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Modelling and simulation of InGaP solar cells under solar concentration: Series resistance measurement and prediction

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Abstract

One of the important parameters, that commonly affect solar cell performances, is the series resistance. Such effect becomes more pronounced when working under higher illumination intensities due to higher generated photocurrents. Therefore, it is necessary to predict series resistance effects under such conditions. To know more about the series resistance effect and its interpretation, InGaP based solar cell performances were investigated, using high solar concentration levels (73.36 X, 201.19 X). To facilitate the prediction of series resistance effect, as a function of insolation level, a computerised analytical model, using neural network, is presented.

Keywords: InGaP; Series resistance; Neural network; Concentrator solar cells

1. Introduction

InGaP based solar cells are reported in both photovoltaic [1–4] and photoelectrochemical [5–8] devices. For concentrator cells designed for high solar illumination intensities, e.g., several hundred suns or more, it is essential that Ohmic losses in the cell be very small. Expressed in terms of an effective series resistance, the series resistance-area product typically should not exceed a few $m\Omega\,cm^2$. The series resistance in a solar cell may seriously affect its maximum conversion efficiency [9–11]. Earlier studies, conducted under varying illumination intensities, used a set value of series resistance R_S. The concept of an effective series resistance parameter, R_S, is only based on an approximate model. Despite that, the model provides a practical method to estimate Ohmic losses and to design concentrator solar cells. For this reason, it is important to be able to measure R_S with reasonable accuracy.

The purpose of this paper is to study the series resistance effect on InGaP based solar cell efficiencies. In order to predict the series resistance effects, an analytical model using the neural network may be employed, as described here.

2. Experimental

P–n InGaP junctions were prepared by n-doping on a p-type wafer originally grown on a 200 μm Ge substrate by epitaxy. The n-type side was 200 nm thick, with doping density 2×10^{18} Si atoms/cm^3. The p-type side was 800 nm thick, with doping density 2×10^{17} Zn atoms/cm^3.

The InGaP cells (∼2 cm × 2 cm) were coated with Ag metal. The front grid was made of 2 bus bars, 1 mm wide, with about 80 fingers of 5 μm between them. Contact thickness was 2.5 μm, while sheet resistance was 900 Ω/□. The cells were mounted on Thermalclad substrates, which are commonly used for hybrid electronic circuits. The contacts were made by pressure on one of the two bus bars, with two spring arrows, as shown in Fig. 1.

All conversion measurements were conducted under solar radiation. The concentrator system used, Fig. 2, is advantageous

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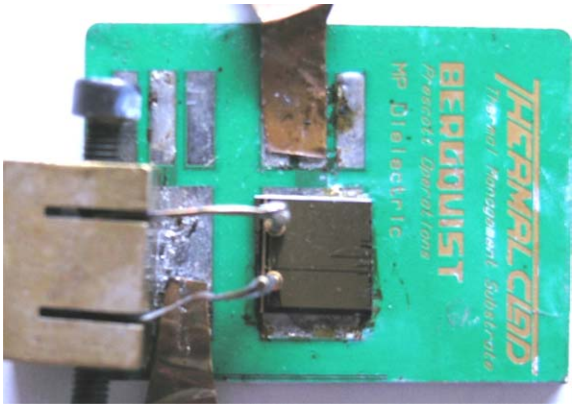

Fig. 1. InGaP solar cell display.

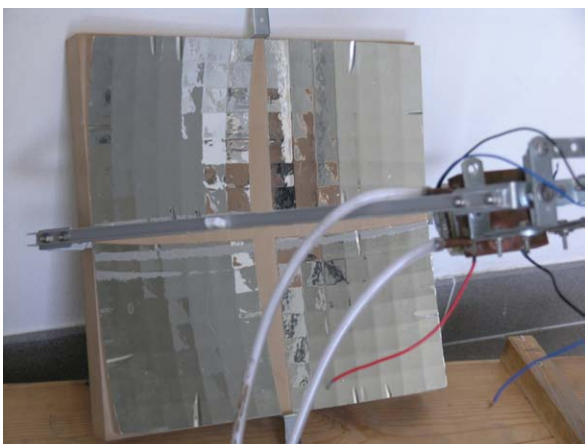

Fig. 2. The experimental Bloc.

for giving good illumination uniformity at the focus. The focus was 2 cm × 2 cm in area and was slightly larger than the dimensions of the tested cells.

