Data article

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

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\textbf{ABSTRACT}

Hydrogenated amorphous Si (aSi:H) solar cells are strongly affected by the well known Staebler–Wronski effect. This is a worsening of solar cell performances under light soaking which results in a substantial loss of cell power conversion efficiency compared to time zero performance. It is believed not to be an extrinsic effect, but rather a basic phenomenon related to the nature of aSi:H and to the stability and motion of H-related species in the aSi:H lattice. This work has been designed in support of the research article entitled “Role of electric field and electrode material on the improvement of the ageing effects in hydrogenated amorphous silicon solar cells” in Solar Energy Materials & Solar Cells (Scuto et al. [1]), which discusses an electrical method based on reverse bias stress to improve the solar cell parameters, and in particular the effect of temperature, electric field intensity and illumination level as a function of the stress time. Here we provide a further set of the obtained experimental data results.

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Specifications table

| Subject area | Physics  |
|--------------|----------|
| More specific subject area | Photovoltaics  |
| Type of data | Tables, figures  |
| How data was acquired | Cascade probe station with micro chamber - HP 4156B semiconductor parameter analyzer - 92191–1000 Newport solar simulator - Thermostatic chuck with a Temptronic thermal controller working under N2 flux  |
| Data format | Analyzed  |
| Experimental factors | The hydrogenated amorphous Si (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 thicknesses and intrinsic (i) a-Si:H layer of various thicknesses. The analyzed samples had a AGC ASAHI GLASS VU-type substrate with \( \approx 700 \) nm thick SnO2:F as transparent conductive oxide (TCO) deposited by sputtering; the cells were deposited by plasma enhanced chemical vapor deposition (PECVD) under the same conditions at \( 255^\circ C \); the top electrode was a \( 900 \) nm thick ZnO:Al (AZO) TCO. The entire solar cell sequences was glass substrate/SnO2:F/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  |
| Experimental features | All the solar cell electrical measurements were performed in substrate configuration, i.e. with the illumination light entering from the top AZO contact  |
| Data source location | Institute for Microelectronics and Microsystems, National Research Council, Catania, Italy  |
| Data accessibility | Data are with this article  |

Value of the data

- The solar cell improvement under reverse bias stress application is quantitatively reported;
- Data of the temperature dependence of the solar cell parameter change under reverse bias stress are shown;
- Clear evidence of the reversibility of the solar cell parameter change depending on the polarity of the applied stress is shown.

1. Data, experimental design, materials and methods

1.1. Light induced degradation of solar cells under short circuit condition

To define the sample preparation conditions we have studied the role of the \( \text{H}_2/\text{SiH}_4 \) ratio during the PECVD deposition of the a-Si:H layers at \( 255^\circ C \) on the time zero performance of the solar cells, given the important role played by the \( \text{H}_2 \) dilution [2–6]. We prepared two different typologies of samples using various different dilution ratios \( R \), defined as the \( \text{H}_2/\text{SiH}_4 \) ratio. A number of a-Si:H solar cell types were used in this analysis. One group was single-junction p–i–n cells with p and n-type a-Si:H layers of both 20 nm thickness and with the intrinsic (i) layer of either 45 nm or 250 nm thickness. The second group was a tandem a-Si:H/a-Si:H cell where the two i layers were 45 nm and 250 nm, respectively. Fig. 1 shows the \( I–V \) characteristics of these samples measured under AM1.5G spectrum with illumination intensity of 1.5 suns. From the figure it is evident that in each case the samples with \( R=5 \) dilution show better short circuit current. The effect is attributed to a better photo-carrier lifetime. In all cases, however, the a-Si:H films are amorphous, not micro-crystalline, and without any clear sign of Si nanocrystals, as shown by Raman and TEM analysis (not reported). For all the experiments reported in the following part of the paper, we have used single junction a-Si:H solar cells with 250 nm i layer and prepared with a dilution \( R \) equal to 5.

To study the degradation of our solar cells under light soaking and, consequently, to define a reference baseline, we have analyzed the effect of light soaking stress under short circuit conditions
on all the major solar cell parameters/figures of merit. As expected, under this condition it is observed
an increasing solar cell degradation as a function of stress time, and the degradation rate is an
increasing function of the incident light intensity [1,7] (Fig. 2).

