

PHOTOVOLTAICS / SEMICONDUCTORS

Mass-produced electronics such as photovoltaics and semiconductors require efficient methods of manufacture and quality control. Hyperspectral imaging (HSI) can provide this non-contact, on-line monitoring and can be used to identify off-specification products based on thin film characteristics and material composition. HSI can also be used in the same way in a research lab or on a smaller scale. One advantage of push-broom hyperspectral imaging cameras over other monitoring devices is the low light exposure required to image the sample. Because only one line of the sample is illuminated at a time and imaged rapidly, the risk of damaging the material with a high heat-load is significantly reduced.

Solar Cell Quality Control

Researchers at East China Normal University in Shanghai have developed a hyperspectral imaging system that is used to identify cracks and characterize other contaminants and defects early in the production cycle of solar cells. Hyperspectral images capture the diffuse light reflectance to distinguish cracks on polished specular surfaces. (Li, 2010). Film thickness measurement during production is another important HSI application.

Thin Film Measurement Using Spectral Interference Fringes

Thin film characterization, including film thickness, refractive index, reflectivity and homogeneity, is important for photovoltaics and semiconductors, as these factors greatly affect the performance of the product. Single point spectral-photometric and spatial uniformity measurements are also critical in these processes. By understanding the interaction between the thin film and light, the characteristics of the thin film can be determined using the interference pattern (or fringes) created from the partial reflection/transmission of the thin film surfaces. The thickness of a thin film can be calculated if both the angle of incidence and refractive index are known. Both sides of the thin film reflect light and have a phase relationship dependent on the two optical path lengths. The phase relationship creates an interference pattern that can be used to calculate the thickness of the thin film using the equation below. This equation assumes a constant index of refraction; more complex formulas can be used in cases of significant changes in the refractive index as a function of wavelength.

$$d = m / (2 D_n \sqrt{(n^2 - \sin^2\theta)})$$

Where:

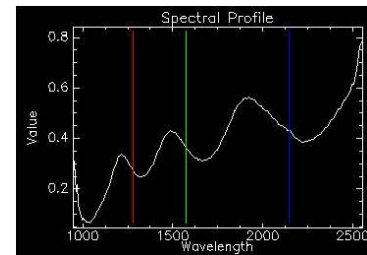
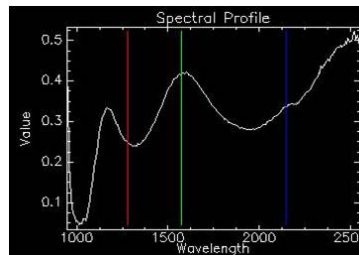
d = film thickness

m = number of fringes in wavelength region

n = refractive index

θ = angle of incidence

D_n = wavelength region used ($\lambda_1 - \lambda_2$, in wavenumbers)



The same measurement and calculation of thickness can be performed using hyperspectral push-broom type cameras, covering the whole surface of the samples, as described in the next example.

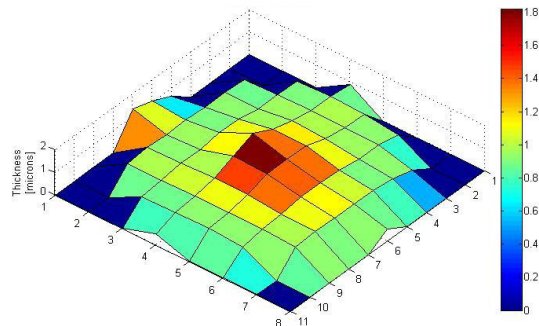
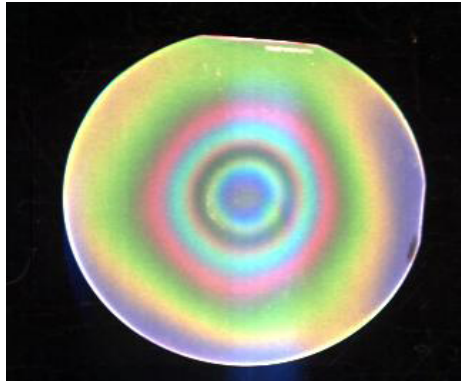
Full Surface Thickness Measurement

As an example, a 4-inch diameter silicon wafer with a thin but non-uniform diamond coating was placed on the linear sample stage of a SWIR spectral camera system. Typical near infrared spectra obtained from the various points on the wafer showed a strong interference pattern. Interference peaks were further apart for the thinner layer areas as shown in the first spectrum above, whereas the thicker layer produced fringes closer together as seen in the second spectrum.

Thickness was calculated using the generic formula shown earlier. The diamond coating on the wafer used in this example was very uneven. The following surface plot displays a grid of varied thicknesses, indicating that the layer at the center of this wafer is much thicker than the area towards the edges.



To obtain optimal results for different film thicknesses, it is important to use the appropriate wavelength range. A variety of imaging cameras, optics and sources are available for spectral regions from the UV to the long-wave infrared. Middleton Research staff can help with the selection of appropriate equipment for a specific application and integrate the system with the necessary hardware components, software and prediction methods.



Diamond coating thickness

Non-Imaging Multi-Channel Arrangements

Some applications call for the measurement of thickness data at different discrete points rather than the full image surface. In order to measure multiple discrete thickness values simultaneously, a hyperspectral line camera can be fitted with a multi-arm fiber bundle, with each arm positioned at different sampling points predetermined by the application requirements. A range of up to 100 measurement points can be covered with different fiber bundle assemblies while the length of the fibers can be selected to accommodate the particular industrial setting.

From Lab to Process

An important advantage of hyperspectral imaging is that the same camera can be tested and calibrated in the laboratory and then transferred to the production line to monitor the manufacturing process. This will streamline the transition to efficient, cost-saving on-line quality monitoring. In an on-line application, it is advantageous to calculate and display results at the frame rate of the camera output. To effectively manage the voluminous data generated from continuously moving samples, the data is transformed online, producing compressed data results. The Middleton Research High-Speed Prediction Engine™ is an optimized, dedicated real-time parallel calculating device. It includes an input specific to the type of camera used, options for taking reference measurements, and a simple Ethernet output for the thickness results. Please see the Complete Systems chapter for more information.

References

Li, Q., et al. (2010). Detection of physical defects in solar cells by hyperspectral imaging technology. *Optics & Laser Technology*, 42 (2010), 1010-1013.