THE DIFFUSION LENGTH OF MINORITY CARRIERS IN CdS FILMS USED FOR SOLAR CELLS

S. MELINTE, A. JEFLEA, M. MOISE and N. MATEESCU
Polytechnic Institute of Iassy, Iassy 6600 (Rumania)
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Summary

A simple method of determining the diffusion length of the minority carriers in an Al–CdS Schottky-type diode is presented. The results obtained are reproducible and are in good agreement with the values reported by other workers who used different measurement methods.

1. Introduction

The diffusion length of the minority carriers is an important parameter which affects the efficiency of solar cells. In this work the diffusion length in CdS is determined using the spectral photoresponse method.

2. Experimental details and theory

The CdS films were prepared by thermal evaporation onto a heated thin silver film in a vacuum. A transparent aluminium film device of diameter 0.50 cm was prepared by thermal evaporation through a mask [1].

The system used to measure the spectral response is shown in Fig. 1.

The diffusion length of minority carriers in CdS films 3–8 μm thick with $R_{\square} = (2\text{–}10) \times 10^3\ \Omega/\square$ was measured using the steady state surface photocurrent method [2]. In this method the specimen surface is illuminated by chopped monochromatic radiation with an energy slightly higher than that of the CdS gap. The photogenerated electron–hole pairs diffuse throughout the surface and are separated by the electric field of the depletion regions. The surface photovoltage resulting from this behaviour is measured as a function of the wavelength. The incident light intensity is adjusted to produce a constant surface photovoltage.

When light is incident on the surface of the semiconductor opposite to the

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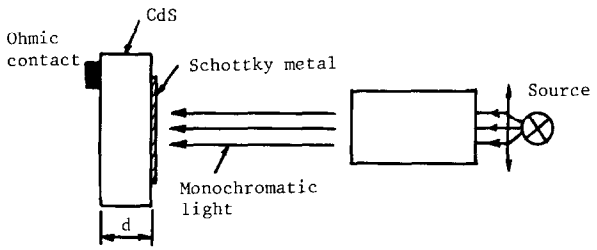

Fig. 1. Schematic diagram of the system used to measure the spectral response.

metal, the solutions of the transport equations [3–5] yield the following expression for the current generated at the junction by a single transmission of light through the layer:

$$j_1 = \gamma q \Phi_1 \left(\frac{\alpha L}{1-\alpha^2 L^2}\right)\{v+\alpha D-\exp(-\alpha d)\}\left[\frac{D}{L}\left\{\sinh\left(\frac{d}{L}\right)+\alpha L\cosh\left(\frac{d}{L}\right)\right\}+\right.$$
$$\left.+v\left\{\alpha L\sinh\left(\frac{d}{L}\right)+\cosh\left(\frac{d}{L}\right)\right\}\right]\left\{v\sinh\left(\frac{d}{L}\right)+\frac{D}{L}\cosh\left(\frac{d}{L}\right)\right\}^{-1} \quad (1)$$

γ is the efficiency of generation of an electron–hole pair by an absorbed photon (which is assumed to be equal to unity), q is the electronic charge, Φ_1 is the photon flux entering the layer, α is the absorption coefficient, L is the diffusion length of the minority carriers, v is the surface recombination velocity, D is the diffusion constant and d is the thickness of the layer. The carriers which are collected must be generated at distances of L or less from the junction. Therefore for a thick absorption layer with $d \gg L$ the incident light must not be strongly absorbed during its passage through the layer, *i.e.* the wavelength λ must obey the condition $\alpha(\lambda)d < 1$. In the limit of $d \gg L$ and $\alpha d < 1$, eqn. (1) becomes

$$j_1 \approx q\Phi_1 \alpha L \exp(-\alpha d) \quad (2)$$

When light enters the semiconductor from the metal, the collected current is [3]

$$j_2 = q\Phi_2\left(\frac{\alpha L}{1+\alpha L}\right) \quad (3)$$

for $d \gg L$ and $\gamma = 1$.

If the collection efficiency η, which is defined as the number of carriers collected per incident photon, is given by

$$\eta = \frac{j}{q\Phi_0} \quad (4)$$

where Φ_0 is the incident photon flux, the total current collected will be the sum of the currents generated during each successive light transmission. For transparent metal film junction devices the light may initially enter the semiconductor layer through the metal as shown in Fig. 1. Then eqn. (3) gives the response to the first transmission with $\Phi_2 = T_m\Phi_0$ where T_m is the transmission

of the metal film on the layer. The collection efficiency is

$$\eta = \frac{T_m \alpha L}{\alpha L + 1} \tag{5}$$

The measurements were made at a strongly absorbing wavelength so that only the first transmission need be considered.

