Area distribution of dark diode leakage currents in a-Si:H solar cell panel

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***Abstract* — The effectiveness of solar cell panels depends from the shunt and series resistance of the panel. Significant power losses caused by the presence of a shunt resistance are typically due to manufacturing defects, rather than poor solar cell design. Low shunt resistance causes power losses in solar cells by providing an alternate current path for the light-generated current. High leakage current in the reverse diode characteristics decreases the shunt resistance. High shunt resistance is necessary for quality solar cells and is a measure for the quality of the used technology operations. In the present work an example is given for the area distribution of reverse dark diode leakage currents in large area solar cell panel /0.8 m^2/. The observed high leakage currents within local areas of the panel are due to contaminations during the cleaning of the substrates, technology ambient and transportation between the different technology steps. Control diode structures could be successfully used for periodical control of established manufacturing process.**

***Index Terms* — a-Si:H, multijunction diode, solar cell.**

I. INTRODUCTION

For the performance evaluation of solar cell panels in the mass production the current density-voltage $J(V)$ measurement is a fundamental technique. The open-circuit voltage V_{oc} is measured when no current flows through the solar cell, whereas the short-circuit current density J_{sc} is measured when the voltage is equal to zero. The fill factor FF is defined as the product of *JMPP* and *VMPP* divided by the product of J_{sc} and V_{oc}, where *JMPP* and *VMPP* are the current density and voltage corresponding to the maximum power produced by the solar cell. V_{oc} and *FF* are evaluated from $J(V)$ measurements, whereas J_{sc} is usually established from external quantum efficiency measurements for 2 reasons: (a) the active area of the solar cell, which is necessary to determine the current density, is not always well defined, and (b) the spectrum produced by the sun simulator does not exactly correspond to air mass*(AM)* 1.5. Useful characteristic is the External Quantum Efficiency *(EQE)* which is a measure of the probability for an incident photon at a given wavelength to create an electron/hole pair that will contribute to the external current density of the solar cells. In some cases Micro-Raman spectroscopy Fourier-Transform Photocurrent Spectroscopy (FTPS), SEM, SIMS, AFM, etc., can be applied. The Micro-Raman spectroscopy is a characterization technique used to evaluate the average crystalline volume fraction (i.e. the crystallinity) of the microcrystalline intrinsic layers present in the solar cells. The FTPS can be applied to intrinsic layer characterization within working devices - solar cells. This technique allows the evaluation of: the optical gap, the Urbach slope (which is a measure of bandtails disorder) and the defect-related absorption, which, in amorphous silicon, is known to be proportional to dangling bond density.

Both light and dark *I-V* measurements have been commonly used to analyze the effects on cell performance of series resistance and other parameters [l-5]. Forward dark current-voltage measurements were proposed as a diagnostic or manufacturing tool [6]. The procedure used for dark *I-V* measurements on solar cells involves covering the cell to eliminate light-generated current, using a power supply to force electrical current through the cell from the positive contact to the negative, and then measuring current and voltage simultaneously as the voltage of the power supply is increased from zero to a predetermined upper limit. The resulting direction for current flow is opposite to that when the cell is exposed to light, but the electrical configuration still results in the cell's *p-n* junction being in "forward bias", as during typical operation.

As a result, dark *I-V* measurements can be used like light *I-V* measurements to analyze the electrical characteristics of a cell.

In this paper we present a method for evaluation of the area distribution of defects due to contaminations, nonhomogenous thickness of the semiconductors layers or impurity redistribution within the semiconducting layers.

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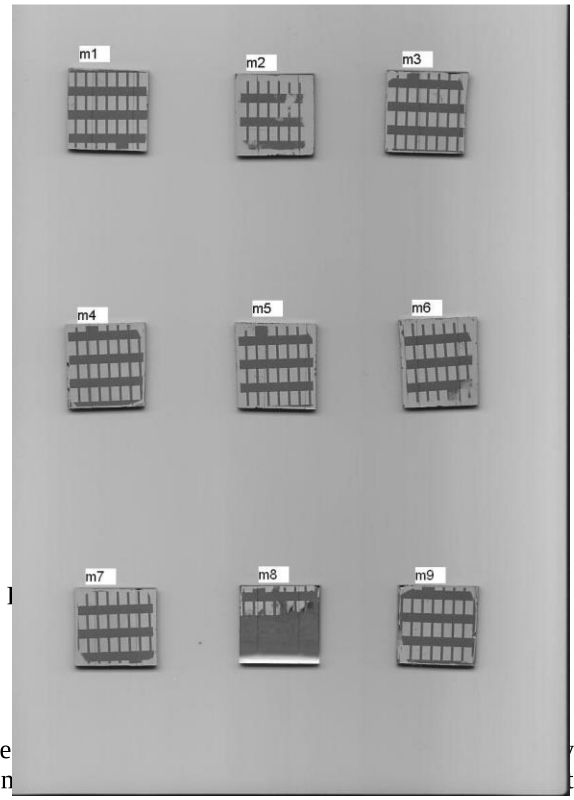
Examples are given for dark reverse diode characteristics at a few characteristic places of a-Si:H solar cell panel.

