ON THE NATURE OF ANOMALOUSLY HIGH PHOTOVOLTAGE (A.H.P.) IN CdTe FILMS

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Abstract

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ON THE NATURE OF ANOMALOUSLY HIGH PHOTOVOLTAGE (A.H.P.) IN CdTe FILMS

Although almost 10 years have passed since the discovery of the a.h.p. effect in CdTe (^1), its nature is still not fully clear. After the work of E. I. Adirovich, V. M. Rubinov, and Yu. M. Yuabov (^2), it became clear that an a.h.p. film is a miniature battery of series-connected macrophotocells; however, neither the mechanism by which photovoltage arises in the individual microphotocells, nor their number and arrangement in the film, nor the manner of their series connection has been clarified up to the present time.

In work (^3), E. I. Adirovich, V. M. Rubinov, and Yu. M. Yuabov drew attention to the fact that the question of the mechanism by which a.h.p. arises reduces to determining which of two alternatives, a) or b), takes place:

a) the photovoltaic effect is produced in microscopic $(p-n)$-junctions (the $p-n$-junction model);

b) the photovoltaic effect is determined by diffusion processes (the Dember effect) in microregions homogeneous in type of conductivity.

E. I. Adirovich, V. M. Rubinov, and Yu. M. Yuabov indicated two criteria for distinguishing these mechanisms.

1) The existence of an inversion of the sign of a.h.p. when the angle of illumination is varied within the range 0–180°. The presence of such an inversion, according to Adirovich, Rubinov, and Yuabov, corresponds to the Dember model of a.h.p.

2) The appearance of saturation on the curve of the dependence of the photovoltage V_ϕ on the light intensity L at relatively small L, which testifies in favor of the $p-n$-junction model.

Both of the indicated criteria are not reliable. The first of them reflects rather the structure and arrangement, in the a.h.p. layer, of individual microphotocells than the mechanism of excitation of a.h.p. The second can likewise occur under both mechanisms. Therefore conclusions drawn on their basis may prove erroneous. We have studied the a.h.p. effect in CdTe films and have come to the conclusion that the mechanism by which photovoltage arises in them is different from that indicated in work (ˆ2) and in Goldstein' s original work (ˆ4, ˆ5).

We believe that the distinction between the two above-mentioned models of the origin of a.h.p. can be made by comparing the dependences

$$V_\phi = V_\phi(L) \quad \text{and} \quad \sigma = \sigma(L),$$

where σ is the conductivity of the a.h.p. layer.

For both models indicated above, the dependence $V_\phi = V_\phi(L)$ can be represented in a similar way.

In the case of the $p-n$-junction model

$$V_\phi = \frac{kT}{e}\sum_1^N \ln\left(1+\frac{i_{fi}}{i_{si}}\right) = N\frac{kT}{e}\ln\left(1+\overline{\frac{i_{fi}}{i_{si}}}\right), \tag{1}$$

where i_{fi} is the photocurrent in the i-th $p-n$-junction, and i_{si} is the saturation current in the reverse direction; $\overline{i_{fi}/i_{si}}$ is the mean value of their ratio. Since i_{fi} is proportional to L, while i_{si} changes little with the illumination intensity; relation (1) can be written in the form

$$V_\phi = N\frac{kT}{e}\ln(1+\alpha_1 L), \tag{2}$$

where α_1 is a quantity that depends only weakly on the intensity.

In the case of the diffusion model

$$\begin{aligned} V_\phi &= \frac{kT}{e}\frac{b-1}{b+1}\sum_1^N \ln\frac{\sigma_{2i}}{\sigma_{1i}} = \frac{kT}{e}\frac{b-1}{b+1}\ln\prod_1^N\left(1+\frac{\Delta\sigma_i}{\sigma_{1i}}\right) \\ &= N\frac{kT}{e}\frac{b-1}{b+1}\ln\left(1+\overline{\frac{\Delta\sigma_i}{\sigma_{1i}}}\right), \end{aligned} \tag{3}$$

where b is the ratio of carrier mobilities; σ_{2i} and σ_{1i} are the values of the total conductivity at the boundaries of the i-th microregion, and $\Delta\sigma_i$ is their difference.

The character of the dependence of $\Delta\sigma_i/\sigma_{1i}$ on the light intensity can easily be established for the case of not very large excitations, $\Delta\sigma_i/\sigma_i < 1$. σ_1

Fig. 1. Dependence of the conductivity σ of an A.P.V. CdTe film on the light intensity L. The dashed line denotes $\sigma = aL^{1/2}$.

