Application Note for Industry

Multi-Layer Thickness Measurement
with Low-Coherence Interferometry

Keywords: thickness measurement, thickness profile, thin film coating, thick film coating, coating thickness measurement, 3D industrial inspection, low coherence interferometry, white light interferometry, fiber-based profilometry, hard-to-reach surfaces, tube dimensional measurement

Introduction

Low coherence interferometers deliver thickness measurements of materials and coatings in a variety of precision applications: the production and inspection of medical devices and optical lenses, quality control inspection of high grade thin tubing dimensions, inspection of thick film coating on MEMS devices, measurements of high grade glass and polymer components, etc.

A fiber-based optical profiler (profilometer) provides reliable non-contact thickness measurements for single layer and multilayer films. It scans at high speed (1-30k samples per second or higher) and measures with sub-micron precision. At each point, the profiler acquires the exact location of the upper and lower limit of every film layer. In addition to calculating the thickness of each film, it acquires the topography and roughness of all substrates. It is suitable for both lab and high-volume production setup.

How Multilayer Thickness is Measured

"Low coherence interferometry", also known as "white light" or "optical" interferometry, uses broadband light in the infrared range (1300 nm). The profiler splits a single source light into two paths, directing one beam to a sample surface (Figure 1a) and the other to a reference mirror. Light signals returning from the sample and reference arms are recombined, causing a pattern of signal interference, which is recorded in the form of an interferogram (Figure 1b).

The profiler software optically separates and analyzes the interferogram peaks. It uses each material's index of refraction to calculate the layer thickness. If desired, the upper and lower surfaces of each substrate can also be characterized and imaged and their roughness calculated.

Fiber-based Profilers vs. Full-field Profilers

Optical profilers can be full-field (microscope-like) or fiber-based. A full-field profiler is limited to inspecting stationery samples that fit onto its stage. It acquires one small area at a time. For bigger areas, the images must be stitched together.

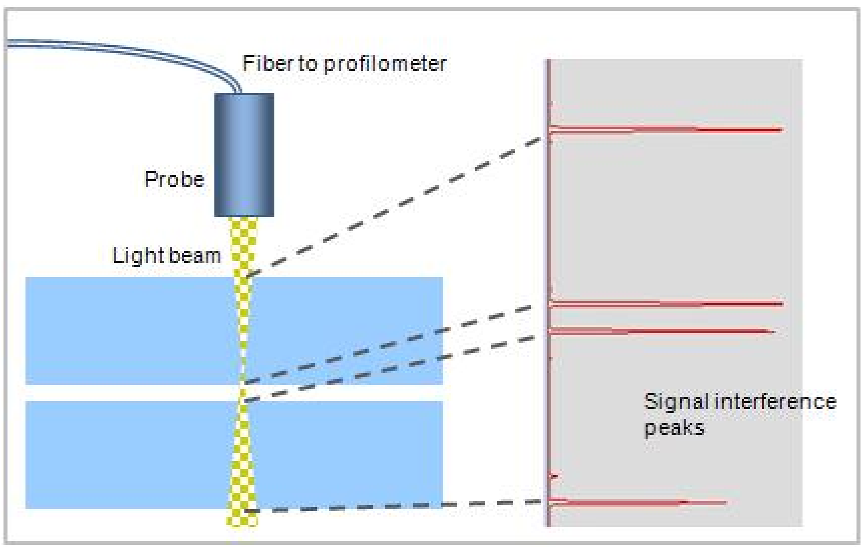

Figure 1: Multi-layer film scanning
a) Optical probe scans through two sheets of glass (each 0.95 mm thick) separated by a 0.2 mm air gap. Total optical length is 4 mm.

b) Interferogram

Interference peaks (fringes) occur at the interfaces of substrates, where the index of refraction changes. The height of each peak is proportional to the magnitude of change of index of refraction. Two adjacent peaks locate the top and bottom of each substrate. Optical thickness can be calculated.

