Hyperspectral Thin Film Measurement System

Thin Film Measurement Using Spectral Interference Fringes

High technology industries use thin films extensively in a wide range of applications, including semi-conductors, sensors, optical detectors, photovoltaic devices, beam splitters, mirrors, anti-reflection coatings, and filters. Thin film characterization, including film thickness, refractive index, reflectivity and homogeneity, is therefore of great importance in many applications. 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 by 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 following equation:

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

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 above equation results in an estimate of a material's thickness assuming a constant index of refraction for the material. In cases where the material's index of refraction changes significantly over the wavelength range, one can use a more complex formula to compensate.

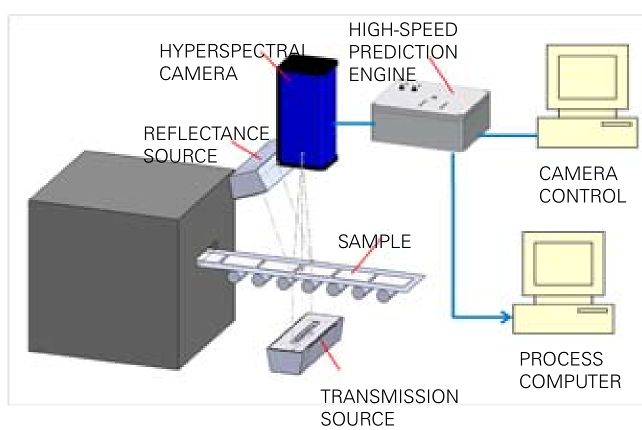
The same measurement and calculation of thickness can be performed using hyperspectral push-broom type cameras covering the whole surface of the samples. The result of the measurement is a hypercube of spectral data, with the full spectrum recorded for each point on the surface of the sample.

Hyperspectral Measurement System

The MRC-920-050 measurement system for industrial applications consists of a SWIR hyperspectral camera, a diffuse reflectance light source and a High-Speed Prediction Engine™ that is a designated high-speed computer for handling the large amount of data produced by the camera. The picture below depicts one possible configuration of the camera and Prediction Engine™ that would be mounted over the production line at the manufacturing site.

The samples to be measured are typically moved past the camera in a manufacturing setting by use of a continuous web or conveyor belt system. Samples must move at a constant rate in front of the camera in order to scan the whole surface. The camera simultaneously measures all of the spectra of the entire viewing line at a rate of 10-100 frames per second. The camera is controlled by the SpectralDAQ™ software and the camera output is fed into the High- Speed Prediction Engine™ optimized for the calculation of thickness at the speed of the camera video output.

Additionally, the thin film measurement system may be used in an at-line or laboratory setting by placing the measurement samples on a linear stage controlled by the camera and the SpectralDAQ™ software.



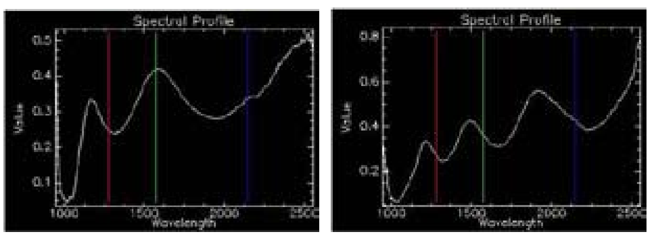
Different Wavelength Ranges

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 used for spectral regions from the UV to the infrared. However, calculation techniques and system arrangements are similar in all wavelength ranges.

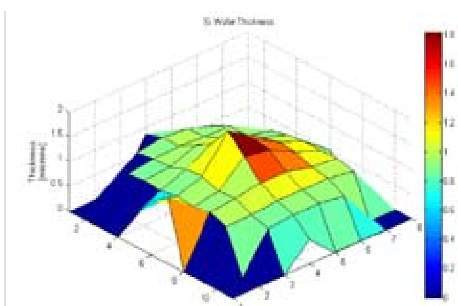
Camera Type	Detector	Wavelength
UV	UV-Silicon	200-400nm
Vis-VNIR	Silicon	400-1100nm
NIR	InGaAs	900-1700nm
SWIR	TE-MCT	970-2500nm

Full Surface Thickness Measurement

As an example, a 4" diameter silicon wafer with a thin but non-uniform diamond coating was placed on the linear sample stage of a Specim 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 below, whereas the thicker layer produced fringes closer together as seen in the second spectrum shown below.

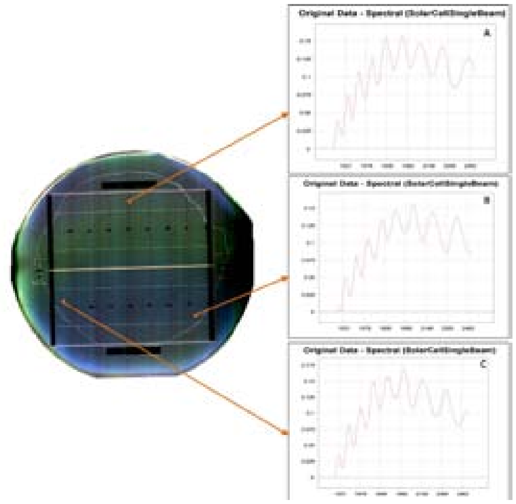


Thickness was calculated using the generic formula shown earlier. The diamond coating on the wafer used in this example was very uneven, with the layer being much thicker towards the center. The following surface plot displays a grid of varied thicknesses, indicating that the layer at the center of this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



Thickness Measurement Example

Hyperspectral imaging can be used to measure the thickness of materials such as amorphous silicon, copper indium gallium selenide (CIGS), or protective films used in photo-voltaic solar cell technology. To demonstrate this method, a solar cell wafer was imaged and several spectra from various points were used to calculate the thickness across the sample. The figure at the top of the next column displays spectra and the calculated thicknesses from three selected points on a solar cell wafer.



Solar Cell Wafer: Spectra from several points were used to calculate thickness of the sample. Calculated thickness at above points are: (A) 5.10 µm, (B) 6.39 µm, and (C) 5.25 µm.

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, designated real-time parallel calculating device. It includes an input specific to the type of camera used, options for taking reference measurements, and a simple USB output for the thickness results.

When the sample is a web, a film or a strip, the thickness data is displayed with dedicated display software communicating with the Prediction Engine.

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 20-100 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.

Specifications and Ordering Information

Please contact Middleton Research to discuss your specific application. Staff can assist with determining appropriate camera solutions and other system components for numerous wavelength ranges.