Wavelength scanning interferometry for measuring transparent films of the fusion targets

F. Gao*, X. Jiang, H. Muhamedsalih and H. Martin
Centre for precision Technologies, University of Huddersfield, Huddersfield, HD1 3DH, UK

Abstract

Wavelength scanning interferometry is an effective method for the measurement of both engineering surfaces and structured surfaces. Currently its main applications in surface metrology are limited primarily to surfaces with reflections occurring from the uppermost of the surfaces. When a transparent thin film is measured by wavelength scanning interferometer the reflection signals from both top and bottom surfaces of the film will interfere with the reference signal. At the same time the reflected signals from these two surfaces will also interfere with each other. Effective separation of the interference signals from each other is the key to achieving a successive measurement of the film. By performing an frequency-domain analysis to separate and reconstruct these interference signals, the measurement of the top and the bottom surface finishes of the film as well as the film thickness map will be achieved. In this paper theoretical analysis of wavelength scanning interferometry for transparent film measurement is discussed. Experiments with thin film layers of Parylene N coated on glass slide surface, which are provided by the HiPER target fabrication group are studied and analysed.

Keywords: Wavelength scanning interferometry, thin film, surface finish, frequency-domain analysis.

1. Introduction

Thin films are widely used in optics, semiconductor and materials industries to provide specific functions to the coated devices. Effective measurement of film thickness and refractive index of the films are important factors which determine the function and performance of a coated device. Conventionally the film thickness and refractive index are measured by spectral photometry or ellipsometry methods [1, 2]. Both methods can only measure film thickness at the sampling points. Recently, scanning white light interferometry has been extended in its application from surface measurement to film thickness measurement. It can measure the surface finishes of a film as well as film thickness over the whole measurement field [3-5].

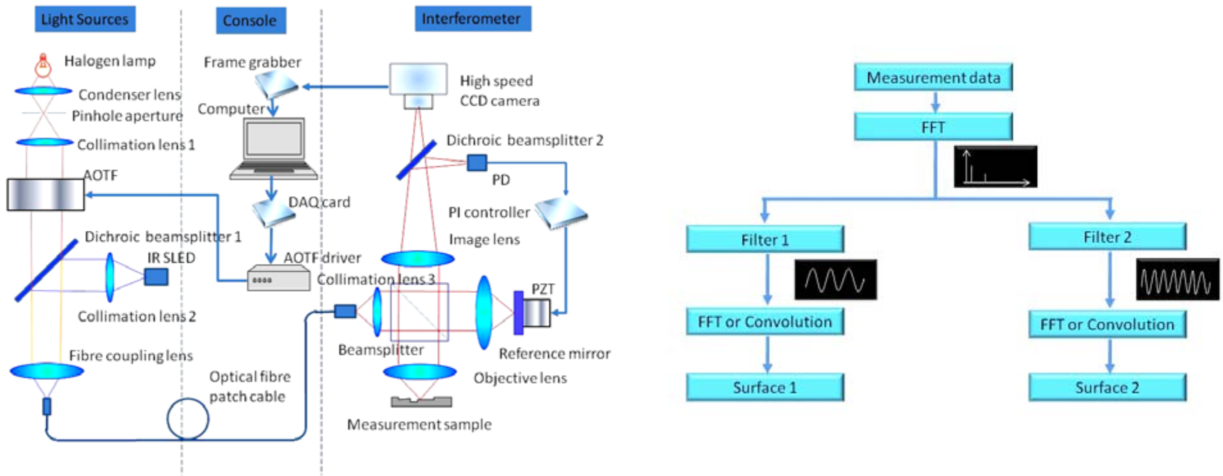
In the European high power laser energy research facility (HiPER) the surface finish on both top and bottom surfaces of a Parylene N film layer as well as its thickness are critical for applications such as the manufacturing of cryogenic target capsules. In order to achieve a fusion reaction all the target capsules are expected to be measured accurately before been filled with deuterium/tritium fuel mix and propelled into the reaction chamber. To perform the measurements quickly efficiently is one of the keys issues for realising a sustained, controlled

