

Photovoltaic Applications – Part I

The following article is an excerpt from our recent application note on photovoltaic applications. The full note discusses many additional applications, including textured silicon, thin film silicon, CdTe, CIGS, and organic PV. To receive a copy of the full article, please contact vinlow@jawoollam.com.

Spurred by recent energy price increases, photovoltaic (solar) cells are gaining popularity as an important source of energy. With improved cell design and manufacturability, a variety of cell materials and designs are now in production, including second-generation thin-film devices. Experimental next-generation cells, such as organic thin films, promise low production cost and ease of manufacturing.

Regardless of the material used, most solar cell designs rely on thin films, and the natural choice for studying and monitoring the performance of these films is Spectroscopic Ellipsometry (SE). SE is ideal for measurement of film thickness and optical constants as well as other properties that describe the quality and nanostructure of all types of films. SE is commonly applied to a wide range of photovoltaic materials from anti-reflection coatings and transparent conductors to the active semiconductor layers.

As new solar cells move out of the research lab and into commercial manufacture, SE systems are there to help monitor production uniformity. Page 6 shows the J.A. Woollam Company AccuMap-SE[®] system. It incorporates a high-speed M-2000[®] spectroscopic ellipsometer that scans panels up to 1.1 by 1.5 meters, and features high-speed alignment to reduce measurement time to a few seconds per data point. In this work, we review current and emerging applications of SE to different solar cell films, structures and devices.

Silicon Solar Cells

At present, crystalline silicon solar cells dominate PV energy conversion worldwide. Silicon technology has been around for decades. The smooth, mirror-like cells of the past have given way to monocrystalline or multi-crystalline silicon with textured surfaces. Texturing

reduces reflected light significantly. To further capture incoming light, a thin film anti-reflection (AR) coating is commonly added to the surface. A popular AR material is silicon nitride (SiN_x), as its index of refraction makes a good impedance match between air and the semiconductor. Nitride film thickness and refractive index determine how effectively reflected light is suppressed.

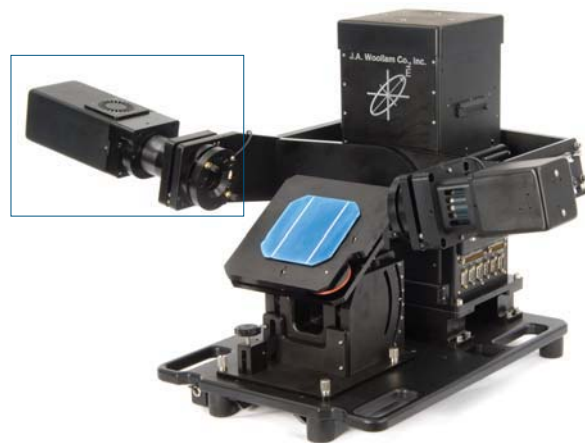


Figure 1. Intensity optimizer on an M-2000 spectroscopic ellipsometer allows convenient control of measurement signal to match the ideal range for any sample.

SE can be used to measure AR coatings on textured silicon, but this requires advanced instrumentation and methods. Because textured surfaces greatly reduce reflected signal, the T-Solar[™] M-2000[®] spectroscopic ellipsometer was developed to include an intensity optimizer (shown in Figure 1) which adjusts to maximize reflected signal from each sample. Even with optimized intensity, rough textured surfaces push measurements to oblique angles above 75°.

Figure 2 shows data collected from a textured multi-crystalline silicon sample with a single-layer AR coating.

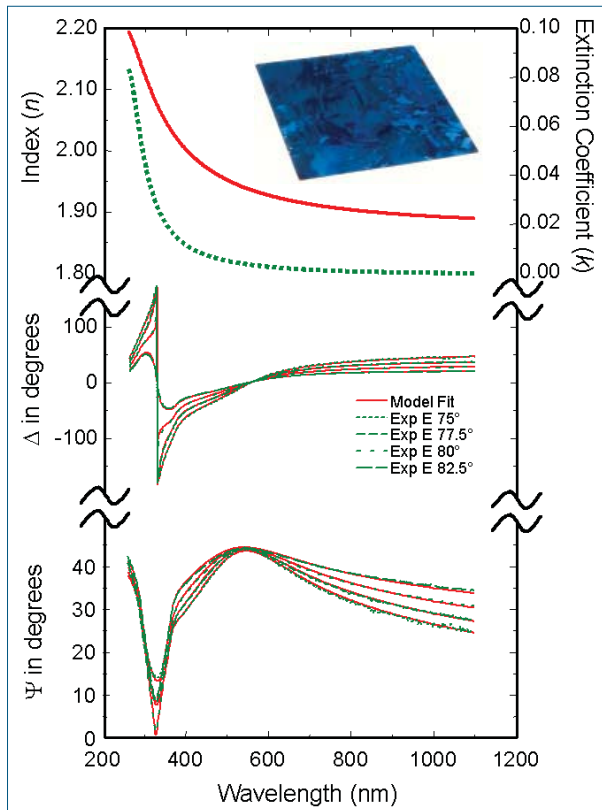


Figure 2. Measured data and corresponding model fit for a single-layer AR coating on multicrystalline silicon. Resulting optical constants for the AR coating are also shown.