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determines in this case the conductivity of the photoelement, while $\Delta\sigma_i$ is the magnitude of the current flowing through the element. Since i_f is proportional to L, relation (3) can be written in the form

$$V_\phi = N\frac{kT}{e}\frac{b-1}{b+1}\ln\left(1+\frac{\alpha_0 L}{\sigma}\right), \tag{4}$$

where α_0 is a quantity that changes little with a change in the light intensity.

Relation (4) differs from (2) in that the second term under the logarithm sign depends not only on the intensity of the light flux, but also on the conductivity of the sample. Since σ, in turn, is a function of the light intensity, the dependence $V_\phi = V_\phi(L)$ proves to be different in the two models. Owing to this difference, it is possible to distinguish between the two mechanisms.

Already in Goldstein' s first paper (^{4}) it was indicated that, in A.P.V. CdTe films, the dependence of the photovoltage on the light intensity follows relation (2), which occurs in the p—n-junction model; this served as the impetus for the emergence of the p—n-junction model of the A.P.V. CdTe layer. This assertion by Goldstein entered a number of textbooks on photoelectric phenomena (^{6}, ^{7}); however, analysis of the data presented in (^{3}), and our measurements of the dependence of V_ϕ on L in A.P.V. CdTe films, show that this assertion is incorrect.

We have established that in CdTe films, at not very large degrees of excitation $\Delta\sigma/\sigma < 1$, but with $\sigma_l \gg \sigma_{\text{dark}}$, σ varies over a broad range of intensities as $L^{1/2}$, and only at high light intensities does it vary somewhat faster than $L^{1/2}$ (Fig. 1). Therefore, if the Dember mechanism of the appearance of photovoltage were operative in CdTe anomalous-photovoltage films, then V_ϕ would have to be expressed by the relation

$$V_\phi = N\frac{kT}{e}\frac{b-1}{b+1}\ln(1+\alpha_{1/2}L^{1/2}), \tag{5}$$

where $\alpha_{1/2}$ is a constant only slightly dependent on the light intensity. It is convenient to check which of the two relations, (2) or (5), applies by determining which of the two functions $d\lg L/dV_\phi = f_1(1/L)$ or $d\ln L/dV_\phi = f_2(1/L^{1/2})$ proves to be linear.

Fig. 2. a—dependence of $d\lg L/dV_\phi$ on $1/L$; b—dependence of $d\lg L/dV_\phi$ on $1/L^{1/2}$

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Figure 2: Fig. 2. a—dependence of $d\lg L/dV_\phi$ on $1/L$; b—dependence of $d\lg L/dV_\phi$ on $1/L^{1/2}$

In the case of the $(p-n)$-junction model

$$\frac{dV_\phi}{d\ln L} = 2.3L\frac{dV_\phi}{dL} = 2.3N\frac{kT}{e}\frac{\alpha_1 L}{1+\alpha_1 L},$$

$$\frac{d\lg L}{dV_\phi} = A + B\frac{1}{L}. \tag{6}$$

In the case of the diffusion (Dember) model

$$\frac{dV_\phi}{d\ln L} = 2.3L\frac{dV_\phi}{dL} = \frac{2.3N}{2}\frac{kT}{e}\frac{b-1}{b+1}\frac{\alpha_{1/2}L^{1/2}}{1+\alpha_{1/2}L^{1/2}},$$

$$\frac{d\lg L}{dV_\phi} = A_1 + B_1\frac{1}{L^{1/2}}. \tag{7}$$

The constants A, B, A_1, B_1 have the values

$$A = \frac{e}{2.3kT}\frac{1}{N}, \qquad B = \frac{e}{2.3kT}\frac{1}{N\alpha_1},$$

$$A_1 = \frac{2e}{2.3kT}\frac{b+1}{b-1}\frac{1}{N}, \qquad B_1 = \frac{2e}{2.3kT}\frac{b+1}{b-1}\frac{1}{N\alpha_{1/2}}.$$

Figure 2 gives plots of the dependence of $d\lg L/dV_\phi$ on $1/L$ and $1/L^{1/2}$ for one of the CdTe anomalous-photovoltage films studied. The plots for all the other films studied are analogous. It is seen that the dependence $d\lg L/dV_\phi$ is linear with $L^{-1/2}$ as well, and that this dependence holds over a broad range of variation of L, exceeding three orders of magnitude. This gives grounds for concluding that in APV films there apparently occurs a diffusion mechanism for the appearance of the photovoltage.

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