* Corresponding author. Tel.: +44 1484 472769; fax: +44 1484 472161.
E-mail address: f.gao@hud.ac.uk (Feng Gao)

fusion reaction. In most cases thin film measurement methods using optical interferometry are only interested in film thickness measurement [6]. The interference signals are created by the two interfaces of the film. It cannot satisfy the above demands. Wavelength scanning interferometry (WSI) is an effective method for surface measurement of engineering surfaces and structured surfaces [7]. Currently its main applications in surface metrology are limited primarily to surfaces with reflections occurring from the uppermost surfaces. When a transparent thin film is measured by wavelength scanning interferometer the reflection signal from both top and bottom surfaces of the film will interfere with the reference signal. At the same time the reflection signals from these two surfaces will also interfere with each other. Effective separation of the interference signals from each other is the key to achieving a successful measurement. By performing an extensive frequency-domain analysis to separate and reconstruct these interference signals, the measurement of the top and the bottom surface finish of the film as well as a film thickness map can be achieved.

2. Measurement principle

Figure 1(a) shows the measurement system which is composed of two interferometers that share a common optical path. A measurement interferometer illuminated by a white light source is used to acquire three dimensional surface data of the sample in real time. A reference interferometer illuminated by an infrared (IR) Super-luminescent Light Emitting Diode (SLED) is used to monitor and compensate the environmental disturbance to the normal direction of the system. An Acousto-Optic Tuneable Filter (AOTF) is implemented to select the source light wavelength to the interferometer. The interferogram of the filtered light is detected by the CCD camera.



(a) (b)

Fig. 1. (a) schematic diagram of the WSI system; (b) data processing chart to separate and reconstruct the two film surfaces.

The selected light wavelength is determined by

$$\lambda = \Delta n \alpha \cdot {}^{v_a}\!/\!{}_{f_a} \tag{1}$$

where Δn is the birefringence of the crystal used as the diffraction material, α is a complex parameter dependant on the design of the AOTF. v_a and f_a are the velocity and frequency of the acoustic wave, respectively. The wavelength of the light that is selected by this diffraction can therefore be varied simply by changing the driving frequency, f_a As a result, different wavelengths of light will pass through the AOTF in sequence so that a series of interferograms of different wavelengths will be detected by the CCD. The absolute optical path difference (OPD) is given by

$$h(x,y)=\frac{\Delta\varphi(x,y,\Delta k)}{2\pi\Delta k} \quad (2)$$

where $h(x, y)$ is the OPD on pixel (x, y) , k is the wave number which is the reciprocal of wavelength. It can be calculated in real time through analyzing interferogram captured by the CCD by means of FFT analysis or convolution [7-8].

For the WSI system, reflected signals from both top and bottom surfaces of a film can produce interference signals with wavefronts from a reference as well as each other. Effective separation and identification of the interference signals is the key to film thickness and coating surface measurement. Figure 1(b) shows the analysis method that was used for separating the two surfaces of the film and reconstruction of the surfaces. First, FFT analysis was used to ascertain the two dominant frequencies in the captured data. Then the captured data were filtered with two band-pass filters designed according to the FFT analysis results. By applying the filters to the measured signal, interference signals between the reference mirror and both the top and bottom surfaces of the film can be separated. The separated signals can be used to reconstruct the surface topography of the top and bottom surfaces.

3. Measurement results and discussion

A Parylene N film with 10 µm nominal thickness, provided by the HiPER target fabrication group was measured by WSI. The film is coated onto a glass microscope slide with a refractive index of 1.51. Parylene N is a polymer which is highly crystalline material. It is a primary dielectric, exhibiting a very low dissipation factor, high dielectric strength, and a dielectric constant invariant with frequency [9]. It is widely used as thin film coating material. The refractive index of the Parylene N film is 1.661. In order to make the measurement results more assessable a cut was made to the sample to form a step of the coating film on the glass substrate. A measurement on the edge of the step was made by WSI. A measured image is shown in figure 2(a). A measured interferogram on point A of the Parylene N film surface is shown in figure 2(b). This interferogram contains all the interference information between the reference mirror and the two film surfaces. Figure 2(c) shows the interferogram on point B of the glass substrate.

