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P. S. NESTERENKO

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Fig. 1

Figure 1: Fig. 1

Abstract

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ON THE PHOTOELECTRET STATE IN CdS SINGLE CRYSTALS

(Presented by Academician A. V. Shubnikov, 3 VII 1963)

Stable photopolarization, i.e., the photoelectret state (p. s.), is also observed in CdS single crystals ([1]). In view of the absence of data in the literature, it is of interest to establish the existence of a correlation between the characteristics of the p. s. and the photoelectric parameters of the crystals.

In the present work, carried out at room temperature, CdS single crystals of dimensions on the order of $4\times4\times0.2$ mm^3 were investigated; they had been grown by gas-phase synthesis and had not undergone additional treatment. They possessed one maximum of longitudinal photoconductivity at $\lambda_0 = 516$–520 mμ and negligible photosensitivity near 700 mμ. The design of the measuring capacitor was described earlier in ([2]). The tube electrometer permitted measurement of currents down to $5\cdot10^{-15}$ A with a time constant of 2 sec at an input resistance of 10^{11} Ω. For visual observation of the kinetics of photodepolarization, a UIPIP-2 amplifier and an ENO-1 oscillograph were connected. Illumination of the crystals was carried out from a UM-2 monochromator, the radiant energy being measured by a Zeiss thermopile.

Fig. 1. Spectral distribution of the photodepolarization currents (1) and longitudinal photoconductivity (2) of a CdS single crystal, referred to unit incident energy

1. Experiments carried out by us in the spectral region 0.45–1 μ show that the p. s. is formed in the crystal only in the interval 0.7–1.1 μ. The measure of the charge released during photodepolarization was taken, as usual ([3]), to be the initial (maximum) value of the discharge current i_m. The spectral dependences of the depolarization current $i_m(\lambda)$ and of the longitudinal photocurrent $I_f(\lambda)$, obtained for one and the same crystal and referred to unit incident energy, are presented in Fig. 1. To obtain the curve $i_m(\lambda)$, the p. s. (polarization) was produced at a constant value of the field and illumination of the crystal with one and the same λ in the above-mentioned spectral region (0.7–1.1 μ). Depolarization of the photoelectret

Fig. 2

Figure 2: Fig. 2

was carried out by illuminating it with different wavelengths. Light with λ_0 produces instantaneous depolarization independently of the degree of photosensitivity of the crystal. At large values of the depolarizing λ (λ_d), between λ_0 and $\lambda_1 \sim 700$ mμ, the depolarization currents (per unit

of the incident energy) decrease, but depolarization continues to remain complete. However, for $\lambda_d > \lambda_1$ the release of charge from the crystals became incomplete, and their complete depolarization in this case was accomplished by illumination in the interval λ_0–λ_1.

Owing to the deterioration of the differentiating properties of the electrometer input circuit for pulsed signals, the kinetics of photodepolarization is observed with some distortion. Taking into account the influence of the input circuit ([4]) leads to the conclusion that, upon depolarization with λ_0, the pulse of the discharge current i has the form of a decaying exponential

$$i = i_0 \exp -(t/\tau)$$

with the intrinsic time of the process τ, coinciding (within the accuracy of the measurements) with the Maxwell relaxation time $\tau_M = \varepsilon/4\pi\sigma$ of the crystal under study; ε is the dielectric constant of CdS ($\approx$ 11.6, according to ([5])), and σ is the specific conductivity. This result is in agreement with the theory of photoelectrets ([6,7]). Changing λ_d in both directions from λ_0 (at the same intensity of the depolarizing light) led to a slight increase in τ. For $\lambda_d > \lambda_1$ the depolarization process was substantially slowed and proceeded with a clearly expressed leading front of increase of the discharge current. We note that, for depolarization with λ_0, the steepness of the mentioned front did not exceed the cutoff time (2 msec) of the photo-shutter used.

