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Optimal distance between current collecting electrodes of the solar cells

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Abstract

In this work we consider the generation and recombination processes in the top layer of a solar cell. We show that the current generated from the solar cell depends on the distance between two surface coplanar adjacent current collecting electrodes with parallel configuration as well as on their width. Based on the obtained results we can estimate the optimal distance between two adjacent collecting electrodes. We also make calculations for collecting electrodes with square configuration. The comparison between the two types of electrode configurations shows that the square configuration is more efficient, and it has even better advantage for high quality solar cells designed on the basis of crystalline semiconductors.

Keywords: Solar cell; Electrode; Optimal distance; Diffusion length

1. Introduction

There are many works on the design and the operation behavior of solar cells. Most of them are related to thin film solar cells and their purpose is to improve the cells' construction in terms of the produced power.

In [1] the authors show that the ratio between the covered and uncovered metal areas of an a-Si:H solar cell affects the degradation behavior of the cell. A comparison between the cell operations with different junction design has been made in [2]. In the same work the limitations for improving the cell performance are pointed out by using a-SiC:H window layers. In [3] theoretical analysis has been made which shows that higher cell efficiency can be reached by grading the Fermi level of the *i*-layer. Efficiency of 9.46% is obtained on the basis of amorphous silicon solar cells with graded boron-doped active layers [3]. The progress of the conversion efficiency in various types of amorphous silicon solar cells is summarized and discussed in [4]. A computer model to simulate amorphous MIS solar cell is developed in [5]. The presented results in [5] show different possible ways to vary cell parameters in order to improve the cell efficiency.

In [6] a simulation method that can evaluate the power loss due to the resistance of the current collecting electrodes is described. Based on the simulated *I–V* curve of the cell the authors have proposed a method for optimizing the distance between the collecting electrodes in the case of concentrated sunlight. A digital method is proposed in [7] for minimization of the resistive losses in the collecting electrodes.

In this work we derive the dependence of the collected current from cell electrodes from the distance between adjacent electrodes and from their width for two type (parallel and square) electrode configurations. On the basis of these dependences the optimal distance between the top coplanar electrodes is calculated.

2. Theory

The schematic diagram of a solar cell based on a crystalline semiconductor is given on Fig. 1. However, the

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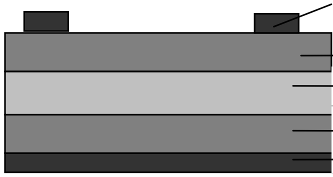

Fig. 1. Scheme of the cross section of a solar cell.

considerations that follow below are more general and are also valid for thin film cells. These considerations concern the determination of the optimal distance between coplanar current collecting electrodes.

2.1. Parallel configuration of the current collecting electrodes

We consider a solar cell with a parallel or so called "comb configuration" of the current collecting metal electrodes (see Fig. 1). Under illumination with fixed light intensity and load resistor the solar cell will produce current I_0 and voltage V_0. It is important to optimize the distance between the current collecting electrodes for the solar cell performance. If this distance is larger than the optimal one then the carrier losses due to recombination are higher. If this distance is smaller, the active area of the solar cell at a constant width of the collecting electrodes decreases and hence the generated carriers are less.

We assume homogeneous illumination over the entire cell surface. We will analyze half of the area because the processes are symmetrical relative to the middle of the two adjacent electrodes. The length of the collecting electrode is assumed to be one.

The light generated carriers in the Si depletion region are separated by the internal electric field of the solar cell junction and holes go into the p layer while the electrons are swept in the n-type silicon and later they go to the back metal contact. Thus, the concentration of the majority of the carriers in the p-layer (p_0) is increased by $\Delta p(x)$. It can be assumed that the diffusion in the lateral direction (x-axis) of the non-equilibrium holes takes place in the p-region. At the same time, the light generated electrons increase the concentration of the majority of the carriers in the n-region, but the non-equilibrium electrons with concentration $\Delta n(x)$ flow in lateral direction in the back metal contact. Thus, the excess carriers are separated by the depletion region of the p–n junction and if they can recombine they can do it only through the junction.

