Correlation between the Physical Parameters of Solar Cells Measured by Mechanical Means and by PV-Reflectometer

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Abstract

Correlation between the Physical Parameters of Solar Cells Measured by Mechanical Means and by PV-Reflectometer. RODERICK FAISON (Virginia State University, Petersburg, Virginia 23806) Bhushan Sopori (National Renewable Energy Laboratory, Golden, Colorado 80401).

Photovoltaics are becoming an increasingly popular means of producing energy. The main attraction of this energy is that it is nonpolluting and uses a renewable energy source, the sun. In addition, most commonly used photovoltaic cells are made of silicon. This offers another advantage since silicon is one of the most abundant elements on earth. At this point researchers expect that the PV industry can now benefit from collective standardization and improved process control. The PV Reflectometer is a system currently being developed to monitor process control. It is capable of measuring the wavelength dependence of reflectance of an entire wafer (or cell) up to 6-in. by 6-in. in size. The Reflectometer can already provide a variety of information for researchers, but in order for it to be adapted commercially, a means of calibration must be developed. Each solar cell production facility uses slightly different fabrication processes, so calibration is necessary to accommodate the variations. An ideal way of making this calibration is by directly relating the physical characteristics of cells to Reflectometer readings. A distinct pattern is found in doing this. The larger the area of metallization of a cell, the higher the readings from the Reflectometer. These results show promise in developing an effective means of calibration, but with new materials for cell production being developed regularly, continued testing will be necessary.

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Introduction

In a world where natural resources seem to be becoming scarcer every day, the search for sources of renewable energy has become a priority. The conversion of sunlight into electricity by photovoltaic (PV) cells is an ideal source of nonpolluting and plentiful power that answers this need. As an alternative energy source, a one-kilowatt PV system prevents 150 lb. of coal from being mined, prevents 300 lb. of CO_2 from entering the atmosphere, keeps 105 gallons of water from being consumed, and keeps NO and SO_2 from being released into the environment each month. (Solar Energy International)

The science of photovoltaics began in 1838, with a pair of French physicists working on the generation of electricity through chemical reactions. The physicists noticed that exposing the apparatus to sunlight increased the output of electrical energy. In 1954, Bell Laboratories announced the development that finally brought photovoltaics out of the lab and into the realm of practical application, the single-crystal silicon cell.

Most commonly used photovoltaic cells today consist of a silicon wafer that has boron impurities on one-side and phosphorus impurities on the other. The phosphorus electron-rich side of the cell faces the sunlight. The energy present in the sunlight frees the electrons in the PV cell. These freed electrons accumulate at the cell conductors, from which they are allowed to flow out into an electrical circuit, providing electricity.

Over the past few years, the PV industry has grown rapidly. It is expected that the PV industry can now benefit as a whole from collective research, standardization, and process control. The PV industry is already using some degree of process monitoring, but a full-fledged process control has to await development of suitable measurement techniques (Sopori, 1999).

At the National Renewable Energy Laboratory (NREL), scientists are well on their way to developing a method for this purpose. This new method is capable of in-line measuring and monitoring of several solar cell processing steps, such as texturing, AR coating and metal contact properties. The measurement technique is rapid and specifically designed for solar cells and wafers. This new measurement system is collectively called "PV Reflectometer" (Sopori, 1988).

The PV Reflectometer rapidly measures the wavelength dependence of an entire wafer (or solar cell), up to 6 in. by 6 in. in size. It uses a concept based on the reciprocity principle in optics. The Reflectometer consists of a highly absorbing spherical dome, about 12-18 inches in diameter, with openings at the top and at the bottom. The topside of the dome has a lens and aperture assembly that couples the light reflected from the sample into an optical fiber. The other end of the fiber feeds into a low-resolution monochromator, whose output is detected by a Si photo diode and analyzed by a computer. The bottom of the dome has a square flange within which the test sample is placed. Lights positioned at the top and sides of the sphere shine light onto the sample. The sample is placed on the platform in such a way that the signal, consisting of the reflected light seen by the detector, is due only to the sample. The entire system is designed to eliminate all possible scattering of the light except that reflected by the test wafer (Sopori, 1999).

