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Reflectance Spectroscopy: Rapid Quantitative Measurements in Commercial Production of Si Solar Cells

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Reflectance Spectroscopy: Rapid Quantitative Measurements in Commercial Production of Si Solar Cells

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ABSTRACT

The reflectance spectrum of a wafer/solar cell is used to measure physical parameters of the wafer and its structural components and interfaces. New applications of the reflectometer have been developed, which enable determination of the average parameters over the entire wafer/cell, as well as their spatial mapping. Measurements can be made in less than 100 ms. This method is well suited for commercial monitoring of solar cell processing.

1. Objectives

The photovoltaic (PV) industry is keenly interested in incorporating process-monitoring technology in solar cell manufacturing lines as a means of improving solar cell yield and thereby lowering manufacturing cost. A typical solar cell line involves a host of process steps, which include sawing, texturing, deposition of antireflection coating(s), junction formation, and metallizations. Because a solar cell facility processes a large volume of wafers, typically 50,000 to 100,000 a day, the measurement technique must be rapid. Unfortunately, the techniques developed for the microelectronics industry are not suitable for process monitoring in solar cell manufacturing. Hence, there is a need for fast, real-time, low-cost techniques that can measure suitable parameters for monitoring solar cell processing. In an ideal case, it is best to have one approach that can work on many process steps. This minimizes the cost of equipment, training, maintenance, and spare parts.

2. Technical Approach

Reflectance spectroscopy is a very versatile technique for measuring physical parameters of semiconductor wafers and devices. A broadband reflectance-spectrum of a semiconductor device (or any stratified structure consisting of a semiconductor and dielectric films) can provide information on such parameters as thickness and interface roughness of each layer. Combining spectroscopy with scatterometry can further enhance the ability of reflectance spectroscopy. This combination can be used for characterizing non-conformal structures on a wafer/solar cell.

GT-FabScan 6000 (previously known as the Sopori or PV Reflectometer) was developed to measure a variety of solar cell physical parameters in a single measurement using reflectance spectroscopy. This system rapidly acquires a reflectance spectrum, reflectance (R) vs. wavelength ( ), of the entire wafer or cell, and deconvolves these data to obtain surface roughness, texture quality, antireflection (AR) coating thickness, front-metallization parameters (height and area of metallization), and backside reflectance. Because GT-FabScan 6000 can make measurements very rapidly (typically in <40 ms) and without physically contacting the wafer, it can be used to monitor various process steps in the commercial production of solar cells.

The basic principles of our reflectometer have been described previously [1-3]. The use of reciprocal optics enables the entire wafer/cell to be made in a single measurement. We have now developed new applications for the system, including measurement of average wafer/cell thickness and mapping capabilities.

Thickness measurement is based on determining changes in reflectance due to absorption within the wafer thickness. Figure 1 illustrates the principle of reflectance-based measurement. This figure shows calculated reflectance of two double-sided textured Si wafers, 50 m and 250 m in thickness. In high-absorption region I, the reflectance of the two wafers is the same (that of the front surface). In lightly absorbing region II, the light encounters multiple reflections within the thickness of the wafer/cell and R depends on the wafer/cell thickness. In the nearly nonabsorbing region III, the reflectance is about the same because the semiconductor absorption is quite low.

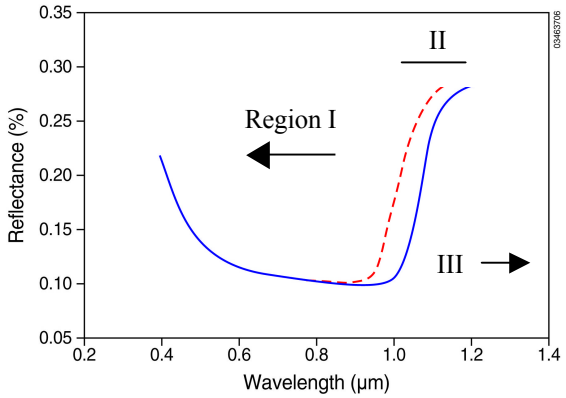

Fig. 1. Calculated reflectance spectra of double-side textured wafers 50 m thick (dotted) and 300 m thick (solid).

As seen in Fig. 1, the reflectance in region II decreases with an increase in thickness. The change in the reflectance can be quantitatively related to the thickness through calculations, using *PV Optics* [4]. The accuracy of the measurement was determined by the following procedure: the reflectance spectrum of a front-textured/back-polished

wafer was measured, then the backside of the wafer was polished and the spectrum measured again. Figure 2 shows measured reflectance spectra; the thickness removed by polishing was about 20 m.

