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ScienceDirect
Energy Procedia 6 (2011) 743–749
Energy Procedia

The effect of reverse current on the dark properties of photovoltaic solar modules

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Abstract

Forward and reverse dark current-voltage (I-V) and capacitance-voltage (C-V) characteristics of commercial amorphous silicon solar modules, were measured in order to study their performance under the influence of induced reverse currents. Maximum module surface temperatures were directly related to each value of the induced reverse current and in to the amount of current leakage respectively. Microscopic changes as a result of hot spots defects and overheating of the solar module, linked to reverse current effects, were also documented and discussed. Experimental evidence showed that different levels of reverse currents are confirmed to be a major degrading factor affecting the performance, efficiency, and power of solar modules.

Selection and/or peer-review under responsibility of [name organizer]

Keywords: Photovoltaic module, degradation, temperature, microscopic damage.

doi:10.1016/j.egypro.2011.05.084

1. Introduction

The use of photovoltaic modules consisting of solar cells as a source of energy has inspired many scientists since the early fifties of the past century [1], and still is a major field of research. A lot of extensive studies focus on the quality, design and efficiency of solar modules in an attempt to offer more power and cost efficient products. Nevertheless, degradation is expected whatever advanced technology and quality control systems are implemented. Experimental research performed by inducing typical defects showed that, the existence of defects of any type and anywhere in the solar cell will surely play a degrading factor and influence its dark current voltage (I-V) characteristic [2].

The overheating [3], the light induced damage [4, 5], or total or partial shading influence the (I-V) characteristics and the total power output of the photovoltaic module. This problem may become more serious when the shaded cell or cells get reverse biased because serious and permanent local damage in certain cells may lead to the destruction of the entire photovoltaic module [6].

A simple experimental way is to subject typical photovoltaic modules to selected amounts of reverse currents for different time durations, and then study the changes in their dark characteristics especially for the highly used amorphous silicon [7] modules. The changes in this case could provide valuable data on the performance and efficiency of photovoltaic modules under the effect of reverse currents.

In this paper we use small amorphous silicon photovoltaic modules to study their degradation after the application of a reverse current as in the case of shaded cells. Several amounts of reverse current are applied for different periods of time and the dark I-V and C-V characteristics are measured, the module in this particular case, is treated as a PN junction. A temperature probe and a microscope are used to monitor the surface temperature and to look for any structural damage.

2. Experimental set up

The study was performed on small commercial off the shelf (COTS) photovoltaic modules formed by an assembly of four amorphous silicon solar cells, with an operation voltage of 1.5V. These modules are available on the market and are generally used to power up calculators and other small electronic gadgets. We want to study the dark characteristics so, during the experiment, the modules were placed in a dark grounded box in order to prevent any unwanted electrical or light interference. In dark, the electrical behaviour of a photovoltaic module becomes similar to the behaviour of a PN junction. An automated current source is used to induce a reverse current trough the module in order to stress it and degrade it, as if it was a reverse current through a PN junction, but in this case the current intensity is maintained at a fixed value to prevent catastrophic breakdown also known as an avalanche regime. Also a temperature probe is used to constantly monitor the surface temperature of the module. We first applied a reverse current of 10 mA (milliamperes) for 10 minutes, the current was then cut off and when the module cooled down to room temperature, dark I-V (current voltage) and C-V (capacitance voltage) measurements were performed. The reverse current was applied again for another 10 minutes and the same measurement were then performed and so on until we reached 60 minutes of applied reverse current. The latter procedure was repeated on another module but for a current value of 20 mA, then 30 mA , and finally 100 mA. At each step microscopic snapshots were taken in order to check up for any structural damage.

