Diffraction of x rays and electrophysical properties of crystals

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Investigations were made of the photoelectric electromotive power (photo-emf) produced when semiconductor crystals with *p-n* junctions are exposed to x rays under conditions when the x rays are diffracted by the crystal lattice.

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When x rays are absorbed in semiconductor crystals, the greater part of the energy is consumed in generation of electrons and holes. If a *p-n* junction is present in the crystal, then, under the influence of its field, the carriers become spatially separated, and this leads to accumulation of charges of opposite signs in both regions of the junction—i.e., to the appearance of a photo-emf ϵ. It is known that absorption of x rays in a crystal depends strongly on the angle of incidence on the crystal, $\Theta = \theta - \theta_B$, near angles corresponding to Bragg diffraction. This is clearly reflected in the angular dependence of the yield of the secondary radiation (photoelectrons, fluorescent radiation, etc.), which are produced in the course of absorption of the x rays (see Ref. 1 and the literature cited therein). An analogous behavior can be expected also for the function $\epsilon(\Theta)$. Investigations of this kind call for monochromatization and rather high angular collimation (approximately several seconds) of the x rays, which leads to a sharp decrease of the intensity of the beam incident on the crystal. There is the danger that with such weak fluxes the induced photo-emf is too negligibly small to be registered. However, as shown by the present investigation, the produced photo-emf not only lends itself to measurement, but these measurements can also be used to trace the character of the $\epsilon(\Theta)$ dependence.

The photo-emf was measured on silicon samples with *p-n* junctions parallel to the surface. We used high-resistance *p*-type material. At a depth $\sim 2\ \mu$m, diffusion of phosphorus atoms was carried out with surface concentration $\sim 10^{20}$ at/cm^3. The thickness of the *p*-region was 300 μm. On both surfaces of the plate, pointlike ohmic contacts were produced at the center. The samples were installed in a special goniometric head, electrically insulated from the goniometer casing, and was screened against the action of the external radiation. The voltage was measured with a digital microvoltmeter with voltage sensitivity $\sim 0.1\ \mu$V. The diffraction reflection $R(\Theta)$ and the photo-emf $\epsilon(\Theta)$ were registered with a two-crystal spectrometer in which the crystals were parallel (Fig. 1). The monochromator was a germanium crystal with surface orientation in the $\langle 110 \rangle$ direction. The tube operating conditions were $U = 40$ kV and $J = 9$ mA. At an incident-beam area 0.01×0.5 cm, the intensity reached 10^5—10^6 counts/sec. Cu K_α radiation was used.

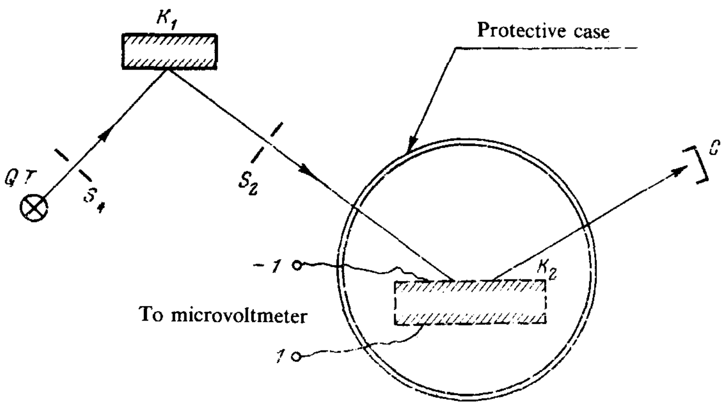

FIG. 1. Diagram of experiment: *QT*–x-ray tube; S_1 and S_2—slits; K_1 and K_2—monochromator crystal and investigated crystals; *C*—radiation counter.

