Academician of the Academy of Sciences of the Ukrainian SSR V. E. LASHKAREV, A. V. LYUBCHENKO,

M. K. SHEINKMAN

1965

SovietRxiv

Abstract

Full Text

Physics

Academician of the Academy of Sciences of the Ukrainian SSR V. E. LASHKAREV, A. V. LYUBCHENKO,
M. K. SHEINKMAN

DETERMINATION OF THE PARAMETERS OF RECOMBINATION CENTERS IN CADMIUM SULFIDE BY MEANS OF THE KINETICS OF INFRARED QUENCHING OF THE PHOTOCURRENT

Although the phenomenon of infrared (IR) quenching of the photocurrent in semiconductors of the type $A_{II}B_{VI}$ has long been known and has aroused constant interest,* up to now only the stationary characteristics of this phenomenon, or the slow transient processes associated with it (seconds and minutes), have been investigated.

However, as will be shown in the present work, investigation of the kinetics of IR quenching using sufficiently short pulses of IR light makes it possible to determine such important parameters of recombination centers in crystals as the cross sections for electron capture by them. These investigations also enabled us, for the first time, to determine the capture cross section of an IR photon γ by the slow-recombination center in CdS.

Data from measurements of various stationary characteristics of photoconductivity ([1]) and studies of the kinetics of the photocurrent under pulsed illumination by intrinsic light ([3–5]) have led to a recombination model of photoconductors of the $A_{II}B_{VI}$ type with two classes of recombination centers—slow (r-centers) and various fast ones (s-centers).

From a large number of CdS single crystals we selected those in which, in the spectral range of the illumination used, only one r-level and one s-level appeared. The sticking levels in this case were practically filled and did not affect the kinetics of the photocurrent, as special experiments convinced us.

On the basis of the above, the following picture of IR quenching of the photocurrent may be imagined. Photoholes generated by the exciting light are rapidly captured by r- and s-centers with the corresponding probabilities g_r and g_s ($g_r + g_s = 1$), proportional to the concentration of electrons on them. A pulse of IR light transfers electrons from the valence band to vacancies on r-centers. If the total number of photons in an IR pulse incident on 1 cm^2 is denoted by I

Fig. 1

Figure 1: Fig. 1

$$\left(I = \int_0^{\Delta t} l\, dt, \text{ where } l \text{ is the intensity, } \Delta t \text{ is the duration of the IR pulse} \right),$$

and the concentration of vacancies on r-centers by P_r, then the concentration of the liberated photoholes is, evidently, equal to $\pi = \gamma P_r I$. A fraction g_r of these holes will again be captured by r-centers, and a fraction g_s by s-centers. Consequently, as a result of the action of the IR pulse an additional concentration of photoholes $\pi_s = g_s \gamma P_r I$ will appear on the s-centers. In this case the recombination rate at these levels will increase, which will lead to IR quenching of the photocurrent. Simultaneously with the quenching process, the reverse process of photocurrent recovery will also proceed, since the recombination rate through r-centers decreases. If the IR-light pulse is weak (the photocurrent is quenched by a small fraction of its value) and its duration $\Delta t \ll \tau_s, \tau_r$, where τ_s and τ_r are the characteristic recombination times of electrons at the s- and r-levels, respectively, then it can be shown that the photocurrent will begin to decrease only after the end of the IR pulse, and this decrease will be

* For bibliography on the question see, for example, ([1,2]).

will occur according to an exponential law with time $\tau = \tau_s$. Having reached a minimum, the photocurrent will begin to recover, also according to an exponential law with time $\tau = \tau_r$.

Oscillograms of the processes of photocurrent decay and its recovery are shown in Fig. 1 (a, b are one and the same oscillogram at different sweeps).

Fig. 1. Oscillograms of decay (a) and recovery (b) of the photocurrent after the action of a short ($\Delta t = 2.5 \cdot 10^{-6}$ s) IR pulse in the presence of exciting illumination. Both oscillograms were taken on one and the same specimen under identical experimental conditions, but at very different sweeps. a: 1 cm corresponds to $10 \cdot 10^{-6}$ s; b: 1 cm corresponds to $2 \cdot 10^{-3}$ s.

measuring the dependences $\tau_s(n)$ and $\tau_r(n)$, where n is the concentration of photoelectrons produced by the illumination, one can find the probabilities of electron capture by s-centers, C_s, and r-centers, C_r, since $\tau_s = 1/C_s n$ and $\tau_r = 1/(C_r n + \text{const})$, as follows from analysis of the scheme. The values of C_s and C_r found by us for CdS (at room temperature) are as follows: $C_s = (4 \div 20) \cdot 10^{-10}$ cm$^3 \cdot$ s^{-1}; $C_r = (3 \div 5) \cdot 10^{-13}$ cm$^3 \cdot$ s^{-1} (the mobility value used in determining n was taken to be 200 cm^2/V $\cdot$ s). We note that the values of C_r are close to those obtained by us earlier by another method ([4]). The measured temperature dependence of the cross sections C_s and C_r in the range $-150 \div +50^\circ$ proved to be weak.

