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Comparison of 1D and 3D analysis of the front contact influence on GaAs concentrator solar cell performance

Beatriz Galiana*, Carlos Algora, Ignacio Rey-Stolle

Instituto de Energía Solar – Universidad Politécnica de Madrid (IES-UPM), ETSI de Telecomunicación, Avda. Complutense s/n, 28040 Madrid, Spain

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Abstract

An extensive analysis of the front contact influence on concentrator GaAs solar cell performance has been carried out. The fill factor, open circuit voltage and efficiency have been calculated by varying the front contact specific resistance and the metal sheet resistance for 500X, 1000X and 2000X. An optimum front grid design has also been developed. The simulations have been carried out using a 3D model based on distributed circuit units, and by a classic lumped model, showing the need to use distributed models to achieve an accurate concentrator solar cell modeling as well as a precise front grid design.

Keywords: Modeling; Concentrator solar cells; Front grid design; Front contact; Gallium compounds

1. Introduction

High concentrated PV systems seem to be one of the most competitive ways for terrestrial photovoltaic applications [1]. In the last few decades a very significant effort has been made to increase the efficiencies of III–V solar cells. With regard to single-junction solar cells, efficiencies of 26.2% at 1000X and 25% at 2000X have already been achieved [2]. For multijunction solar cells at high concentration, an efficiency of 29–30% has been achieved at 1000X [3]. For medium concentrations, efficiencies of 39% at 236X have been

*Corresponding author. Tel.: +34 91 5441060; fax: +34 91 5446341.
E-mail address: beatriz@ies-def.upm.es (B. Galiana).

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measured [4]. As a result of such high concentrations, there is a severe and non-homogenous voltage drop in the front grid because of the high current. This phenomenon can be even more intense resulting from the lack of uniformity in concentrated sunlight [5].

In addition to the research on semiconductor structure to improve the solar cell performance, an intensive effort has been made to evaluate the ohmic losses in concentrator solar cells accurately. A lot of work has been carried out to evaluate the influence of some front grid aspects, but ignoring others [6–11]. In all previous studies the models were quasi-2D and the resistive effects were treated in a lumped way. Recently, a 3D model based on elementary electrical units was developed by treating different ohmic losses in a distributed way [12]. The lack of accuracy in modeling concentrator solar cells by a 1D or quasi-2D model was also proved [12]. This 3D model includes all the different ohmic losses such as the front grid, semiconductor layers, back and front contacts, the busbar and the number and position of the external connections. This implies that previous work modeling concentrator solar cells needs to be reviewed using a 3D model. Consequently, the purpose of this work is firstly to verify the 3D model with new experimental data of a real GaAs solar cell, secondly, to analyze the influence of the front grid characteristics in concentrator solar cell performance, for a wide range of front contact characteristics and for different concentrations, to be used as a prediction tool for the electrical behavior of the device (FF, V_{OC} and η), thirdly, to show the potential of the 3D model to optimize a front grid design, and finally to show the need to use a 3D model for a proper understanding of the concentrator solar cell behavior, instead of a classic 1D model with lumped parameters.

2. The 3D distributed model

A single-junction solar cell has traditionally been described analytically by means of the Eq. (1), where J_L is the photocurrent density, A is the solar cell area (cm^2), P is the solar cell perimeter (cm), r_S is the series resistance ($\Omega\,\text{cm}^2$) and r_P is the shunt resistance ($\Omega\,\text{cm}^2$)

$$I = J_L A - [J_{01}A][e^{qV/KT} - 1] - \left[J_{02d}A + J_{02p}P\right][e^{qV/KT} - 1] - \left(\frac{V + r_S J}{r_P}\right)A = I = I_L - I_{01}[e^{qV/KT} - 1] - I_{02}[e^{qV/KT} - 1] - \left(\frac{V + R_S I}{R_P}\right). \quad (1)$$

The equivalent circuit is shown in Fig. 1 where the recombination phenomena have been divided into three diodes: (a) the neutral region recombination with saturation inverse current density J_{01} and ideal factor equal to 1; (b) the depletion region with saturation

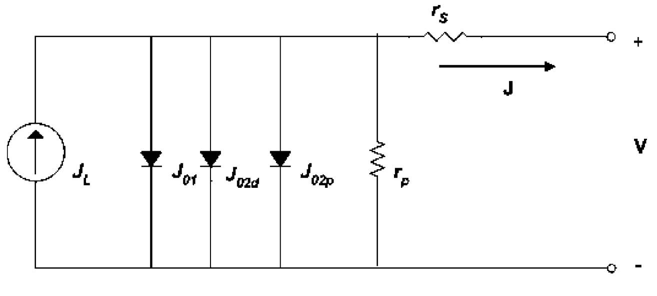

Fig. 1. 1D model for a single-junction GaAs solar cell consisting of three diodes, a series lumped resistance, a shunt lumped resistance and a current generator.