II. EXPERIMENTAL

The relative area distribution of defects in the semiconductor layers was estimated through the reverse saturation currents in the diode structure. Samples were cut from different places of 0.8 m^2 solar cell panel (Fig.1).



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contact the metallization of the glass was used. The solar cell was a-Si:H double the metallization of the glass diode *nip-nip* structure, as is shown in Fig. 2.

Equivalent circuit for pin-type solar cells is shown in Fig. 3. The controlled current sink J_{rec} depends on i-layer "quality", R_{shunt} originates from micro-shunts in the semiconductor bulk of the cell or at the laser scribed edges; R_{series} is given by contacts and TCO; the diode is characterized by the reverse saturation current J_o and n, where J_o is given by material band gap, defect density N_{defect} and by cell thickness *di*. The dark current density under steady-state conditions for the planar solar cell in thermal equilibrium with the blackbody is given by:

$$J = J_0\left[exp\left(\frac{qV}{kT_c}\right)-1\right], \tag{1}$$

where the reverse saturation current density J_0 is expressed by:

$$J_0 = q\left[F_{co} + R(0)\right], \tag{2}$$

where F_{co} and $R(0)$ are the rate (per unit area per unit time) of radiative, respective nonradiative recombination in thermal equilibrium.

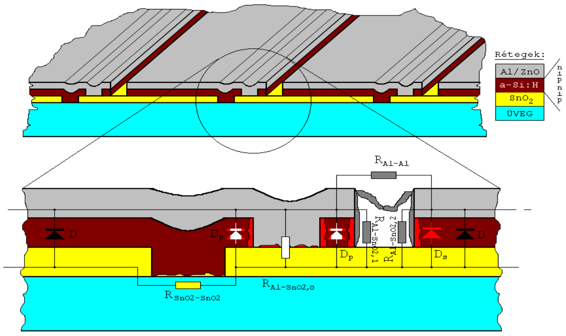

Fig. 2. Cell diode structure.

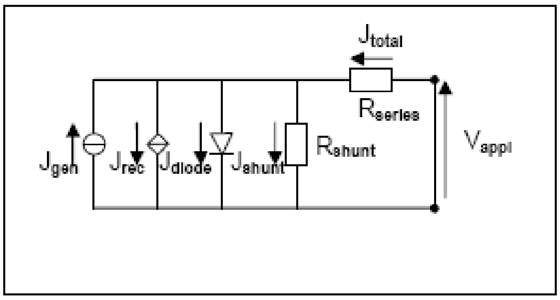

Fig. 3. Equivalent circuit for pin-type solar cells.

The radiative recombination current density is given by:

$$J_r = qF_{co},\ F_{co} = t_c Q_c\,, \tag{3}$$

where t_c the probability that an incident photon of energy greater than E_g is absorbed by the solar cell and produces an electron-hole pair, and Q_c the rate of photons of frequency greater than n_g, per unit area per unit time, emitted by the blackbody at a temperature T_c (expressed by Planck's formulas).

For better performance of solar cell panels as high as possible shunt resistance must be realized. Contaminations and the rough with high asperities on the surface of the semiconductor layer (Fig. 4) may cause weak points with low resistance and high leakage currents. Reflow of the conductive materials at laser scribed edges can also shunt the structure (Fig. 5).

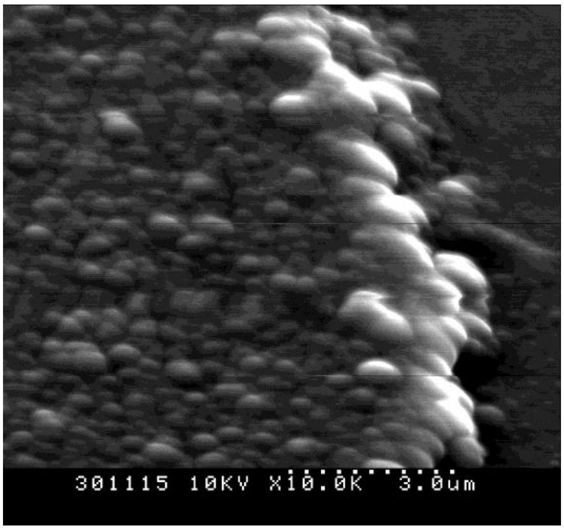

Fig. 4. SEM of cell semiconductor layer.