In a fiber-based profiler, light is emitted and collected by a minute non-contact probe that can be located far from the interferometer enclosure. The probe acquires one sample point at a time (at 1,000-30,000 samples per second) and is displaced with a positioning mechanism to acquire an entire profile or surface.

Fiber-based profilometry offers significant advantages:

- hard-to-reach surfaces, such as the insides of narrow tubes or cylinders, become measurable with a suitable rotation and pullback mechanism.
- moving surfaces are measured continuously and in real time since the probes acquire long profiles and scan at high speed, at a standoff distance of up to 150 mm. Examples include multi-layer sheet webs on production lines, exteriors of rotating cylinders or surfaces of molten or evaporating materials.
- multiple probes attached to a single profiler may be time-multiplexed by use of an optical switch, such that thicknesses are measured in multiple locations simultaneously, thus lowering the cost for multiple units.
- the probes operate even in unfriendly environments – radioactive or high vacuum chambers, or in extreme temperatures, ranging from cryogenic to very hot.
- A fiber-based optical profiler is also practical for measuring thicknesses of opaque coatings when combined with LIBS technology.

Data Processing

The profiler processor application software converts optical interference data into micron-precision thickness measurements. In production context, this stream of data is typically forwarded to process control software. Statistics on thickness measurements can be calculated in real time.

Scan Depth and Precision

The optical profiler probe scans through objects from 10 µm to 8 mm thick, with a vertical resolution better than 1 µm. This is superior to ultrasound scanning, which reaches the precision of only 30 to 100 µm. Coatings thicker than 8 mm can be measured by combining measurements of multiple optical probes.

Acquiring Thin Tube Dimensions

A thin tube, such as a medical catheter (<1.5 mm thick), is an excellent candidate for multi-layer optical profiling. When a probe is displaced transversally over the tube as in Figure 2a, the tube cross-section profile can be captured and defects detected. The tube dimensions acquired from this setup are listed in Table 1.

