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Role of electric field and electrode material on the improvement of the ageing effects in hydrogenated amorphous silicon solar cells

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ABSTRACT

The effects of prolonged exposure to reverse bias DC electric fields and illumination as a function of temperature in hydrogenated amorphous Si (a-Si:H) photovoltaic p–i–n cells have been investigated. These are strongly affected by the well known Staebler–Wronski effect, occurring during light soaking of a-Si:H photovoltaic cells. In this work we show that the application of a reverse bias stress in presence of illumination not only slows down the solar cell ageing kinetics but even produces an improvement of the cells parameters as a function of stress time. We discuss the effect of temperature, electric field intensity and illumination level. We also show that different types of bottom contact over which the a-Si:H is grown by PECVD have a strong influence on the recovery-improvement kinetics: SnO:F (FTO) transparent conductive oxide (TCO) and molybdenum bottom contacts to the p-type a-Si:H layer are here compared. Finally, we demonstrate that an analogous improvement (reduction) of sheet resistance is observed in single thin films of doped a-Si:H deposited on SiO_2 under the application of high intensity electric fields.

1. Introduction

It is well known that after the first few hundreds of hours of illumination ("light soaking") the a-Si:H photovoltaic cells have a noticeable reduction of power conversion efficiency, mostly due to the "Staebler–Wronski" effect [1]. This reduction is mainly attributed to dangling bond defects whose density under light illumination increases compared to the initial value, reaching a saturation steady-state at about 10^{17} cm^{-3} [2,3]. The stabilization of defect concentration in the a-Si:H materials after extended light soaking is probably what renders the a-Si:H PV technology commercially viable. From a basic physics point of view the main idea is that the illumination provides the energy to break the so-called "dilute" H phase and thus creating dangling bonds [4,5]. In fact, a short anneal at about 150 °C can largely restore the solar cell performance. Such effect is also largely responsible for the positive relative efficiency temperature coefficient of a-Si:H solar cells and its very good performance in hot climates [6]. Recent studies show that rather than by low temperature thermal annealing the light-induced degradation in the a-Si:H solar cells can be totally recovered by the application of a reverse bias while the cells are exposed to illumination. These works focus on the behaviour of the solar cell power conversion efficiency and fill factor. It was found that the rate of recovery of degradation depends strongly on the electric field, on the temperature and on the light intensity [7,8]. The authors suggested that their findings might be due to field emission of either electrons or holes from the metastable defects rendering these defects charged and therefore mobile or to hydrogen ion motion, possibly on the internal surfaces of micro voids. In a recent report it was shown that in micromorph solar cells the required reverse bias for solar cell partial recovery after light soaking is less than that of single-junction a-Si cell, and that the microcrystalline Si bottom cell acts as a hydrogen reservoir, indicating the crucial role played by H to passivate the defects responsible for a-Si:H cell degradation after light soaking [9]. In this work we show that the application of a strong electric field in reverse bias not only slows down the solar cell ageing kinetics but also even produces an improvement of the cell parameters as a function of stress time. We separate the different contributions to the overall solar cell efficiency, i.e., the short circuit current, open circuit voltage, fill factor, etc. In particular, we show the particularly relevant effect observed in the behaviour of the series resistance (R_S) and of the open circuit voltage (V_{OC}). Moreover, we show that the type of

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bottom contact to the p-type a-Si:H layer has a strong influence on the recovery kinetic: FTO and molybdenum are here compared, and they show major differences. We finally show that under the application of high intensity electric fields in reverse bias the sheet resistance of single layers (not solar cells) of p-type doped a-Si:H films deposited on SiO_2 improves (it is reduced), and this circumstance may in part explain the results on the solar cells. The overall set of experimental results provides new information on possible approaches to improve the a-Si:H solar cell performances.

2. Experimental details

The a-Si:H solar cells used in the present study were single-junction p–i–n cells with p- and n-type a-Si:H layers of both 20 nm thickness and the intrinsic (i) a-Si:H layer thickness of 250 nm. The analysed samples had two different substrates: in a first case the AGC ASAHI GLASS VU-type substrate with ≈ 700 nm thick SnO_2:F as TCO was used; the second one was composed by a n-type Si wafer covered with SiO_2 for isolation on which $a \approx 700$ nm thick Mo film was deposited by sputtering. The p–i–n a-Si:H cells were deposited on the two different substrates by plasma enhanced chemical vapour deposition (PECVD) under the same conditions at 255 °C. The top contact at the n-type a-Si:H layer was in all cases a TCO layer of ZnO:Al (Aluminium doped Zinc Oxide, AZO) of 900 nm thickness deposited by sputtering. In summary, the entire solar cell layer sequences (illustrated in Fig. 1) were either SnO_2:F/p–i–n a-Si:H/AZO or Mo/p–i–n a-Si:H/AZO. The final geometries (circular with diameters varying from 0.01 to 0.64 cm) were defined by photolithography and selective etching of the AZO/p–i–n films. In the case of cells with FTO bottom contact the initial power conversion efficiencies at 1 sun with AM1.5G spectrum illumination were typically about 5.5% with open-circuit voltage of 0.8 V, short-circuit current densities of 12 mA/cm^2 and fill factor of 60%. In the case of the cells with Mo bottom contact the efficiencies were typically about 5% with open-circuit voltage of 0.85 V, short-circuit current densities of 12 mA/cm^2 and fill factor of 47%. The differences between these two types of cells are discussed in detail in references [10–12] and they are attributed to differences in substrate texture and photocarrier lifetime.