Fig. 2. Dependence of the total (1), dark (2), and photopolarization (3) on the polarizing voltage for CdS crystals

2. Under the action of a constant voltage in the range 30-300 V, dark polarization also arose in the crystals, measured likewise by the photodepolarization method. Typical dependences of the dark and photopolarization on the polarizing voltage are given in Fig. 2. The decay of the dark polarization to zero usually proceeds faster, which makes it possible to measure the photopolarization separately ([8]). The latter fell to 5% of its initial value (measured after a one-minute dark holding) during the first 3 hours of the crystals' stay in the dark with short-circuited electrodes. For two crystals this time was 7-9 hours (Fig. 3).

Fig. 3. Dark decay of photo- (1) and dark (2) polarization in individual CdS crystals

Fig. 3

Figure 3: Fig. 3

Figure 4 graph: spectral distribution curves versus wavelength λ

Figure 4: Figure 4 graph: spectral distribution curves versus wavelength λ

3. It was mentioned above that the p.s. was excited by light from the region 0.7–1.1 μ. Spectral dependences, taken for different crystals, indi-

point to the existence of a selective maximum of the p.e.s. at the corresponding $\lambda_{\text{m.p.e.s.}}$ in this region. A comparison with the photosensitivity, characterized by the ratio of the resistances (k_R) of the crystal in the dark and under illumination with λ_0 (under identical conditions), showed that at small $k_R(\sim 100)$ $\lambda_{\text{m.p.e.s.}}$ was located near $0.75\,\mu$. In the case of large $k_R(10^3$—$10^4)$, the values of $\lambda_{\text{m.p.e.s.}}$ for different crystals lay between 0.85 and $0.95\,\mu$.

4. In the course of the experiments it was clearly observed that switching on the polarizing light (in the p.e.s.-formation regime) leads to a "flash" of current flowing through the crystal. Repetition of this operation immediately after the creation of the p.e.s. did not produce a new "flash," which appeared only after the lapse of longer dark pauses. The appearance of an analogous "flash," described by A. D. Shneider ([9]), during quenching of the photoconductivity of CdS led us to investigate jointly the spectral distribution of the p.e.s. and the infrared quenching of the photocurrent (at the same intensity of the infrared light). The results obtained in this way for crystals with high photosensitivity are presented in Fig. 4. For crystals with low photosensitivity, the maxima of the p.e.s. and of infrared quenching almost coincided and were situated near $0.75\,\mu$. Let us add that the spectral distribution of the p.e.s. (curve 1, Fig. 4) was recorded by photopolarizing the crystal at constant voltage and by illuminating it with light of various wavelengths. Measurement of the maximum depolarization current i_m was carried out under strictly identical conditions by illuminating the photoelectret with light at the photosensitivity maximum ($\lambda = \lambda_0$).

Fig. 4. Spectral distribution of the photoelectret state (per unit incident energy) (1) and infrared quenching of longitudinal photoconductivity (at the same intensity of infrared light) (2) for CdS single crystals with high photosensitivity.

The experimental results obtained in the present work reduce to the following. In single crystals a photoelectret state is observed, which arises upon illumination of the crystal in the near infrared region ($\lambda > 0.7\,\mu$). Thus the spectral distribution of the photopolarization of the crystal is shifted into the long-wavelength region relative to the spectral distributions of the longitudinal photocurrent and photodepolarization. On the other hand, the spectral distribution of photopolarization coincides with the spectral distribution of infrared

quenching and this, apparently, indicates that a common mechanism underlies these phenomena. The results obtained can be interpreted relatively simply if one takes into account that in the region of maximum photosensitivity ($\lambda \sim \lambda_0$) the photocurrent in CdS is of a through-going character and therefore does not lead to the formation of a p.e.s. It is not excluded that the destruction of the p.e.s. immediately after short-circuiting the electrodes is the result of injection or extraction of current carriers ([1]). The mechanism of formation of the p.e.s. in the near infrared region, coinciding with the mechanism of infrared quenching of the photoconductivity of CdS, is due to the excitation of carriers from trapping levels (with activation energy $\simeq 1.3$ eV) into the band and their subsequent redistribution over the volume of the crystal. It is not excluded that responsible for the formation of the photoelectret state are holes ([10–16]). However, within the framework of the experiments described, it is not yet possible to resolve this question.

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