3. Results

The forward dark I-V current of the tested modules is shown in figures 1 and 2. We are only presenting the results for induced reverse currents of 10 mA and 100 mA knowing that for other values of current, the effects and variations are similar but increase as we increase the reverse current. When plotted in logarithmic scale the obtained dark I-V curve could be divided in two parts, the first going from 0V to approximately 2V (the nominal operation voltage V_{oc} as defined by the manufacturer) and the second going from 2V to 10V. In the first part, for voltages below V_{oc}, we observe a certain tilt in the curve that could be related to a leakage current within the module ($<V_{oc}$), supposedly negligible in normal operating conditions. But when the module is subjected to a reverse current we observe a considerable increase of the leakage current after 10 minutes and then it almost stabilises as the time progresses. This is a major indication that some regions of the photovoltaic module are leaking current at very low voltage, and these defected regions are created within the first 10 minutes of applying a reverse current. When observed on a microscope, the surface of the module appear to have some damaged areas that look like burned spots and which the size does not vary with time. We believe that these areas are responsible for the leakage that appears on the I-V characteristic. During the stressing period, when the reverse current is applied, the flow of electrons is forced to get through the junction along a certain path or runway. The only possible mean to achieve this is by punching through the weakest areas of the module surface which will turn into burned areas. The word burned may be slightly exaggerated because these areas are not fully degraded, otherwise we would have observed a total breakdown, but they rather became less resistant from the surrounding surface. If the current becomes larger, it is perfectly logical to have larger affected areas, which is the case in our modules. The second part of the curves ($>V_{oc}$) is hardly changing for a reverse current of 10 mA (figure 1), meaning that we have not reached a full breakdown regime therefore the module could still be considered as operational. When the module is stressed with a 100 mA reverse current the leakage current is certainly larger but it still not enough to consider a breakdown, the module's operation is rather altered. This is crucial for understanding the degradation of photovoltaic modules if they ever got reverse biased, small reverse currents does not seem to affect the output of the module but larger currents tend to slightly change it.

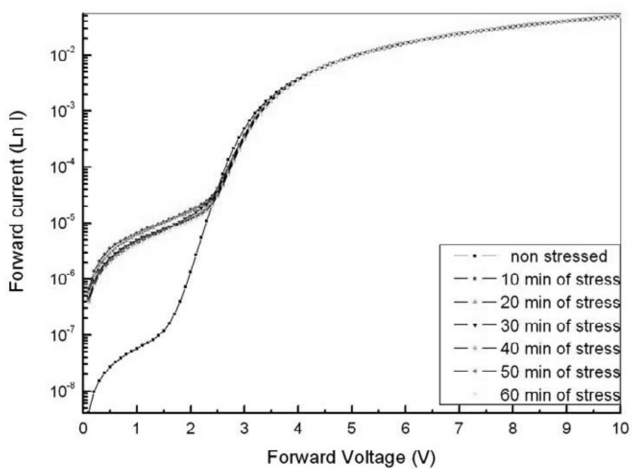

Fig. 1. The I-V characteristic of a photovoltaic module subjected to a stressing current of 10 mA, presented on a logarithmic scale

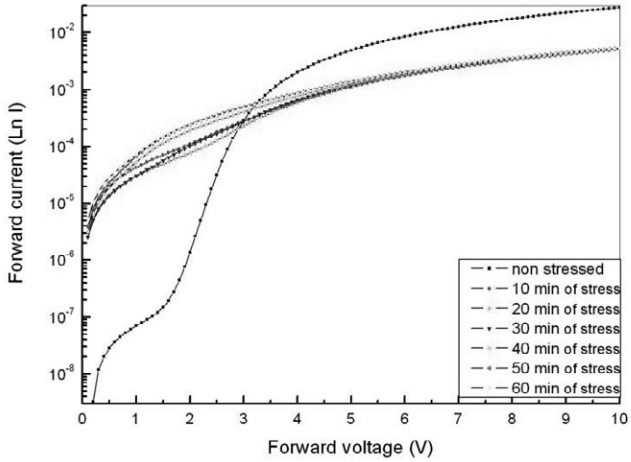

Fig. 2. The I-V characteristic of a photovoltaic module subjected to a stressing current of 100 mA, presented on a logarithmic scale