The data are analyzed to determine the thickness and refractive index of the coating. The coating refractive index, shown in Figure 2, decreases as the surface becomes rougher. The coating index on this textured surface is 10% lower than the values from a smooth, polished silicon surface.

Texturing also lowers the film density, which can be modeled by mixing the fully dense reference film optical constants with air (void) in an effective medium approximation (EMA). As the surface becomes rougher, the void fraction increases, and this significantly lowers the refractive index. Textured silicon itself has a lower optical density, which reduces the substrate index – thus the AR coating is still an effective match.

Texturing monocrystalline silicon surfaces produces a regular pattern of pyramids as shown in Figure 3 (inset). Measurement of monocrystalline structures requires special measurement geometries which are provided by the T-Solar system. Figure 3 compares data from coated, textured monocrystalline silicon measured first with the standard SE sample geometry, and then using the T-Solar special geometry. Data oscillations that provide AR coating information are suppressed in a standard SE

measurement, but are prominent when pyramidal texturing is accounted for. Thus, T-Solar SE measurement geometry is critical for film characterization on textured monocrystalline silicon. The resulting nitride layer optical constants (Figure 4) are modeled using a Tauc-Lorentz oscillator. This dispersion equation describes both refractive index and UV absorption with only a few free parameters. Again, the refractive index is lower than that of the films on a smooth surface due to lower optical densities on textured surfaces.

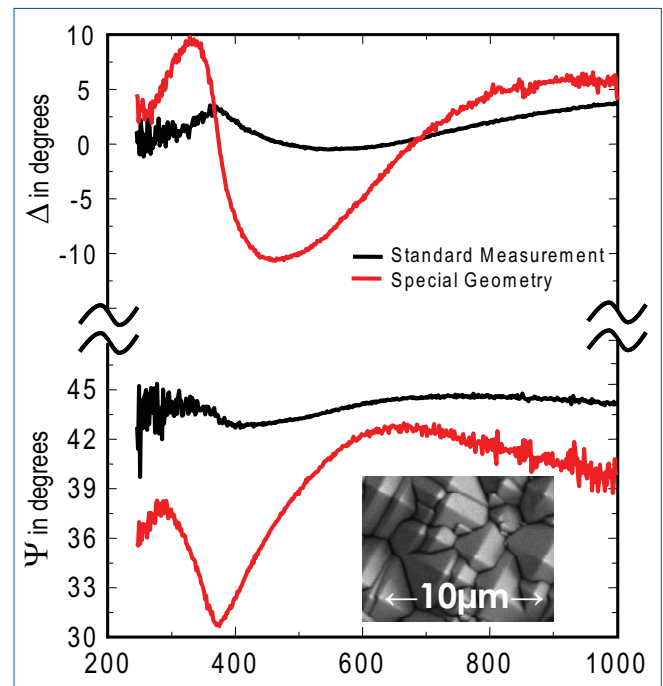


Figure 3. Two data sets from a textured monocrystalline silicon wafer coated with a single-layer SiNx film. The first data set uses the standard SE geometry, while the second data set uses the special geometry of our T-Solar system to enhance measurements from the pyramid structures (shown in the inset SEM image).

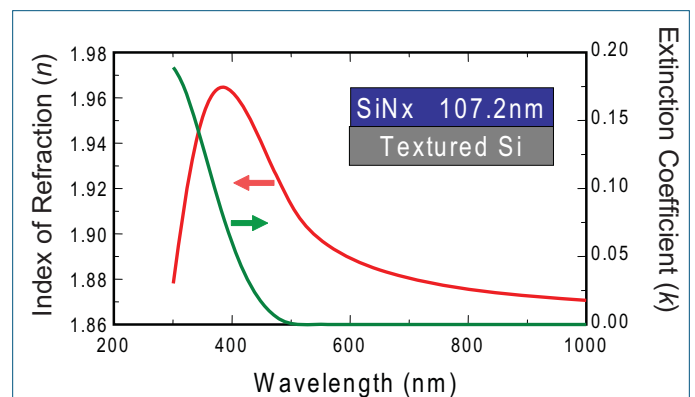


Figure 4. Resulting SiNx optical constants and thickness measured from the textured monocrystalline silicon surface using special T-Solar geometry.