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Measuring Thicknesses of Films by Optical Coherence Tomography (OCT)

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Abstract

Optical coherence tomography (OCT) is a powerful optical method, noninvasive and noncontact diagnostic method. Although it is usually used for medical examinations, particularly in ocular exploration; it can also be used in optical metrology as measure technique. In this work, we use OCT to measure thicknesses of films.
In OCT, depth profiles are constructed by measuring the time delay of back reflected light by interferometric measurements. Frequency in *k*-space is proportional to optical path difference.
Then the reflectivity profile is obtained by a Fourier transformation, and the difference between two successive peaks of the resulting spectrum gives the film thickness.
Several films, food-type, of different thicknesses were investigated and the results were very accurate.

Keywords: OCT, Optical metrology, Nondestructive testing, Film thickness.

1. Introduction

The tomography is an imaging technique, which consists of reconstructing the volume of an object from a series of remote measurements outside the object. These measurements may be made at the surface or at some distance. The result is a reconstruction of certain properties within the object, depending on the type of information that provide sensors (optical, ultrasonic ...) (Drexler W., 2008), (Fercher A. F., 2009).

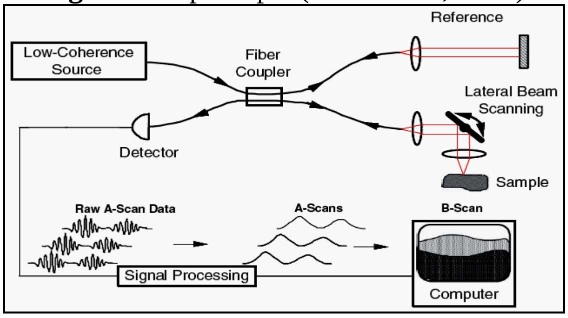
Tomography, a mathematical point of view, is divided into two stages. Firstly it requires a direct model, i.e. a model of physical phenomena measured. The inverse model or reconstruction is then rendering the three-dimensional character, based on the results of the direct model (Koprowski R., 2011).

2. Principle of OCT

The optical coherence tomography (OCT), comparable in its principle to ultrasound imaging, is a non-destructive imaging technique based on the use of optical sources with low temporal coherence, provides high-resolution microstructures profiles embedded in materials or biological tissue (Zysk A. M., 2007). Optical coherence tomography uses infrared light, where photons can pass through the material medium and highlights in sufficient numbers to be exploited. Thus, OCT is a method performed without contact, non-invasive, and with high spatial resolution.

Most OCT systems are based on the Michelson interferometer described in figure 1.

Fig-1. OCT principle (Drexler W., 2008)



A light source with spectral width Δλ and central wavelength λ_0 sends a light beam onto a separator which divides it into two sub-beams. One beam is directed onto a reference mirror and the other to the test sample. The two reflected beams recombine and interfere when they return to the separator. An OCT signal is generated when the reference mirror is axially moved. If the light source is low coherence, the detector will distinguish intensity fluctuations when the distances traveled by light in the two arms are nearly equal. Thus, each "element" within the sample retransmits an OCT signal detected by a suitable length of reference arm, a cutting depth is obtained in the sample when the reference mirror is scanned .In the case of a Gaussian spectrum source, the FWHM *lc* of the OCT signal is inversely proportional to the spectral width of the source, that defines the coherence length of the source:

$$l_c = \frac{2\ln 2}{\pi} \cdot \frac{\lambda_0^2}{\Delta\lambda \cdot n} \tag{1}$$

Where *n* is the refractive index of the medium.

This parameter is of fundamental importance because it represents the OCT depth resolution of a profile. The transverse resolution is determined by the used lens (objective). By the principles of Gaussian optics, the transverse resolution can be determined as follows:

$$\Delta z = \frac{4\lambda_0}{\pi} \cdot \frac{f}{d} \tag{2}$$

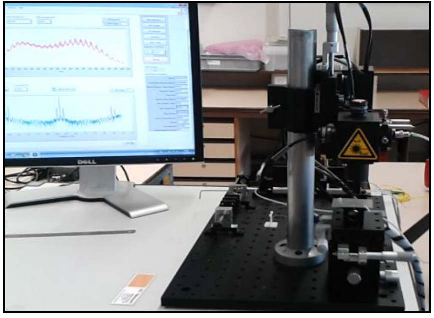
Where *f* is the focal length, *d* is the diameter of the beam incident on this objective.

