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Abstract

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ON THE FORM OF THE SPECTRAL DISTRIBUTION OF THE PHOTOCONDUCTIVITY OF CdS SINGLE CRYSTALS

The question indicated in the title has been considered in works ([3–7]). However, the methods used, as well as the ambiguity of the results obtained, leave the question of the causes of the decrease in photoconductivity in the short-wavelength part of the intrinsic-absorption band unresolved. Thus, in works ([4–6]) an attempt is made to explain the decrease in photoconductivity by a decrease in the proper lifetime τ of the photocarriers as a consequence of surface recombination. At the same time, the method used by Lamb ([5]) (measurement of photocurrent at a frequency of 100 kc), it seems to us, still requires further substantiation and comparison with known methods; and the method used by Bube ([6]) (equalization of the photocurrent at different wavelengths), as will be shown below, does not lead to unambiguous results. Fassbender and Seraphin ([7]) state that they did not observe a decrease of $\tau(\lambda)$.

Meanwhile, in addition to the noted dependence $\tau(\lambda)$, the causes of the decrease of the photocurrent in the region of intrinsic absorption may also be: a decrease in the mobility of the photocarriers, an increase in the coefficient of reflection of light, and a fall in the quantum yield β (or in the photocurrent yield a, proportional to it ([1])) in this region.

The present work is devoted to an experimental verification of the assumptions expressed above.

The experiments were carried out on CdS single crystals obtained by synthesis of cadmium and sulfur vapors*. The electrodes were applied by evaporating indium in vacuum. The light source was a UM-2 monochromator, at whose entrance there was a special incandescent lamp (340 W). The light intensity could be varied over wide limits.

The spectral characteristic of the photocurrent was recorded under conditions of stationary illumination of the specimen; in this case the intensity of quanta of different wavelengths L_p incident on the specimen was kept constant and was equal to $36 \cdot 10^{12}$ quanta/cm^2 sec. The investigation of the spectral dependence of the proper lifetime of the photocarriers was carried out as follows.

Figure 1

Figure 1: Figure 1

The instantaneous proper decay time of the photocurrent at the moment the light was switched off (τ^0) was measured by determining, from the initial portion of the decay—always rectilinear—the time of decay of the photocurrent by 5-10% from its stationary value ($\Delta t_5, \Delta t_{10}$). The light intensity at each wavelength was chosen to be the same as when recording the spectral dependence of the photocurrent (L_p).

The time τ^0 was then determined as $10\Delta t_{10}$ or $20\Delta t_5$. An analogous procedure (measurement of the photocurrent decay time by 5 or 16%) was also used in the works of Lamb ([5]) and Bube ([6]), with, however, the essential difference that in our case the number of incident quanta of different wavelengths was equalized, in contrast to the equalization of the photocurrent in Bube' s work ([6]).

* For the preparation of the crystals the authors express their gratitude to I. B. Mizetskaya.

The yield of photocurrent a_0 was measured from the amplitude of the initial portion of the oscillogram of the rise of the photocurrent under illumination by light pulses of duration much shorter than the intrinsic relaxation times of the photoconductivity (0.5 msec) and with a dark interval between pulses of 3 min. ([1]). During the dark interval, the photoactivation ([2]) of the specimen by the light pulses decayed completely. The value of the yield (differential yield a_0) was also measured by the same method, but in the presence of additional constant bias illumination of the specimen by light of the same spectral composition as in the pulse, but of considerably higher intensity. The intensity of the bias illumination at each wavelength was chosen so that the photocurrent due to the bias illumination was equal to the photocurrent corresponding to the spectral characteristic.

Fig. 1. Spectral dependences: **1** —photocurrent I_ϕ; **2** —instantaneous intrinsic time τ^0; **3** —yield of photocurrent a_0; **4** —yield a_d. Curves **3** and **4** are reduced to the same scale at the point $\lambda = 4610$ Å.

The mobility of the photocarriers was determined from measurements of the conductivity and of the Hall effect*. As the experiments showed, the mobility does not depend on wavelength in the region 4500–5500 Å to an accuracy of 10%.

Measurements of the coefficient of reflection of light showed that, on passing to strongly absorbed light, the reflection coefficient practically does not change, and its value in the region of intrinsic absorption does not exceed 20%.

As is seen from Fig. 1, the curve $\tau^0(\lambda)$ has a minimum at the maximum of the photocurrent; the spectral dependences $a_0(\lambda)$ and $a_d(\lambda)$ have a character analogous to $I_\phi(\lambda)$, with a sharper maximum for $a_d(\lambda)$.