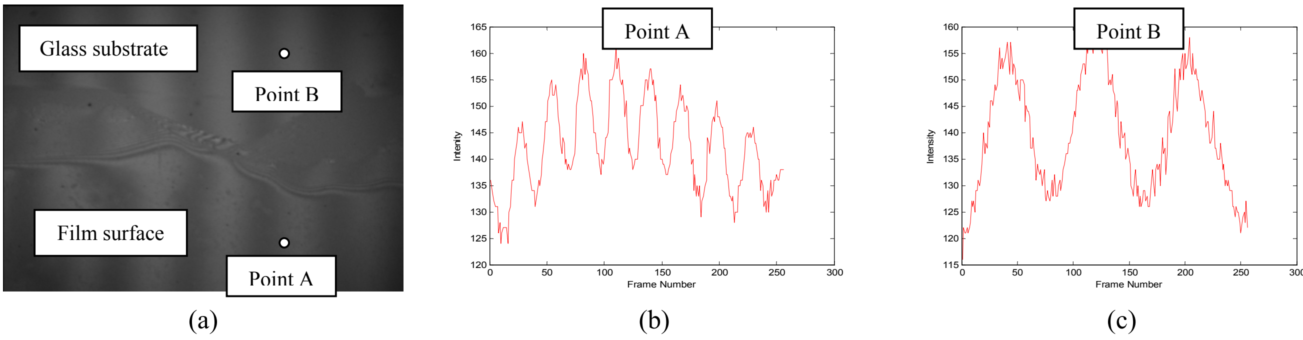
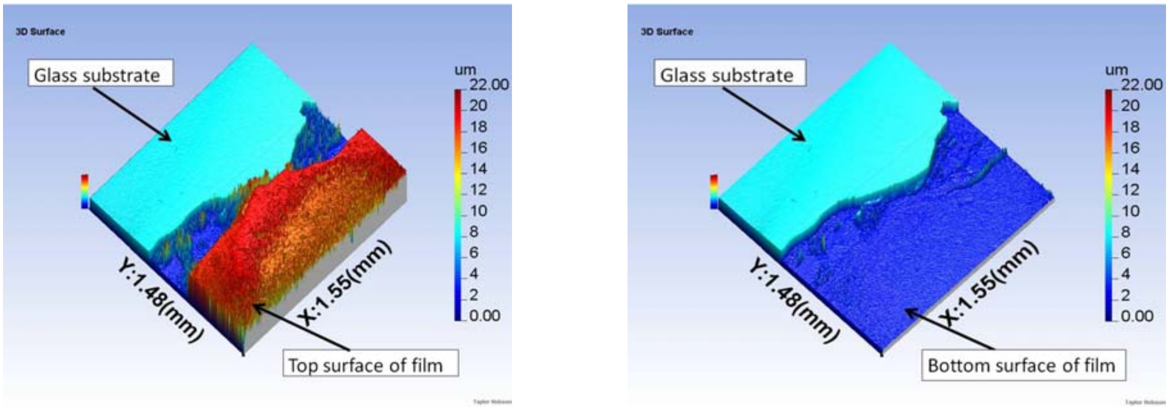


