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ScienceDirect

Solar Energy 107 (2014) 220–226

SOLAR ENERGY

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Analytical model and photovoltaic parameters improvement of polysilicon solar cells with porous silicon emitter

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Received 6 February 2014; received in revised form 13 May 2014; accepted 15 May 2014
Available online 28 June 2014

Communicated by: Associate Editor Nicola Romeo

Abstract

The present study aimed to develop a simple analytical model that simulates the performance of thin polysilicon solar cells with porous silicon (PS) contact on the front surface. It provides an analytical solution to the complete set of equations needed for determining the effect of this material on the performance of the cell when acting as an antireflective coating agent. The simple analytical expressions of the emitter reverse saturation current density and light-generated current density were also obtained. The PS layer was noted to induce a decrease in emitter reverse saturation current density and an increase in solar cell photovoltaic parameters. Overall, the findings revealed that the emitter region should not be treated as a 'dead layer' because contact with the thin PS layer front surface was noted to improve the open-circuit voltage, photocurrent, and cell efficiency values by about 20 mV, 4.5 mA/cm^2, and 3.3%, respectively.
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Keywords: Solar cells; Polysilicon; Porous silicon emitter; Efficiency improvement

1. Introduction

Although polycrystalline silicon represents a key component in the production of solar cells, it has often been reported to suffer from a number of undesirable defects that interfere with the electrical properties of semiconductor materials (Noor Mohammad and Rogers, 1988; Morante et al., 1997; Petkovic and Stojadinovic, 1992; Dugas, 1996; Ben Arab et al., 1990; Ba et al., 1993). These limitations have triggered the search for alternative techniques capable of enhancing polysilicon solar cell efficiency. Most of the analytical models so far proposed in the literature indicate that this goal could be achieved through reducing cell thickness, particularly of thin-film silicon, provided that cell surfaces are well passivated and that optical absorption is adequately enhanced (Rohatgi and Rai-Choudhury, 1984; Trabelsi et al., 2011; Oliveira et al., 2009). Recent research indicates that this can be attained through the incorporation of surface texturing that help reduce optical reflection. Several researchers have highlighted the important effects of reducing optical reflectivity and decreasing optical absorption on the enhancement of polycrystalline solar cell performance. In this context, various studies have indicated that, owing to its attractive optical properties, porous silicon (PS) is a promising candidate for application in the photovoltaic industry (Trabelsi et al., 2011; Bergmann et al., 2002; Bilyalov et al., 2002; Strehlke et al., 1997; Dou et al., 2013; Brenal, 2004; Ben Rabha et al., 2012) particularly as an antireflective coating agent (Martin-Palma et al., 2001; Alamo et al., 1985; Salmen et al., 2012; Trabelsi, 2013; Yae et al., 2006; Belhadj Mohamed et al., 2013).

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http://dx.doi.org/10.1016/j.solener.2014.05.025
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Nomenclature

q	electron charge
U_T	thermal voltage
n_{i0}	intrinsic carrier density
$L_p^+(L_p^{++})$	diffusion length of minority carriers in the polysilicon (PS) emitter
$D_p^+(D_p^{++})$	diffusion constant of minority carriers in polysilicon (PS) emitter
$N_d^+(N_d^{++})$	doping level in the polysilicon (PS) emitter
$\alpha(\lambda)(\alpha^*(\lambda))$	absorption coefficient in the polysilicon (PS) at a wavelength λ
$\phi(\lambda)$	incident photon flux
$R(\lambda)$	reflection coefficient at the front surface
$W_e(W_{PS})$	polysilicon (PS) emitter thickness
H	total cell thickness
d	grain width
$\Delta p^+(\Delta p^{++})$	excess hole density in the polysilicon (PS) emitter
$J_{phE}^{n^+}(J_{phE}^{n^{++}})$	polysilicon (PS) emitter light-generated current density
$J_{0E}^{n^{++}n^+}(J_{0E}^{n^+})$	emitter reverse saturation current density for PS (metal) contact solar cell
J_{0B}	base reverse saturation current density solar cell