The PV Reflectometer can provide a variety of information for researchers, and it also provides a powerful means of process monitoring and control on production lines.

The Reflectometer has many assets; for example, it measures large-area samples, it is rapid, and it is suitable for in-line monitoring. Though its assets are numerous and its applications can apply to fields study as well as production, a means of calibration has not yet been developed for its readings. The reflectometer must be calibrated because each solar cell production facility uses slightly different cell fabrication processes and the quality of the device surface can vary. Calibration is necessary to accommodate this variation. Therefore, in this project we will compare the data collected from solar cell samples using the reflectometer with data collected by other methods. We will use the Dektak[3] profilometer and optical microscope to develop a correlation between the physical parameters of solar cells and the readings collected by the reflectometer. Once an effective means of calibration for various surfaces is established, the PV Reflectometer can be adapted for commercial use and raise process control and monitoring in the PV industry to a new level.

Materials and Methods

PV Reflectometer Measurements

To establish a starting point for our research, we tested solar cell samples from Siemens Solar Industries using the PV Reflectometer. Four measurements were taken for each sample in order to find the average reflectivity for the entire area. With each measurement, the origin of the light shining on the sample was changed. For the first run, light came from the "tx," or top-x bulbs (bulbs located at the top of the dome aligned horizontally). Light in the second run, "ty," also came from the top of the dome but from bulbs aligned vertically. The third and forth runs followed this same pattern but utilized bulbs perched on the sides of the dome (sx and sy, or side-x and side-y). The data generated from these measurements were analyzed by computer to derive parameters related to the surface of the cell, and saved for future reference. After collecting data using this method, we realized that we could acquire more accuracy if we ensured that all bulbs used were of the same intensity. Therefore, we made a second run and instead of switching between sets of bulbs for each measurement, we simply rotated the sample 90 degrees, and used only one set of bulbs. This created more consistency in the measurements.

Dektak^3 Profilometer Measurements

To measure the actual physical parameters of the samples, we used the Dektak^3 profilometer. This precision tool operates in a Microsoft Windows environment and is routinely used to measure film thickness, surface roughness, and substrate curvature. It works by moving a diamond-tipped stylus over the specimen to be tested and having a computer interpret the up-and-down movements of the stylus as ridges and valleys in the surface. For this experiment our specimens were solar cell samples. A total of six measurements were taken for each sample. Since the samples contained metallization lines moving in two directions, three measurements were taken from each of the two directions perpendicular to the lines. The software used with this instrument allowed us to calculate both the width and height of each line of metallization on the surface. After each measurement and calculation was made a data sheet was printed out and saved.

Calculating the Area of Metallization

The next step in our research was to calculate the total area of metallization on each sample. The Dektak^3 provided most of the measurements needed to do this. The only things left to be found were the lengths of the lines, subtractions for overlaps in the lines, and a final formula. The lengths of the lines were found manually with a ruler. We were then able to make deductions for the overlaps using the widths found with the Dektak[3]. Two final area formulas were developed because the samples came in two different sizes. These calculations were made on a spreadsheet using Microsoft Excel.

Results

PV Reflectometer Measurements

The reflectometer compiled a wealth of data. It gave us a spreadsheet listing the reflectivity for each corresponding wavelength of light. To compress this data we decided to use only the side y and side x measurements. These measurements gave us the strongest signals. We also used only the reflectivity readings between a set number of wavelengths to give us a good average of the entire spreadsheet. To correlate the reflectivity with the height of the metal grid, we used wavelengths between 500 and 800 nanometers. For the area correlation, wavelengths between 440 and 460 were used.

Dektak3 Profilometer Measurements

The Dektak[3] printed graphs outlining the up and down movements of the stylus. From each graph, the computer made two measurements, perim and ash. The perim, or perimeter, measured the width of each metal grid line on the sample. The ash, or average step height, measured the height of the grid lines.

