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Abstract

Full Text

PHYSICS

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THE ENERGY OF IONIZATION BY ELECTRONS IN GERMANIUM CRYSTALS

(Presented by Academician D. V. Skobel' tsyn, 27 X 1956)

Energy losses by fast particles passing through crystals are connected with ionization, i.e., with the appearance of pairs of excess charge carriers—electrons and holes. The mean energy ε expended in the formation of one carrier pair depends on the character of the excitation. The magnitude of ε in ionization by particles, in particular by fast electrons, determines the efficiency of conversion of the energy of β- and γ-radiation into electrical energy by means of semiconductor devices ([1,2]), and the efficiency of registering radiations by means of crystal counters and dosimeters.

The magnitude of ε for fast electrons in germanium crystals has been estimated in a number of works ([3,2]) concerned with the question of direct conversion of β-radiation energy into electrical energy. A direct measurement of ε in germanium was carried out by McKay for the case of ionization by α-particles. The values of ε obtained by McKay are 3.0 ± 0.4 eV ([4]) and 2.94 ± 0.15 eV ([5]).

We have carried out experiments to determine the mean ionization energy in germanium under excitation by electrons with energies of 5-15 keV.

In the experiments, N-type crystals with P—N junctions obtained by alloying with indium ([6]) were used. Irradiation was performed from the side opposite the indium electrode. The electrons completely lost their energy in the N-type region. A method was applied that consisted in determining the ratio of the flux of holes N_2 through the P—N junction, caused by the generation in the crystal of excess pairs by the primary electrons, to the flux of primary electrons N_1*. We shall denote the ratio of these fluxes by β_1. The magnitude N_2 was determined from the short-circuit current of the P- and N-regions I_2, flowing in the external circuit through the device, whose resistance was sufficiently small in comparison with the differential resistance of the P—N junction at zero R_0 ([6]) (see Fig. 1).

Thus,

$$\beta_1 = \frac{N_2}{N_1} = \frac{I_2}{I_1},$$

where I_1 is the primary current corresponding to the flux of fast electrons.

Fig. 1

Figure 1: Fig. 1

As a result of recombination at the surface and in the bulk, the flux of holes N_2 is always smaller than the number of carrier pairs N_0 actually formed per unit time, but it is proportional to it up to quite considerable intensities of the exciting beam, i.e.,

$$N_2 = \alpha N_0.$$

The magnitude of the "multiplication" coefficient β will be expressed as

$$\beta = \frac{N_0}{N_1} = \frac{\beta_1}{\alpha} = \frac{I_2}{\alpha I_1}.$$

* Measurements of induced conductivity in homogeneous bars do not give sufficiently reliable results because of the difficulty of controlling the rate of surface recombination, which varies differently in the irradiated and "shadow" regions of the crystal.

The value of ε can be written as

$$\varepsilon = \frac{V}{\beta} = \frac{\alpha I_1 V}{I_2},$$

where V is the energy of the primary electrons. The quantity α was determined independently by generating excess carrier pairs with monochromatic light of known intensity. The reflection coefficient of germanium in the wavelength range 0.6–2 μ was measured in our laboratory and practically coincided with the values known from the literature (^{7}). The quantum yield was taken to be equal to unity.

In the crystals we investigated, the quantity α did not depend on the wavelength of the light up to wavelengths at which, under illumination, a noticeable part of the light flux passes through the crystal without being absorbed. In our experiments, for measuring α we used light with $\lambda = 1.05\,\mu$, absorbed mainly in a layer of thickness no more than $1.0\,\mu$, i.e., approximately in the region of ionization by electrons.

Fig. 1

The quantity α depends strongly on the conditions at the surface of the crystals and changes during evacuation of the apparatus and electron bombardment. For continuous monitoring of α during the measurements, simultaneous irradiation of the crystals with electrons and light was used. For this purpose an electron gun was made, whose design made it possible to direct the light beam along the electron beam (see Fig. 1).

In front of the irradiated crystal there were diaphragms, which defined the beam and collected the secondary electrons. The secondary-emission coefficient at $V = 5$–15 kev proved to be approximately 0.3.

A control calorimetric experiment was carried out in which the energy carried away by secondary electrons and x-ray radiation was estimated, and it was shown that this energy amounts to approximately 4% of the energy of the electron beam incident on the crystal.

The experiments were performed at pressures of 10^{-4}–$2 \cdot 10^{-6}$ mm Hg. No dependence of ε on pressure was found within the range $2 \cdot 10^{-6}$–10^{-4} mm Hg.

Series of measurements on crystals subjected to different surface treatments (etching in hydrogen peroxide and in the CP-4 mixture) (^{8}) gave identical values of ε. The value of ε, averaged over 4 series of measurements, proved to be 3.7 ± 0.4 ev.

Within the range of values of V from 5 to 15 kev, ε does not change. This indicates a small magnitude of the energy losses of the primary electrons in the surface oxide film formed during etching of germanium.

The close agreement of the values of ε for ionization by electrons and by α-particles is apparently explained by the fact that in the latter case a considerable fraction of the charge-carrier pairs is produced under the action of relatively fast δ-electrons. One also cannot exclude the possibility of radiative transfer of energy inside the crystal from the region of dense ionization by photons formed in the direct recombination of electrons and holes.

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