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Principles and Applications of Reflectometery in PV Manufacturing

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ABSTRACT

Principles, system configuration, and applications of a new reflectometer, PV Reflectometer, are described. This system can be used for rapid measurement of physical parameters of solar cells in commercial production.

Introduction

Reflectometery (or reflectance spectroscopy) is routinely used in a variety of metrological applications for determination of chemical composition, material identification, and measurement of optical properties of materials. These measurements are typically made by small-beam spectrometers to measure local reflectance, which is then used to determine local material parameters. The small-beam instrumentation is used for two main reasons—to ensure that the measured region is uniform in material properties, and small-beam optics are relatively easy to make. For a nonuniform sample, one often uses scanning techniques to map variations in the material properties.

Reflectometery can also be a powerful tool in photovoltaic (PV) manufacturing to monitor various solar cell fabrication processes. In fact, it is used in a simple, qualitative form (as a visual examination) by process-technicians and engineers to check quality of sawing, texturing, and thickness of antireflection (AR) coating (using color) for QA purposes. But quantitative measurements become quite tedious and time-consuming. The main difficulty arises from a need to make measurements on the entire wafer or a solar cell. One approach to overcome this difficulty is to use large-beam optics that will allow the entire cell to be measured at once, eliminating the need for scanning.

We have recently developed a novel reflectometer, PV Reflectometer, which measures the reflectance spectrum of an entire wafer or cell, up to 6-in x 6-in in size [1-4]. Because a solar cell is a composite of several materials, the measured total spectrum must be deconvolved to obtain parameter values for various segments of the cell—AR coating, metallization, texture height, and roughness. Here we describe applications of this instrument and how the results can be interpreted.

PV Reflectometer—principles and system configuration

The reflectometer is designed to make measurements of the entire wafer/cell, thus enabling it to "average" the parameter values. To enable large-area measurement, we use the principle of reciprocity illustrated in Figure 1.

Figure 1a shows conventional configurations of incident and reflected beams. Figure 2b shows the reciprocal approach used in our system.

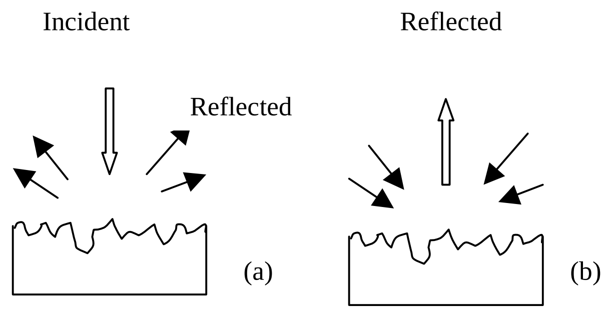

Figure 1. Illustration of the principle of reciprocity.

Figure 2 is a schematic of the PV Reflectometer. It consists of a highly *absorbing* spherical dome, about 12-18 inches in diameter, with openings at the top and at the bottom. The bottom opening terminates in an optical baffle that houses a platform to support the test wafer. The dome has two sets of diverging light sources. One set is located near the top of the dome (specular source, not shown in the figure) and the other is near the great circle (diffuse source). The entire system is designed to eliminate all scattering of the light except by the test wafer. The topside of the dome has a lens and an aperture assembly that couples the light reflected from the sample into a detector array through an optical fiber. The data taking/handling, calibration, and system control are done by a computer that generates the reflectance (R) vs. wavelength (λ) plot for the test sample.

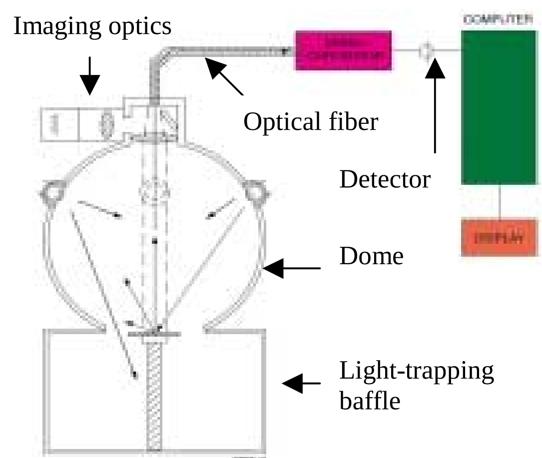

Fig. 2. A schematic of the PV-Reflectometer.

The total reflectance of the test wafer/cell can be expressed as:

$$R_T(\lambda) = \sum_i R_i(\lambda),$$

where i = metal, AR coating, Si. Spectral deconvolution is used to separate the reflectance contribution from various segments of a wafer/solar cell and to characterize that segment. We consider a simple case of reflectance of a textured and AR-coated cell with front and back metallizations. A typical R vs. λ plot is illustrated in Figure 3.

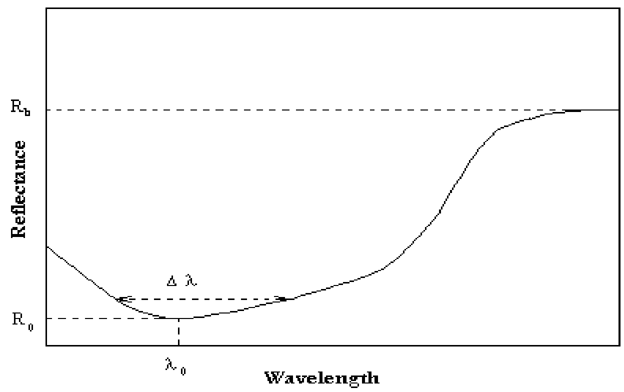

Figure 3. A typical R vs. λ plot from the reflectometer.

