Coherence Correlation Interferometry (CCI)

Accurate measurement of optical coating thickness

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Introduction

Most optical coatings are used to enhance reflection or transmission properties of a substrate material within an optical system. They usually consist of one or more thin layers of various materials in order to achieve the desired reflection/transmission ratio. These layers are deposited on an optical component such as a lens or mirror. The performance of an optical coating is dependent on the number of layers, the thickness of the individual layers and the refractive index difference at the layer interfaces. The optical coatings used on precision optics fall into a number of categories such as anti-reflection coatings, high-reflection coatings, beamsplitter coatings, filter coatings, extreme ultraviolet coatings and transparent coatings.

Optical coatings are used widely in numerous technologies and the list of applications is growing all the time. Typical applications include coated spectacles, camera lenses, LCD screens, mobile phones and astronomical telescopes. For example, most flat panel displays including LCD, OLED, and many other display technologies employ transparent conductive oxides (TCOs) to transport current. It is very important to measure the thickness of liquid crystal layers and for OLED displays the layers such as emissive, injection, buffer, and the encapsulation layer.

In addition, it is very important to minimise the coating thickness so as to reduce mechanical stresses that might distort the optical surfaces or cause detrimental polarization effects for optimizing the optical design. For anti-reflection coatings, the layer thickness must be an odd number of quarter wavelengths in order to eliminate the reflections at a specific wavelength.

Ever-increasing demands are leading to advances in optical coating techniques. It is essential to control both thickness and uniformity for most optical coatings in order to ensure the quality, efficiency and function of optical devices. An accurate and fast metrology tool is therefore essential.

A number of metrology tools have been employed to measure film thickness. These include conventional methods of spectrophotometry, ellipsometry, and physical step measurement[1]. Coherence Scanning Interferometry (CSI) is becoming a popular technique because of its high lateral resolution and speed. However, one of the limitations of traditional interferometry is the thickness of the coating that can be measured. Typically it needs to be larger than 1.5 μm to obtain accurate data. It is now possible to measure thicknesses down to 50 nm or less using Coherence Correlation Interferometry (CCI)[1] together with HCF (Helical Complex Field)[3] techniques. Other methods have also been used to investigate film thickness, for example wavelength scanning interferometry, prism coupler and thermal wave detection with a laser beam[1].

> *"It is essential to accurately control both thickness and uniformity for most optical coatings to ensure the quality, efficiency and function of optical devices. Coherence Correlation Interferometry (CCI) provides exceptional accuracy over a wide range of film thicknesses."*
>
> **Dr Yang Yu, Applications Scientist, Taylor Hobson Ltd.**

Applications

Optical coatings are significant in wide range of technologies. Typical applications include LCD screens, camera lenses, coated spectacles, mobile phones and astronomical telescopes.

Coherence Correlation Interferometry (CCI)