2. Quantitative evaluation of the solar cell improvement under reverse bias stress

We now show how the application of a strong reverse bias during the light soaking dramatically
changes the wear out kinetics. Table 1 reports data of the major solar cell parameters/figures of merit
as function of the stress time observed by applying a fixed reverse bias of $-12$ V under a light
exposure with AM1.5G spectrum at 1.5 equivalent suns [1]. By observing the values, it is evident that
the solar cell characteristics under the reverse bias stress are improving as the stress time increases.

3. Analysis of the effect of temperature during reverse bias stress

As reported in [1], it was observed that the application of a strong reverse bias stress to the a-Si:H
solar cells rather than simply slowing down the wear out rate under light soaking [8], indeed
improves the solar cell characteristics. We have therefore analyzed the role of the solar cell
temperature on the improvement kinetics in reverse bias stresses at $-12$ V under a light exposure of
1.5 suns. Fig. 3 shows the effect of the solar cell temperature during the stress. It is evident that
the largest solar cell improvement effect is around 40–50 $^\circ$C, which represents in this case the ideal
heating treatment. Lower or higher temperatures produce less improvement. This indicates that the
temperature represents a further important factor to be considered in the solar cell recovery/
improvement mechanism. This circumstance may be due to the fact that either the solar cell
improvement is related to a short range atomic species diffusion phenomenon or other mechanisms
become important at larger temperatures.

4. Reversibility of the solar cell parameter change depending on the stress polarity

As observed in the case of p single substrates [1], where the sheet resistance goes up and down
following the sign of the applied voltage pulse, also in the case of the complete a-Si:H solar cells we
observe reversible changes in the solar cell power conversion efficiency finding monotonic trends in
response to forward and reverse bias stress. As example, we report the results of experiments
performed with stresses in forward (F) and reverse (R) bias, +0.6 V and −2 V, respectively. Each voltage stress lasted 4000 s and it was performed under a light exposure of 1 equivalent sun. Fig. 4 reports the normalized solar cell power conversion efficiency as a function of time for two different stress sequence conditions, i.e., RFRFRF and the opposite FRFRFR. That is, in one case we start to stress the cell with −12 V (noting a considerable increment of efficiency) and in the other we first apply a positive bias of +0.6 V (noting a fall in efficiency). As clearly shown in Fig. 4, in both cases we observe a noticeable solar cell efficiency growth.

Fig. 2. Normalized data trend analysis (short circuit conditions) for (a) $J_{SC}$, (b) $V_{OC}$, (c) $R_{OC}$, (d) FF and (e) efficiency as a function of light soaking time for increasing sun intensity.
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Table 1
Quantitative evaluation of the solar cell improvement under reverse bias stress. Major solar cell parameters/figures of merit as a function of stress time at fixed reverse bias of −12 V under a light exposure of 1.5 suns.

| Stress time (s) | $J_{SC}$ (mA/cm²) | $R_{OC}$ (Ω cm²) | $R_{SC}$ (kΩ cm²) | FF (%) | $V_{OC}$ (V) | Eff. (%) |
|----------------|-------------------|-----------------|------------------|--------|-------------|---------|
| $t=3$          | 11.13             | 11.61           | 1.69             | 60.58  | 0.802       | 5.39    |
| $t=35$         | 11.14             | 11.44           | 1.59             | 61.00  | 0.805       | 5.45    |
| $t=65$         | 11.16             | 11.41           | 1.56             | 61.53  | 0.805       | 5.50    |
| $t=100$        | 11.15             | 11.33           | 1.92             | 61.78  | 0.806       | 5.52    |
| $t=400$        | 11.15             | 10.48           | 1.66             | 63.02  | 0.810       | 5.67    |
| $t=1000$       | 11.18             | 10.84           | 1.62             | 61.47  | 0.822       | 5.62    |
| $t=5000$       | 11.21             | 10.27           | 1.82             | 64.52  | 0.835       | 6.03    |
| $t=8000$       | 11.24             | 8.24            | 2.28             | 66.48  | 0.827       | 6.16    |
| $t=11,000$     | 11.28             | 8.26            | 1.92             | 66.00  | 0.835       | 6.17    |

Fig. 3. Normalized efficiency data trend analysis as a function of stress time for increasing temperature intensity observed applying a fixed reverse bias of −12 V under a light exposure of 1.5 equivalent suns.

Fig. 4. Normalized efficiency data trend analysis as a function of stress time in response to contrary and alternating voltage bias (+0.6 V and −12 V) applied for 4000 s each under a light exposure of 1 equivalent sun.
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