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THE SURFACE RECOMBINATION AND REFLECTION INFLUENCE ON QUANTUM EFFICIENCY OF PHOTOVOLTAIC DEVICES

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ABSTRACT

A new procedure is proposed for the evaluation of the basic parameters of photovoltaic structures. which takes into account the back side reflection and corresponding surface recombination rate. The device response is calculated from the continuity equation[1]. Using the generation term which takes into account the reflection both from the front and from the back side of photovoltaic structure[2], modified expressions for the carrier concentration and current are obtained: using these, the quantum efficiency is determined. Its values, calculated in this way, differ from the ones obtained in the usual way, especially near the absorption edge. The applied technique enables a simple theoretical prediction of the basic parameters of photovoltaic structure.

INTRODUCTION

One of the most frequently used types of infrared detectors is the one using the photovoltaic effect on $n^{+}p$ layers, the substrate being either a p or an n^{+} region. Depending in the intended use and required characteristics. these detectors can be made from various semiconductor materials (silicon, gallium arsenide, indium phosphide, etc). One of their most important characteristics is quantum efficiency, the ratio of the photocurrent electrons to the incident photons. This quantity depends, among others, on the properties of the boundary surfaces of the detector.

The standard procedure of photovoltaic structure calculations neglects the reflection from the back side of the structure[1], or takes into account only its influ-

ence to the photocurrent in one of the device regions. In some cases, however, neither the influence of the back side reflection nor the total contribution of other device zones can be neglected[3,4]

In this work we calculate the response of the photovoltaic device in a general case, taking into account in a straightforward manner the contribution of the all three main detector regions (n^+ layer, depletion zone and p region), as well as the back side reflection and the surface recombination rates on the front and back surfaces. We assume that the device thickness is high enough to neglect the interference effects. An other assumption is that the p and n regions are homogenously doped. The current densities in each device region are calculated using a simple one-dimensional model with a modified generation term.

THEORY

Let us consider the structure given in Fig. 1. S_p and S_n denote the surface recombination rates on the p and n boundary surfaces respectively, R_1 and R_2 are the front and back side reflection coefficients, while Φ denotes the number of incident photons per unit area of the device. α is the absorption coefficient.

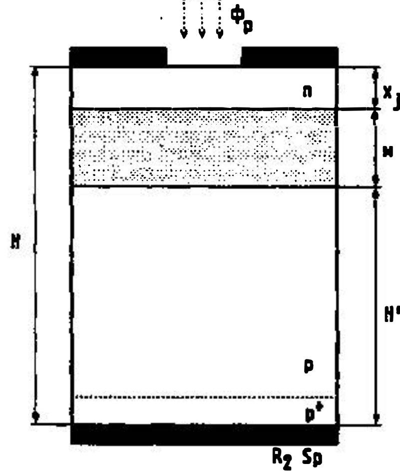

Fig. 1: Photovoltaic structure

In order to evaluate the response of the photodevice, we will use the procedure given in [5] and first apply it to determine the contribution of the p-region to the total current density. Let us write the continuity equation[6,7] in the following form:

$$\frac{d^2(n_p-n_{po})}{dx^2} - \frac{n_p-n_{po}}{L_n^2} = -\frac{\alpha}{D_n}\,\frac{(1-R_1)\,\Phi_o\left(e^{-\alpha x} + R_2\, e^{-\alpha(2H-x)}\right)}{1-R_1R_2\, e^{-2\alpha H}} \tag{1}$$

Its boundary conditions are:

$$n_p-n_{po} = 0 \qquad \text{for } x = x_j+w \tag{2}$$

$$D_n\frac{d\,(n_p-n_{po})}{dx} = -\,S_n\,(n_p-n_{po}) \qquad \text{for } x=H \tag{3}$$

In the above expressions n_p and n_{po} denote the non-equilibrium and equilibrium minority carrier concentrations respectively, D_n is the electron diffusion coefficient, while L_n denotes the electron diffusion length. The right-hand term (generation term) in eg. 1 may be written as follows[2]:

$$g(x) = \Phi_1 e^{-\alpha x} + \Phi_2 e^{\alpha x} \tag{4}$$

The solution of (1) for the first part of the generation term $\Phi_1 e^{-\alpha x}$ is well known[1]. The solution for the second term may be obtained from it by simply replacing Φ_1 by Φ_2 and α with $-\alpha$.

The total current density is:

$$J = J_p + J_n + J_w$$

where J_p denotes the density of the photocurrent generated in the n-region, J_n is the photocurrent in the p-region and J_w in the depletion layer. Thus in the case of homogenously doped n and p regions, the corresponding photocurrent densities are:

$$J_p = \frac{q(1-R_1)\,\Phi_o}{1-R_1R_2\,e^{-2\alpha H}}\left[F_p(\alpha,\gamma_p) - R_2\,e^{-2\alpha H}\,F_p(-\alpha,\gamma_p)\right] \tag{6}$$

$$J_p = \frac{q(1-R_1)\,\Phi_o}{1-R_1R_2\,e^{-2\alpha H}}\left[F_n(\alpha,\gamma_n) - R_2\,e^{-2\alpha H}\,F_n(-\alpha,\gamma_n)\right] \tag{7}$$

$$J_p = \frac{q(1-R_1)\,\Phi_o}{1-R_1R_2\,e^{-2\alpha H}}\left[F_w(\alpha, w) - R_2\,e^{-2\alpha H}\,F_w(-\alpha,\gamma_w)\right] \tag{8}$$

The above notation is in accordance with [8].

The quantum efficiency is calculated using well known equation:

$$\eta = J/q\Phi_o \tag{9}$$

NUMERICAL CALCULATIONS

In the calculations of the total quantum efficiency of a real photovoltaic structure we used the parameters of the silicon solar cell at ambient temperature

(T = 300 K) similar to those given in [1]. The parameters of the structure were as follows: the width of the n region was 0.5 μm; for zero bias the width of the depletion region was w = 0.47 μm. We supposed that the surface recombination rates on the front and on the back surface were approximately equal, $S_n = S_p = 100$ cm/sec. This is a real situation, because in practical application there is always a tendency to decrease the surface recombination rate as much as possible by an appropriate treatment of the contact surfaces. In the literature, however, one can encounter an approximation in which S takes infinitely high value on the back surface. The carrier diffusion lengths were $L_n = 230$ μm and $L_p = 98.6$ μm. The diffusion coefficients were $L_n = 36$ cm^2/sec and $D_p = 13$ cm^2/sec. The results of our calculation are shown in Fig. 2: curve 1 is drawn for $R_2 = 1$ and total structure thickness of 41μm. Curve 2 is for the same thickness, but for $R_2 = 0.1$. This curve also represents the case when $R_2 = 0$ and H = 20 μm. In this way we show that the influence of the back side is very strong and in our case corresponds to the double decrease of the device thickness. The lowest curve (3) is obtained at H = 20 μm and $R_2 = 0.1$.

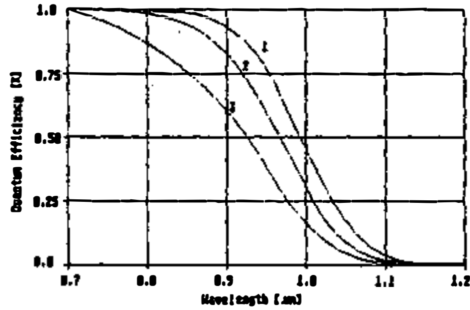

Fig. 2 Calculated quantum efficiencies of silicon photovoltaic structures

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