Application Note #583

Thickness Measurements of Opaque and Transparent Films or Coatings with WLI

Accurate control over film thickness and uniformity is essential for throughput and performance in the automotive, aerospace, semiconductor, medical, and research industries. The modern standard for 3D, non-contact measurements of surface topography and texture is white light interferometry (WLI), also known as coherence scanning interferometry (CSI). It is the only method that provides film thickness, coating uniformity information, and roughness of both film and substrate over large areas, all in a single measurement that takes only a few seconds to obtain. This application note describes film thickness metrology with WLI, particularly through-film measurements of transparent thick and thin films and opaque film step measurements.

Traditional Step Measurements for Thickness

The simplest method of determining thickness of opaque, non-transparent, or (sometimes) transparent films is by measuring a step from the top of the film to the bare substrate. The maximum measurable thickness is only limited by the profiler’s vertical scan length, which is up to 10 mm on Bruker WLI profilers. Minimum measurable thickness is 50–100 nm (below which most films are no longer opaque), depending on the film material. Automatic step measurement analysis with nanometer repeatability is a standard part of Bruker’s Vision64® analysis software.

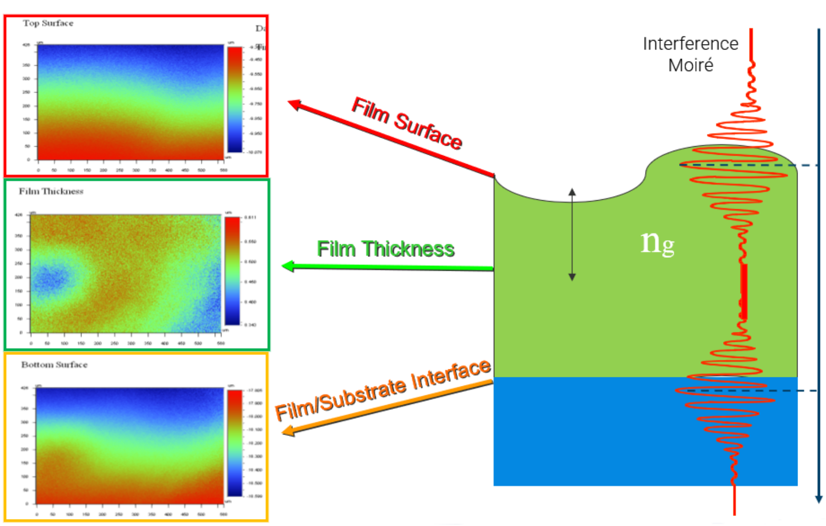

FIGURE 1

For each coating interface, fringes are formed at the top of the film and film/substrate interfaces as VSI scans down in measurement.

Through-Film Measurements of Thickness

The thickness of semi-transparent films can alternatively be obtained by measuring through the film to the substrate, which provides meaningful film measurements anywhere on the sample. Interferometric objectives employed in WLI measurements develop the moiré fringe envelope when passed through focus. Using a special Vertical Scanning Interferometry (VSI) measurement mode, an interferometric objective is translated vertically such that the upper and lower film surfaces pass through focus, causing an interference fringe envelope pattern on each coating surface. For each scan location in the field of view, two sets of interference fringes are developed for each camera pixel as the objective moves downward: one corresponding to best focus at the top of the film, the second corresponding to the film/substrate interface, as shown in Figure 1.