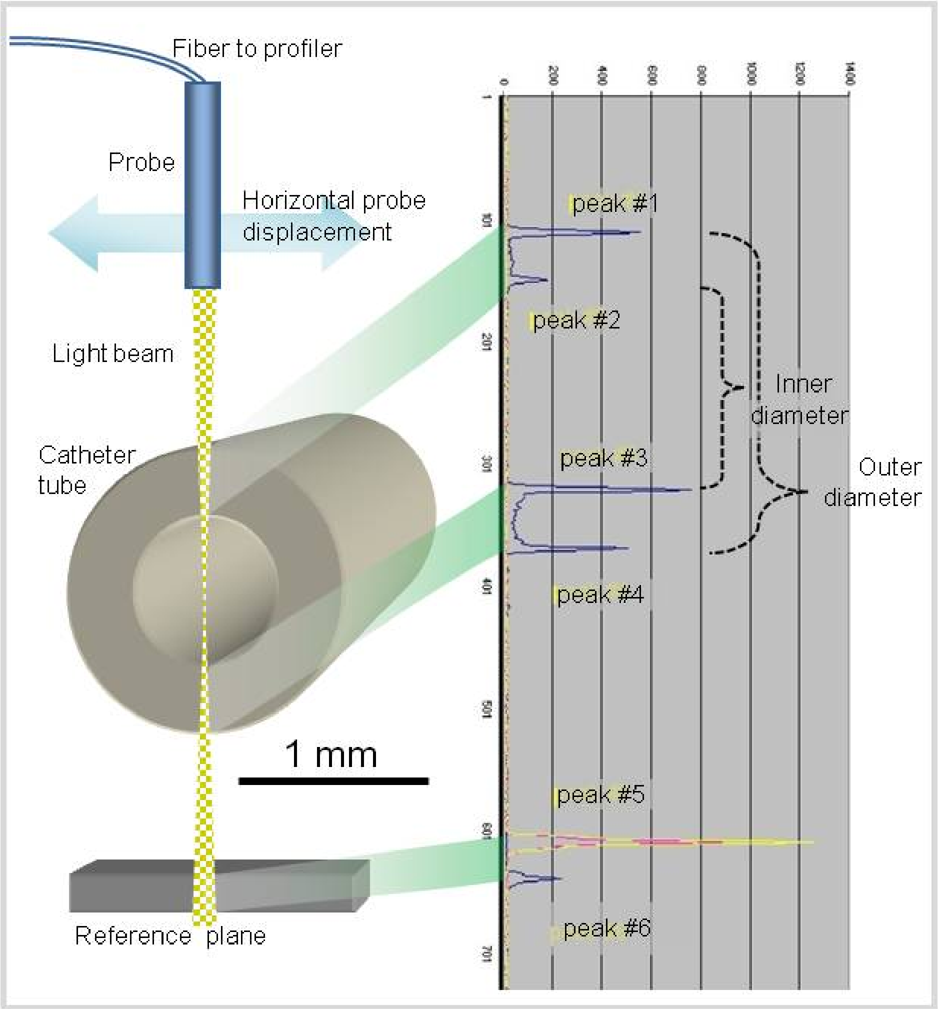

Figure 2: Cross-sectional scanning of a thin catheter tube
a) Probe setup*
b) Interferogram showing interference signals from the midpoint of the tube

*If, as in this installation, a reference plane is set up and scanned at the same time as the object, both the thickness and the index of refraction may be captured in a single measurement.

Catheter Tube Dimensions	Measurement
thickness of upper wall	0.131 mm
thickness of lower wall	0.162 mm
inner diameter	0.852 mm
outer diameter	1.145 mm
calculated index of refraction (at 1300 nm)	N=1.512

Table 1: Catheter tube measurements

To inspect tube dimensions continuously at production time, two fixed probes may be set up near an extruder exit (Figure 3). Scanning in two planes simultaneously gives sufficient optical information to verify, in real time, the uniformity of wall thickness and of the tube's inside and outside diameters. This allows operators to adjust production parameters quickly if pre-set uniformity limits are trespassed.

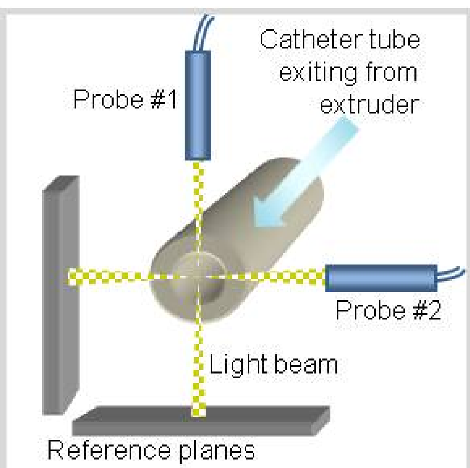

Figure 3: Double probe configuration for long profile scanning of an advancing catheter tube, at point of extrusion.

Figure 4: Profile of 6"diameter wafer with unevenly applied thick film of photoresist coating (~250 µm thick, equivalent to approx. 400 µm optical thickness). The x:y aspect ratio is 10:1.

Measuring Thick Film Photoresist Coating

Photoresist is generally applied onto electronic wafers by spray coating or spin coating. In either case, its thickness uniformity is critical to avoid subsequent under- or overexposure to UV radiation during the patterning process of photolithography.

A fiber-based optical profiler measures film thickness of up to several millimeters, surpassing ellipsometers, whose thickness measuring tops out at 250 µm. The profiler provides micron-precision thickness measurements as well as surface roughness analysis and imaging (Figure 4). Measurements are obtained in real time, even possibly during coating application.

