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Fig. 1

Figure 1: Fig. 1

Abstract

Full Text

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PHYSICS

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STUDY OF THE SPECTRAL DEPENDENCE OF PHOTOIONIZATION OF SENSITIZING CENTERS IN CADMIUM SULFIDE

In work ([1]) it was shown that impurity photoconductivity in CdS is associated with photoionization of sensitizing centers (r-centers ([2])). From the work of other authors (for example ([3])) it is known that the spectral dependences of the impurity photocurrent, measured at equal photon fluxes, differ from sample to sample, especially in the long-wavelength region. It is easy to see that this difference may be due either to the simultaneous quenching action of the impurity light or to the presence of phototransitions of electrons from "fast" recombination centers (s-centers ([2])) into the c-band, whose intensity depends on the wavelength and varies from sample to sample. To determine which of these two mechanisms occurs, we studied the kinetics of the impurity photocurrent under different constant illuminations from the region of fundamental absorption.

Fig. 1. Scheme of electronic transitions upon illumination of a CdS sample by intrinsic (L) and impurity (L) light. The intensities of the transitions are indicated in the figure. β_r, β_s, γ are the corresponding photon-capture cross sections; $N_{r,s}$ and $P_{r,s}$ are the concentrations of electrons and vacancies at the corresponding centers, N, P are the concentrations of free electrons and holes.

Figure 1 shows a scheme of possible electronic transitions under the action of intrinsic (L) and impurity (L) light. Impurity light can cause transitions from r-centers to the c-band (exciting), from the v-band to r-centers (quenching), and from s-centers to the c-band (s-transitions). The intensity of transitions from the v-band to s-centers may be neglected because of the smallness of P_s ([3–5]). By the method described in ([4]), it is easy to obtain that, after a short pulse of impurity light $\Delta t \ll \tau_s, \tau_r$ against the background of intrinsic constant

Fig. 2

Figure 2: Fig. 2

illumination, the relaxation of the additional photocurrent (in the linear regime ([4])) will, with sufficient accuracy, proceed according to the law:

$$\nu/I = (\beta_s N_s + g_s \gamma P_r) e^{-q_s t} + (\beta_r N_r - g_s \gamma P_r) e^{-q_r t}, \quad (1)$$

where $\tau_r, sq_{r,s}^{-1}$ are the characteristic times of the s-part (fast) and r-part (slow) of the photocurrent relaxation curve ($\tau_r \gg \tau_s$); I is the total number of quanta of impurity light in the pulse (per 1 cm^2); ν is the magnitude of the increment to the intrinsic photocurrent; g_s is the probability of hole capture at s-centers ([4]).

For the measurements we used CdS single crystals grown by recrystallization from the gas phase. The intrinsic illumination was light from an incandescent lamp, passed through a $CuSO_4$ solution and a ZhS-18 filter. The source of short pulses of impurity light was a spark discharge with a rise time of $\simeq 1$ μs and a decay time to 10% of $\simeq 5$ μs. Interference filters were used to monochromatize this light.

Figure 2 shows oscillograms of the impurity photocurrent pulses ($\lambda = 684$ mμ) at different intensities of intrinsic bias illuminations. Curve 1 was obtained under illumination from the region of linearity of the lux-ampere characteristic (l.a.c.). The absence of an s-section in this curve indicates that, under these illuminations, $\beta_s N_s, g_s \gamma P_r \ll \beta_r N_r$, i.e., the impurity photoconductivity from s-centers and the influence of quenching transitions may be neglected. Let us also note that in our samples, as in ([4]), in the linear region of the l.a.c. $N_r \simeq \mathfrak{N}_r \gg P_r$, where $\mathfrak{N}_r$ is the concentration of r-centers. Curve 2, recorded under illumination from the l.a.c. region with slope 0.5, has an s-section. Since the quantity N_s cannot increase with increasing L, the s-section corresponds to the term $g_s \gamma P_r$ in (1). The "amplitude" of the s-section increases with increasing L in the l.a.c. section with slope 0.5 (curve 3), while quenching is observed after stimulation. With a further increase of L in the l.a.c. region with slope < 0.5 (curve 4), the quantity $g_s \gamma P_r$ becomes saturated. At complete saturation $g_s \to 1$, $P_r \to \mathfrak{N}_r$ ([4]). The ratio of the amplitude of the positive pulse on curve 1 to the s-section on curve 4 is equal to β_r/γ. It follows from Fig. 2 that for λ684 mμ, $B_r/\gamma \simeq 1.3$.