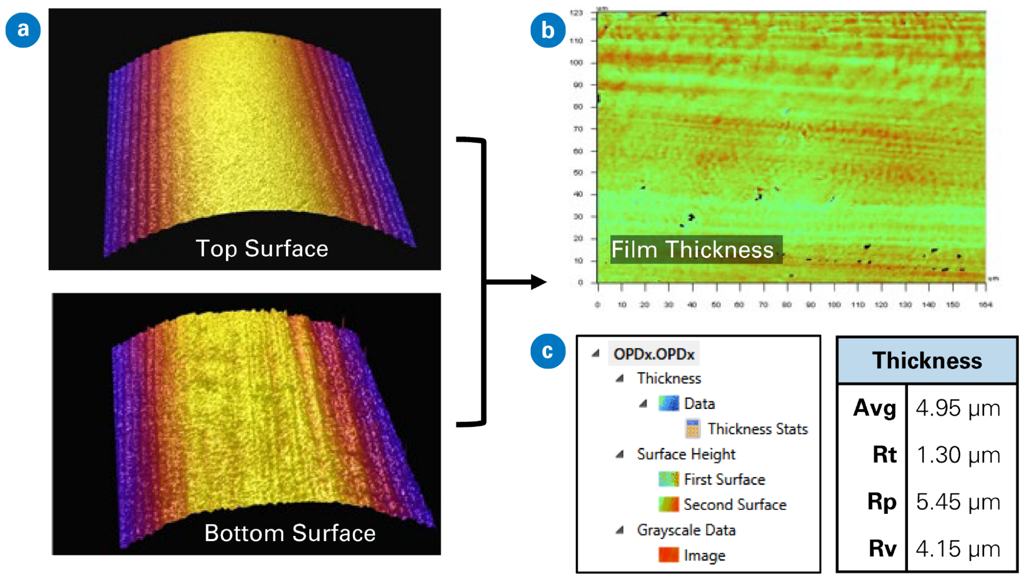

FIGURE 2

Cylindrical thick film analysis process: (a) top and bottom surfaces are measured, then (b) the cylindrical form is removed, and thickness is calculated with (c) the analysis tree to obtain thickness and surface finish metric outputs.

Choice of objective lens dictates measurable film thickness, both due to light penetration and fringe envelope separation. Lower magnification objectives have a lower numerical aperture (NA), meaning more vertical light enters the film and penetrates deeper, enabling thicker films to be measured. On the thin film side, 50x and higher objectives have a shorter depth of focus and higher NA, enabling resolution of small distances between the two fringe sets of films less than 2 µm thick. The thinnest films will have overlapping fringe envelopes regardless of objective choice, necessitating a dedicated thin film data analysis discussed later.

Transparent Films ≳2 µm (Thick Films)

Thick Film Analysis, a Vision64 software option, determines thickness based on the fringes and separation of fringe envelopes. The analysis first determines the vertical center of each fringe envelope, then calculates the distance between their centers for each camera pixel. This distance is divided by the film's index of refraction to determine an accurate thickness, as seen in Figure 3a.

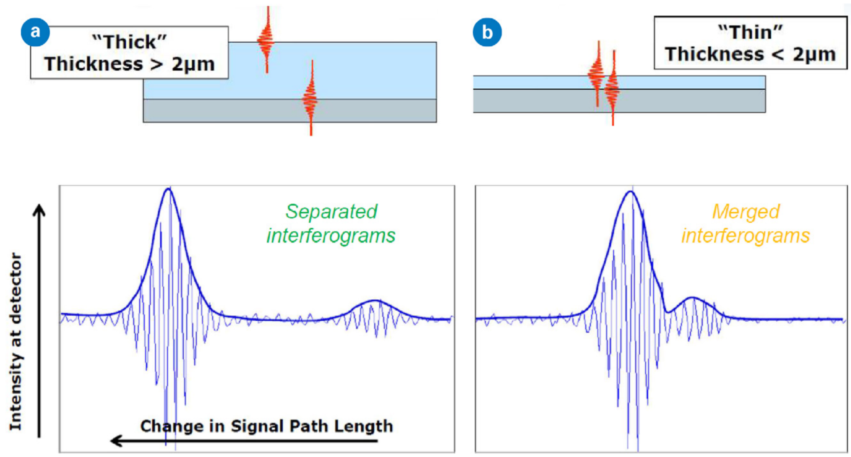

FIGURE 3

Fringe envelope using Thick Film Analysis for (a) >2 µm, where the envelopes are separated, and (b) <2 µm films, where the envelopes overlap and merge together.

