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RAPID MAPPING OF AR COATING THICKNESS ON Si SOLAR CELLS USING GT-FABSCAN 6000

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ABSTRACT

A new technique for rapid mapping of the thickness of an antireflection (AR) coating on a solar cell is described. A filtered, reflectance (intensity) image of the AR-coated wafer is generated by a CCD camera mounted on a GTFabScan. This image is converted into a thickness image using a transformation relating local AR thickness to the local intensity in the image plane. The thickness map is generated in <100 ms.

INTRODUCTION

Until recently, the objective of using an AR coating on a solar cell has been to minimize its reflectance and maximize the light trapping ability to obtain highest photocurrent for the incident solar spectrum. Typically, the AR coating for a textured Si solar cell should consist of a uniform, 750 Å-thick, dielectric film of refractive index 2 to 2.4. However, the low-cost techniques used for deposition of AR coatings on commercial Si solar cells do not yield very uniform films. It is believed that a good trade off between the cost and the cell performance would favor a "reasonable" variation in the film parameters (thickness, refractive index). Typically, AR coatings used in the PV industry exhibit a variation of about 100 Å in the film thickness. It is estimated that this nonuniformity leads to a photocurrent density loss of about 1 mA/cm^2.

In the current solar cell technology, AR coating deposition and its subsequent processing must combine many additional functions that include: (i) a barrier to fire-through, screen-printed contacts, and (ii) participation in the hydrogen diffusion for impurity/defect passivation. These functions demand much higher uniformity of the coating. For example, in a metallization firing by an RTP-like process, a variation in the film thickness leads to variation in the local reflectance and the absorbed energy. These can lead to spatial variations in the cell temperature, producing changes in the quality of the contact. Thus, there is a need for development of a technique for rapid measurement of AR coating thickness and mapping the thickness variations. Some methods already exist for measuring thickness of dielectric films on planar wafers. They are based on ellipsometery or interference, and use a small beam to scan the wafer. These methods are slow and not suitable for wafers that have rough or textured surfaces.

Here we describe a new technique for measurement and mapping of AR coatings on Si solar cells. This technique uses an existing instrument, GT- FabScan 6000, which can perform a variety of measurements for process monitoring in PV manufacturing. The system generates an image of the AR thickness and presents it in a color format using false colors. This measurement is made in less than 100 ms. Development of this application enables GT-FabScan 6000 to not only measure average values of various physical parameters of solar cells but also generate thickness maps. These maps are valuable for monitoring the operation of the coating deposition machine, and control other processes such as fire-through metallization and hydrogen passivation.

PRINCIPLES OF MAPPING AR COATING THICKNESS

The new technique uses the thickness dependence of the local reflectance from the cell/wafer, at a selected wavelength, to determine the corresponding thickness. Figures 1, 2, 3 and 4 illustrate the principle of this technique. Figure 1 shows reflectance spectra (R Vs λ) of planar, AR coated solar cells for different thicknesses (0.05 μm to 0.1 μm) of the coating. The coating material is assumed to be SiN:H with a refractive index of 2, and the calculations are made using *PV Optics*. These plots show that for $\lambda > \lambda_0$ (λ_0 = wavelength for minimum reflectance), the reflectance increases as the AR coating thickness decreases. Figure 2 is a plot of reflectance Vs (1/t) for different wavelengths. It is seen that for a broad wavelength range, this relationship is nearly linear. Figures 3 and 4 show similar plots for textured wafers. In

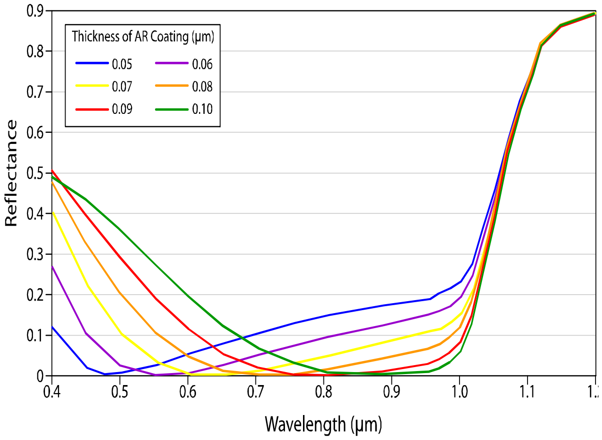

Figure 1. Calculated reflectance spectra of AR-coated, planar solar cells of different AR thicknesses, using *PV Optics.*

