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Effect of buffer layer on minority carrier lifetime and series resistance of bifacial heterojunction silicon solar cells analyzed by impedance spectroscopy

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Abstract

By combining information on solar cell layer structure and electrical response analyzed by impedance spectroscopy, relevant knowledge is obtained about photogenerated carriers recombination and extraction. The inclusion of a-Si:H buffer layers on the response of bifacial heterojunction silicon solar cells prepared by hot-wire chemical vapor deposition is studied. Impedance analysis indicates that the effect of the buffer layer is twofold: (a) effective minority carrier lifetime is improved by one order of magnitude, confirmed by alternative quasi-steady-state photoconductance, and (b) whole series resistance is increased. Both effects seem to compensate each other so as to get similar efficiency and fill factor.

Keywords: Solar cell; Impedance spectroscopy; Buffer layer; Chemical vapor deposition; Carrier lifetime

1. Introduction

The static current–voltage characteristic of solar cells is routinely used to extract fundamental cell parameters and check device performance. It has been seldom recognized [1–4] that useful knowledge may be gathered by analyzing ac characteristics of solar cells in addition to dc curves. Impedance spectroscopy (IS) measurements taken over a broad frequency range (Hz–MHz) provide information on any system that is composed of a combination of interfacial and bulk processes, such as transport, recombination and interfacial states in solar cells [5]. The experimental method is straightforward but the interpretation of the results needs detailed models for assessing the mechanisms involved.

Simple ac equivalent circuits of solar cells should incorporate the capacitive effect corresponding to the excess minority carriers (C_d usually denoted the diffusion capacitance) in parallel with the depletion layer capacitance C_j (see Fig. 1a) [6]. Resistive effects arise from the minority carrier recombination R_r [7] and shunt resistances R_t. An additional series resistance is needed to model the contact effect R_s. In the forward bias direction the diffusion capacitance increases due to the minority carrier accumulation in the absorber layer and excess the junction capacitance, $C_d > C_j$ [8]. The ac equivalent circuit in this situation is represented in Fig. 1b, assuming also $R_t \gg R_r$. This simple equivalent circuit behaves like a parallel *RC* subcircuit in series with R_s. It is expected that impedance contributions from layers in which transport is determined by majority carriers are assimilated into R_s. However, intrinsic buffer layers can contribute with additional subcircuits despite their thickness in the nanometer scale (Fig. 1c), in which C_b and R_b account for the dielectric and resistive response of the buffer layer, respectively.

In this work we show that impedance spectroscopy provides detailed information on the factors determining the photovoltaic efficiency of different configurations of bifacial heterojunction

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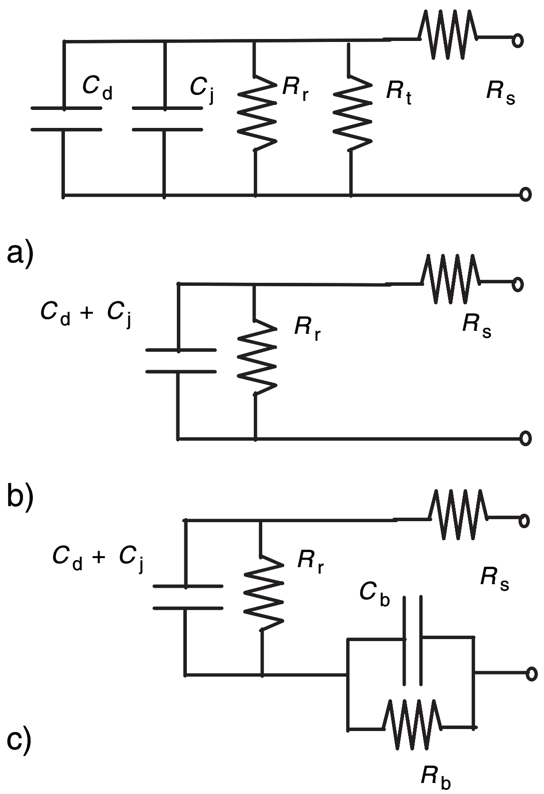

Fig. 1. (a) General solar cell ac equivalent circuit. (b) Simplification in case of $R_t \gg R_r$. (c) Additional contributions from intrinsic buffer layers.

thin film silicon solar cells. These devices are an excellent alternative for the fabrication of high efficiency silicon solar cells in an entirely low temperature fabrication process [9–12]. However, knowledge about transport and recombination mechanisms taking part in this device is still incomplete. Then, IS measurements can offer a new and valuable insight into the interface between crystalline and amorphous silicon.