Inspecting Optical Lenses

To inspect an intraocular lens or a contact lens the profiler provides a cross-sectional image (Figure 5) and calculates material thickness at any point desired. It can show volume density maps and 3D isosurfaces. The results can be analyzed for cracks, bubbles and other defects, and lens

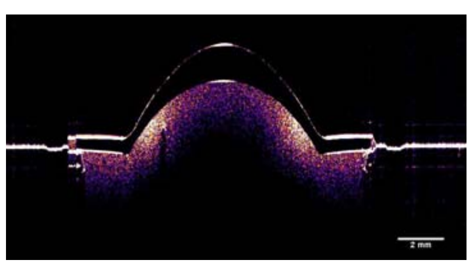

Figure 5: Cross-section image of an intraocular lens on its supporting lower mold

curvatures can be calculated.

Measuring Thick Film in Evaporation Chambers

Radiography plates and electronic wafers are commonly coated with a thick film of a semi-conductor (e.g. amorphous selenium) or metal (e.g. aluminum or gold). Even a micron imprecision of the thickness measurement is costly in this process as plates with too thin a coating are discarded, whereas unnecessarily thick coating is wasteful and expensive.

To achieve uniform coating, manufacturers install plates or wafers on a rotating mechanism inside a vacuum evaporation chamber, which contains the material to be evaporated. Gradual heating of the chamber induces evaporation and deposition on the plates. The thickness of the coating, and therefore the stopping point of the deposition process, are estimated from the rate of deposition, resulting in occasional costly waste.

A fiber-based optical profiler replaces thickness estimation with a reliable high-precision measurement. With the non-contact probe, which scans surfaces up to 150 mm away from its lens, there are options even for this hostile environment. A probe can be positioned outside the chamber to measure through its window.

Alternately, it can be inside the chamber, protected by an extra glass plate. The profiler thus scans the rotating plates, measures the deposition thickness, and determines the optimal process stopping time.

Multiple probes may be attached to a single interferometer through time-multiplexing with an optical switch. By offering simultaneous measurements in multiple locations, such a setup lowers the cost per inspection unit.

Finding Hidden Defects in Balloon Catheters

Cardiologists use balloon catheters (Figure 6) in vascular procedures, such as coronary angioplasty. Production quality controls are of paramount importance during catheter-balloon assembly. For example, manufacturers must guarantee extremely high quality of adherence between the catheter surface and the tail of the balloon. An optical profiler delivers high precision imaging and measurements of the balloon-catheter connection, facilitating detection of joint defects.

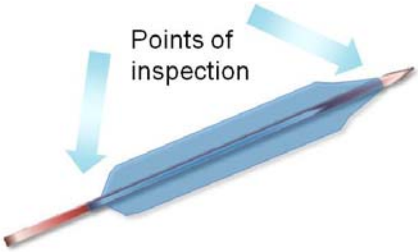

Figure 6: Balloon Catheter

Using LIBS with Fiber-based Profilometry to Measure Opaque Coating Thickness

Laser-induced breakdown spectroscopy (LIBS) is a technique used to identify the atomic structure of a sample. A LIBS device pulses a powerful laser beam focused on a sample. It vaporizes some material and then performs spectral analysis on the resulting plasma. Fiber-based profilometry can be used in conjunction with LIBS to measure the depth to which material has been removed. Since the light sources used for both techniques are in the same range, customized devices have been constructed using a common light path configuration. These devices are ideal for measuring thicknesses of non-transparent coatings.

Conclusion

Fiber-based optical profilers are in demand for their high speed, sub-micron precision, reliability, and versatility of installation. New applications for this technology are constantly emerging, and include measurements of:

- medical coating
- semiconductor coating
- conformal coating
- fuel cell coating
- solar cell coating
- high grade glass such as in the optical industry
- multi-layer plastics and films
- high grade (single layer or multilayer) polymer tubing
- BoPET film
- multi-layer lid stock: OPET films, adhesive layers, heat-seal films
- cast film
- multi-layer label stock

Novacam encourages technicians and engineers in charge of coating or similar applications to send us component samples for measurement.

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