Microelectronics Journal 39 (2008) 1433–1438

Contents lists available at ScienceDirect

Microelectronics Journal

journal homepage: www.elsevier.com/locate/mejo

Effect of the interface states on the cell parameters of a thin film quasi-monocrystalline porous silicon as an active layer

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ARTICLE INFO

Article history:
Received 11 March 2008
Accepted 14 June 2008
Available online 12 August 2008

Keywords:
Semiconductor
Solar cell
Quasi-monocrystalline porous silicon
Photovoltaic parameters

ABSTRACT

Unlike crystalline silicon, quasi-monocrystalline porous silicon (QMPS) layers have a top surface with small voids in the body. What is more pertinent to the present study is the fact that, at a given wavelength of interest for solar cells, these layers are often reported, in the literature, to have a higher absorption coefficient than crystalline silicon. The present study builds on existing literature, suggesting an analytical model that simulates the performance of an elementary thin QMPS (as an active layer) solar cell. Accordingly, the effects that the interface states located at the void–silicon interface and that the porosity of this material have on the cell parameters are investigated. Furthermore, the effects of the optimum base doping, QMPS thickness, and porosity on the photovoltaic parameters were taken into consideration. The results show that the optimum base doping depends on the QMPS thickness and porosity. For an 8 μm thickness, the film QMPS layer gives a 35.4 mA/cm^2 for short-circuit current density, 15% for conversion efficiency, and 527 mV for open-circuit voltage when the value of the interface states is about 10^{12} cm^{-2} and the base doping is about 2×10^{18} cm^{-3} under AM 1.5 conditions.

1. Introduction

The use of thin crystalline silicon solar cells, fabricated by various versions of large transfer processes, is one of the most promising approaches to achieve both high performance and low cost, and this is due to its low material cost and ease of manufacturing [1–4]. Quasi-monocrystalline porous silicon (QMPS) is a very promising material for the production of inexpensive and efficient solar cells for terrestrial photovoltaic applications. Recently, such layers have been reported to have significantly higher absorption coefficient compared to crystalline silicon at the interesting range of the solar spectrum for photovoltaic solar cell applications [5,6].

A semi-empirical model has been developed to account for the higher absorption coefficient of QMPS layer which predicts the absorption coefficient of QMPS layer for different thicknesses, porosities and void sizes [5]. The transport parameters, such as the minority carrier mobility and lifetime in QMPS layer, have also been reported [7,8].

In QMPS the presence of voids in the body and interface states dramatically attenuates the electronic proprieties of this material and, consequently, its photovoltaic parameters. Extensive research has been carried out to understand the properties of the QMPS material and to suggest useful techniques and models to achieve high performance. Modeling the performance of QMPS cells has been the subject of several review papers [7,8]. It is demonstrated that the recombination of minority carriers at void–silicon interface decreases the photovoltaic parameters of QMPS solar cells, particularly the open-circuit voltage [7].

The objective of this paper is to extend the theory developed by Banerjee et al. [7] to further investigate the effects of the density of interface states, physical parameters, namely porosity and void radii, and the optimum base doping on the photovoltaic parameters of thin QMPS solar cells.

2. Model calculation

The schematic structure for analyzing an n^+p QMPS solar cell is shown in Fig. 1. The doping levels in the top and the base regions are assumed to be uniform; hence, no field exists outside the space charge regions. The voids in the body of the QMPS layer are assumed to be spherical in size and uniformly distributed.

2.1. Short-circuit current density

The short-circuit current density $J_{sc}(\lambda)$ collected from the solar cell is given by

$$J_{sc}(\lambda)=J_{n,sc}(\lambda)+J_{scr,sc}(\lambda)+J_{p,sc}(\lambda) \quad (1)$$

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doi:10.1016/j.mejo.2008.06.068

Nomenclature

q	electron charge
a	void radii
P	porosity
V_T	thermal voltage
P_{in}	power density output (AM 1.5)
L_n^* (L_p)	effective diffusion length of minority carriers in the base (emitter) region
D_n^* (D_p)	effective diffusion constant of minority carriers in the base (emitter) region
τ_n^* (τ_p)	effective minority carrier lifetime in the base (emitter) region
N_a (N_d)	dopant concentrations in the base (emitter) region
N_t	interface states at void–silicon interface
$\alpha^*(\lambda)$	absorption coefficient in the QMPS at a wavelength λ
$\phi(\lambda)$	incident photon flux
$R(\lambda)$	reflection coefficient at the front surface
W_p (W_n)	thickness of the base (emitter) region
W	width of the depletion region
H	QMPS layer thickness
S_p (S_n)	recombination velocity at the front (back) contact
J_{sc}	short-circuit current density
J_0	reverse saturation current density
V_{oc}	open-circuit voltage
η	conversion efficiency
P_m	maximum power output of solar cell
V_m (J_m)	voltage (current density) at maximum power output