Fig. 2. Relaxation curves of the impurity photocurrent ($\lambda = 684$ mμ) at different intensities of intrinsic illuminations (in relative units): 1—1; 2—24; 3—280; 4—1000. s_2, s_3, s_4 are the "amplitudes" of the s-sections on the corresponding curves; s_1 is negligibly small and is not indicated. It is seen that $s_1 \ll s_2 < s_3 \simeq s_4$.

The absence of influence of transitions from s-centers into the c-band made it

Fig. 3 and Fig. 4

Figure 3: Fig. 3 and Fig. 4

possible to measure the spectral distribution of β_r by studying the stationary impurity photoconductivity under constant quenching infrared (i.r.) illumination (L_Γ). In order to eliminate the influence of quenching transitions $\gamma P_r L_p$, a quenching i.r. illumination of such intensity was used that the impurity photocurrent was reduced by this illumination by approximately a factor of 100, which corresponds to the fact ([5]) that recombination to within 99% occurs through s-centers. If, for all measured wavelengths λ of the impurity light, the same concentration of electrons in the c-band is established (by adjusting $L_p(\lambda)$) in the presence of a constant illumination L_Γ, then the quantities N_r and P_s, the concentration of electrons at trapping levels N_f, and also the intensity of the exciting transitions $\beta_r N_r L_p$ are thereby maintained constant. Then

$$\beta_r(\lambda) = \frac{C_s P_s N}{N_r} \frac{1}{L_p(\lambda)}. \tag{2}$$

The impurity light of the required spectral composition was obtained from a GOI mirror monochromator. The quenching i.r. light was isolated by an IKS-3 filter from the light flux obtained from an incandescent lamp. The selection of the intensities L_p required for establishing a constant photocurrent under i.r. illumination L_Γ was carried out by changing the filament current of the monochromator illuminating lamp. The intensity of the light $L_p(\lambda)$ was measured with a calibrated germanium photodiode.

The dependences $\beta_r(\lambda)$ obtained from formula (2) agree well for the samples studied. It turned out that the experimental values of $\beta_r(\lambda)$ satisfy the empirical dependence

$$\beta_r = \beta_0 (E - E_{cr})^2, \tag{3}$$

where β_0 is a constant, E is the photon energy, and E_{cr} is the ionization energy of the r-center.

Figure 3 shows the dependence $\sqrt{\beta_r(E)}$ for various CdS samples, with the scale factor β_0 chosen so that the values of β_r at $E = 2.0$ eV coincide for all samples. It follows from Fig. 3 that the energy of optical release of an electron from an r-center into the conduction band is

$$E_{cr} = (1.36 \pm 0.02) \text{ eV}.$$

For the same samples, the spectral dependences of the impurity photocurrent at a constant photon flux were measured; these are presented in Fig. 4.

Fig. 3. Spectral dependences of $\sqrt{\beta_r}$ for 6 CdS samples

Fig. 4. Spectral dependences of the impurity photocurrent at a constant photon flux for the same 6 CdS samples as in Fig. 3

The curves for the different samples are shifted along the ordinate axis until they coincide at $E = 2.0$ eV. It is seen from Fig. 4 that the spectral dependences of the photocurrent at equal photon fluxes undergo a large scatter (more than two orders of magnitude at $E = 1.45$ eV) while $\beta_r(E)$ is practically identical. This scatter is caused by the different degree of filling of the vacancies of the r-centers in the different samples. The latter is independently confirmed by the larger amplitude of the s-section of the impurity-photocurrent relaxation curves for samples with a steeper long-wavelength decline of the impurity photocurrent.

The data obtained make it possible to determine β_r/γ, $\beta_r(E)$, and E_{cr}, and also to give a qualitative explanation of the scatter in the spectral dependences of the impurity photocurrent at a constant photon flux.

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