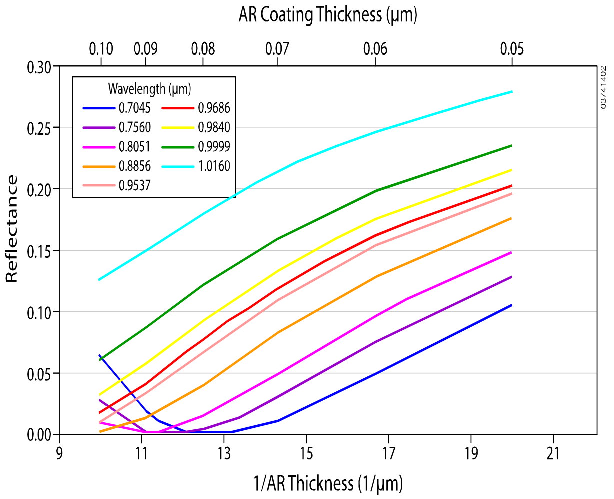

Figure 2. Plots showing relationship between reflectance and (1/thickness) at different wavelengths for a planar, AR-coated, wafer.

particular, Fig. 4 shows a linear fit for a selected wavelength, λ = 0.8 µm. The important conclusion is that one can assume the local reflectance of an AR coated wafer is inversely proportional to the film thickness, if the reflectance is measured at a suitable wavelength. This feature can be deployed in a somewhat simple way by suitably illuminating the AR coated sample and using a camera (with a bandpass filter) to image the (1/t)-map, which can then be converted into a t-map. These measurements can be done easily using digital camera systems.

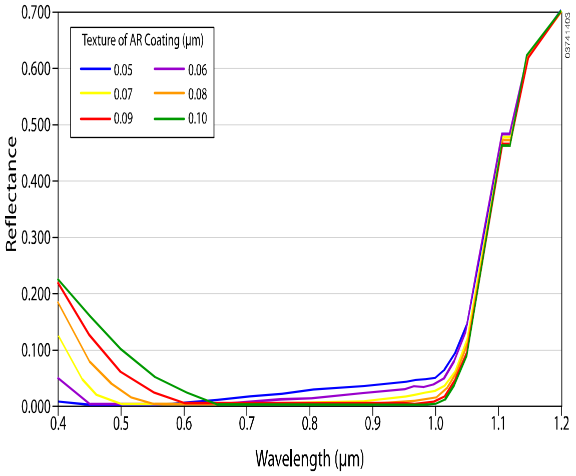

Figure 3. Calculated reflectance spectra of AR-coated, textured wafers of different AR thicknesses, using *PV Optics.*

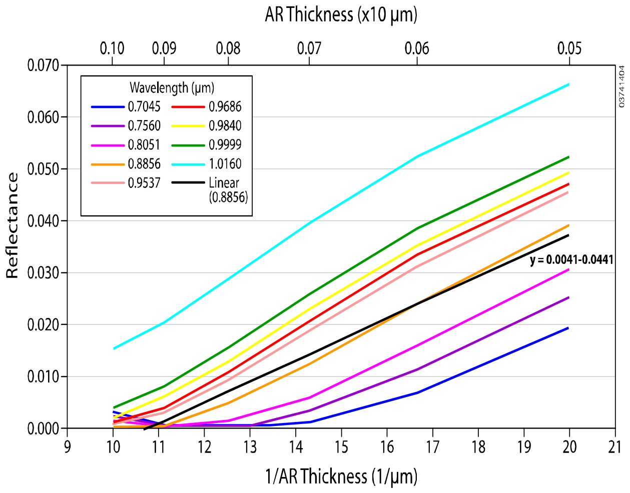

Figure 4. Plots showing relationship between reflectance and (1/thickness) at different wavelengths for a textured, AR-coated wafer.

MEASUREMENT SYSTEM

The thickness mapping is easily accomplished in GT-FabScan 6000 (previously known by other names i.e., Sopori Reflectometer or PV Reflectometer). In its normal operation, GT-FabScan 6000 rapidly measures reflectance spectrum, reflectance (R) Vs wavelength (λ) of the entire wafer or cell, and deconvolves these data to obtain surface roughness, texture quality, AR coating thickness, wafer thickness, metallization parameters (height and area of metallization), and backside reflectance. Because GT-FabScan 6000 can make measurements very fast, typically in less than 100 ms, it can be used for monitoring various solar cell process steps. For film thickness mapping, the wafer is placed in the reflectometer, where it is illuminated from all sides and the reflectance normal to the wafer is measured, see Figure 5. In the normal operation, the R Vs λ is measured by a diode array spectrometer. For the present application of film thickness mapping, the DAS is replaced with a CCD camera fitted with a bandpass filter. The filtered image, in response to the illumination by the optical source of the GT-FabScan 6000, represents a local intensity, which is inversely proportional to the AR coating thickness. The camera image is processed and assigned a false color scheme to identify thickness distribution. Figure 5 shows a schematic of GT-FabScan 6000 with a mapping option. Here the light reflected normal to the wafer is passed through a bandpass filter and imaged with the camera.