2. Sample preparation and experimental conditions

The heterojunction silicon solar cells studied in this work are obtained on p-type polished float zone silicon wafers (100) of thickness 400 μm following a method described elsewhere [13]. The inner structure of the studied solar cells is summarized in Table 1, with all the films deposited by hot-wire chemical vapor deposition technique [14]. In both cases, the solar cells are defined with an area of 1.4 cm^2 by sputtering 90-nm thick indium tin oxide (ITO) layers onto the emitter and back contact. The front grid and back contact are obtained by evaporating silver in high vacuum. Then, the main structural difference between Cells A and B is the inclusion of hydrogenated amorphous silicon (a-Si:H) buffer layers in the second case. Therefore, IS measurements are performed in order to study the effect of including a 5-nm thick buffer layer. As we will next show the buffer layer improves the effective minority carrier lifetime τ_{eff} by more than one order of magnitude. However, this intrinsic buffer layer increases the whole series resistance with an additional term R_b (Fig. 1c). For the studied configurations, both effects seem to compensate each other so as to get similar cell parameters for efficiency and fill factor (FF).

The impedance measurements were carried out using an Autolab PGSTAT-30 equipped with a frequency analyzer module in the frequency range between 1 MHz and 1 Hz. Ac oscillating amplitude was as low as 10 mV (rms) in order to maintain the linearity of the response. Impedance spectra were recorded either in the dark under varying bias voltage or in open circuit conditions under varying illumination from 0.05 sun up to 1.5 sun. This last measuring procedure yields a more homogeneous distribution of excess minority carriers because dc current is not allowed.

Table 1
Heterostructures analyzed in this work

Cell name	Emitter		Back contact	
	n-doped	Intrinsic	Intrinsic	p-doped
A	μc-Si:H (50 nm)	–	–	μc-Si:H (50 nm)
B	a-Si:H (50 nm)	a-Si:H (5 nm)	a-Si:H (5 nm)	μc-Si:H (50 nm)

3. Results and discussion

As observed in Fig. 2 the incorporation of buffer layers increases the value of the open-circuit potential (V_{oc}) from 546 mV (Cell A) up to 577 mV (Cell B). As known, V_{oc} is related to the excess carrier density, what implies higher electron density in Cell B than in Cell A for 1 sun irradiance level. This is in fact an expected result because buffer layers inhibit to some extent the charge carrier recombination. On the other hand, the short-circuit current is slightly higher for Cell A (27.7 mA cm^{-2}) than for Cell B (24.2 mA cm^{-2}). However, this difference is probably due to a better quality of the ITO antireflecting coating in Cell A. In conclusion, both solar cells yield a conversion efficiency of around 9% with FF over 60%.

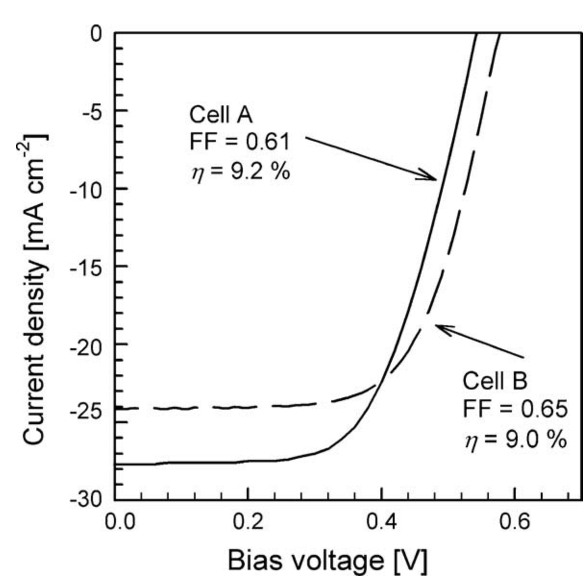

Fig. 2. Current–voltage characteristics of bifacial heterojunction solar cells measured under 1 sun-irradiance (1000 W m^{-2}) conditions. (solid line) Cell A and (dashed line) Cell B.