Equation (5) can be rewritten in a linear form in terms of α^{-1} and η^{-1}:

$$\eta = \frac{T_m}{1 + (1/L)\alpha^{-1}} \tag{6}$$

or

$$\eta^{-1} T_m = 1 + \frac{1}{L}\alpha^{-1} \tag{7}$$

The calculated values of T_m [6] were used to plot $T_m \eta^{-1}$ *versus* α^{-1} for a well-known $\alpha(\lambda)$ dependence (Fig. 2).

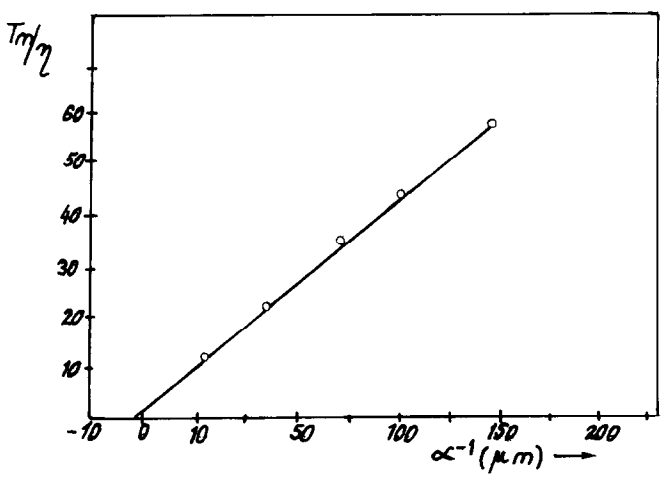

Fig. 2. Collection efficiency *vs.* absorption coefficient for CdS.

3. Results

Two procedures can be used to determine the diffusion length of the minority carriers from the spectral response.

(a) When the incident light enters the cell structure from the semiconductor the diffusion length is

$$L = \frac{\eta_{max} q d}{(1 - R_s)(1 + R_m)} \tag{8}$$

where η_{max} is the maximum collection efficiency, d is the thickness of the semiconductor layer and R_s and R_m are the reflection coefficients of the semiconductor and the metal respectively.

(b) When the incident light enters the cell through the transparent metal (in our case an aluminium layer 12.5 nm thick), the collection efficiency is given by eqn. (7) and hence L can be determined.

To determine the diffusion length from the reflection coefficients, it is necessary to know η_{max}. This can be found from the relation

$$\eta_{max} = \left(\frac{I_{sc}}{qP_i} \frac{hv}{a} \times 100 \right)_{V=0}$$

where q is the electronic charge, P_i is the incident power (30 mW cm^{-2} in this case) and a is the area of the cell. η_{max} was calculated from the maximum spectral response shown in Fig. 3. The diffusion length was then determined from eqn. (8) using the published values of $R_s = 0.90$ [7] and $R_m = 0.60$ [4] for CdS. A value of 0.215 for the diffusion length L was determined from the maximum value of the spectral response which occurred at $\lambda = 650$ nm (Fig. 3).

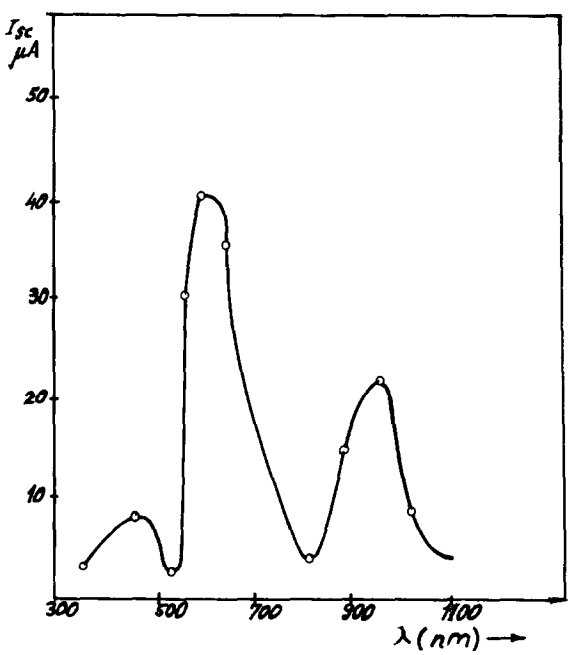

Fig. 3. Spectral response of CdS.

In case (b), when the incident light passed through the transparent metal aluminium which has $T_m = 0.157$–0.170 [6] in the spectral range $\Delta\lambda = 0.4$–1.0 μm, the diffusion length was estimated from Fig. 2 using eqn. (7). The values of the absorption coefficient $\alpha(\lambda)$ for CdS were taken from ref. 8. Both the calculation and the graphical method gave an average value of 0.275 μm for L.

The values obtained using procedures (a) and (b) are similar and are in good agreement with the results obtained by other workers using different methods [5]. These values ranged between 0.2 and 0.46 μm for CdS thin films.

4. Conclusion

The values of the diffusion lengths determined using the two procedures are in good agreement. The method is simple and the results are reproducible for various thicknesses of the semiconductor layer and the transparent metallic layer.

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