The problems associated with the use of PS layer in contact with the crystalline silicon have been extensively investigated. Reports indicate that, due to the intrinsic properties of the PS, several factors have to be considered before its ultimate application in commercial photovoltaic technology (Strehlke et al., 1997). Most of these limitations are, in fact, attributed to the high resistivity of porous silicon (a metallic contact on its surface is expected to have a poor electrical behavior) and its fragility in the high-temperature processes characteristic of the fabrication of silicon solar cells. From a qualitative perspective, voids might be unsupportive for carrier mobility whose lifetime might be reduced by the highly doped wafers used for its formation. Besides, small voids may not bring about significant reductions in terms of carrier mobility (Bilyalov et al., 2002).

Despite the promising potential reported for PS in the literature, little experimental work has so far been performed to explore the performance of this material as an antireflective coating for thin mono- and poly-silicon solar cells and its potential contribution with regards to enhancing the optical absorption of crystalline silicon (Martin-Palma et al., 2001; Alamo et al., 1985). A previous analytical study by the authors (Trabelsi, 2013) allowed to determine the contribution that this material has on the internal quantum efficiency (*IQE*) of the polysilicon solar cell when acting as an antireflective coating agent and, more specifically, to explain the phenomena associated with its application. The data on the performance of polysilicon solar cells with PS contact on the front surface remain, however, very limited.

Accordingly, the present study aims to present a comprehensive analytical model to improve the photovoltaic parameters of polysilicon solar cells with PS contact on the front surface. It considers an elementary $n^{++}/n^+/p/p^+$ polysilicon solar cell with a thin film PS at the front side. The model presented in this work is based on a simple analytical approach that draws on effective recombination velocity (ERV) and other relevant data recently reported in the field (Ben Rabha et al., 2012). Using a plain analytical model, the present study shows that the minority carrier injection in the PS region could be simply described by an ERV. This approach allows for the accurate description of the complex minority-carrier transport in the PS region, in the dark and under illumination. The increase in the photovoltaic solar cell parameters, due to porous silicon, is derived. The dependence of the emitter reverse saturation current density J_{0E}, light-generated current density J_{phT}, open-circuit voltage V_{OC}, and conversion efficiency η on cell parameters is also discussed.

2. Theory

Fig. 1 presents a three-dimensional schematic diagram including the physical and structural parameters of the $n^{++}/n^+/p/p^+$ solar cell that consists of thin film polycrystalline silicon (n^+, p and p^+ regions) with a porous silicon

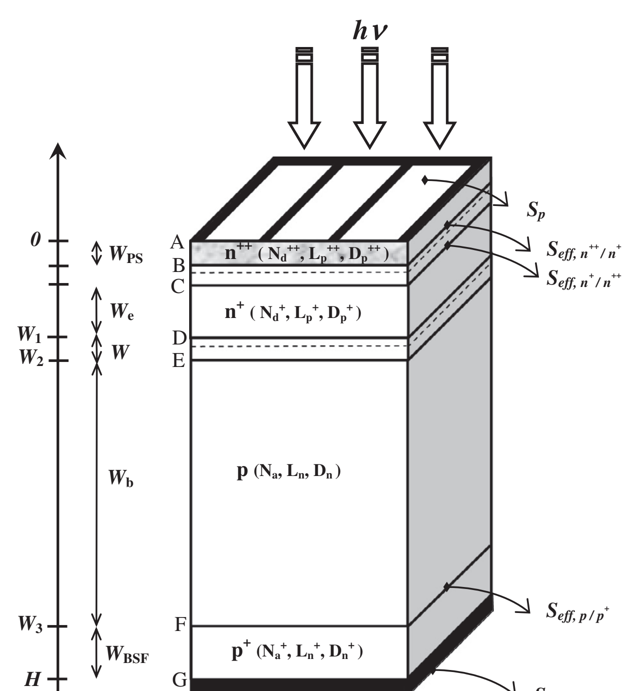

Fig. 1. Three-dimensional schematic model for an elementary polysilicon solar cell with PS emitter.

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