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Impact of series and shunt resistances in amorphous silicon thin film solar cells

M. Fortes *, E. Comesaña, J.A. Rodriguez, P. Otero, A.J. Garcia-Loureiro

Centro de Investigación en Tecnoloxías da Información (CITIUS), University of Santiago de Compostela, Santiago de Compostela, Spain

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Abstract

In this paper hydrogenated amorphous silicon (a-Si:H) thin film solar cells have been investigated using advanced simulation tools and the obtained electrical values were compared with experimental results. The analysis considers the effects of series resistance and shunt leakage. The simulation tool is parameterized with standard theoretical models for the density of states in the mobility gap, generation/recombination statistics, and experimental optical data of a-Si:H thin films. Experimental measurements were used to implement a textured TCO. Calculation of the illuminated and dark current voltage characteristics for the initial and stabilized states of the ideal solar cell was done. The ideal device was adjusted to the experimental curves using a non-ohmic model for the shunt leakage (simulated as microscopic pip structures, arisen due to aluminum diffusion) and an ohmic series resistance, finding good correspondence. The simulation shows that these mechanisms reduce the cell's efficiency in around an absolute 1%.

Keywords: a-Si:H thin film solar cell; Current voltage characteristic; Non-ohmic shunt resistance; Series resistance

1. Introduction

Photovoltaic (PV) modules fabricated with hydrogenated amorphous silicon (a-Si:H) technology have acquired great interest in the last years. This is mainly due to two reasons. First, their fabrication cost is lower to that of crystalline silicon modules, and second, the monolithic serial connection employed for cells results into higher module voltages (Lechner and Schade, 2002). Other advantages of using thin film a-Si:H modules include: enhanced power output under high temperature conditions (due to smaller temperature coefficients), greater absorption of diffuse radiation, and shorter lower energy payback time.

The possibility of using a-Si:H in the production of PV modules on a large scale caused in recent decades a great interest in modeling and understanding the electronic processes that occur in devices made with this material. The involved physical phenomena are complex thus, it has become imperative to use numerical simulation to solve the physical models that describe the operation of such devices. Simulations may help to understand the physical processes that take place during the cell operation and should also allow to determine the mechanisms that limit its performance. Moreover, they are expected to reduce the amount of expensive experimental work and to speed-up the development of new improvements which lead to better properties and lower production costs.

In this work, we present the results obtained in the two-dimensional simulation of single junction (pin) thin film a-Si:H solar cells and its comparison with experimental results, including the influence of shunt leakage and series resistance. In the first part of the paper we introduce the experimental solar cell (Section 2), describe the procedure to obtain the experimental measurements (Section 3) and present the simulated ideal device (Section 4). Next, we

* Corresponding author. Tel.: +34 881816473.
E-mail address: montserrat.fortes@rai.usc.es (M. Fortes).

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make some comments about the simulation tool and the modifications of the parameterization to simulate an ideal a-Si:H pin structure (Section 5). Following, we analyze the nature of the parasitic currents present in the experimental solar cell (Section 6) and our strategy to simulate them (Section 7). Then, we show the curves calculated for the ideal pin structure (Section 8.1). Following, we describe the results of adding the mentioned defects into the ideal dark (Section 8.2) and illuminated (Section 8.3) J–V characteristics. And finally, in the last section (Section 9), we present the conclusions derived from this work.

2. Thin film amorphous silicon solar cell

The samples described in this paper were manufactured by T-Solar Global S.A. (Grupo T-Solar S.A. Global, 2012), an independent Spanish photovoltaic electricity producer and module manufacturer (Vetter et al., 2009). The production process of these large area (5.72 m^2) thin film solar modules is based on a-Si:H pin structure deposition on float glass with a Transparent Conductive Oxide (TCO) layer. This process is also known as superstrate configuration because it follows the direction of incident light, in other words, the substrate is above the actual device structure. The back contact of the device consists of Al-doped Zinc Oxide (AZO), and metal coatings which act as reflectors for the non-absorbed light in the first path through the pin structure (Beyer et al., 2007) (see Fig. 1).

