CONTACTLESS ELECTROLUMINESCENCE FOR SHUNT-VALUE MEASUREMENT IN SOLAR CELLS

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Abstract: In recent years, there have been many new applications of PhotoLuminescence and ElectroLuminescence for use in silicon wafer, solar cell, and module characterization. This paper will present data and modeling for a contactless electroluminescence measurement of shunt values on solar cells. In this scheme, a large fraction of the free-standing solar cell is illuminated. A small fraction of the cell area is shadowed to be dark, and “viewed” by an electroluminescence photodetector. The sensor sees a “dark” region of the cell, largely indicative of the PN-junction voltage everywhere on the solar cell due to the gridlines on a finished cell. At low illumination, the gridlines can maintain a nominally constant voltage across a solar cell because the lateral currents are small. An analysis analogous to the standard Suns-Voc technique is used to extract shunt values. A simple interpretation of Suns-EL data is also demonstrated. The measurement represents a simplification over a PL method, yet avoids the electrical contacting usually associated with EL measurements. Some artifacts associated with PL shunt detection are avoided in this method since the excitation is dark injection from the junction, which depends directly on the voltage present on the cell gridlines.

Keywords: Electroluminescence, Photoluminescence, Recombination, Shunts, Silicon.

1 INTRODUCTION

For many types of solar cells, shunting due to metallization and other factors represents a significant yield loss. It would be desirable to have a simple contactless sensor to detect this defect. Many imaging techniques have been demonstrated that accomplish this[1,2,3]. In the context of available techniques, this paper will define a very basic apparatus with a physical model to display and interpret the data for reporting the global shunt loss in solar cells.

Measurements of the global value for junction shunts using PL have been reported[4]. However, since the PL signal measures the average carrier density in the wafer, the result can deviate significantly from accurately predicting the junction voltage and therefore the shunt value, which is usually referenced to the junction or cell terminal voltage. The excitation from light can result is an average carrier density away from the junction that sensed, but is weakly correlated or even independent of the junction voltage in some cases. Correction methods have been described[4].

In electroluminescence, a voltage is applied directly to the junction. The EL signal is then very closely indicative of the junction voltage since all of the minority carriers in the wafer are injected from the junction. However, EL is not contactless. As generally practiced, electrical contacts are used to inject current into the solar cell.

In this paper, it is proposed that for finished solar cells, the electrical contacts can be eliminated for an EL measurement. By illuminating part of the cell and shadowing another small fraction of the cell area, the EL signal can be obtained from the shadowed portion of the cell. This is essentially a contactless EL measurement of the solar cell. Generally, the shunting effects are most evident at an illumination of 0.01 to 0.05 suns under open-circuit conditions, when the solar cell voltage is just below the maximum power voltage. At these low intensities, a small-area shadowed region of the solar cell is easily maintained at the nominal cell voltage, since the current densities into this dark region through the gridlines and emitters are 1/20th to 1/100th of the current densities that the cell will be running at under operating conditions at the maximum power point.

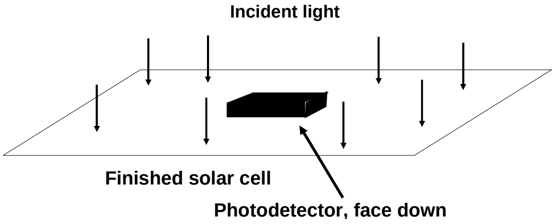

Figure 1. A solar cell is illuminated. A small photodetector shadows a small fraction of the cell, while detecting the band edge electroluminescene signal from the solar cell.

2 EXPERIMENT

The experimental configuration is shown in Fig. 1. A high-efficiency backside-contact solar cell was used in this work. Light from a flash-lamp was incident onto the top of the solar cell. A photodetector (another small solar cell) was placed on top, face down, to detect band-edge luminescence. This photodetector covered about 10% of the solar cell area.

External resistors were attached to the cell to introduce known shunt values. Light I-V, Suns-Voc[5], and Suns-Electroluminescence curves were taken for this solar cell, in order to compare and contrast the 3 methods of obtaining shunt-loss values.

An example of the Light-IV and Suns-Voc curves is shown in Fig. 2. The effect of the shunt is clearly shown in both the light IV and the Suns-Voc curve as expected. The short-circuit current in the cell is reduced by the 10% shadow area introduced by the photodectector as shown in Fig. 1.

