Laser scanning of amorphous silicon photovoltaic modules with different bias conditions

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A single junction amorphous silicon photovoltaic module has been examined using a laser scanning system under different bias conditions. Laser scanning can be used as a tool to investigate non-destructively cell-to-cell performance and reveal possible material defects undetectable by other methods. In this study the resulting photocurrent maps of the module, generated by the laser scanning system, were very uniform when low or no bias was applied. When high light bias or high forward bias conditions were applied two cells revealed a much higher signal than the other cells in the module. This elevated photocurrent signal has been interpreted as resulting from internal shunting of the cell. It is concluded that laser scanning a thin film amorphous silicon photovoltaic module using high and low or no bias conditions reveals shunted cells in the module. For module cell-to-cell performance investigations low bias is sufficient, with high bias the signal of some cells may be misinterpreted as delivering an exaggerated performance. The results demonstrate that forward current bias reveals comparable results to the use of light bias. The advantage of forward current bias with respect to light bias is that the question of uniformity influencing the measurement results is much reduced.

Keywords: laser scanning, photovoltaic module, bias, photocurrent map.

1. Introduction

Laser scanning of photovoltaic modules and the interpretation of the scanning results have been described in many references [1–4]. The two goals of laser scanning encapsulated modules are to learn about the photocurrent characteristics of and variations over a single cell and to gain information about cell-to-cell performance comparisons in the module. The laser scanner yields a combined charge generation and collection efficiency map of a device where any variation in the generation or collection efficiency of the device appears as a change in the corresponding current [4]. Laser scanning is a useful, non-destructive tool to investigate failure mechanisms of the module e.g. after accelerated lifetime testing. The manufacturer can use the information gained from laser scanning measurement as part of its quality control procedures.

In this study an amorphous silicon photovoltaic module was laser scanned with different bias conditions. The possible conclusions of the resulting photocurrent map were analysed.

The dependence of the amorphous silicon module performance was investigated in dark in short circuit, under full bias light and under forward bias conditions. The dependence of the different bias conditions on the differences in the resulting signals were investigated. The laser scanning signal generally depends on several cell parameters and the actual signal obtained is proportional to both the cell's photocurrent and its shunting resistance. Under some conditions the least efficient cells may even show the highest response [3].

The results of the scans show that both with full light bias and with high forward current bias some cells stand out of the others giving a very uniform, much lower signal. With low bias light, low forward current or in short circuit the signals of the cells are rather uniform. Thus as a conclusion the cells that give very high photocurrent signal compared to the other cells in the module can be interpreted according to Eisgruber and Sites [3] as being leaky or shunted cells. The different bias conditions of light and forward bias do not seam to effect the result. However a measurement also with no bias condition is necessary for the comparison. If the module is measured only with e.g. full light bias, the results might be misinterpreted as instead of being shunted cells to as being high performance cells.

2. Experimental

2.1. Equipment

The laser scanning equipment is very similar to that described by Matson and Emery [4]. The set up is illustrated in Fig. 1. A collimated 632.8 nm He-Ne chopped laser beam passes through a focusing system and a scan head, which is a computer controlled couple of galvanometric mirrors steering the beam over the test device. An Iwatsu

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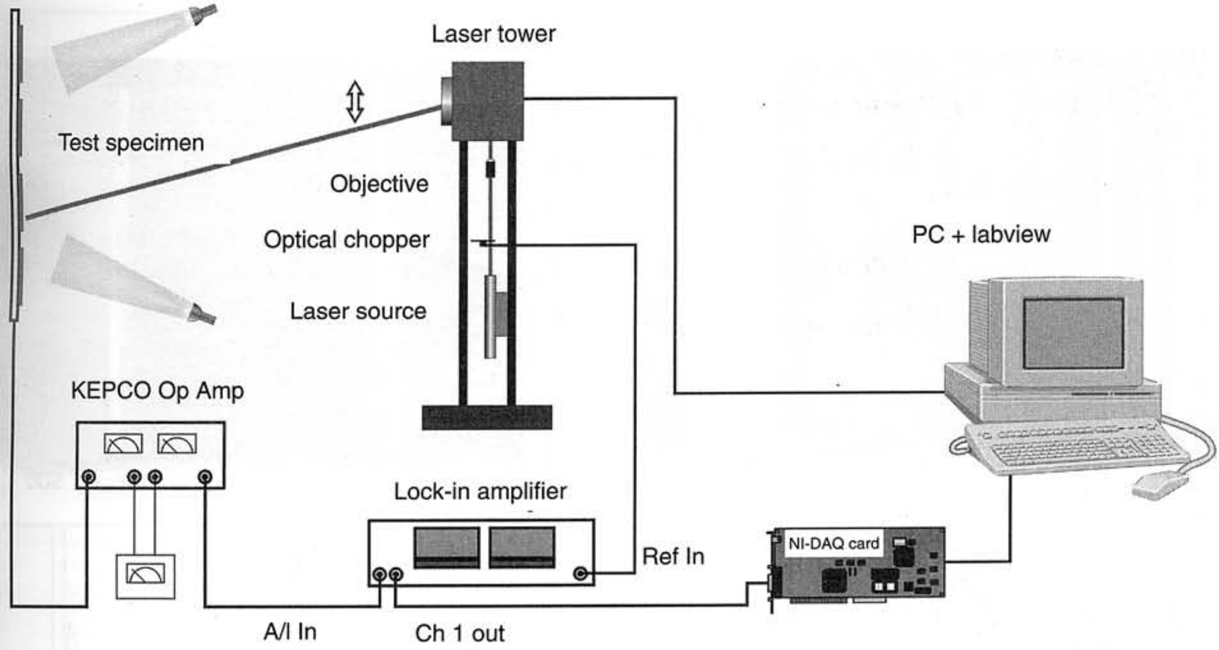