Metal Area vs. Reflectivity

The final results of this experiment allowed us to produce various graphs that directly correlate the results obtained from the reflectometer to the results obtained from the Dektak. We produced two sets of graphs. The first set utilized the first readings from the Reflectometer when different sets of light were used. The second set of graphs was produced when we decided to use only one set of lights and rotate the sample. Figures 1 and 4 display the correlation between the average finger height of the metal grid on the samples, and the reflectivity, measured $(R_{sy}-R_{sx})/2$. Figures 2 and 3 display the correlation between the total metal coverage of the samples and the reflectivity, measured $(R_{sy}+R_{sx})/2$

Discussion and Conclusion

As seen in the figures, an obvious correlation was found between the metallization on the samples, measured by the Dektak[3], and the reflectivity measured by the reflectometer. Figures 3 and 4 were produced from the first set of data we collected from the Reflectometer using different sets of lights. The graph correlating the total area of metallization and reflectivity showed instant promise. There is an obvious line formed by the gradual increase in reflectivity as area of metallization increases. With the second graph we formed however, correlating the finger height and reflectivity, the relationship was not so clear. This graph showed scattered points with no obvious line in sight. The difficulties we encountered with this graph led us to our second testing technique with the Reflectometer. In this technique we used the same set of light bulbs and rotated the sample, instead of switching between the sets of bulbs and leaving the sample stationary. We did this in order to have a consistent light intensity. As Figures 1 and 2 show this technique proved successful. In the graph correlating the area of metallization to the reflectivity there is still an obvious line formed. More importantly, in the graph correlating finger height and reflectivity, we finally had success. An obvious line was formed and the correlation was made.

The results gathered from this experiment allowed us to take our first steps in developing a concrete means of calibrating the Reflectometer. However these are only the first steps. To further this we research there has to be continued testing and minor improvements to the PV Reflectometer system. With these, I am confident that in the near future the Reflectometer will be capable of being adapted commercially and providing process monitoring to further advance the PV industry.

