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Abstract

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ON THE DETERMINATION OF THE NUMBER OF MICROPHOTOCELLS IN CdTe a.c.p. FILMS

In the work of É. I. Adirovich, V. M. Rubinov, and Yu. M. Yubov ([1]) it was shown that a.c.p. films are miniature batteries of a large number of consecutively connected microphotocells; however, the question of the number of such photocells entering into the battery, and of the magnitude of the photovoltage on an individual microphotocell, has remained open up to the present time.

The first attempt to determine the number of microphotocells belongs to Goldstein ([2]). Starting from the assumption that the individual microphotocells in a CdTe a.c.p. film are $(p-n)$-junctions, and assuming that the photovoltage of an a.c.p. film V_ϕ can be expressed by the relation

$$V_\phi = N\frac{kT}{e}\ln(1+k_0L), \tag{1}$$

where N is the number of photocells, L is the intensity of the incident light, k_0 is a quantity dependent on temperature but independent of the intensity (k, T, and e have their usual meaning), Goldstein determined the quantity N from the slope of this curve. Having determined N from the curves $V_\phi = V_\phi(L)$, measured at different temperatures, he found that for one and the same film it proved necessary to ascribe different numbers of microphotocells at different temperatures. This change in the number of $p-n$-junctions with temperature was regarded as real and was explained by the fact that, with increasing temperature, some $p-n$-junctions cease to operate. However, it turns out that the number of photocells determined by formula (1) is not only different for different temperatures, but also different for different portions of the curve $V_\phi = V_\phi(L)$ obtained at one temperature.

Table 1 contains data obtained by us for one of the CdTe a.c.p. layers by this method (specimen No. 5, layer length 5 mm). The quantity k_0 was determined from the value of B

$$B = \frac{d \lg L}{d \lg V_\phi} = 2.3 \frac{1 + k_0 L}{k_0 L} \lg(1 + k_0 L), \tag{2}$$

and from the value of k_0, N was calculated from (1) for each experimental value of V_ϕ and L.

Table 1

L, rel. units	V_ϕ, V	k_0	N	L, rel. units	V_ϕ, V	k_0	N
6.31	121	3.71	1490	0.1585	33	56.8	594
3.98	105	5.45	1325	0.1	27	80.6	510
2.51	90.5	7.1	1240	0.0631	22	87.5	480
1.585	77	9.91	1110	0.0398	17	132	403
1.0	65	14.1	975	0.0251	14	222	286
0.631	55.5	20.6	855	0.01585	11	351	225
0.398	47	29.4	764	0.01	8.5	556	174
0.251	39	41.6	656				

It is seen from the table that the values of k_0 and N, calculated for different portions of the curve $V_\phi = V_\phi(L)$, differ sharply. When L changes by a factor of 600, N changes by almost an order of magnitude (from 174 to 1490), while k_0 changes by more than two orders of magnitude.

Such a discrepancy in the values of the quantities k_0 and N, which should not depend on L, indicates the unsuitability of relation (1) for describing the dependence of the photovoltage of a photoconductive CdTe layer on the illumination intensity.

In paper ([3]) it was shown that the mechanism of the occurrence of photovoltage in a CdTe layer is diffusive in character and that the dependence of the photovoltage on light intensity must be expressed by another relation, namely:

$$V_\phi = N \frac{b-1}{b+1} \frac{kT}{|e|} \ln(1 + \alpha_{1/2} L^{1/2}), \tag{3}$$

where $b = u^-/u^+$ is the ratio of the mobilities of the current carriers; $\alpha_{1/2}$ is a certain quantity independent of the light intensity, constant at the given temperature; N, k, T, e have their former meanings.