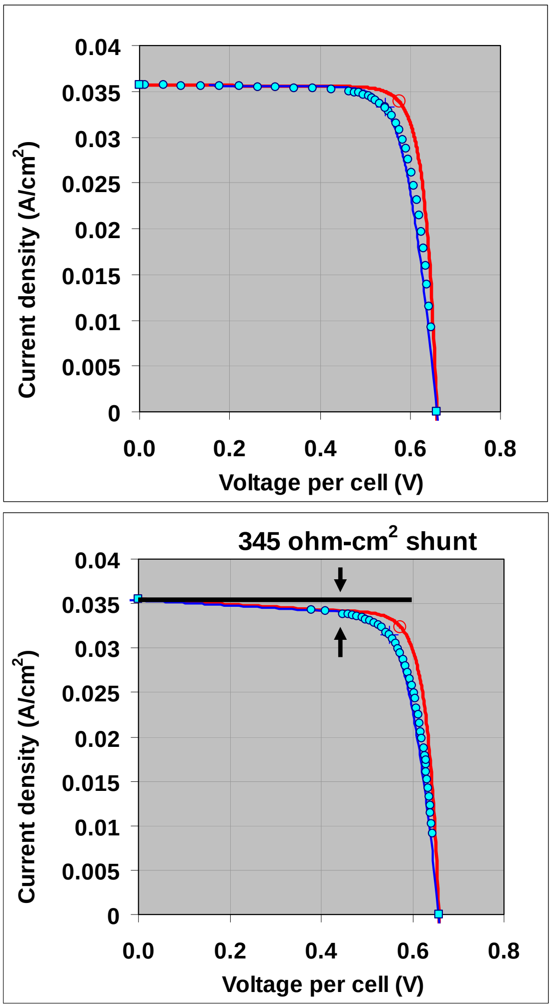

Figure 2. The Light-IV curves (data points), Suns-Voc curves, (red lines) and series-resistance-corrected Suns-Voc curves (blue lines) are compared for a cell without an intentional shunt (top) and with an external resistor attached to simulate a shunt (bottom).

A comparison of the Suns-Voc curves and the EL curves from the photodetector are shown in Fig. 3. The data points are the Suns-Voc data, and the solid lines are the EL data from the photodetector. The EL data has been converted to voltage in the usual way[4], and normalized to the Suns-Voc data at 0.2 suns.

The EL data plotted in this way is in very good agreement with the Suns-Voc data. The resolution of the shunting effects is very clear.

At one sun, the EL data indicates lower voltage by about 6mV. This could be due to the series resistance voltage drops in the gridlines and emitters that are required to bias the region of the cell that is in the dark. The gridlines transport current from the illuminated portions of the cell to the shadowed fraction. This voltage drop could be greatly reduced by using a small photodector, perhaps 2-5% of the cell area instead of the 10% used here. Additionally, a strategic placement of the detector near a busbar could be used to minimize these effects.

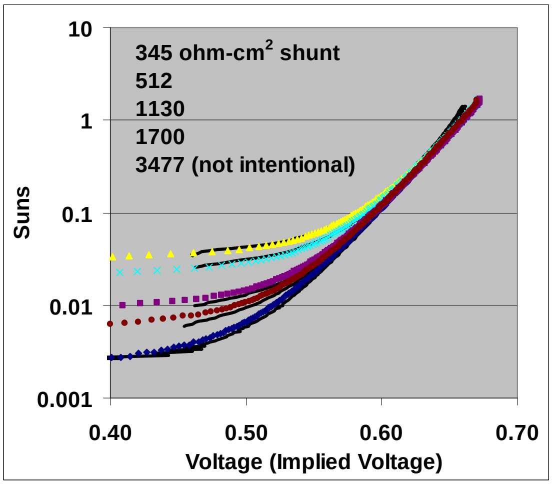

Figure 3. A comparison of Suns-Voc data (symbols) with EL data (curves). The EL data was normalized to the suns-Voc data at 0.2 suns.

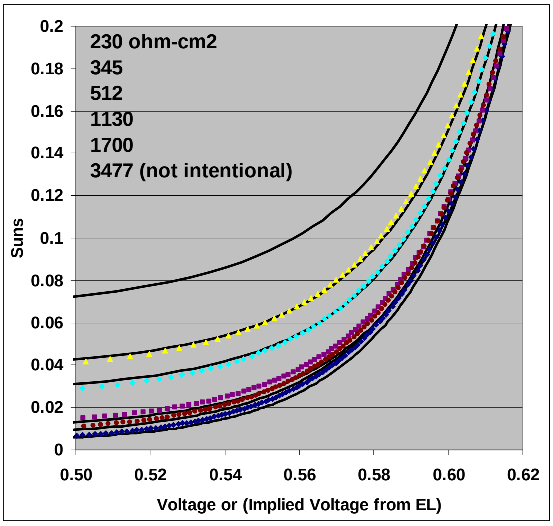

Figure 4. A comparison of Suns-Voc data (symbols) with EL data (curves) in the particular region of interest for detecting shunts.

In any case, at 0.2 suns, where the data was calibrated to the Suns-Voc data, the difference would be about 1 mV. At illumination intensities less than 0.1 suns, where the shunting is clearest, the voltage drops between illuminated and shadowed regions of the solar cell are quite negligible.

Fig. 4 shows the detailed data in the region of interest (around the maximum power point voltage) using a linear scale for intensity. A very good correspondence of the Suns-Voc and the EL data is seen in this range of particular interest.

The same EL data is shown in Fig. 5 in the format of an IV curve, in the region of the maximum power point.