Fig. 1. The system set up for laser scanning measurement.

double PSD lock-in amplifier detects the signal generated by the laser. The chopping frequency was 1.2 kHz in all measurements described in this paper. Such a frequency guarantees both speed up for measurement and detection of the shunting effects [3].

2.2. Bias set ups

The bias light was provided by a circular lamp system with 24 halogen lamps. The light intensity of the lamps can be regulated in four lamps at a time individually. Since its circular shape around the module being measured this lamp system provides a very uniform bias light over the module. The forward current bias was provided by a Kepco bipolar operational amplifier type BOP50/4. It was used in the voltage mode.

2.3. Measurements

The module measured was a single junction amorphous silicon module. The photocurrent was measured via a resistance of 1 Ω. The first measurement was done in the dark and thus the module was kept in short circuit. In the second measurement the module was measured with full intensity light bias of 200 W/m^2. However, since halogen lamps were used, from their intensity 120 W/m^2 fall to crystalline silicon region and in the amorphous silicon region the intensity is even less. The third measurement was done with half intensity light bias of 100 W/m^2. For this measurement the lamp system caused some disturbances in the measurement seen as noise in the result. This noise was probably due to high frequency harmonic of the lamp, which was not filtered by the chosen chopping frequency. The He-Ne laser after passing a neutral density filter and a diaphragm had an effective area of 4 mm^2 and irradiance of 10 W/m^2.

The measurements with forward current bias were done with 100 mA and 50 mA currents. During the forward current bias measurements no light bias was used and the measurement was done in dark. The time constant for the lock-in amplifier was kept in all the measurements at 12.5 ms and before each subsequent measurement point there was a waiting time of 100 ms. The full scale sensitivity of the lock-in amplifier was set to 30 μV or 100 μV. The signal read from the analogue output of the lock-in amplifier constantly ranged from 0 V to 10 V regardless of the settings.

3. Results

The resulting photocurrent maps of the laser scanning with different bias conditions are presented in Fig. 2–6. The amorphous silicon module was the first laser scanned in the dark in short circuit (Fig. 2). The response is quite even throughout all the cells. With full intensity bias light (Fig. 3) the ninth and the last cells in the module stand out with much higher response than in the other cells. With half intensity bias light (Fig. 4) the photocurrent map is very similar to that measured in short circuit, only the overall response is shifted up because of the different behaviour of the photodiode in light. The photocurrent map measured with 100 mA forward current bias in dark (Fig. 5) is again very similar to that measured with full intensity bias light. In this case the overall response is shifted down compared to the full intensity light bias photocurrent map again because of photodiode behaviour. The two cells that had higher response when measured with full intensity light and high forward current biases have, in the photocurrent