The operating parameters of the camera (contrast or Gamma, and brightness) and the bandpass filter can

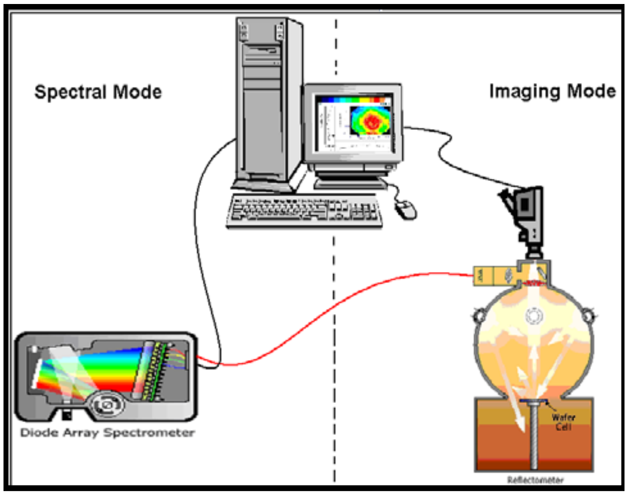

Figure 5. A schematic of GT-FabScan 6000 with a camera attachment for mapping.

be selected so that the local intensity of the image of the AR coated wafer is inversely proportional to the AR thickness. The intensity of the image at any point in the image plane, $I(x_i, y_i)$, is described as:

$$I(x_i, y_i) = R(x_o, y_o) * T(\lambda) * M$$

Where M is the magnification, $T(\lambda)$ is the transmittance of the bandpass filter, and $R(x_o, y_o)$ is the local reflectance of the element (x,y) in the object plane. The bandpass filter is selected to have a linear relationship between the transmission of the filter and film thickness.

RESULTS/DISCUSIION

To demonstrate that the mapping displays the actual thickness variations, we taper-etched a TiO_2 coating deposited on a textured wafer. The sample was dipped in a dil.HF (which reduced the film thickness uniformly) and then slowly pulled out producing a tapered layer. Figure 6 is a schematic of the etched taper on the sample. Figure 7 is the thickness distribution for this sample obtained by the new technique. This figure shows that a continuous taper in the film thickness, between 236 Å and 103 Å, is generated. The color legend of uniformly distributed colors is shown on the top side of the figure.

Figure 8 shows the thickness map of a textured Si wafer (4.5-in x 4.5-in), coated with an AR coating of TiO_2. The film thickness is the largest in the center of the wafer, about 800 Å. The color legend, at the top of figure, identifies the thickness distribution over the wafer. Also shown are the vertical and horizontal line scans of thickness through the center of the wafer identified by the cursor marker.

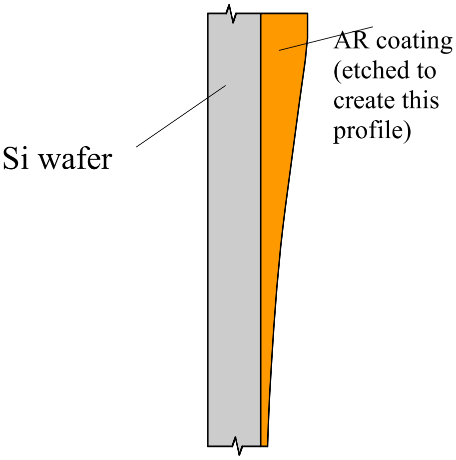

Figure 6. A cross sectional view of a taper-etched AR coating on a textured Si wafer.

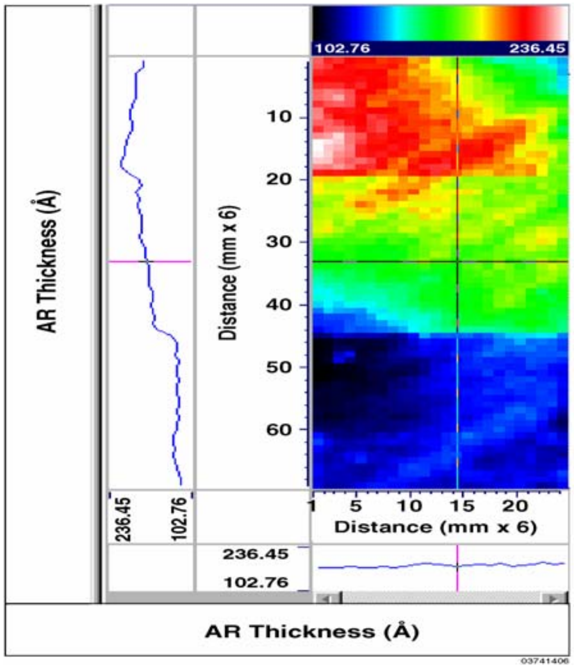

Figure 7. A map of thickness variation of the taper-etched film on a textured wafer.

