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SCIENCE DIRECT
Solar Energy Materials & Solar Cells 90 (2006) 1721–1733
Solar Energy Materials & Solar Cells
www.elsevier.com/locate/solmat

Analysis of photocurrent in the i-layer of GaAs-based n–i–p solar cell

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Received 29 March 2005; accepted 25 September 2005
Available online 9 November 2005

Abstract

A numerical investigation of the intrinsic layer effect on the improvement of GaAs n–i–p solar cell performances is presented. Solution of Poisson's equation together with continuity equations for electrons and holes allows the determination of carrier's density, electric field and recombination profiles within the i-layer. The analysis examines the effect of i-layer thickness on the electric field, recombination rate and collection efficiency. It is found that increasing the i-layer thickness increases the absorption while it reduces the electric field and increases the recombination rate. The three competing parameters have to be monitored simultaneously so as to obtain an optimal thickness. To achieve this, the variation of the total photocurrent is used as indicator. The photocurrent shows a sharp increase in the domain of very thin i-layers ($<0.5\,\mu$m) then a saturation is reached for thicker layers ($>1\,\mu$m), the simulation is performed for thicknesses up to $2\,\mu$m.

Keywords: Solar cell; p–i–n structure; Photocurrent; Recombination

1. Introduction

The efficiency of GaAs solar cells continues to rise as device design is optimised, material quality improves and device processing progresses. GaAs and its alloys provide a wide range of design options. A cell can contain several layers of slightly different compositions and doping that allow the control of the generation and collection of charge carriers. The

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0927-0248/$ - see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.solmat.2005.09.008

space-charge region (SCR) in a simple p–n junction has important collection efficiency. The electric field within this region has a significant role; it separates the photocreated carriers preventing them from recombining consequently increasing the collection efficiency. Therefore, the influence of recombination in the SCR is negligible. In common p–n junction SCR is very thin compared to the cell thickness. To increase the width of this region an intrinsic layer (i-layer) is sandwiched between n- and p-layers. The electric field in this region is generally high; the photogenerated carriers are accelerated out of the depletion region before they can recombine. PIN structures have found wide applications particularly in microwave devices and as photodetectors. During the last decade GaAs p–i–n solar cells have received a lot of attentions mainly because of their high efficiency and important photocurrent. Bett et al. [1] at Fraunhofer ISE in their experimental work found that inserting an i-layer in a GaAs solar cell increases its photocurrent by about 7%, at AM1.5 global condition, without affecting the open-circuit voltage. Increasing the width of the intrinsic layer in one hand increases the absorption, on the other hand, the electric field is decreased and the recombination is increased. P–i–n diodes have been investigated by many authors using different models, numerical and analytical [2–5].

Most of the early work on p–i–n diodes was in relation to their power rectifiers application. In the work of Naito et al. [2] a closed form solution for the forward characteristics of a p–i–n silicon diode was suggested. They included separately the effect of recombination and the carrier–carrier scattering effect on carrier's diffusion coefficient. Later Ben Hamouda et al. [3] used a numerical technique to determine the carrier lifetime of a p–i–n diode where they improved the early model of Davies [3] by including the effect of carrier–carrier scattering and Auger recombination.

A p–i–n structure as photodiode was examined by Lee et al. [4], they suggested an analytical characterisation, impulse response function, based on a number of assumptions including the separation of carriers into dark and photogenerated components, the p–i–n was modelled as a parallel plate capacitor, assuming large recombination velocity at the electrodes and fixed carriers velocity. Using these assumptions they were able to obtain expressions of photogenerated hole and electron concentrations by solving the continuity equations by means of Green's function method.

In recent work of Aperathitis et al. [6,7], GaAs p–i–n structure was investigated for photovoltaic applications, using both experimental and theoretical methods. They examined the effect of i-layer on the dark properties of GaAs solar cells including the incorporation of multiple quantum wells.

The work reported here analyses the role of the intrinsic layer on the enhancement of the photocurrent of a n–i–p GaAs solar cell. The effects of absorption, recombination and electric field within the intrinsic layer are emphasised in order to obtain an optimised i-layer thickness.

2. Model

The insertion of an intrinsic layer in a p–n junction is known to improve the performance of solar cells. The improvement consists mainly of the enhancement of the collection efficiency therefore the increase of photocurrent. The photocreated electrons and holes in the intrinsic region see an aiding electric field at the junctions and exit the n–i and i–p junctions, respectively. Whereas, electrons and holes are prevented from entering the intrinsic region from either sides of the diode because of the retarding electric field. As the