Acknowledgements

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Figures

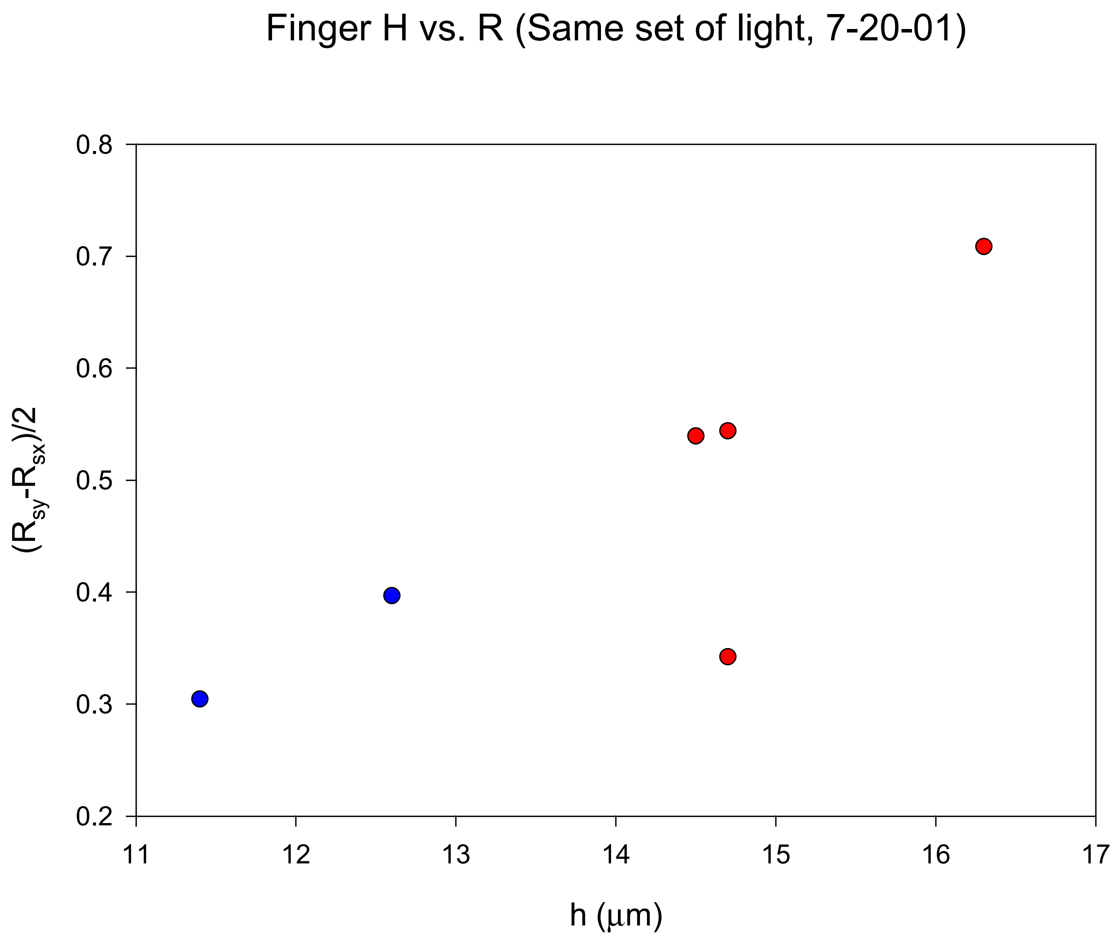
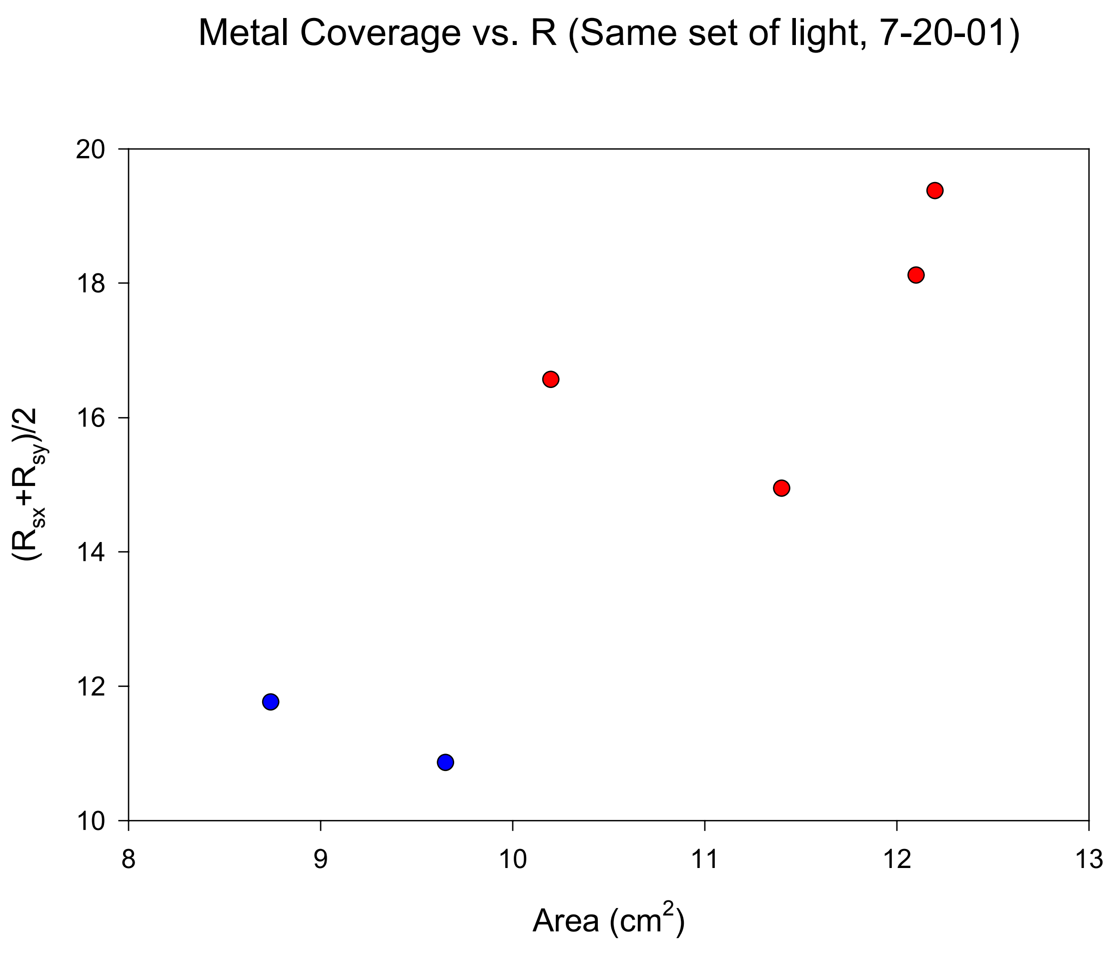