The solar cells were analysed by measuring the *I–V* curves under illumination conditions in a Cascade probe station with micro chamber, with the voltage varying in the −1 to 1 V range by using a HP 4156B semiconductor parameter analyser. To understand how electric field could affect the recovery-improvement kinetics, through regular time slots, we stressed the cells by using a reverse bias voltage varying in the 0 to −18 V range. Stress durations varied exponentially in the 10–10,000 s range. To compare the two types of bottom contacts all constant voltage stress processes in reverse bias and all the *I–V* measurements were performed in substrate configuration, i.e., with the illumination light entering from the top AZO contact. Illumination with an AM1.5G spectrum of the photovoltaic cells was achieved by using a 92191-1000 Newport solar simulator assisted, in some cases, by a mirror system and Fresnel lens to illuminate the samples either at very low, or, on the contrary, under high sun concentration with high intensity light (up to 30 suns). For the comparison of the solar cells realized on FTO and on molybdenum substrates, the illumination was provided through a white light source system. For the sample temperature control, all the measurements were performed in the 0–70 °C range by using a thermostatic chuck with a Temptronic thermal controller working under N_2 flux.

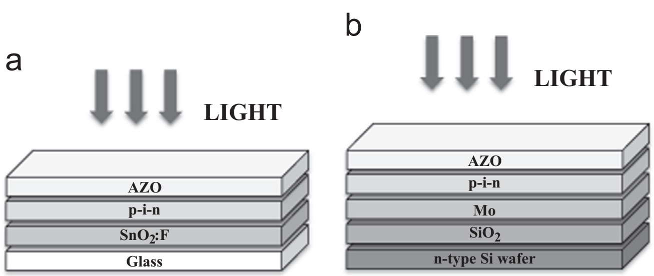

Fig. 1. Schematic structures showing the layers sequence of (a) the solar cell having FTO as bottom contact and (b) the solar cell using Mo as bottom contact.

3. Results and discussion

As first step, to define a reference baseline, we have studied the degradation of the solar cells under light soaking in short circuit conditions, observing the well-known Staebler–Wronski a-Si:H ageing effects [13–20]. To speed up the solar cell wear out, we have increased the intensity of the incident light through illumination under concentration to a large number of equivalent suns. Fig. 2 shows examples of power conversion efficiency data in short circuit conditions as a function of stress time for various light intensity levels. As expected, in short circuit conditions the degradation rate is an increasing function of the incident light intensity. In particular, the decrease of efficiency under light soaking becomes larger as the light intensity rises. The solar cell efficiency, the J_{SC}, and V_{OC} parameters get worse with the stress time, with an approximately linear trend when plotted in a semi logarithmic scale, i.e. as a function of the logarithm of stress time. Series resistance has a more complex behaviour, dependant upon the illumination levels. At high illumination, as the other parameters, it also worsens with stress time. The behaviour found in the light soaking under short circuit conditions is observed both in the samples with FTO bottom electrode and in the samples with Mo, though Fig. 2 refers only to the case of samples with FTO (see in Ref. [23, Fig. 2]).

Starting from the above baseline in short circuit conditions, we have analysed how the application of a reverse bias to the cells during the light soaking changes the wear out kinetics. Fig. 3 shows an example of a sequence of *I–V* measurements on a solar cell stressed for various times, up to 11,000 s, at −12 V reverse bias and at 1.5 suns illumination intensity. Fig. 3 reports the initial *I–V* curve of the fresh solar cell and after stress for various times, monitored by temporarily stopping the stress and recording the *I–V* characteristics. It is evident that the *I–V* curves are shifting toward higher power conversion efficiencies as the stress time increases, that is, the solar cell characteristics are improving under the reverse bias stress (see in Ref. [23, Table 1]).

In fact, the level of reverse bias during stress has a strong effect on the kinetics of the solar cell *I–V* characteristics evolution. To

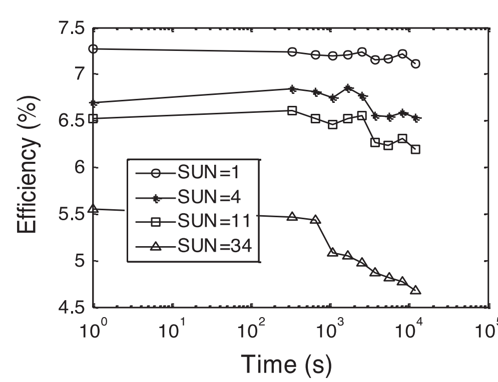

Fig. 2. Efficiency data (short circuit conditions) and related trend as a function of stress time for increasing sun intensity.