The continuity equations, in stationary one dimensional case, for the electron and hole current densities in the back metal layer and p-type Si region, respectively, are:

$$-\frac{\mathrm{d}J_\mathrm{n}}{\mathrm{d}x} = -q\frac{\Delta n(x)}{\tau} + qn_\mathrm{g}, \qquad (1)$$

$$\frac{\mathrm{d}J_\mathrm{p}}{\mathrm{d}x} = -q\frac{\Delta p(x)}{\tau} + qp_\mathrm{g}. \qquad (2)$$

Here $\Delta n(x)/\tau$ and n_g are the recombination and generation rates for electrons. Respectively, $\Delta p(x)/\tau$ and p_g are the recombination and generation rates for holes. Since, the electrons and the holes are created and recombined as couples their recombination and generation rates are equal for each x value. Then

$$\frac{\mathrm{d}J_\mathrm{n}(x)}{\mathrm{d}x} = -\frac{\mathrm{d}J_\mathrm{p}(x)}{\mathrm{d}x} \qquad (3)$$

and

$$\Delta n_x = \Delta p_x. \qquad (4)$$

Thus, (also due to the Coulomb interaction) the carriers diffuse as coupled charges ($\Delta n(x) = \Delta p(x)$), towards the closest current collecting electrode. If we consider x as half of the distance between two adjacent metal electrodes we can conclude:

$$J_\mathrm{p}(x) = -J_\mathrm{n}(x). \qquad (5)$$

The relations expressed in (4) can be considered as a condition for electro-neutrality of the solar cell. Thus, the total charge in a volume enclosed by surfaces that are perpendicular to the x-axis is zero. Then according to the Gauss law the electric field in the x direction is constant. For example, at the position photo-sensitive detectors i.e. in the case of non-homogeneous surface illumination the electrical field in lateral direction can be constant up to several centimeters [8]. Based on these considerations we assume, as a first approximation, that the lateral electrical fields in the p-region (E_p) and in the back metal layer (E_n) are constants.

The x components of the current densities are:

$$-J_\mathrm{n}(x) = q\left(-\mu_\mathrm{n}[n_0 + \Delta n(x)]E_\mathrm{n} + D_\mathrm{n}\frac{\mathrm{d}\Delta n(x)}{\mathrm{d}x}\right), \qquad (6)$$

$$J_\mathrm{p}(x) = q\left(\mu_\mathrm{p}[p_0 + \Delta p(x)]E_\mathrm{p} - D_\mathrm{p}\frac{\mathrm{d}\Delta p(x)}{\mathrm{d}x}\right), \qquad (7)$$

where n_0 and μ_n are the equilibrium concentration and the mobility of the electrons, respectively, in the back metal contact, while E_n is the electrical field in lateral direction in this contact. The quantities p_0, μ_p and E_p are related to the p-region. From Eqs. (4)–(7) we can derive an equation for the holes in the top illuminated p-region of the solar cell:

$$\frac{\mathrm{d}\Delta p(x)}{\mathrm{d}x} - \frac{q}{kT}\frac{\mu_\mathrm{n}E_\mathrm{n} - \mu_\mathrm{p}E_\mathrm{p}}{\mu_\mathrm{n} - \mu_\mathrm{p}}\Delta p(x) - \frac{q}{kT}\frac{(\mu_\mathrm{n}n_0E_\mathrm{n} - \mu_\mathrm{p}p_0E_\mathrm{p})}{\mu_\mathrm{n} - \mu_\mathrm{p}} = 0 \qquad (8)$$

At boundary condition $\Delta p(x = 0) = \Delta p_0$ (here we consider x as half of the distance between two adjacent current collecting electrodes) the general solution of Eq. (8) is:

$$\Delta p(x) = \left(\Delta p_0 + \frac{\mu_\mathrm{n}n_0E_\mathrm{n} - \mu_\mathrm{p}p_0E_\mathrm{p}}{\mu_\mathrm{n}E_\mathrm{n} - \mu_\mathrm{p}E_\mathrm{p}}\right)\exp\left(\frac{q}{kT}\frac{\mu_\mathrm{n}E_\mathrm{n} - \mu_\mathrm{p}E_\mathrm{p}}{\mu_\mathrm{n} - \mu_\mathrm{p}}x\right) - \frac{\mu_\mathrm{n}n_0E_\mathrm{n} - \mu_\mathrm{p}p_0E_\mathrm{p}}{\mu_\mathrm{n}E_\mathrm{n} - \mu_\mathrm{p}E_\mathrm{p}}. \qquad (9)$$