Table 1 shows the results of ten measurement repeats for several semi-transparent films thicknesses. This data highlights the optical profiler's excellent repeatability and accuracy over the 3–26 µm thickness range for various magnifications over large lateral areas.

Thickness (nm)	Objective	Std Dev (nm)	Error (%)
3283	50x	1.2	0.04
11726	50x	8.7	0.07
16044	20x	13.8	0.09
2654	5x	13.0	0.05

TABLE 1

Repeatability for semi-transparent films using various objectives measured by the Thick Film Analysis.

For the analysis to determine thickness accurately, the film's index of refraction must be well-known, homogenous, and usually measured independently by such means as reflectometry. If the index is not known, the step measurement method from the film surface to the substrate is used and the index of refraction can then be back-calculated and entered.

Transparent Films <2 µm (Thin Films)

For films thicknesses less than approximately 2 µm where the fringe envelopes are almost merged (see Figure 3b) causing difficulties to distinguish them, the thin film measurement mode was developed for these challenging applications. *Thin Film* is a fringe-signal modelling algorithm using a merit function, which measures the agreement from the measured data and a built fitting model. The fitting model, as visually seen in Figure 4, is created by a measurement model from the bare substrate after selecting magnification along with the film and material calibration models provided within Vision64 for many common film and substrate materials.

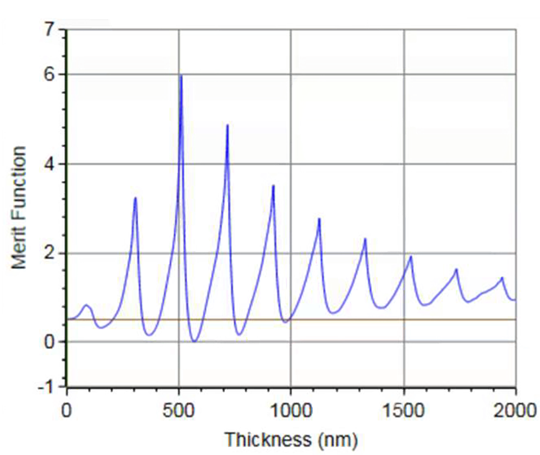

FIGURE 4

Example of a 600 nm thin film merit function model.

If a film model is not provided, customer-specific models can easily be constructed by creating a table with various *n* and *k* optical values for the wavelengths covered for the new coating material. Once proper thin film models are created for the materials to be measured, Vision64 can automatically measure and determine the film thickness with predetermined boundaries and has great correlation to calibrated thicknesses as seen in Table 2.

	Nominal (nm)	Measured (nm)	Error (%)
1	394	365	-7.4
2	499	498	-0.2
3	632	611	-3.3
4	731	721	-1.4
5	829	821	-1.0
6	929	925	-0.4
7	1023	1020	-0.3
8	1123	1120	-0.3

TABLE 2

Thin film measurement table for correlation of certified thicknesses measured from 400–1100 nm for SiO_2 film on Si.

Advantages of WLI for Film Thickness Metrology

WLI can be used to measure a large variety of film types and thicknesses, with either the step method or through-film measurements, and has a number of significant benefits:

- With through-film measurements, WLI measures film thickness for every camera pixel in the field of view, highlighting variations in thickness and uniformity across an area up to 15 mm in a single, quick measurement.
- Topography of both the film and substrate surfaces is returned, giving the most comprehensive view of coating uniformity and surface textures.
- A white-light interferometer's range extends to tens of micrometers using the thick film mode and 10 mm using the step measurement method.
- Optical profiling can characterize surfaces that many other techniques cannot reach, such as the inside of coated cylinders or the bottom of narrow trenches.
- Since WLI requires no sample preparation, the method offers non-contact, non-destructive analysis with immediate fast feedback.

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