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Fluctuation model for p–n heterojunction solar cells

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Abstract

Influence of the roughness (microrelief) of an active interface in p–n junction solar cells (SC) on the photovoltage (the open-circuit voltage V_{oc}) has been studied. Nonuniformity of contact potential difference between p- and n-regions leads to barrier height fluctuation that are exponentially enhanced when dealing with barrier current. This results in some decrease of the V_{oc} value. Three theoretical models of averaging open-circuit voltage were used. Experimental results on p^+-$Al_xGa_{1-x}As/p^+$-n-GaAs heterostructure SC with various microrelief, obtained by the anisotropic chemical etching, are compared with theoretical calculations.

Keywords: Fluctuation model; Heterojunction solar cells; Microrelief interface; Anisotropic etching

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1. Introduction

Contrary to conventional texturing of front surfaces of solar cells (SC) for reduction of optical losses (see, for example, Refs. [1,2]), the objective of this report is an analysis of the influence of rough interface (serving to separate the electron–hole pairs by the built-in electric field of p–n heterojunction) on the SC photoelectric properties [3]. As a rule, semiconductor surface texturing leads to increase the short-circuit photocurrent, however, the value of the open-circuit voltage V_{oc} may both increase and decrease. It depends on the

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relation between increase of both the rate of electron–hole pairs generation and the dark saturation current.

Earlier [4] we have studied the influence of the roughness of active interface in metal–semiconductor contact (Schottky barrier) on photocurrent and photovoltage.

In this work we present the results of theoretical analysis of the influence of the lateral nonuniformity (fluctuation) of emitter layer doping on the open-circuit voltage of p–n junction or heterojunction SC. One-, two- and three-exponential models have been used for simulation of SC dark *I–V* characteristics. The calculation of average $\bar{V}_{oc}$ was also carried out by two methods: by the averaging of currents and by the averaging of charges. To discriminate models which are realized in the investigated SC a comprehensive characterization of them is needed.

We present and compare the results of experimental studies of averaged open-circuit voltage in SC made on the basis of p^+-$Al_xGa_{1-x}As/p^+$-n-GaAs heterosystem with flat or rough interfaces formed on microrelief (anisotropically etched) n-GaAs surfaces using various modification of liquid-phase epitaxy (LPE) and vapour phase epitaxy (VPE) techniques.

2. Theoretical analysis of open-circuit voltage in solar cells with p–n interface fluctuations

Different models have been developed to take account for the lateral SC nonuniformities. If a SC has considerable lateral inhomogeneities in one cell parameter such as open-circuit voltage V_i, the expression for averaged over surface open-circuit voltage $\bar{V}_{oc}$ may be presented in the following form [3]:

$$\bar{V}_{OC} = \left(\sum_{i=1}^{n} \frac{A_i}{A} \cdot \frac{1}{V_i} \right)^{-1}. \tag{1}$$

Here A_i is the area of the *i*th structure element with the *i*th value of hole concentration in the p layer, and A is the total area.

Another model is offered when presence of a relief leads to some peculiarities of acceptor atoms diffusion from growing p-layer into n-substrate. As a result, normal (Gaussian) lognormal distribution of holes in the p-emitter layer is realized. The following factors were taken into account. First, we took the Gaussian distribution of distance between Fermi level and v-band edge in the emitter layer, i.e., the quantity

$$E_{fp} = kT\ \ln(\mathrm{p}/\mathrm{n}_i), \quad f(x,\sigma) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left[-\frac{x^2}{2\sigma^2} \right], \tag{2}$$

where σ is the distribution width (dispersion), $x = \ln(\mathrm{p}/\bar{\mathrm{p}})$ and $\mathrm{p}(\bar{\mathrm{p}})$ is the local (mean) concentration of holes in the p-layer. Second, averaging of open-circuit voltage was made in the following ways:

(1) At the averaging of charges of paralleled elementary homogeneous capacitors, changing in formula (1) summation by double integration over the surface area and the x value, can be obtained:

$$\bar{V}_{\mathrm{OC}} = \left[\frac{1}{A} \int_0^A \int_{-\infty}^{\infty} \frac{f(x,\sigma)\mathrm{d}x}{V(\bar{p},x)}\, \mathrm{d}A\, \mathrm{d}x \right]^{-1} = \left(\int_{-\infty}^{\infty} \frac{f(x,\sigma)\,\mathrm{d}x}{V(\bar{p},x)} \right)^{-1}. \tag{3}$$