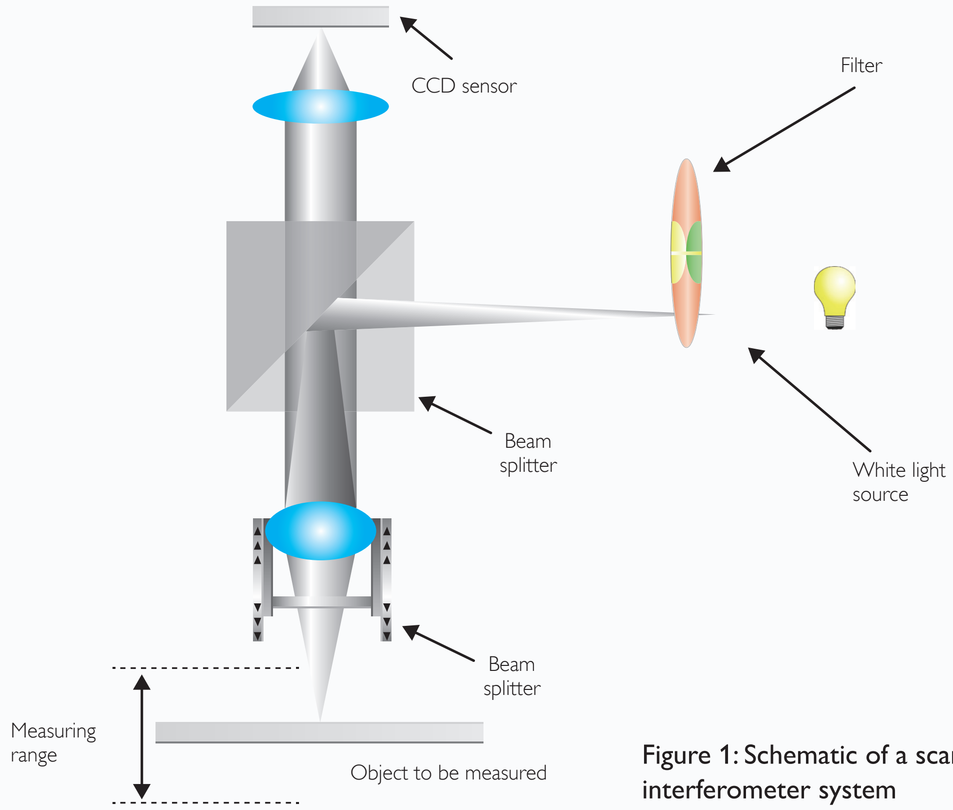


Figure 1: Schematic of a scanning interferometer system

> *"The wide variety of industrial applications mean that Coherence Correlation Interferometry is increasingly important"*
>
> **Dr Mike Conroy, Business Development Manager, Taylor Hobson Ltd.**

A schematic of a scanning interferometer system is shown in Figure 1. Light from the light source is directed towards the objective lens by the upper beam splitter and the light is then split into two separate beams by the lower beam splitter.

One beam is directed towards the sample and the other is directed towards an internal reference mirror. The two beams recombine and are sent to the detector. As the interferometric objective is scanned in the z direction, interference occurs when the path lengths of the two beams are the same. The detector measures the intensity, taking a series of snapshots as the sample is measured.

This creates an intensity map of the light being reflected from the surface, which is then used to create a 3D image of the surface being measured. Different techniques are used to control the movement of the interferometer and also to calculate the surface parameters. The accuracy and repeatability of the scanning white-light measurement are dependent on the control of the scanning mechanism and the calculation of the surface properties from the interference data.

Coherence Correlation Interferometry[1] is becoming increasingly important for measurements in many applications, providing:

- Fully automatic non-destructive measurements
- Accurate and quantitative characterization of surfaces
- Sub-angstrom resolution regardless of the scanning range used
- Fast and convenient sample loading and set-up
- Capability of measuring a wide range of materials
- Highly repeatable measurements
- Roughness and step-height analysis in one measurement
- Film thickness and interfacial surface measurement capability

Measurement of film thickness

"With up to 4 million camera pixels with sub-nanometre vertical resolution and less than 1 µm lateral resolution it is now possible to measure thicknesses down to 50 nm or less using the CCI Optics with patented film thickness software[4]"

Dr Daniel Mansfield, Research Manager and Company Physicist, Taylor Hobson Ltd.

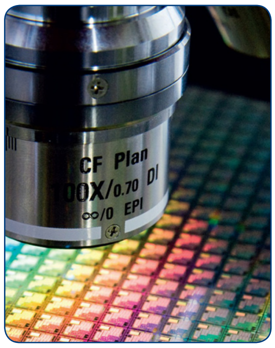
An important extension of interferometry is the ability to measure film thickness. When the interference signals appear at the surfaces of films a special algorithm is used so that the film thickness can be extracted from the interferogram. In some cases the surface information can also be obtained.

The advanced CCI Optics has 4 million camera pixels and each individual pixel will act like its own 1 µm optical probe enabling high speed measurement of multiple film thicknesses with an independent thickness measurement at each point (Figures 2 and 3).

The combination of film thickness software and Coherence Correlation Interferometry (CCI) gives unrivalled thin film measurement capability.[1]

Figure 2: The CCI Optics

Figure 3: CCI Optics close-up



CCI technology provides two different film thickness measurement solutions:

- Thick film (> 1.5 microns)
- Film thickness analysis (down to 50 nm or less)

Traditional thick film measurement

When the thickness of a film is larger than ~1.5 µm (depending on refractive index), SWLI interaction with the layer results in the formation of two fringes, each arising from a surface interface (Figure 4).

The thickness of the film can be determined by locating the positions of the two maxima and applying the refractive index. In addition, the surface information of the two interfaces (air/film and film/substrate) can be obtained from the individual fringes (Figure 5).