While improving the transverse resolution is relatively easy (just increase the numerical aperture), the axial resolution requires increasing the bandwidth of the source.

3. Experimental Work

The picture below illustrates OCT device used for our measurements.

Figure-2. OCT setup



The procedure is to record four OCT signals that must be treated to achieve the investigated film thickness. These are:

- “Dark” signal, obtained by closing the object and reference arms which defines noise level in the OCT system.

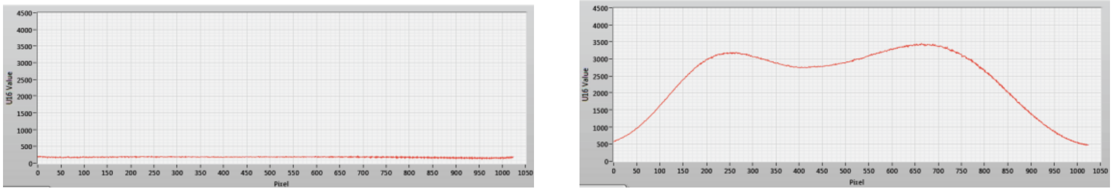
– Reference signal, obtained by obstruction of the object beam.
– Object signal, obtained by the reference beam obstruction.

A treatment under integrated LABVIEW environment, after subtraction of the "Dark" signal, enables us by combination of object and reference signals, to determine the OCT resultant (or interference) signal.

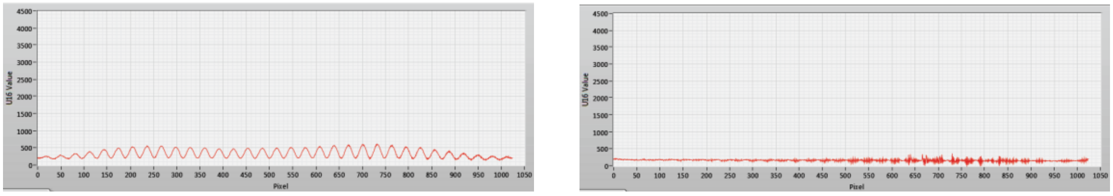
By applying the Fourier transform to the resultant signal, the emerging peaks define the spatial variation of reflections by the front and rear surfaces of the film respectively and of course the desired thickness.

Three transparent films of different color and thicknesses are studied.
Below, and as an example, the signals mentioned above are recorded for the colored film (red film).

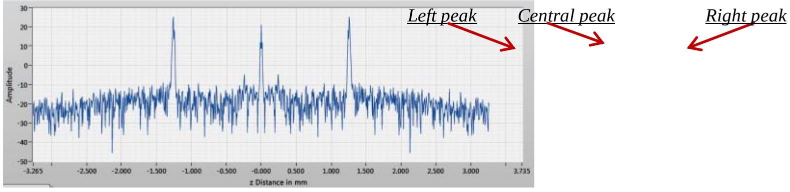
Fig-3. Recording signals related to the colored film



(a) Dark signal (b) Reference signal



(c) Object signal (d) Resultant signal



(e) Resultant signal in Spatial Domain (k-space)

The thickness is defined by the difference of the respective positions of an extreme peak and the central peak. In this case the thickness is 210 µm.
By the same treatment we obtain for the other two films the following results:

Fig-4. Resultant signal in k-space for the transparent film (thickness=13 µm)

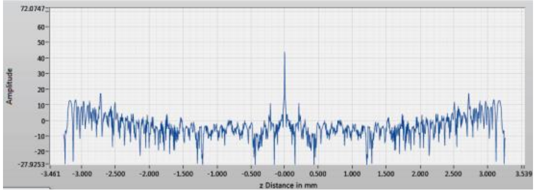
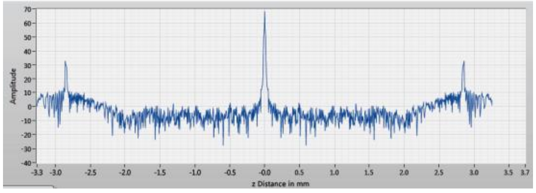


Fig-5. Resultant signal in k-space for the Cellophane (thickness=175 µm)



4. Conclusion

OCT is an effective and reliable technique that can be used in metrology, as we have just seen for the measurement of thickness. We have seen that the frequencies in k-space is proportional to the difference of the optical path traveled by light test, then the “measurand”, which is the thickness in our case, is too. And therefore the measurement is accurate.

In the other hand, to control the uniformity of the thickness, a transverse scan so called B-scan, is completed.

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