V. M. LYUBIN, V. I. FOMINA, L. E. TSYRLIN

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Abstract

Full Text

PHYSICS

V. M. LYUBIN, V. I. FOMINA, L. E. TSYRLIN

FEATURES OF THE CONDUCTIVITY AND PHOTOCONDUCTIVITY OF THIN LAYERS OF THE Se–As SYSTEM IN THE REGION OF STRONG ELECTRIC FIELDS

(Presented by Academician A. N. Terenin, 19 X 1964)

The electrical and photoelectric properties of thin amorphous layers of the Se–As system have been studied in a number of works ([1–5]). Some features of the kinetics of the photoeffect observed in these layers were interpreted on the basis of the effect of trapping of charge carriers. The layers investigated in the present work differed by the content of oxygen as a third component. These layers revealed a number of interesting new properties, the chief of which is the strong influence of the magnitude of the applied electric field on the kinetics of conductivity and photoconductivity.

The starting materials were synthesized by melting Se and As, the ratio between which was varied within the range from 1Se : 1As to 2Se : 1As. Oxygen was introduced by carrying out the synthesis in an air atmosphere or by adding oxides of the CuO type during vacuum synthesis. The samples were prepared by evaporation in vacuum according to the same procedure as in works ([2,5]). The layer thickness varied from 0.3 to 1.4 μ. Semitransparent films of Pt, Au, Al, and SnO_2 were used as electrodes. The experimental procedure was essentially the same as that used in works ([1,2]). An electronic automatic self-recording potentiometer EPPV-51M1 was used as the recording instrument. All measurements were carried out at room temperature.

Fig. 1. Dependence of dark current on time. 1 $-V = 2$ V, 2 $-V = 7$ V

Figure 1 shows typical curves of the change of dark current with time after the voltage is switched on. It is seen that in weak fields the steady-state value of the current is established within several seconds, while in fields $\sim 10^5$ V/cm it is not reached within a time equal to 1 hour.

Figure 2 and Figure 3

Figure 2: Figure 2 and Figure 3

Let us note that in Se—As layers not containing oxygen, an increase of the dark current with time was not observed at all. (In most cases a decrease was observed instead, explained by polarization phenomena ([6]).)

Figure 2 shows the time dependences of the current upon illumination and darkening of the sample. Curve 1, taken in a weak field, practically does not differ from the corresponding curves for oxygen-free samples. Curves 2, 3, and 4, taken at larger field values, have a short-time and a long-time component. Moreover, both the intrinsic time and the relative magnitude of the long-time component prove to be the greater, the greater the field strength. At a field of

Fig. 2. Dependence of the photocurrent on time. $E = 0.38$ lx;
1—$V = 4$ V; 2—$V = 7$ V;
3—$V = 10$ V; 4—$V = 12$ V.
t_1—moment of switching on the illumination; t_2—moment of switching off the illumination

Fig. 3. Dependence of the current on time under short-time illumination. $E = 6.8$ lx; $t_{\text{illum}} \simeq 2$ sec; $V = 9$

$5 \cdot 10^4 \div 10^5$ V/cm, after the light is switched off the photocurrent can, for approximately 1 hour, be maintained at a level of 60-70% of the value reached under illumination. The ratio of the times for establishment of the current in the presence and in the absence of a strong field reached 10^4—10^5.

With increasing electric field, the photoconductivity established under the given illumination also increases significantly.

If, during the slow decay of the photocurrent in a darkened sample, the strong field applied to it is removed, the photoconductivity of the sample rapidly (within 10-15 sec) disappears. Reapplying the field after the indicated time interval shows that the conductivity corresponds to the initial value of the dark conductivity. If the applied field is removed for a shorter time (< 10—15 sec), then upon its reapplication the conductivity proves to be higher than the dark conductivity and increases with time the faster, the shorter the pause was and the greater the value of the residual photocurrent before the field was switched off.

Figure 3 shows curves of photocurrent variation in a strong field for comparatively short duration and high intensity of illumination. The conductivity after switching off the light in these cases has a minimum, and the long-time branch of the curves is increasing.

The totality of these phenomena can be explained on the basis of the following assumption. It is known that the process of direct (interband) recombination of

current carriers in semiconductors is unlikely, so that the corresponding carrier lifetime may be of the order of hours ([7–9]). A substantially predominant role is played by the process of stepwise recombination, when the carrier is first captured at some local recombination level located between the conduction and valence bands. For a carrier situated at a recombination level, however, there is also a certain probability of return to the free state. Our assumption is that a sufficiently strong field substantially increases this probability, so that it begins to exceed the probability of an act of "final" recombination. This effect may be attributed either to a purely electrostatic action of the field on recombination centers (which seems more probable), or to impact ionization of the centers. The electrostatic action may reduce to the appearance of a tunneling effect, but under certain conditions it may also lead to a decrease in the depth of the potential well corresponding to the level. The depth of the recombination levels must be, on the one hand, sufficiently large that their thermal ionization does not play a noticeable role, and, on the other hand, sufficiently small that the action of a field of the order of $5 \cdot 10^4 \div 10^5$ V/cm can be effective. According to an estimate for the tunneling ionization mechanism ([10]), a depth of the order of $0.15 \div 0.2$ eV* may be assigned to the recombination levels; this also satisfies the first of the indicated conditions at room temperature. Here we do not give a mathematical treatment of this hypothesis, but confine ourselves to an attempt at a qualitative explanation on its basis of the observed phenomena.

The circumstance that a carrier captured at a recombination level is more likely to be released again than to recombine finally obviously leads to an increase in the carrier lifetime and, consequently, to the appearance of long-time components in the kinetic curves, to an increase in the steady-state value of the photocurrent, and to a prolonged rise of the dark current. "Final" recombination in this case plays the role only of a certain perturbation with respect to the process of carrier exchange between the free states and the recombination levels. The rate of establishment of quasi-equilibrium between the latter two states is determined by the sum of the probabilities of the direct and reverse transitions, so that this process gives rise to the short-time part of the kinetic curves.

If the probability of an act of "final" recombination is somewhat smaller than the probability of carrier capture at a recombination level, then after the field is switched off and the subsequent rapid drop in conductivity, there will for some time remain at the recombination levels a reserve of carriers which are released again when the field is switched on once more. An analogous reserve of carriers is also created under short-time intense illumination; this leads in that case to the appearance of a rising long-time branch of the conductivity curves after the light is switched off.

Thus, according to our assumption, the peculiarity of the semiconductor materials considered reduces to the fact that recombination in them is practically possible only through shallow levels subject to ionization in a field of the order of $5 \cdot 10^4 \div 10^5$ V/cm.

The anomalous properties of the layers studied here are apparently caused by

the presence of oxygen, although it is not clear in precisely what way. We note, however, that an analogous, though less pronounced, influence of the electric field on recombination processes is observed, in essence, in a number of other semiconductor materials. The phenomena, po-

* In this estimate, the value of the forbidden-band width was taken as ~ 1.7 eV, in accordance with the position of the red limit of the photoeffect.

similar to those described were observed by us in some layers of the type $m\,As_2S_3 \cdot n\,As_2Se_3$ and $m\,Tl_2Se \cdot n\,As_2Se_3$.

A similar explanation can apparently be given for the phenomenon of a prolonged increase of current in Sb_2S_3 specimens ([11]) and for certain anomalous features of the photoeffect in Se layers treated with mercury ([12,13]).

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