A simple deconvolution leads to the derivation of the following approach to determine optical parameters of the cell: (i) λ_0 (wavelength of minimum reflectance) determines the thickness of the AR coating, (ii) R_0—reflectance at λ_0— is used to determine the parameters related to the area of the front metallization, and (iii) R_b (reflectance at $\lambda > 1$ µm) relates to the back reflectance.

Because the solar cell metallization has a 3-dimentional topography, the reflectance has contributions from the horizontal (R_a) and vertical sections (R_b) of cell metallization (see Figure 4). We use directional illuminations to separate these contributions to attain metal area and the height; for a rectangular metallization pattern, we can determine these values from reflectance front-to-back (R_{fb}) and side-to-side (R_{ss}) illuminations.

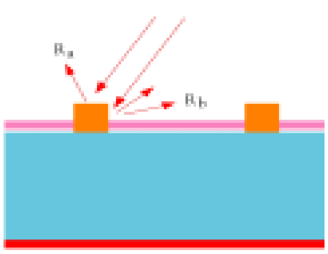

Figure 4. Illustration of scattering from the horizontal and vertical parts of the metallization.

$$R_a = (R_{fb} + R_{ss}) / 2 \quad \text{.........} \quad (1)$$
$$R_b = (R_{fb} - R_{ss}) / 2 \quad \text{.........} \quad (2)$$

Figure 5 shows R_a and R_b calculated from measured reflectance plots for a finished solar cell.

Results and discussion

The measured reflectance plots can be deconvolved to derive physical parameters including surface roughness/texture, AR coating thickness, metallization area and height, and backside metallization properties. The PV Reflectometer makes the entire measurement in a fraction of a second.

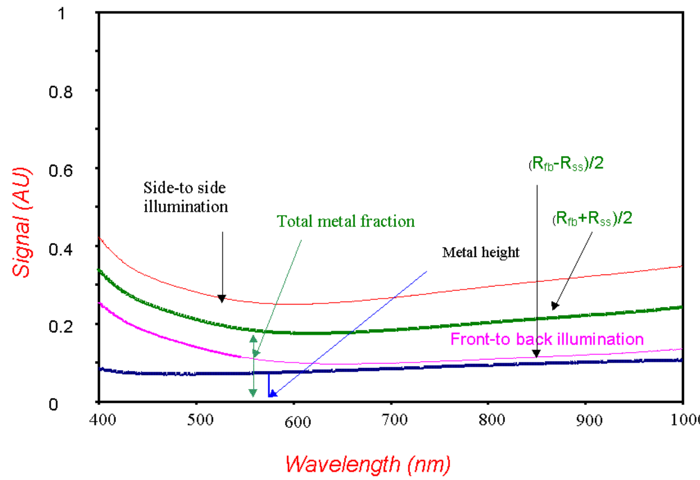

Figure 5. Reflectance plots for two directional illuminations.

Here we show one example of such measurements and compare results from metal area measurements made by the reflectometer with those measured by a profilometer.

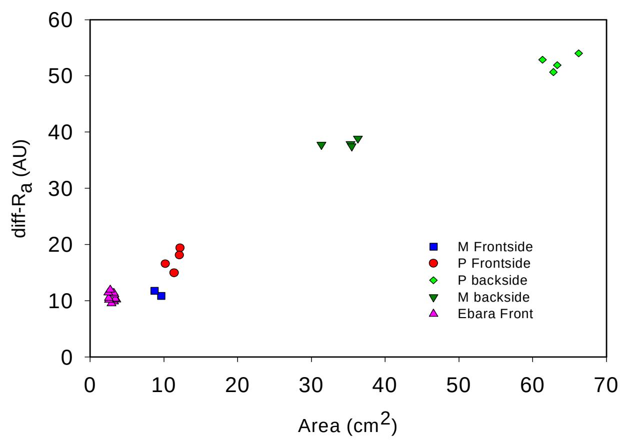

Figure 6. A comparison of metal area obtained by PV Reflectometer and Dektak, for different solar cells.

REFERENCES

[1] B. L. Sopori, "Principle of a new reflectometer for measuring dielectric film thickness on substrates of arbitrary characteristics," *Rev. Sci. Instrum.* **59(5)**, p. 725,1988.

[2] B. L. Sopori, Y. Zhang, and W. Chen, "Process monitoring in solar cell manufacturing," Proc.9th Workshop on Crystalline Silicon Solar Cell Materials and Processing, p. 74-80, August 9-11, 1999, Breckenridge, CO.

[3] B. L. Sopori, Y. Zhang, W. Chen, and J. Madjdpour, "Silicon solar cell process monitoring by PV Reflectometer," *IEEE PVSC, Anchorage, AK, Sept. 2000.*

[4] Bhushan Sopori, U. S. Patent No. 6,275,295.