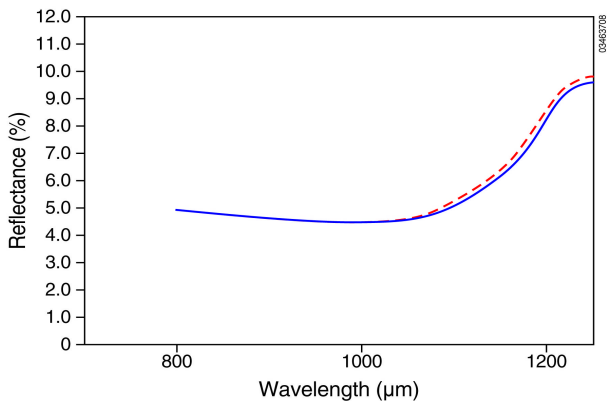

Fig. 2. Measured reflectance spectra of a 125-mm x 125-mm, mc-Si wafer before (solid line) and after thinning (dotted line).

The thickness measured in this way is the average value of the wafer. This technique of wafer-thickness measurement is very valuable for wafers that may not have uniform thickness or planar surfaces (e.g., ribbons).

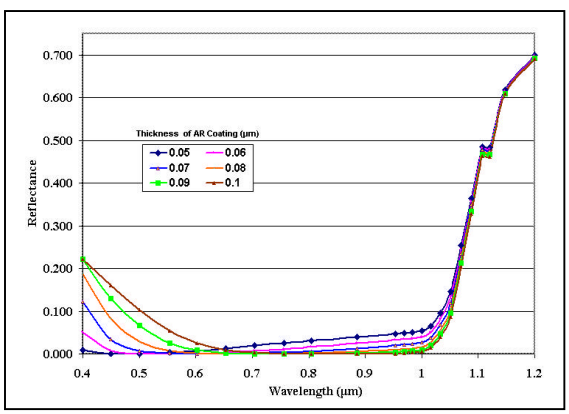

Fig. 3. Calculated reflectance spectra of AR-coated, textured wafers of different AR thicknesses, using *PV Optics*. Refractive index of the coating, n = 2.

In general, the thickness of the wafer or a layer on a wafer can be determined simply by making reflectance measurement at one selected wavelength. Alternately, one can relate wavelength for a given value of reflectance to the wafer thickness. For example, one can relate the reflectance of an AR-coated sample to the thickness of the coating. This relation can be seen from Fig. 3, which shows the calculated reflectance spectra of a double-sided textured wafer. The reflectance at 0.8- m wavelength is inversely proportional to the AR coating thickness. This feature allows a simple camera system to rapidly image the AR coating thickness. Figure 4 shows thickness maps of an AR coating on two textured, 5-in Si wafers, identifying wafer-to-wafer variation.

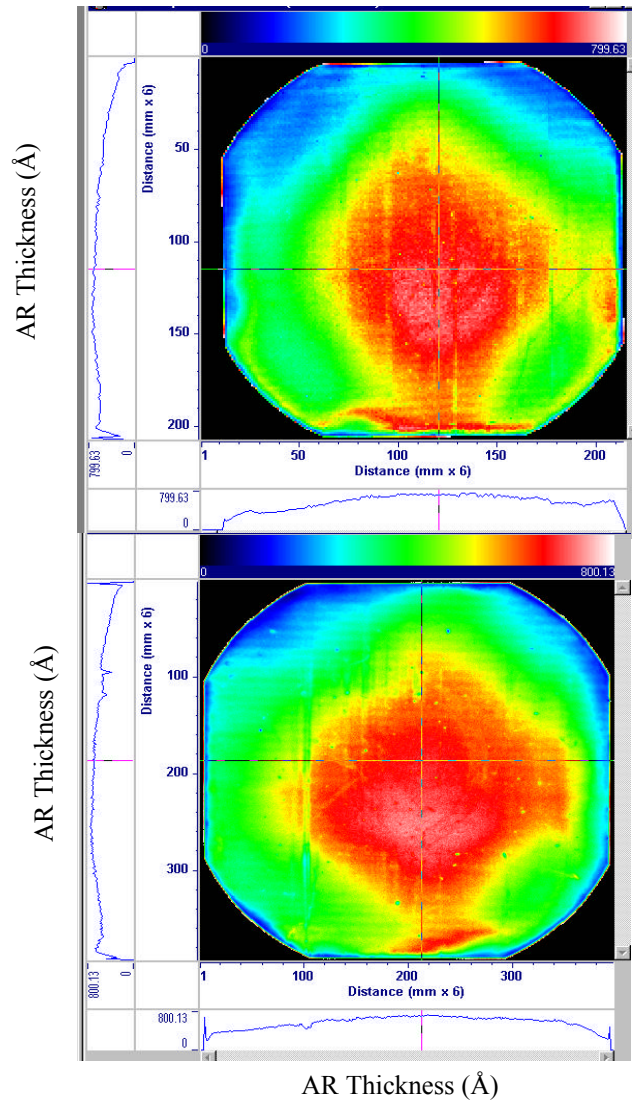

Fig. 4. Thickness maps of AR coating on two textured commercial PV Si wafers showing variations in the thickness pattern in one production run.

3. Conclusions

New applications of GT-FabScan6000 are developed for measuring wafer thickness, and implementing a new camera system to map the wafer parameters. These added capabilities render this instrument well suited for monitoring many process steps in Si solar cell fabrication.

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[4] B. L. Sopori, *Laser Focus*, **34**, 159 (1998).

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