A four-wire measurement was conducted. The four wires were contacted to two copper foils soldered at the substrate. A Kepco external voltage supply was used to counterbalance the voltage drop on the wires under short circuit conditions.

Cooling was performed using a Peltier heat pump. The hot side was cooled down by a high-efficiency heat exchanger with forced air. The Peltier was powered by a (3 A – 12 V) power supply.

The measured parasitic resistance introduced by this set-up was in the order of 20 mΩ. It is a minimal contribution for the tested cells. Under same experimental conditions, a good concentration solar cell shows only little degradation as a result of such parasitic effect.

3. Results and discussion

3.1. Temperature and series resistance effects

Enhancement, of solar cell conversion efficiencies, demands maximization of the three main cell photovoltaic parameters, namely: short-circuit photo-current density (J_{SC}), open-circuit voltage (V_{OC}) and cell fill factor (CFF). As the insolation level is increased (by a factor of C), in J_{SC}, V_{OC} increases logarithmically according to Eq. (1):

$$(V_{OC})_C = (V_{OC})_{1SUN} + U_T \ln C \qquad (1)$$

where U_T is the thermal voltage, typically 26 mV at 28 °C.

Generally CFF increases as V_{OC} increases, mostly because of reduced diode current. However, CFF is most dependent on parasitic factors, such as shunt resistance and, most importantly at high illumination levels, series resistance.

The efficiency-concentration relation is described [12] by Eq. (2):

$$\eta(C)_{R_s} = \eta(C)_{R_s=0} - \frac{P_{R_s}(C)}{C P_i} = \eta(C)_{R_s=0} - \frac{R_s C^2 I_{SC}^2}{C P_i} \qquad (2)$$

which after rearrangement becomes:

$$\eta(C)_{R_s} = \eta(1)\left[1 + \frac{n_f kT}{q V_{OC}(1)} \mathrm{Log}(C) - \frac{R_s C^2 I_{SC}^2}{C P_i}\right] \qquad (3)$$

where

- $\eta(1)$, $V_{OC}(1)$ are respectively the efficiency and the open-circuit voltage under one sun,
- C is the concentration ratio,
- q is the electron charge,
- P_i is the incident power,
- n_f the diode ideality factor,
- I_{SC} is the short-circuit current,
- $\frac{kT}{q} = U_T$ is the thermal voltage.

Practically, the efficiency increases with solar concentration, according to Eq. (3), reaches a maximum and decreases (Fig. 3). The efficiency lowering is due to two parameters: the temperature and the series resistance. The temperature dependence of the cell efficiency is of critical concern in a concentrator cell. This is because high insolation levels may elevate the cell temperatures well above ambient ones. It is well known that temperature affects performances of single junction [13] and

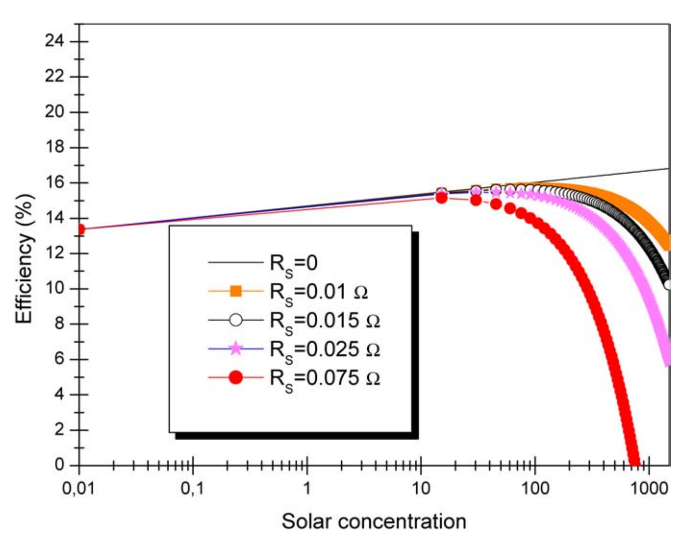

Fig. 3. Variation of the efficiency with solar concentration for different series resistances.