Figure 2

Figure 2: Figure 2

Fig. 3. Spectral dependences: 1 —photocurrent; 2 and 3 —instantaneous proper times τ^0, obtained by equalizing the photocurrent at different wavelengths; 2 —obtained at a photocurrent of 3 μa; 3 —40 μa

Figure 3: Fig. 3. Spectral dependences: 1 —photocurrent; 2 and 3 —instantaneous proper times τ^0, obtained by equalizing the photocurrent at different wavelengths; 2 —obtained at a photocurrent of 3 μa; 3 —40 μa

The obtained dependence $a_0(\lambda)$ $[a_d(\lambda)]$ can be understood on the basis of the exciton mechanism of photoconductivity in CdS single crystals, proposed earlier by one of the authors ([2]). It may be expected that excitons generated at the surface of the semiconductor in a layer $\sim 10^{-5}$ cm, when light is absorbed in the region of the fundamental absorption of the lattice, do not have time to diffuse into the interior of the semiconductor and undergo, mainly, photo-inactive annihilation at local levels associated with the surface structure. On passing to weakly absorbed light, excitons arise throughout the entire depth of the semiconductor and undergo photoactive dissociation, activating the specimen and increasing the number of photocurrent carriers.

Fig. 2. Dependence of the instantaneous intrinsic time τ^0 on the intensity of the incident light L: **1** —illumination with wavelength 5120 Å; **2** —4610 Å.

* These measurements were carried out by A. P. Trofimenko, to whom the authors express their gratitude.

The dependence $\tau^0(\lambda)$ (Figs. 1, 2) can be explained by the dependence of τ^0 on the concentration of photocarriers, as indicated by curves 1 and 2 in Fig. 2. Indeed, it follows from Fig. 2 that as the illumination decreases, which also corresponds to a decrease in the concentration of photocarriers, $\tau^0(L)$ begins to increase. It is interesting to note here that in the region of high illuminations $\tau^0(L)$ remains practically constant.

The sharper dependence $\tau^0(L)$ and the larger absolute values of τ^0 for the wavelength λ 4610 Å we explain by the fact that, under illumination with strongly absorbed light (λ 4610 Å), the concentration of photocarriers proves to be smaller than under illumination with weakly absorbed light (λ 5120 Å), although the thickness of the layer in which the carriers are concentrated is, in the first case, much smaller than in the second. This circumstance, however, ceases to be surprising if one takes into account the sharp decrease in the photocurrent yield α upon transition to the region of short wavelengths (Figs. 1, 3, and 4).

Fig. 3. Spectral dependences: **1** —photocurrent; **2** and **3** —instantaneous intrinsic times τ^0, obtained by equalizing the photocurrent at different wavelengths; **2** —obtained at a photocurrent of 3 μA; **3** —40 μA.

The concentration of photocarriers reaches a maximum at the maximum of the photocurrent and decreases with further increase in wavelength owing to a decrease in the light absorption coefficient (the long-wavelength absorption edge), which also accounts for the increase of $\tau^0(\lambda)$ upon transition to the long-wavelength part of the spectrum (Figs. 1, 2).

The inadequacy of the method chosen by Bube [6] for measuring the dependence $\tau^0(\lambda)$ by equalizing the photocurrent at different wavelengths, and of the attempt to explain the spectral dependence of the photocurrent by means of the resulting $\tau^0(\lambda)$ curve, follows from Fig. 3. It is obvious that by this method different $\tau^0(\lambda)$ curves can be obtained depending on the choice of the magnitude of the photocurrent, which is an experimental parameter. The increase of $\tau^0(\lambda)$ in this case is associated with a decrease in the carrier concentration owing to an increase in the thickness of the photoconducting layer upon transition to weakly absorbed light.

Thus, in our work it has been shown that the cause of the decrease of the photocurrent in the region of the fundamental absorption of the lattice in CdS single crystals is the decrease in the photocurrent yield, and not a decrease in the intrinsic lifetime of the carriers.

In conclusion, attention should be drawn to the fact that many authors postulate that the quantum yield of the photocurrent β is equal to unity over the entire spectral region and, on this basis, estimate the intrinsic lifetime of the photocarriers τ [8,9], or draw conclusions about the ohmic nature of the contacts [10]. In fact, as our experiments show, the assumption $\beta = 1$ is incompatible with the wavelength dependence of the yield that we have observed.

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CITED LITERATURE

1. V. E. Lashkarev, ZhETF, **19**, 876 (1949).

2. V. E. Lashkarev, G. A. Fedorus, Izv. AN SSSR, ser. fiz., **16**, No. 1, 81 (1952).

3. R. H. Bube, Phys. Rev., **98**, 431 (1955).

4. R. H. Bube, J. Chem. Phys., **21**, 1409 (1953).

5. J. Lambe, Phys. Rev., **98**, 985 (1955).

6. R. H. Bube, Phys., **101**, 1669 (1956).

7. J. Fassbender, B. Seraphin, Ann. Phys., **10**, No. 6-7, 374 (1952).

8. A. Rose, Proc. IRE, **43**, 1837 (1955).

9. R. H. Bube, J. Chem. Phys., **23**, 18 (1955).

10. R. W. Smith, Phys. Rev., **97**, 1525 (1955).

Note: Figure translations are in progress. See original paper for figures.