The reverse characteristic of the module is measured by applying a reverse voltage through the junction to verify that no current is flowing, a large current means that the module is broken and no more useful. Figures 3 and 4 show the reverse characteristics of our modules, when degraded by a 10 mA and a 100 mA current respectively, plotted in a linear scale. The reverse dark current (not the current used to stress the device) is certainly higher with respect to the fresh device but it is still within an acceptable margin to not consider a breakdown. A considerable increase in the reverse current is observed after ten minutes of stressing time and then the variation becomes smaller for further periods. In fact, the main degradation is produced when we first apply the stressing current when certain zones of the module are burned out, as previously mentioned, to form a current passage where charges escape through these hot spots once they are created, without damaging other areas, as it will be verified by the microscopic snapshots. This is the reason why longer stressing times do not intensify the degradation, in fact even though the reverse current is increasing with time it seems that the junction is holding and that the burned spots does not leak current in reverse mode at least if the applied voltage is within the nominal values.

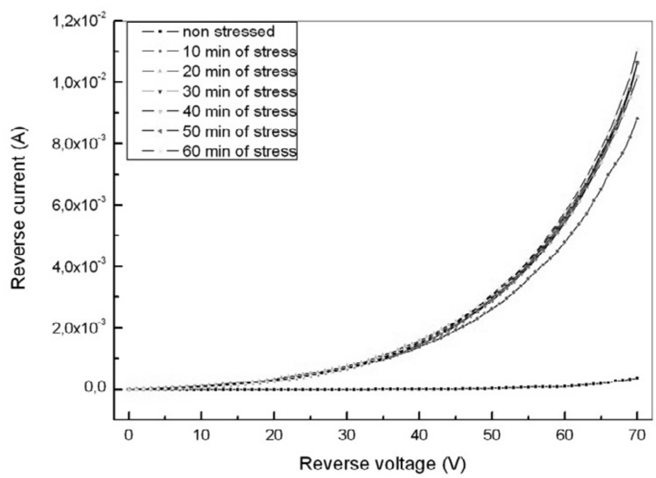

Fig. 3. The reverse I-V characteristic of a photovoltaic module subjected to a stressing current of 10 mA, presented on a linear scale

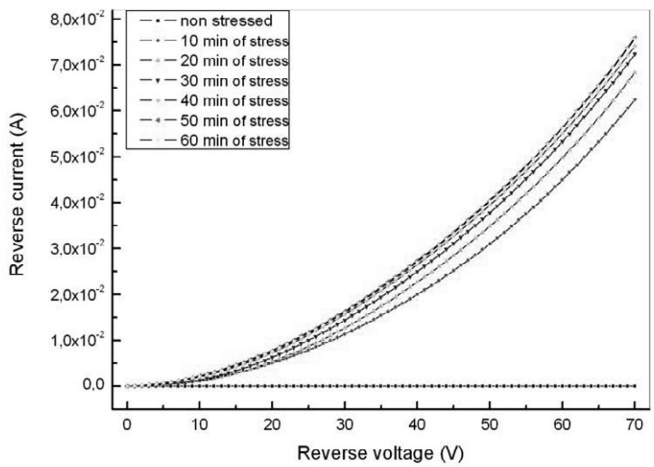

Fig. 4. The The reverse I-V characteristic of a photovoltaic module subjected to a stressing current of 100 mA, presented on a linear scale.

The capacitance voltage characteristic is in accordance with the previous explanation. The C-V curves were measured at a 1 MHz frequency, as seen by figures 5 and 6 for stressing currents of 10 mA and 100 mA respectively. In figure 5 the variation is very little as the capacitance varies from -10 V to +10 V. But in figure 6, were the device is stressed with 100 mA, the variation is more pronounced because there is a bigger leakage current flowing in the module reducing its capacitance. Actually as long as the voltage across the module is less than the operation voltage the capacitance value is constant, then it starts to decrease when a current begins to flow in the forward direction. The large decrease of the capacitance observed in figure 5 is a major indication of a leakage in the stressed module and it also indicates that the burned spots act as defected areas rather than recombination centres, otherwise we would have had a different shape of the C-V curve.

