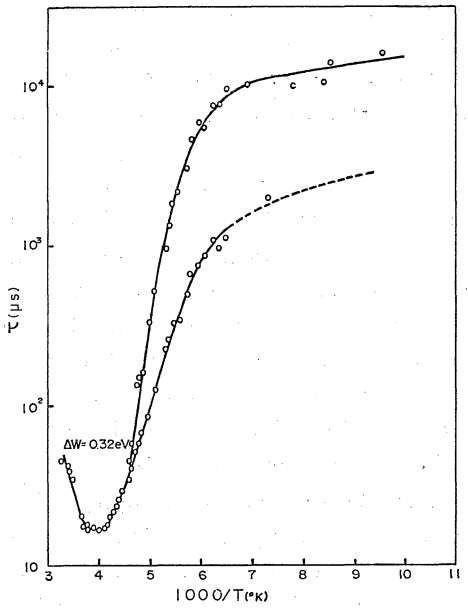

Fig. 5. Minority carrier lifetime, τ, *vs* reciprocal temperature, 1/T, for sample A8−3.

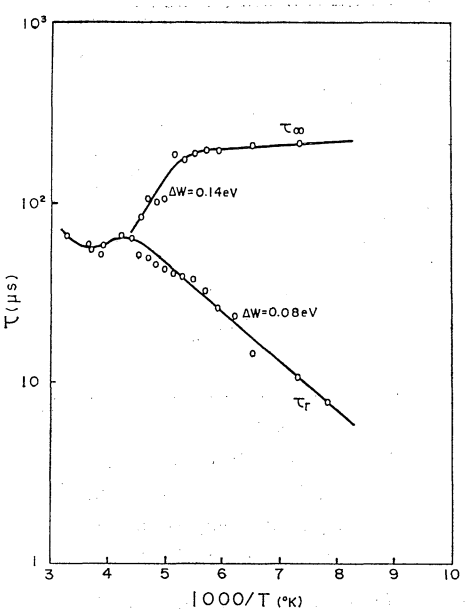

Fig. 6. Minority carrier lifetime, τ, *vs* reciprocal temperature, 1/T, for sample A8−3. (When a steady background light is applied.)

and trapping time constant shift, for this region, along the dotted line in the figure. The measurements of lifetime τ_r corresponded well with the value obtained by adding the presumptive value of τ_r to that of τ_∞. Fig. 5 illustrats the dependence of minority carrier lifetime on temperature for sample A8−3. Although the recombination of holes and electrons has not been visible, the deep trapping is dominant over the recombination at low temperature. When the holes are injected into the sample by a pulse of light accompanied with a steady background light, the longer time constant for the final decay due to trapping does disappear and the recombination level of 0.08 eV comes to be presented (Fig. 6).

The dependece of the position of trapping level ($E_t - E_v$) on temperature measured by the slope of τ_∞ for the sample A8−3 is illustrated in Fig. 7. The trapping level is markedly dependent on temperature in the range lower than 200°K.

A few properties of the recombination center and the trapping centre have been obtained utilizing the dependence of lifetime on temperature, and studies on basic aspects of the recombination of minority carriers in n-type germanium have been carried out.

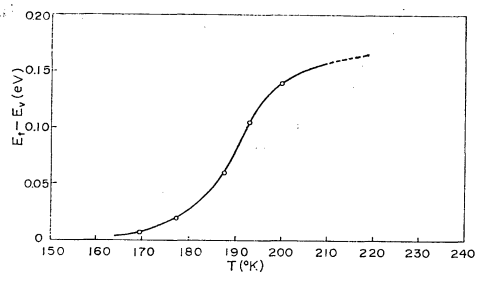

Fig. 7. Dependence of position of trapping level on temperature for sample A8−3.

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