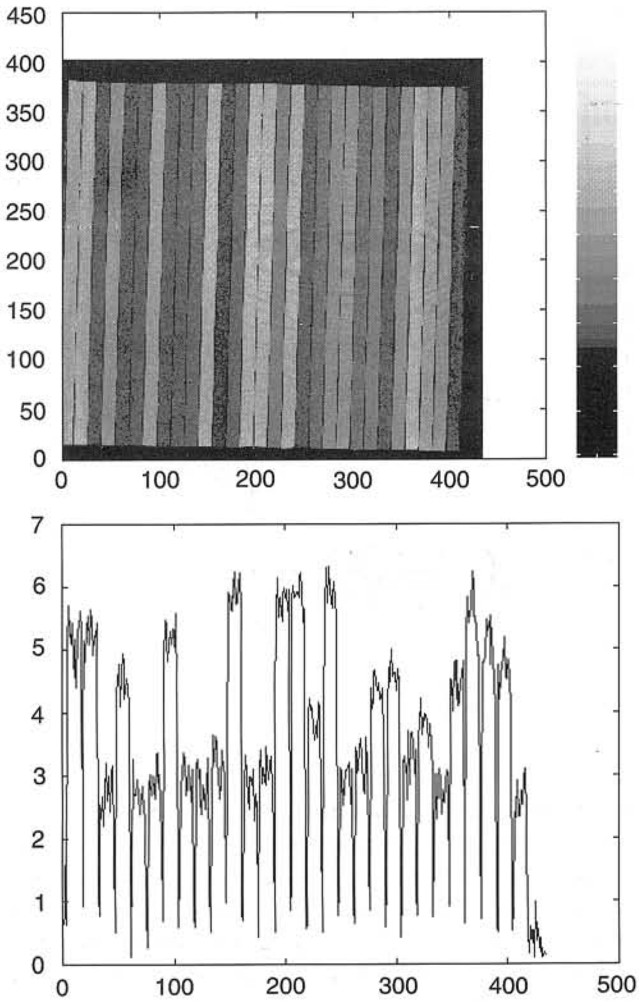

Fig. 2. Laser scanning of amorphous silicon module measured without any bias in dark in short circuit. In the side view on the vertical scale 10 corresponds to 30 μV.

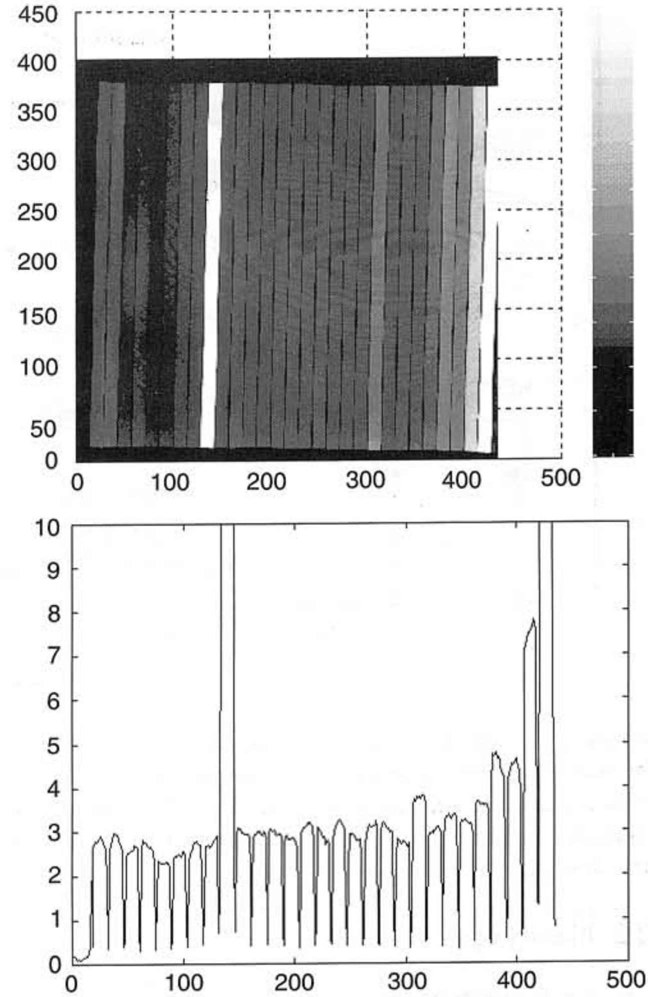

Fig. 3. Laser scanning of amorphous silicon module measured with full intensity light bias. In the side view on the vertical scale 10 corresponds to 100 μV.