Table 2

Sample No. 19, layer length 1 cm, $\alpha_{1/2}$ = 1.5	Sample No. 19, layer length 1 cm, $\alpha_{1/2}$ = 1.5	Sample No. 19, layer length 1 cm, $\alpha_{1/2}$ = 1.5	Sample No. 5, layer length 5 mm, $\alpha_{1/2}$ = 0.77	Sample No. 5, layer length 5 mm, $\alpha_{1/2}$ = 0.77	Sample No. 5, layer length 5 mm, $\alpha_{1/2}$ = 0.77	Sample No. 11, layer length 0.2 mm, $\alpha_{1/2}$ = 6.5	Sample No. 11, layer length 0.2 mm, $\alpha_{1/2}$ = 6.5	Sample No. 11, layer length 0.2 mm, $\alpha_{1/2}$ = 6.5	Sample No. 10, layer length 0.01 mm, value $\alpha_{1/2}$ = 4.6	Sample No. 10, layer length 0.01 mm, value $\alpha_{1/2}$ = 4.6	Sample No. 10, layer length 0.01 mm, value $\alpha_{1/2}$ = 4.6
L, rel. units	V_ϕ, V	$N\frac{b-1}{b+1}$	L, rel. units	V_ϕ, V	$N\frac{b-1}{b+1}$	L, rel. units	V_ϕ, V	$N\frac{b-1}{b+1}$	L, rel. units	V_ϕ, V	$N\frac{b-1}{b+1}$
4.08	378	10700	6.31	121	4440	3.66	2.56	39.0	3.66	0.29	5.02
3.18	370	11200	3.98	105	4460	2.89	2.52	40.0	2.89	0.28	5.26
2.42	348	11350	2.51	90.5	4460	2.34	2.40	39.7	2.34	0.27	5.12
1.865	326	11500	1.585	77	4460	1.94	2.31	38.8	1.94	0.258	5.10
1.365	293	11450	1.0	65	4040	1.62	2.21	39.3	1.62	0.248	5.05
1.0	257	11100	0.631	55.5	4560	1.20	2.06	38.9	1.20	0.236	5.18
0.546	197	10450	0.398	47	4630	0.915	1.94	38.9	0.915	0.220	5.15
0.4275	176	10200	0.251	39	4680	0.585	1.75	38.8	0.585	0.198	5.19
0.207	130	9900	0.1585	33	4670	0.406	1.60	38.7	0.406	0.180	5.20
0.0838	97	10600	0.10	27	4490	0.26	1.425	38.6	0.26	0.157	5.14
0.0194	56	11700	0.0631	22	4590	0.146	1.26	39.4	0.146	0.134	5.14
0.01472	48.5	11200	0.0398	17	4400	0.080	1.075	40.6	0.080	0.108	5.14
0.00778	35	11150	0.0251	14	4550	0.0428	0.88	40.9	0.0428	0.086	5.08
0.0043	24.5	10500	0.0158	11	4500	0.0234	0.64	39.8	0.0234	0.068	5.04
0.00234	18.1	10150	0.01	8.5	4370	0.0138	0.564	39.4	0.0138	0.057	5.21
0.0009	10.4	9300				0.0081	0.472	40.6	0.0081	0.044	5.01
0.00031	5.25	7900				0.0048	0.396	42.0	0.0048	0.035	5.01
0.00012	2.85	6850									
	Average $N\frac{b-1}{b+1}$ = 10500			Average $N\frac{b-1}{b+1}$ = 4500, or 9000 per cm			Average $N\frac{b-1}{b+1}$ = 40, or 2000 per cm			Average $N\frac{b-1}{b+1}$ = 5, or 5000 per cm	

From dependence (3), one can determine from the experimental data $V_\phi = V_\phi(L)$ both $\alpha_{1/2}$ and N. This can be done graphically from the dependence of $d\lg L/dV_\phi$ on $1/L^{1/2}$, expressed by the relation

$$\frac{d\lg L}{dV_\phi} = \frac{2e}{2.3kT}\frac{b+1}{b-1}\frac{1}{N}\left(1+\frac{L^{-1/2}}{\alpha_{1/2}}\right) \tag{4}$$

from the magnitude of the intercept cut off by the straight line $d\lg L/dV_\phi = f(1/L^{1/2})$ on the $d\lg L/dV_\phi$ axis and equal to

$$\frac{2e}{2.3kT}\frac{b+1}{b-1}\frac{1}{N} = \frac{34.4}{N}\frac{b+1}{b-1},$$

and from the slope angle φ of this straight line

$$\left(\operatorname{tg}\varphi = \frac{34.4}{N}\frac{b+1}{b-1}\frac{1}{\alpha_{1/2}}\right).$$

However, determining N and $\alpha_{1/2}$ with the aid of a graphical construction is rather crude, since in most cases the intercept cut off on the $d\lg L/dV_\phi$ axis is small and is determined with very low accuracy. Therefore it is most convenient to determine $\alpha_{1/2}$ from two values V'_ϕ and V''_ϕ for flux intensities respectively L' and L'', namely

$$V'_\phi/V''_\phi = \lg(1+\alpha_{1/2}{L'}^{1/2})/\lg(1+\alpha_{1/2}L''^{1/2}), \tag{5}$$

and then determine the product $N\frac{b-1}{b+1}$ from relation (3) for any value of V_ϕ, by substituting into it $\alpha_{1/2}$ from (5). Knowing b, one can calculate N.

Such a determination of $N\frac{b-1}{b+1}$ was carried out for a number of a.p.n. layers of CdTe. The data for 4 of them, having different dimensions, from 10μ to 1 cm, are presented in Table 2.

It is evident from the data of Table 2 that the values of $\alpha_{1/2}$ and $N\frac{b-1}{b+1}$, determined by relation (5) from the experimental data, are indeed quantities independent of the intensity over a wide range exceeding 4 orders of magnitude.

Table 2 contains data obtained for specimen No. 5, for which the calculated data according to formula (1) are given in Table 1. Whereas in the calculation according to relation (1) N varied by an order of magnitude, in the calculation according to relation (5) the scatter in the value of N does not exceed several percent.

Since in CdTe the mobility ratio $b = u^-/u^+$ is a fairly large quantity (according to various data, b has a value from 5 to 10), the quantity $N\frac{b-1}{b+1}$ is close to N. The values given below were calculated on the assumption that $b = 9$.

In different a.p.n. layers the number of photoelements per unit length (1 cm) is different. In specimen No. 19 it is equal to 10500; in specimen No. 5 it proved to be 9000; in specimens No. 11 and No. 10, 2500 and 5000, respectively.

The magnitude of the photovoltage generated in individual microphotoelements naturally depends on the light intensity, but even at large luminous fluxes $\sim 3 \cdot 10^{17}$ quanta/cm^2·sec (the luminous flux from a 400-W cinema lamp at a distance of 4 cm from the a.p.n. film) this quantity proved to be small. In specimen No. 19 it is 0.046 V, in specimen No. 5 0.050 V, in specimen No. 11 0.020 V, and in specimen No. 10 0.022 V. In order of magnitude these photovoltage values are in full agreement with the photodiffusion mechanism.

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CITED LITERATURE

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