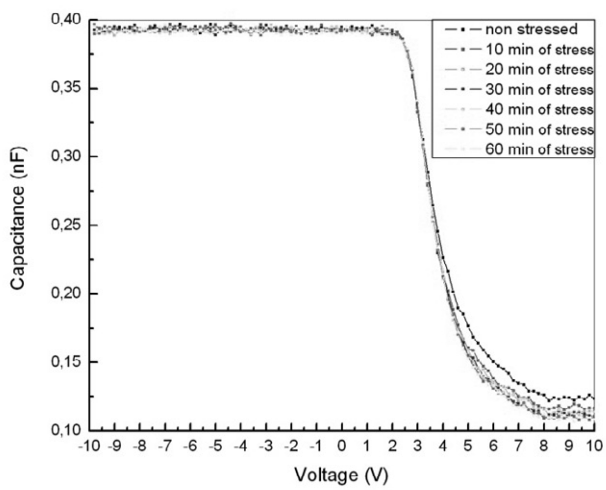

Fig. 5. The C-V curve of a photovoltaic module subjected to a stressing current of 10 mA. The alteration of the curve is minor

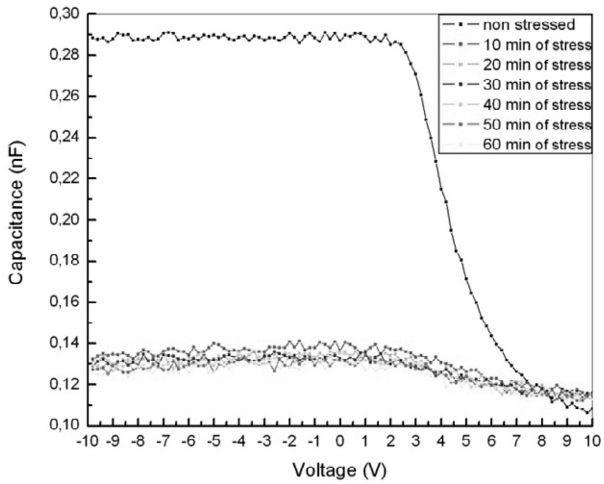

Fig. 6. C-V curve of a photovoltaic module subjected to a stressing current of 100 mA. The alteration of the curve is relatively large due to a big leakage current

Figures 7 (a) and (b) represent microscopic snapshots of the surface of the modules after being subjected to the indicated reverse current. For a reverse stressing current of 10 mA, the size of the hot spots is rather smaller than the ones observed for a current of 100 mA (figure 7b). These hot spots are responsible for all the leakage currents mentioned above and support what was stated previously in this paper. We should note that these damaged areas are created as soon as we apply the stressing current and does not increase or widen with time. The stressing current, punching through these particular areas, increase the temperature of the module during the stress therefore the high temperature combined to the passage of a large quantity of thermalized electrons are the main causes contributing to the creation of these spots.

The surface temperature of the module is represented in figure 8 as a function of the induced stressing current, the temperature linearly increase as we increase the current. The shunt resistance and the series resistance were calculated based on a double exponential model [8], each I-V curve was uploaded to a special software that calculates the electrical parameters as in [8]. For the shunt resistance, we found that this parameter is very high for a fresh device but it decreases as we stress the device. A bigger leakage current means that a smaller shunt resistance is obtained. Surprisingly the series resistance was found unvarying for all devices.