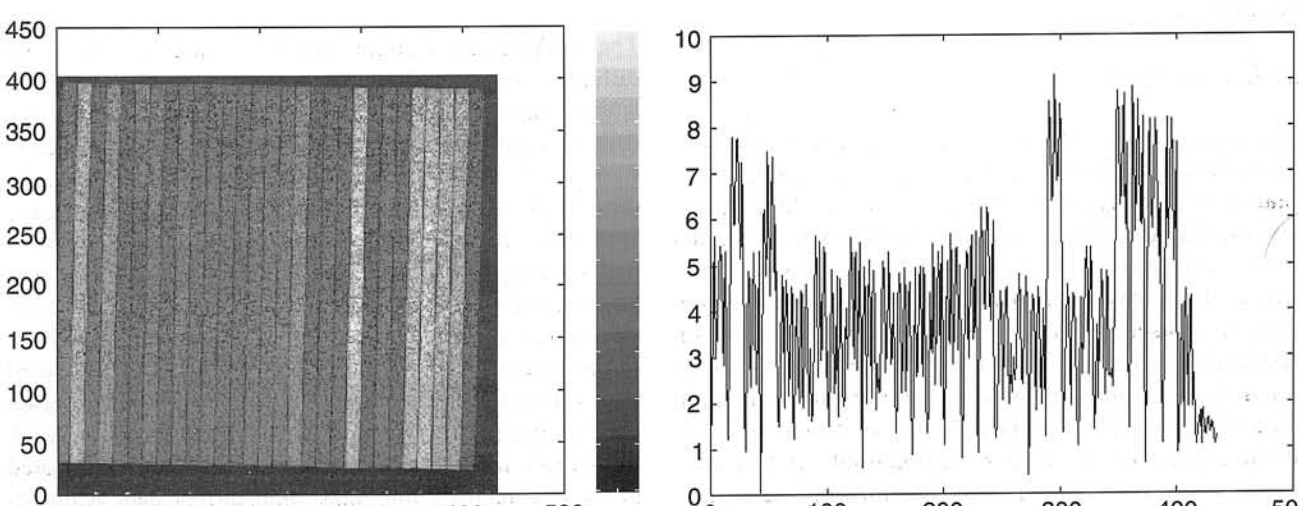

Fig. 4. Laser scanning of amorphous silicon module measured half intensity of the bias light. In the side view on the vertical scale 10 corresponds to 100 μV.

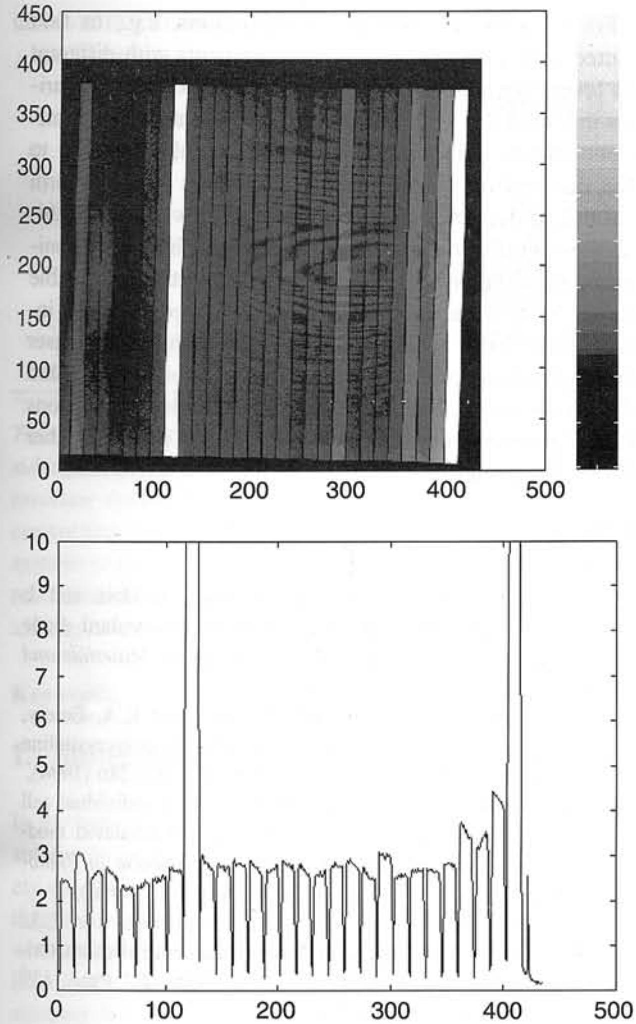

Fig. 5. Laser scanning of amorphous silicon module measured with forward current bias of 100 mA in dark. In the side view on the vertical scale 10 corresponds to 30 μV.