Fig. 2

Figure 2: Fig. 2

For measuring the capture cross section of an IR photon by an r-center, it is essential that the process of photocurrent recovery occurs considerably more slowly than the process of its decay, i.e. $\tau_s \ll \tau_r$, as is seen from the oscillograms presented. In this case it turns out that the quenching process ceases when practically all photoholes p_s have recombined with an equal number of free electrons v, i.e. the quenching amplitude will be

$$|v| = p_s = g_s \gamma P_r I. \tag{1}$$

Fig. 2. 1 –dependence of the quenching amplitude $|v|$ on the stationary concentration of electrons produced by the illumination, n; 2 –lux-ampere characteristic of the stationary photocurrent $n(L)$. The numbers give the exponent α ($n \sim L^{\alpha}$).

With increasing illumination the r-centers are almost completely filled with photoholes ($P_r \to \mathfrak{N}_r$, where $\mathfrak{N}_r$ is the concentration of r-centers), and recombination will be determined by the s-channel ($g_s \to 1$). Obviously, the quenching amplitude then reaches a limiting value equal to

$$|v_{\max}| = \gamma \mathfrak{N}_r I, \qquad \text{i.e.} \quad \gamma = \frac{|v_{\max}|}{\mathfrak{N}_r} \cdot \frac{1}{I}. \tag{2}$$

Figure 2 shows the dependence of $|v|$ on n. It is seen that $|v|$ becomes saturated in the region where recombination proceeds through the s-channel and where, therefore, the lux-

the ampere characteristic becomes sharply sublinear ($\alpha < 0.5$; curve 2).

It follows from formula (2) that, by measuring $|v_{\max}|$, one can find γ, if the quantities $\mathfrak{N}_r$ and I are determined independently.

1) The determination of $\mathfrak{N}_r$ was carried out by the light-flash method, using weakly absorbed light (ZhS-18 filter and a $CuCl_2$ solution ([4])). Since expression (2) contains not $\mathfrak{N}_r$ but the ratio of concentrations $|v_{\max}|/\mathfrak{N}_r$, the latter may be replaced by the corresponding ratio of the amplitudes of the photocurrents, without measuring the mobility.

2) Measurement of I. A light pulse of duration $\Delta t = 2.5 \cdot 10^{-6}$ sec was produced by an ISP-100 lamp. A narrow band with $\lambda = 0.93\,\mu$, corresponding to the quenching maximum, was cut out by a DMR-4 double monochromator. The focused beam of infrared light fell on an inertia-free vacuum photocell F-5, from the load resistance of which the pulse signal was fed to an S1-8 oscilloscope and photographed. Calibration of the F-5 photocell,

i.e., determination of its quantum yield for $\lambda = 0.93\,\mu$, was carried out with stationary infrared light of the same wavelength, using a germanium photocell and a known collection coefficient. The total number of quanta I falling on the photocell during the pulse was found by graphical integration of the pulse shape, with the quantum yield of the F-5 photocell known.

The capture cross section for an infrared photon by the r-level, measured by the method described above, proved to be $0.8 \cdot 10^{-16}$ cm^2. This cross-section value, as we see, is of the order of the geometrical size of an atom.

Institute of Semiconductors
Academy of Sciences of the Ukrainian SSR

Received
11 XII 1964

REFERENCES

1. R. Bube, *Photoconductivity of Solids*, IL, 1962.
2. J. Auth, E. Niekisch, H. Puff, *Zs. phys. Chem.*, **212**, 175 (1959).
3. V. E. Lashkarev, G. I. Glinyanaya, M. K. Sheinkman, *Fiz. tverd. tela*, **5**, 3420 (1963).
4. E. A. Salkov, M. K. Sheinkman, *Fiz. tverd. tela*, **5**, 397 (1963).
5. I. B. Ermolovich, M. K. Sheinkman, *Ukr. fiz. zhurn.*, No. 11 (1964).

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