The front electrode is a textured fluorine doped SnO_2 layer that scatters the light and conducts the current. The doped a-Si:H and intrinsic layers are added by plasma enhanced chemical vapor deposition (PECVD). In T-Solar this system has a cluster configuration; p-layer is deposited in one chamber while i and n layer are deposited in another one to prevent cross-contamination.

The doped layers (p and n) have the function of creating an electrical field through the intrinsic layer (i-layer, where the photocurrent is generated) and of providing a good electrical contact to the end terminals. In the intrinsic layer the light is absorbed and the photogenerated carriers are separated and transported to the corresponding contact. The AZO layer acts as a reflection-enhancing dielectric layer. Lastly, the aluminum metal coating is used as back reflector and contact (Schropp and Zeman, 1999).

It is well known that the a-Si:H exhibits a light-induced degradation during the first illumination hours (Staebler–Wronski effect). This effect causes the creation of new defects (in addition to the initially present dangling bond density) due to the breaking of weak Si–Si bonds (Pankove and Berkeyheiser, 1980). The stabilized (or degraded) efficiency can be around 10–20% lower than the initial one (Staebler and Wronski, 1980). For this reason, in a-Si:H technology, the degraded efficiency is indicated as comparison criteria with the rest of PV devices. The record confirmed stabilized efficiency of a single-junction a-Si:H 1 cm^2 solar cell is 10.09%, and was obtained in 2009 by Oerlikon Solar-Lab in Neuchâtel, Switzerland (Benagli et al., 2009).

The impact of the Staebler–Wronski effect on the cell's response decreases with the i-layer thickness. To achieve a high stabilized efficiency we look for thin i-layers, reason why absorption enhancement techniques (light confinement) are essential (Cannella et al.,2013; Muller et al., 2004). In the analyzed device, the light is confined by introducing a textured front TCO (see Fig. 2) to scatter the light inside the cell. In combination with a high reflecting back contact one achieves longer light paths in the pin structure, which is especially important to absorb light in the 550–800 nm wavelength range (Hegedus and Kaplan, 2002).

3. Experimental J–V curves measurement

With the purpose of improving the efficiency and quality of the modules, T-Solar Global S.A. has installed a scientific laboratory which operates directly beside the production line. Special panels, are produced periodically for

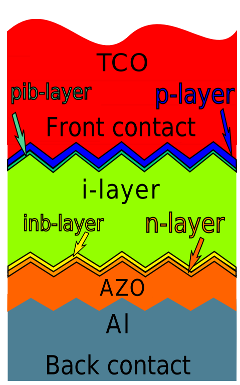

Fig. 1. Schematic representation of the cross-section of the simulated pin a-Si:H solar cell. The exact layer thicknesses are not provided due to they are confidential data.

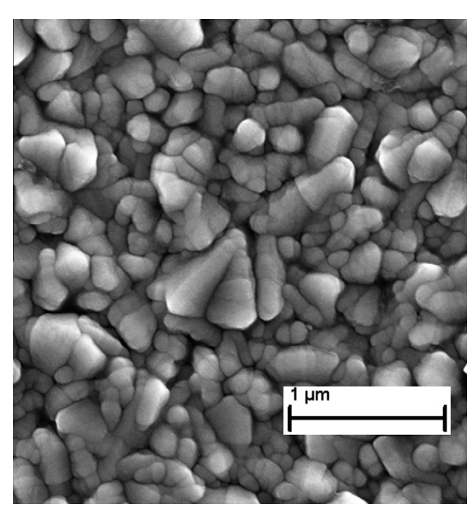

Fig. 2. Scanning electron microscope image of the surface of the on-glass TCO utilized in the T-Solar solar cell. This TCO texture is propagated to the lower layers, causing light dispersion and trapping into the device.