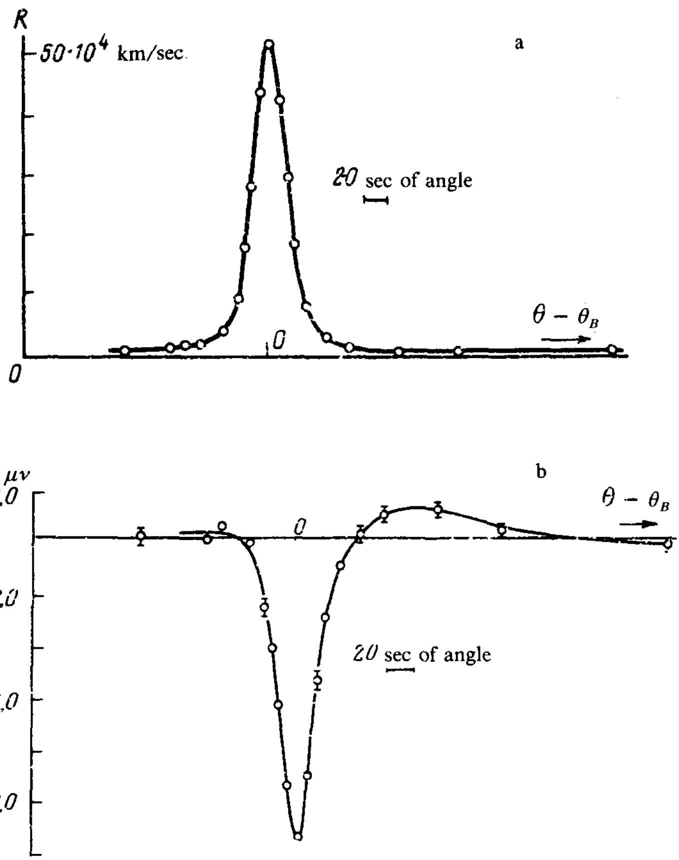

FIG. 2. Angular dependence of photo-emf: a—x-ray reflection curve; b—$\epsilon(\Theta)$ curve.

Figure 2 shows the (111) reflection curve and the corresponding angular dependence of $\epsilon(\Theta)$, measured in Bragg-diffraction geometry at room temperature. The entrance surface for the radiation was the n-region of the crystal. Attention is called to two singularities on the $\epsilon(\Theta)$ curve. The first is the presence of a strong dip at angles at which the x rays are diffracted; the second is that the $\epsilon(\Theta)$ curve has a clearly pronounced asymmetry, whereas the diffraction reflection curve $R(\Theta)$ is symmetrical. The presence of the dip is easy to explain. Whenever there is a strong diffraction of the x rays, the smaller part of the intensity penetrates into the interior of the crystal and consequently fewer carriers are generated. The asymmetry of the curve is due to a more subtle physical circumstance. Relations of just this type were observed earlier in a study of secondary fluorescence. A typical fluorescence-yield curve is shown in Fig. 3, which is quite similar in shape to the $\epsilon(\Theta)$ curve. The nature of the asymmetry of the fluorescence curves is well known. The asymmetry is due to the finite length of the crystal from which the fluorescent radiation emerges (Refs. 1 and 2). On the other hand, in the case of the photo-emf, the analogous parameter that determines the asymmetry of the curve is the length L_D which the carriers transverse during the lifetime τ as a result of their diffusion motion: $L_D = (2D_\tau)^{1/2}$, where D is the diffusion coefficient. On the other hand, from the form of the $\epsilon(\Theta)$ dependence we can estimate relatively simply the value of L_D itself. We have estimated L_D by formulas (6)–(13) of Ref. 1, in which the length of the fluorescence departure was replaced by L_D, i.e., $P_A(z) = e^{-z/L_D}$.

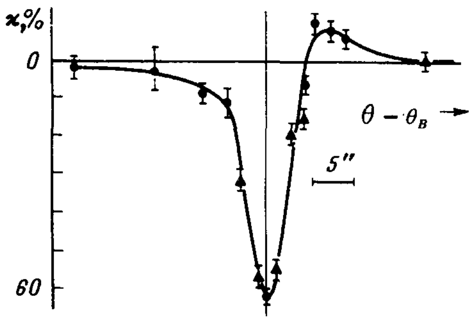

FIG. 3. Angular dependence of the relative quantum yield of the fluorescence: crystals of alloy $Si_{1-x}Ge_x (x = 0,2)$. Simultaneous registration of GeK_β and GeK_α lines. The angle of inclination of the counter relative to the sample surface is 20°.

Taking into account the finite angle interval of the x rays reflected from the first monochromator crystal, the calculations yield a value $L_D = 53\ \mu m$. Electrophysical measurements yield $L_D = 68\ \mu m$. In this case we have fairly good agreement and, by the same token, a demonstration of the realistic possibilities of determining the diffusion length from the $\epsilon(\Theta)$ curves.

It was observed in experiment that $\epsilon(\Theta)$ decreases strongly with decreasing crystal temperature. The value of the photo-emf increases by 10^1—10^2 times when the temperature decreases to -183 °C. It was also observed that the $\epsilon(\Theta)$ curves are sensitive to the presence of a magnetic field with an intensity vector parallel to the plane of the p-n junction. These features of the behavior of the photo-emf give grounds for hoping that the observed effect can become an effective means of investigating a large class of electric properties of crystals, as well as of the characteristics of *p-n* junctions.

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