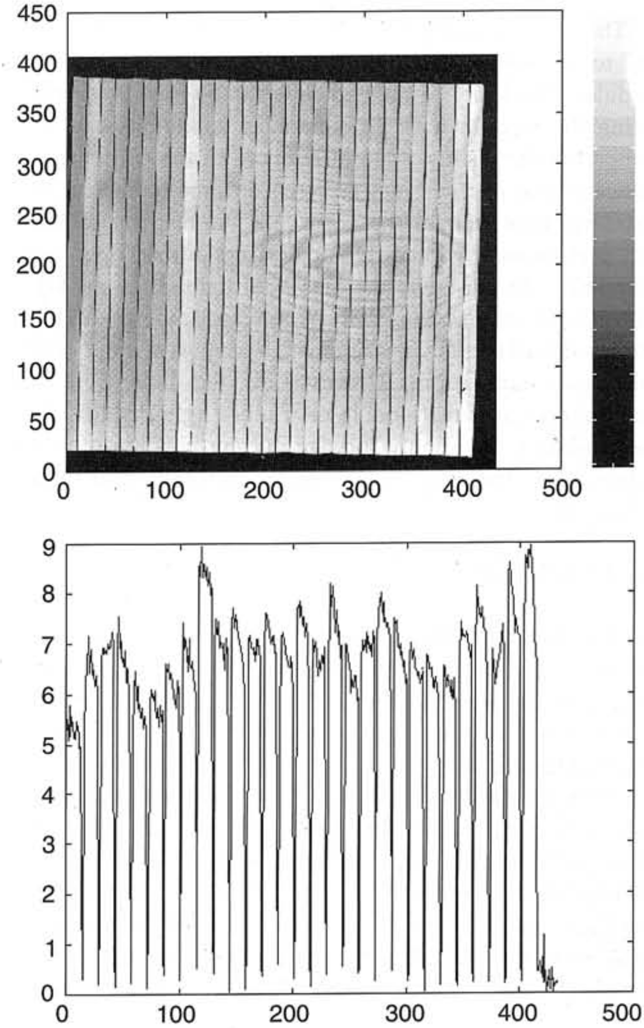

Fig. 6. Laser scanning of amorphous silicon module measured with forward current bias of 50 mA in dark. In side view on the vertical scale 10 corresponds to 30 μV.

map measured with 50 mA forward current bias in dark (Fig. 6), only a a slightly higher response compared to the other cells.

4. Discussion

With low or no bias all the cells produce quite even photocurrent values. With full intensity bias light and with a high, 100 mA forward current bias in dark the photocurrent map shows uniform values in most of the cells I the module. Only the ninth and the last cell in the module have much higher responses compared to the other cells. With low bias these cells have lower or about the same response as compared to the other cells in the module. When comparing the responses between high light intensity and high forward current or low light intensity and low forward current biases, the only difference observed is the photodiode behaviour of the photovoltaic module shifting up the overall response level.

Eisgruber and Sites [3] state that the shunted or leaky cells of the module can be found by comparing the laser scanning results of the module made with different bias conditions. At short circuit or in dark conditions the shunted cells give much lower or no laser induced signal [3]. At some forward currents the impedance of the shunted cells may be larger than that of the good cells. In that case the shunted cells give a larger relative laser induced photocurrent signal. The signal of the leaky or shunted cells increases in height relative to other cells in the module as forward bias increases.

In our study it seems that the laser scanning system has detected two shunted cells in the amorphous silicon module measured. The ninth and the last cell from the left give low signal when measured in short circuit. As the bias increases to full light bias or to high forward current bias, these two cells give a much higher signal compared to the other cells in the module.

The laser scanning system can be used as a powerful tool to investigate the performance of amorphous silicon modules. The leaky or shunted cells can be found by measuring the module with different bias conditions and by comparing the results. Also differences in the cell performance within one cell and between different cells can be observed. However for the good cells the response of the cell performance with different bias conditions does not vary much. In our study the bias light lighted the module with a light intensity uniformity corresponding to ASTM 1021 standard and the measurement was always done in an otherwise dark room. However, if the bias light is non-uniform over the module or if other light disturbs the measurement, using only forward current bias at different values gives the same results more uniformly and more consistently.

For module performance investigations, e.g., to find shunted cell, a comparison of measurements with different bias levels is necessary. However, for cell-to-cell comparisons in a module, measurement in short circuit appears sufficient. When light bias is used care should be taken to have the light uniformly over the module. With uniform light the photocurrent maps of light and forward current biases give similar results, Thus, if the light bias is not uniform it might be better to use forward current to get reliable results. Also, if the module is only measured with full intensity bias light, which is the current standard for laser scanning measurements, the appearance of the shunted cells on the photocurrent map can lead to false conclusions of their performance seaming much better than the other cells in the module.

5. Conclusion

In this study amorphous silicon module was investigated by laser scanning it with different bias conditions. The measurements were done in dark in short circuit, with full and half intensity light biases, and with high and low forward current biases.

With full intensity light and high forward current biases two cells in the module show much higher signal than the other cells. With lower biases the same two cells show a low response compared to other cells. It is concluded that the laser scanning system used has detected two shunted cells in the module and is thus a useful non-destructive tool for further investigations of module performance.

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