Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 124 (2017) 120–125

Energy Procedia

www.elsevier.com/locate/procedia

7th International Conference on Silicon Photovoltaics, SiliconPV 2017

Identifying the location of recombination from voltage-dependent quantum efficiency measurements

Byungsul Min[a]*, Christian Kruse[a], Carsten Schinke[c], Martin Wolf[a], Matthias Müller[b], Hendrik Sträter[b], Matthias Wagner[b], Karsten Bothe[a], Rolf Brendel[a,c]

[a]*Institute for Solar Energy Research Hamelin (ISFH), Am Ohrberg 1, 31860 Emmerthal, Germany*
[b]*SolarWorld Innovations GmbH, Berthelsdorfer Straße 111A, 09599 Freiberg, Germany*
[c]*Dep. Solar Energy, Inst. Solid-State Physics, Leibniz University of Hannover, Appelstr. 2, 30167 Hannover, Germany*

Abstract

This paper investigates process-induced variations of the open-circuit voltage (V_{oc}) using voltage-dependent quantum efficiency measurements. By means of device modelling we show that this method is able to explain the V_{oc} difference of two solar cells, even if they show identical electrical behaviour under short-circuit condition. This paper furthermore explains how the origin of V_{oc} variations can be classified into emitter, base and rear of the solar cell. The simulation results have been experimentally verified with industrial-type passivated emitter and rear cells (PERC) cells made from p-type Czochralski wafers. The proposed analysis method is an attractive way for monitoring V_{oc} variations of solar cells in industrial mass production since there is no need for specially prepared test structures.

Keywords: PERC; quantum efficiency; open-circuit voltage; process monitoring

---

1. Introduction

The open-circuit voltage (V_{oc}) is particularly sensitive to recombination losses. Variations in the recombination rate and thus in the concentration of the electrons and holes directly affect V_{oc}. Hence, an insufficient process

---

* Corresponding author. Tel.: +49-5151-999-644; fax: +49-5151-999-400.
E-mail address: min@isfh.de

10.1016/j.egypro.2017.09.324

stability or quality may result in significant V_{oc} variations. In order to reduce such process-induced variations of V_{oc} and of the corresponding cell efficiency, it is crucial to locate that part of the device that is responsible for the deviation from the targeted V_{oc} value. We analyze the solar cell under different operation conditions, since the respective locations exhibit different injection-dependencies of the recombination rate.

In this article, we perform voltage-dependent differential quantum efficiency measurement [1-5] to explain the process-induced variations of V_{oc}. As an application, we apply our approach to industrial-type PERC cells with p-type CZ wafers. By a combination of device modelling and experiments, we demonstrate that our method allows locating the origin of V_{oc} variations.

2. Principle of the method

The key points of our method are the following: first, the absorption depth is related to the wavelength of light. For a silicon solar cell featuring a front emitter, light of wavelength 300 nm is absorbed completely in the emitter while light of wavelength 1100 nm is absorbed almost homogeneously in the entire cell as shown in Fig. 1. Hence, the quantum efficiency at 300 nm is dominated by recombination in the emitter. This characteristic will be used to distinguish the emitter from the other parts of the solar cell. Second, by analyzing the differential external quantum efficiency (EQE) under forward voltage bias we are also able to distinguish the base from the rear, because it enables to monitor the injection-dependence of the recombination losses. However, this approach requires the saturation of the recombination losses in the base by increasing voltage as shown in next section.

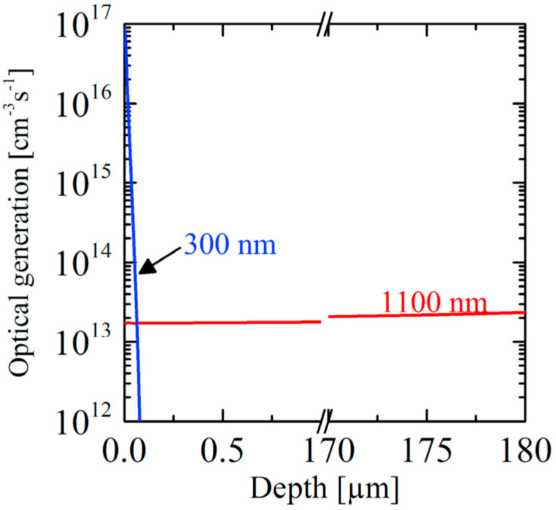

Fig. 1. Simulated optical generation for monochromatic light with wavelengths of 300 nm and 1100 nm as a function of depth from the front.

3. Modelling

We firstly simulate an industrial p-type mono-crystalline PERC cell as the reference, since the PERC design is especially sensitive to process-induced variation of device parameters such as bulk lifetime or surface passivation quality [6]. Starting from this reference cell, we model three different test cells by modifying a specific part (emitter, rear contacts and base) while the other parts of the simulated device remain identical. Compared to the reference cell, the V_{oc} values of these cells are lower ($\Delta V_{oc} = 5.4 \sim 7.8$ mV) but their J_{sc} values are close to J_{sc} of the reference ($\Delta J_{sc} < 0.2$ mA/cm²). We thus consider three different origins for the V_{oc} reduction: 1) the emitter, 2) the rear contacts and 3) the base. We then simulate EQE curves of these three PERC cells with a forward bias voltage ranging from 0 to 700 mV. We model monochromatic illumination with wavelengths of 300 and 1100 nm. The intensity of the light source is equal to 1µWcm^{-2}. There is no bias light, since we do not aim to determine the