Figure 4: Single pixel measurement from a 7 µm thick film

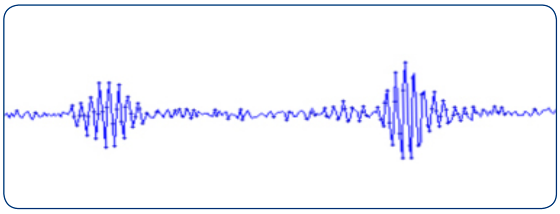
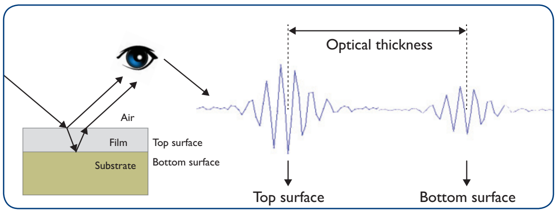


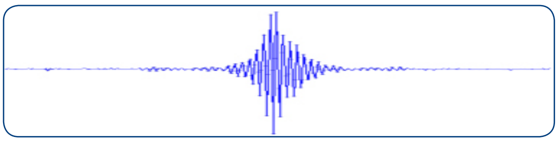
Figure 5: Determination of film thickness



Thick film limitations

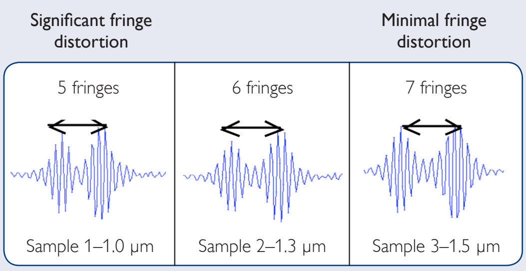
As the thickness of the film decreases, the two fringes become closer and overlap until they appear as a single interference fringe bunch. (Figure 6).

Figure 6: Single pixel measurement from a 270 nm film



For thicknesses of films less than 1.5 µm (depending on refractive index), thickness cannot be extracted using the thick film technique due to the distortion of the fringes (Figure 7). An alternative method has to be employed.

Figure 7: Single pixel fringe for each sample



Fringe distortion increases significantly for film thicknesses below ~1.5 um. This has the effect of displacing the peaks, making it impossible to establish the true thickness of the film using traditional thick film analysis.

Film thickness analysis – the solution

A new solution to this problem (HCF)[3] has been developed to extract the film information. Through the application of the HCF function, Coherence Correlation Interferometry (CCI) has become the ideal method to obtain film thickness information. HCF can be used for thickness measurement with better than 1% accuracy within the range of ~ 5 µm to ~ 300 nm. Film thicknesses down to 50 nm have been measured; however, care needs to be taken with these very thin films as the accuracy depends on the optical properties of the material.

Tests of optical coating using Coherence Correlation Interferometry (CCI)

Tantalum pentoxide (Ta_2O_5) was selected for the tests as it is a typical surface coating material used in the optical industry. It has the required properties of high-index and low-absorption for optical coatings, usable in the near-UV (350 nm) to IR (~8 µm) wide regions. It can sometimes be with silicon dioxide (n = 1.48) for UV laser applications. It is also suitable for hard, scratch-resistant and adherent coatings.

A sample was prepared of BK7 glass partly coated with Ta_2O_5 (nominal thickness 270 nm). This sample was chosen because it would be expected that the standard CCI step height measurements should give an accurate measurement of the film thickness.

Comparison results of film thickness measurement and standard CCI measurements

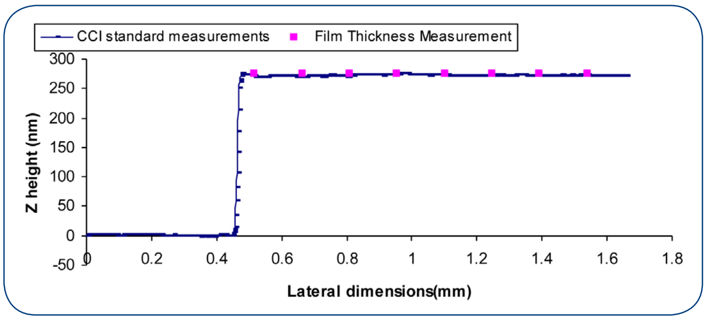


Figure 8: Graph comparing standard CCI measurement data with thin film measurement of Ta_2O_5 thin film coated on BK7 glass

A series of film thickness measurements (HCF) were made on the Ta_2O_5 coating where close to the intersection line between the coating and the glass, in order to compare with a standard step height measurement. As expected, the results of film thickness measurement (HCF) well agree with the step height measurement.

The results show that the HCF technique is ideal for measuring optical film thickness where no substrate exposed, and is an ideal way to measure the film thickness uniformity across a coated surface.

Conclusions

The development of the Helical Complex Field (HCF) functioning together with Coherence Correlation Interferometry provides us with the ideal metrology tool to perform fast and accurate measurements of coated optical surfaces.

Acknowledgments

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