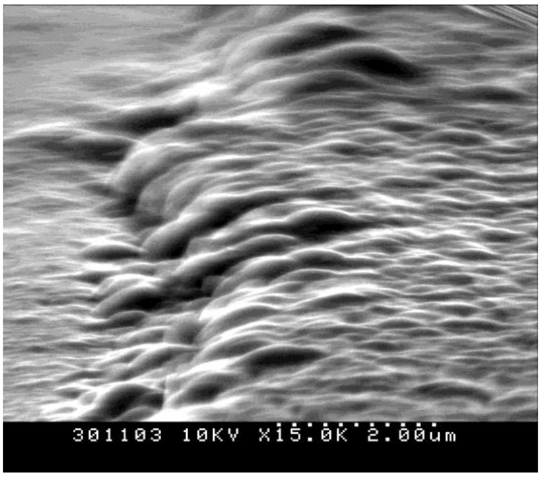

Fig. 5. Reflow of the conductive material at laser scribed edges.

The measured diodes dark reverse current-voltage characteristics are given on Figures 6–8. The characteristics were examined at room temperature using a computercontrolled Keithley 617 Programmable Electrometer.

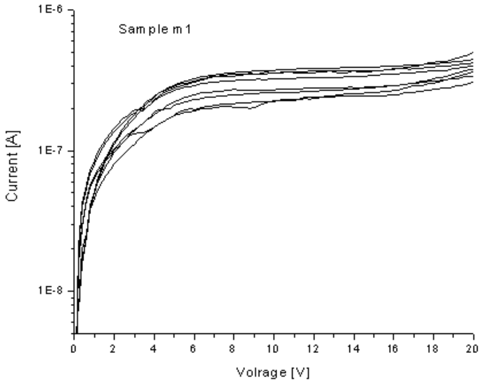

Fig. 6. *IV* characteristics of diodes in Sample 1.

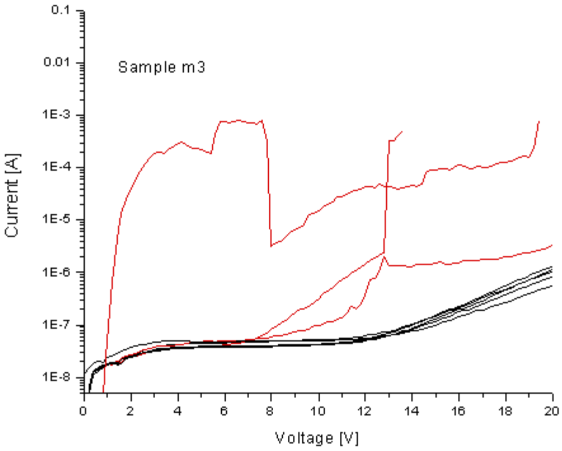

Fig. 7. *IV* characteristics of diodes in Sample 3.

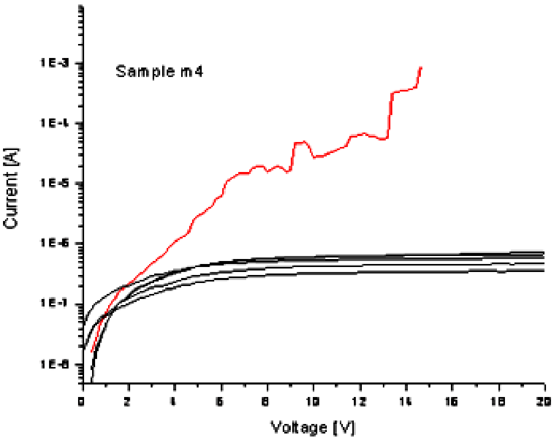

Fig. 8. *IV* characteristics of diodes in Sample 4.

From the presented reverse diode characteristics a few conclusions can be made:

-There are much more defects (diodes with high leakage currents) at the “bottom” end of the solar cell panel. This can be due to contaminations during the handling processes.

-At the same end of the panel the breakdown voltages are lower than these on rest of the panel, but the reverse saturation currents are almost one order lower. It can be concluded that the multijunction structures are better, but much thinner than on the rest area.

-The sharp decrease in the leakage currents in figures 8 and 10 is due to burn out of weak leakage spots.

Diode theory can be applied on the obtained reverse current characteristics for calculation of number of device physical parameters.

III. CONCLUSIONS

At initial stages of new production of solar cell panels it is useful to measure the area distribution of the diode dark reverse currents for establishment of high yield of good devices. This can be done periodically as control test on diodes with laser performed isolated metal contact areas in the top metallization. In this way the function of the panel will be not disturbed.

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