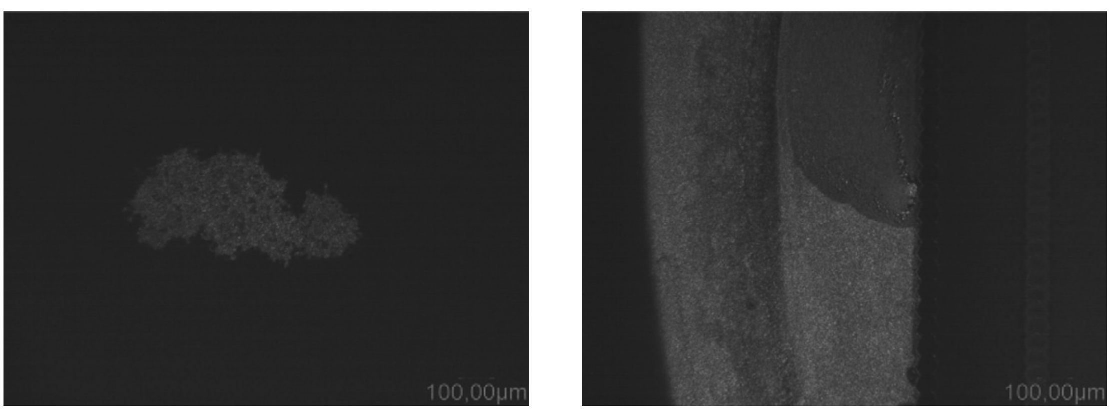

Fig. 7. (a) Microscopic damage observed after a stressing current of 10 mA, (b) Microscopic damage observed after a stressing current of 100 mA.

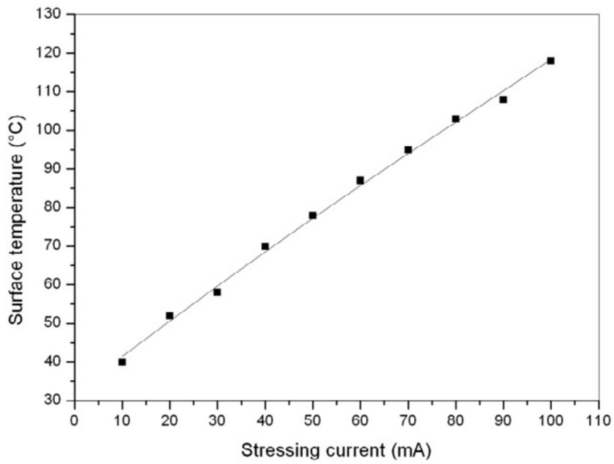

Fig. 8. A linear fit of the surface temperature as a function of the stressing current

4. Conclusion

We have demonstrated the significant damage on photovoltaic modules due to a reverse current that could be generated on shaded solar cells. The dark characteristics of these modules are altered as shown by the measured direct and reverse dark I-V curves. An increasing leakage current through the module is observed on stressed specimens as we increase the stressing reverse current. Microscopic observations showed that hot spots are created during the degradation of the modules which permits a passage of charges contributing to the leakage current.

References

[1] Trivich, D. Photovoltaic cells and their possible use as power converters for solar energy, The Ohio Journal of Science 53 (1953) 300-314.

[2] O. Breitenstein, J. Bauer, A. Lotnyk, J.M. Wagner. Defect induced non-ideal dark I-V characteristics of solar cells, Superlattices and Microstrutures 45 (2009) 182-189.

[3] Masaki Shimaa, Masao Isomurab, Ken-ichiro Wakisakaa, Kenji Murataa, Makoto Tanaka. The influence of operation temperature on the output properties of amorphous silicon-related solar cells, Solar Energy Materials & Solar Cells 85 (2005) 167–175

[4] R.A.C.M.M. van Swaaij, A. Klaver. Comparison of amorphous silicon solar cell performance following light and high-energy electron-beam induced degradation. Journal of Non-Crystalline Solids 354 (2008) 2464–2467

[5] Sumita Mukhopadhyay, Romyani Goswami, Swati Ray. Light induced degradation in nanocrystalline Si films and related solar cells: Role of crystalline fraction. Solar Energy Materials & Solar Cells 93 (2009) 674– 679

[6] R. Ramabadran, B. Mathur. Effect of shading on series and parallel connected solar PV modules. Modern Applied Science 3 (2009) 32- 42

[7] E.A. Schiff. Hole mobilities and the physics of amorphous silicon solar cells. Journal of Non-Crystalline Solids 352 (2006) 1087–1092

[8] R. Habchi, C. Salame. Silicon MOSFET devices electrical parameters evolution at high temperatures. Microelectronics international 25 (2008) 21-24