Figure1



Metal Coverage vs. R (Same set of light, 7-20-01)
20
18
16
14
12
10
8
9
10
11
12
13
(R_sx+R_sy)/2
Area (cm2)

Figure 2

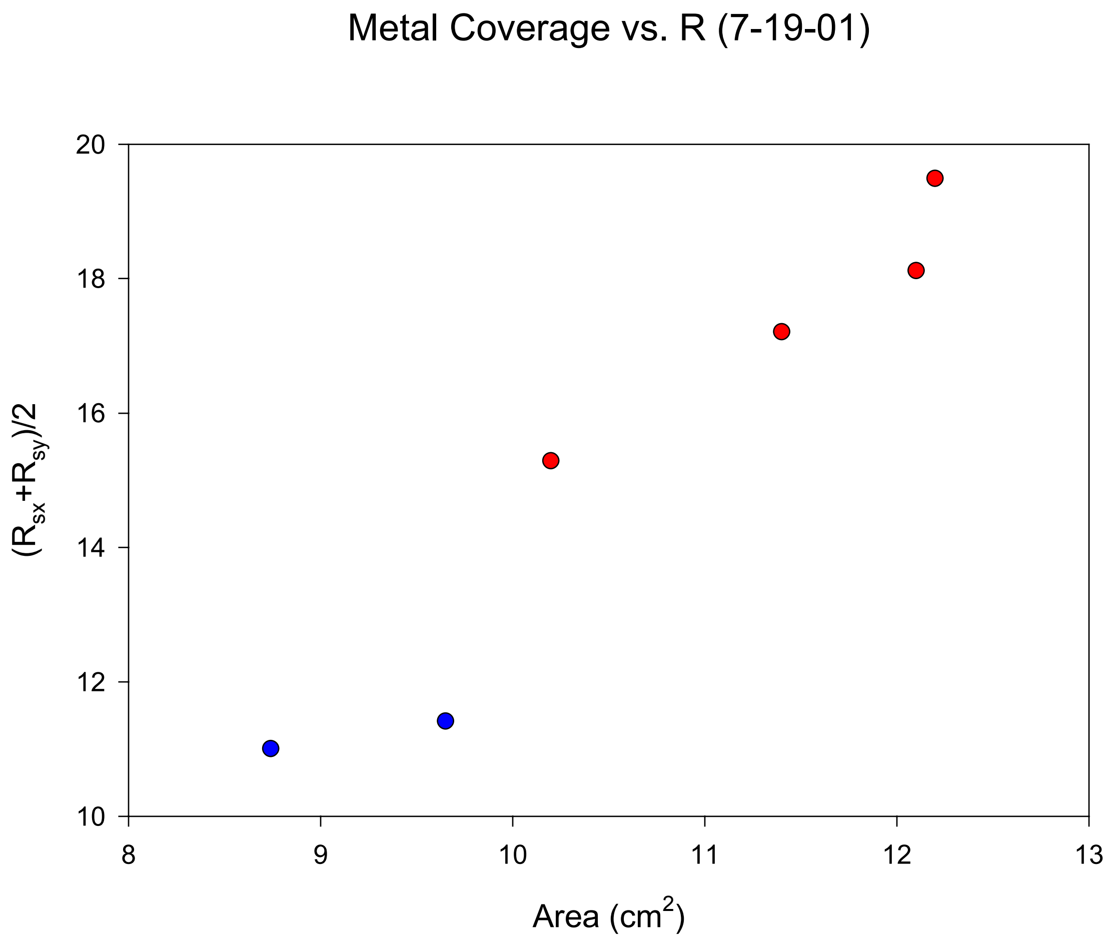
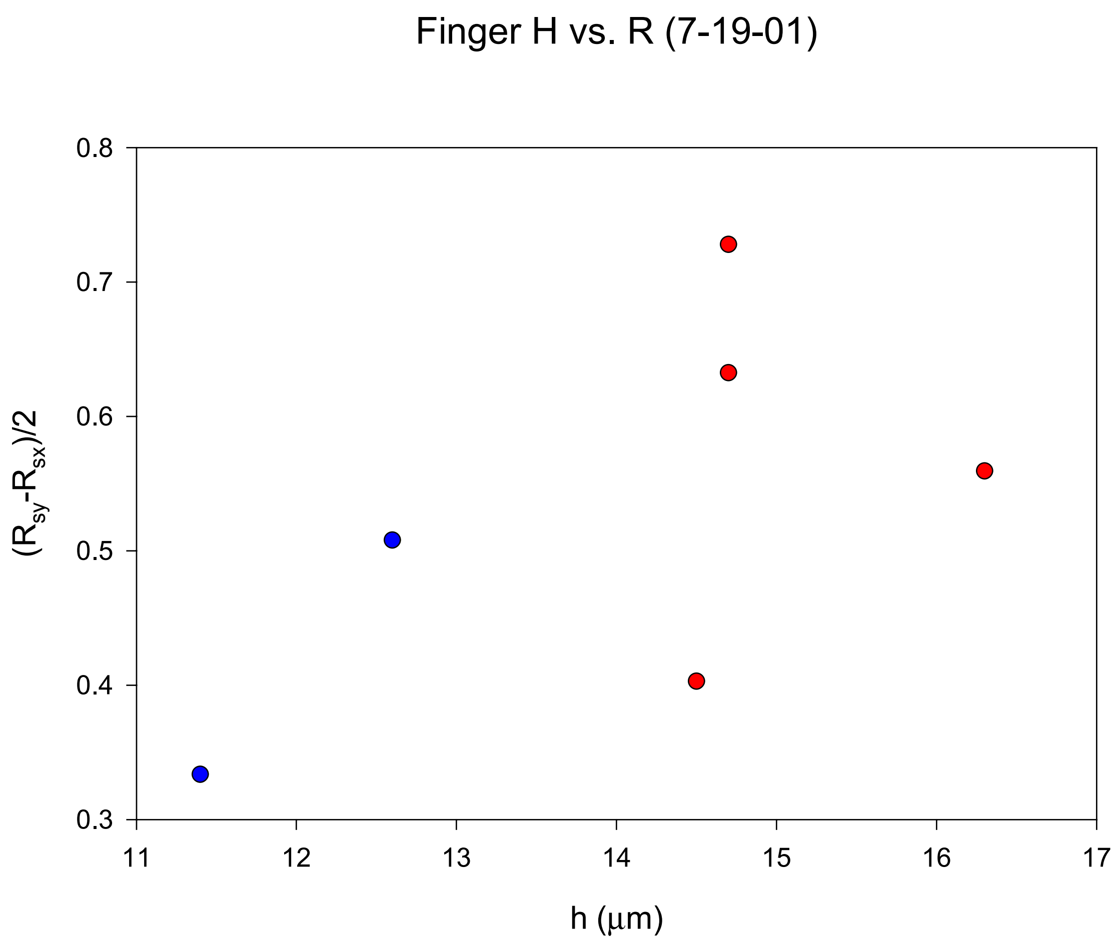

Metal Coverage vs. R (7-19-01)
20
18
16
14
12
10
8
9
10
11
12
13
(Rsx+Rsy)/2
Area (cm2)

Figure 3



Finger H vs. R (7-19-01)
0.8
0.7
0.6
0.5
0.4
0.3
11
12
13
14
15
16
17
$(R_{sy}-R_{sx})/2$
h (μm)

Figure 4