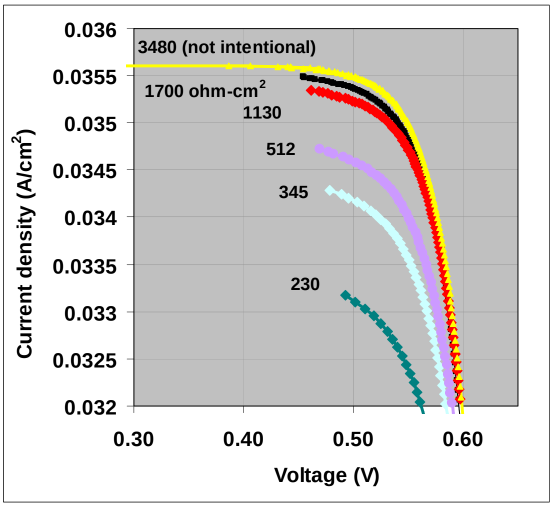

Fig. 5. The EL data in the form of an IV curve near the maximum power point.

Figures 3 and 4 indicate that the EL data can be calibrated into good agreement with the Suns-Voc data over a range of intensities. An absolute calibration of the EL signal can be difficult without this sort of transfer standard from known data. The band-edge emission into the detector can depend on many factors, including IR reabsorption, parasitic IR absorption in the cell, light trapping, surface optical conditions, etc.. It would be much more satisfying to analyze the data without requiring an absolute calibration for the EL signal in order that a wide variety of wafers could be measured without calibration uncertainties.

This is shown in Figure 6. A linear plot of the raw data from the EL detector and the calibrated illumination intensity has some very notable characteristics. In particular, an extrapolation of the linearly increasing region of the EL signal has an apparent intercept with the "Suns" axis. This makes complete sense in the context of the IV curves shown in Fig. 2. For low illuminations on the Suns-Voc curve (low voltages) the current is flowing entirely through the shunt. This is the straight line segment of the IV curve to the short-circuit side of the maximum power point. The EL signal will be negligible in this region. Beyond the knee in the curve, the shunt current becomes very slowly varying, almost constant, since the voltage on the open-circuit side of the maximum power point varies by less than 15%. The vast majority of the additional current on the open circuit side of the maximum power point goes into the solar cell diode recombination current that result from increasing carrier densities. By fitting the EL signal in this straight line region where the current increase in intensity (or voltage) goes into recombination current, the intercept of the curve will be a very good approximation of the shunt loss, conveniently designated in units of fraction of the available photons lost to the shunt.

In other words, the intercept of the fit to the EL data in the linear region is the loss due to shunting, with the EL signal for shunted cells simply offset by the losses in current represented by fractions of a sun. The straight-line segments of the data from Fig. 6 were fit in the range from 0.1 to 0.2 suns. This same interpretation should work very well for PL data, subject to the issues discussed in [4].

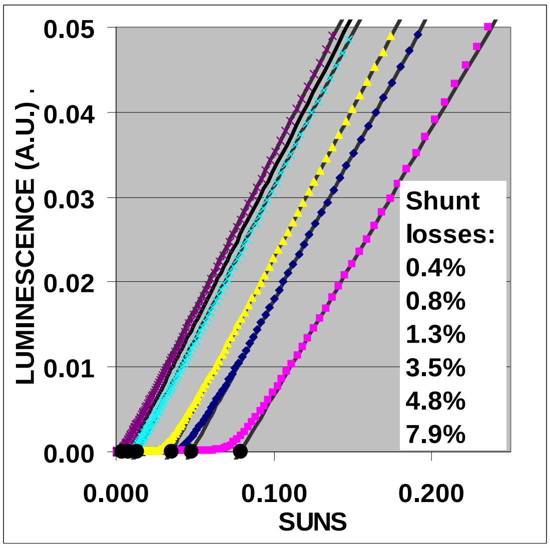

Fig. 6. The EL data, in arbitrary units, plotted against the illumination intensity in suns. The intercept indicates the fraction of available current that is lost to the shunting.

This is an extremely simple interpretation of the EL data in terms of evaluating shunting loss. There is some uncertainty in the resulting values. Especially in the case of heavily-shunted cells where the effects of a shunt extend into the Voc side of the curve, the region to be fit by the line in order to best indicate the shunt loss at the Vmp allows for some variation in the intercept. The interpretation could be improved upon in future work by accounting for these effects and by taking data on a large variety of cells in order to optimize the analysis over a range of cell types and shunt values. However, the sheer simplicity of the method and the clarity of the graphical display as in Fig. 6 is attractive.

3. CONCLUSIONS

This paper proposes a contactless technique for evaluating the shunt resistance losses for finished solar cells. An electroluminescence signal is recorded from a shadowed small-area fraction of an illuminated solar cell. This could be done on free standing solar cells. This data was shown to be in good agreement with Suns-Voc and light I-V data. A simple interpretation of the raw EL data was proposed that does not require an absolute calibration of the EL signal.

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