where $J_{n,sc}(\lambda)$, $J_{scr,sc}(\lambda)$, and $J_{p,sc}(\lambda)$ are the short-circuit current densities that would be collected from the n-type emitter layer, from the junction space–charge layer, and from the p-type base layer at a given wavelength λ, respectively. Similarly for silicon solar cell, the three current densities for QMPS solar cell can be modeled as [9]

$$J_{n,sc} = q(1-R)\frac{L_p\alpha^*\phi}{(1-\alpha^{*2}L_p^2)}\exp(-\alpha^* W_n)\left[\alpha^* L_p + \frac{(S_pL_p/D_p)\cosh(W_n/L_p)+\sinh(W_n/L_p)-(\alpha^*L_p+(S_pL_p/D_p))\exp(\alpha^*W_n)}{(S_pL_p/D_p)\sinh(W_n/L_p)+\cosh(W_n/L_p)}\right] \quad (2)$$

$$J_{scr,sc} = q(1-R)\phi(\lambda)\exp(-\alpha^*W_n)\{1-\exp(-\alpha^*W)\} \quad (3)$$

$$J_{p,sc}(\lambda) = q(1-R)\frac{\phi\alpha^*L_n^*}{(\alpha^{*2}L_n^{*2}-1)}\exp(-\alpha^*(W_n+W)) \times \left[\alpha_i^*L_n^* - \frac{(S_nL_n^*/D_n^*)(\cosh(W_p/L_n^*)-\exp(-\alpha^*W_p))+\sinh(W_p/L_n^*)+\alpha^*L_n^*\exp(-\alpha^*W_p)}{(S_nL_n^*/D_n^*)\sinh(W_p/L_n^*)+\cosh(W_p/L_n^*)}\right] \quad (4)$$

where R is the fraction of photon reflected from the front surface, α^* is the absorption coefficient of QMPS layer [5], D_p and D_n^* are the hole and electron minority carrier diffusion coefficients [7,10], and $L_p = \sqrt{D_p\tau_p}$ and $L_n^* = \sqrt{D_n^*\tau_n^*}$ are the hole and electron minority carrier diffusion lengths (τ_p and τ_n^* are the hole and electron minority carrier lifetime [7,10]).

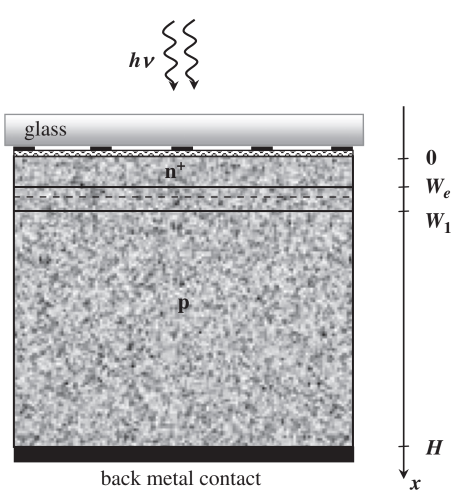

Fig. 1. One-dimensional schematic model of an elementary solar cell with a QMPS as an active layer.

In our calculation, the total short-circuit current density J_{sc} is calculated by [11]

$$J_{sc} = \sum_{i=1}^{n} J_{sc}(\lambda_i), \quad \lambda_i = 0.4 + 0.01(i-1) \quad (5)$$

The photon flux density ϕ (photons/cm / s) under AM 1.5 global normal sun condition can be approximated with the linear equations [11,12] as follows:

$$\phi(\lambda) = (19.7\lambda - 4.7)10^{15} \quad \text{for } 0.4 \leqslant \lambda \leqslant 0.47\,\mu\text{m}$$
$$\phi(\lambda) = (-2.5\lambda + 5.7)10^{15} \quad \text{for } 0.48 \leqslant \lambda \leqslant 1.08\,\mu\text{m} \quad (6)$$

2.2. Open-circuit voltage and conversion efficiency

In general, the total reverse saturation current density J_0 is given by

$$J_0 = J_{n,0} + J_{p,0} + J_{vs,0} \quad (7)$$

where, $J_{n,0}$ and $J_{p,0}$ are the conventional reverse dark saturation current density in the emitter and the base regions, respectively

Table 1
Data used in the numerical calculation

Parameter	Value	Reference
W_n	0.5 μm	
P_I (V)	10^8 cm^{-3}	[7]
N_d	5×10^{19} cm^{-3}	
V_T	25.9 mV	[9]
S_p	10^3 cm/s	
S_n	10^2 cm/s	[5]
P_{in}	100 mW/cm^2	[4]
R	~8%	[15]