CONCLUSION

A new technique for rapid mapping of AR coating thickness has been developed, which can easily be retrofitted on an existing instrument—GT-FabScan. The rapid-mapping capability makes the instrument well suited for online process monitoring and control in PV manufacturing. The advantages of this technique are: it is very rapid—maps the entire wafer in one measurement in less than 100 ms; the measurement is insensitive to the nature of the wafer surface (works on planar, rough, and textured wafers); and because a digital image is obtained, a variety of statistical parameters can be quickly identified. Use of this technique is expected to be very valuable in optimizing hydrogen passivation and fire-through metallization process. In particular, current method(s) of AR-coating deposition need to be evaluated for non-uniformities in the coating thickness and its effects on cell performance. For example, Fig. 9 shows a thickness map of a TiO_2 film on a textured wafer that was in the same batch for AR-coating deposition as the wafer in Fig. 8. As seen, the general distribution-pattern of both wafers is nearly the same, but details of thickness profile are considerably different. It may no longer be sufficient to relate AR-coating effects simply to the loss in photocurrent. It is expected that large variations in the AR-coating thickness can be detrimental to achieving high cell performance in fire-though contact processing.

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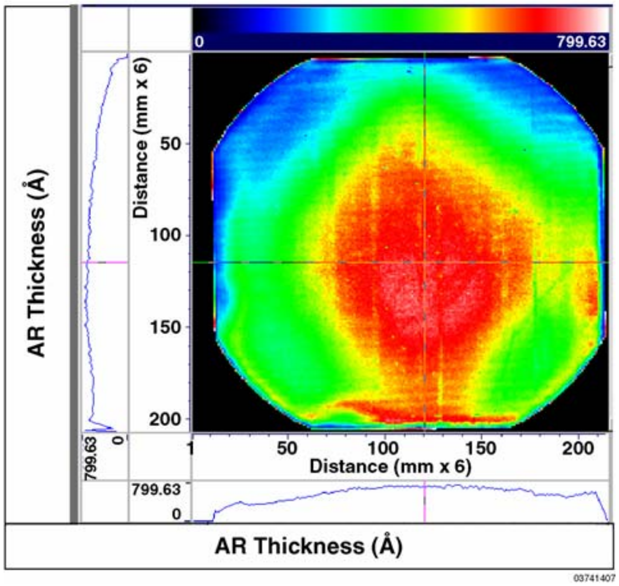

Figure 8. A thickness map of an AR coating on a 4.5-in x 4.5-in, textured wafer generated in 100 ms by GT-Fab-Scan 6000 using the method described in this paper.

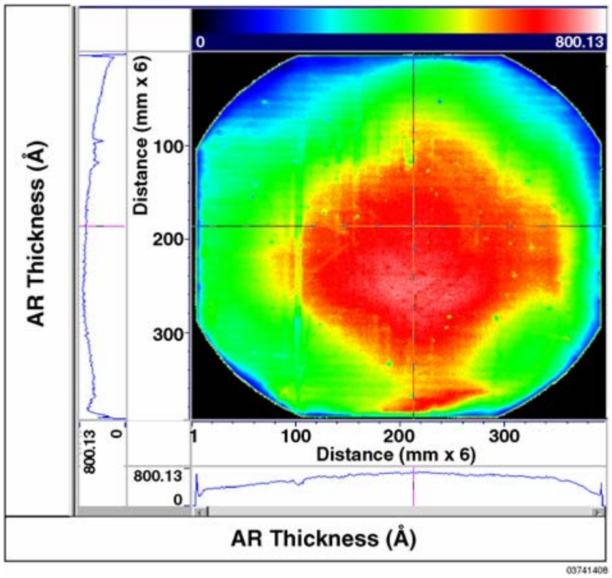

Figure 9. A thickness map of an AR coating on a 4.5-in x 4.5-in, textured wafer that was in the same batch for AR-coating deposition as the wafer in Fig. 8., showing wafer-to-wafer variation due to deposition system

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