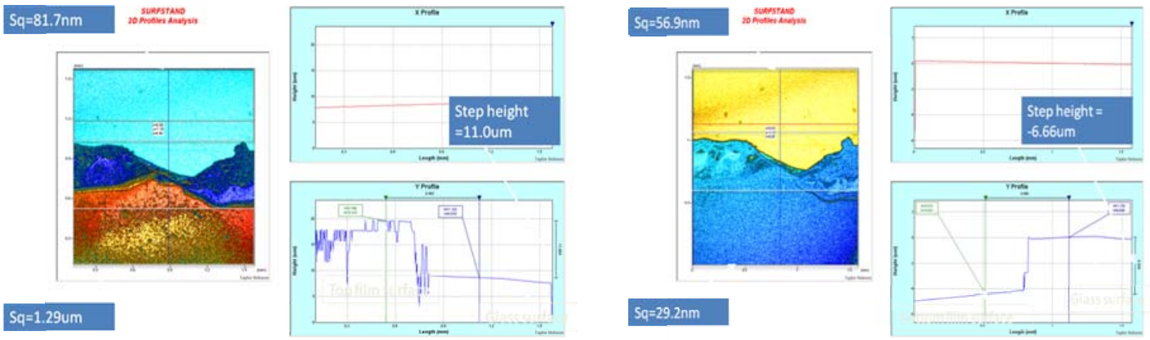
Fig. 2. (a) measured image of the sample surface; (b) interferogram on the film surface; (c) interferogram on glass substrate.

The measured signals were then analysed by applying the signal analysis strategy discussed in the previous section. The reconstructed two surfaces of the film are shown in figure 3. Figure 3(a) shows the top surface of the film forming a step upwards on the glass substrate. Figure 3(b) shows the bottom of the film surface form a step downwards on the glass substrate.



(a) (b)

Fig. 3. measurement data from one area showing (a) top surface of the film and glass substrate; (b) bottom surface of the film and the glass substrate.

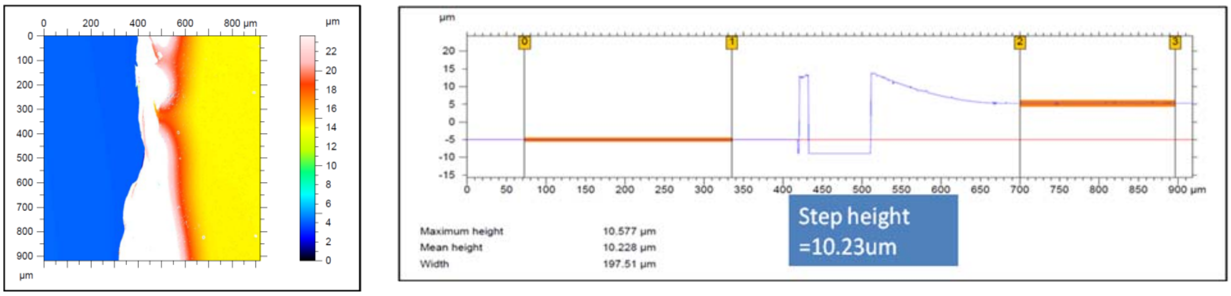


(a) (b)

Fig. 4. (a) reconstructed top surface of the film; (b) reconstructed bottom surface of the film.

The step height of the films were analysed using Surfstand, proprietary software developed at the Centre for Precision Technologies for the analysis of surface measurement data. The step height of the top surface is measured as 11.0 µm which is equivalent to the film thickness. The step height of the bottom of the film is measured as -6.6µm. That yields a total optical path through the film of 17.6 µm. When the refractive index of the Parylene N film is taken into consideration, the measured physical film thickness is found to be 10.6 µm.

For a normal incidence, the phase change on reflection between the two dielectric media Parylene N and glass substrate interface is 180° due to the high to low refractive index change. Conversely, there is no phase change on reflection on the Parylene N/air interface on the top surface. Considering this, the actual film thickness is half of nominal wavelength more compared to the original determined value and is approximately 10.9 µm. The measured step heights are shown in figure 4. Figure 4(a) is the analysis on the top of the film surface. The measured signals on the top surface of the film are quite noisy. This is because the interference signals of the top surface of the film are just located at the edge of the coherence length of our system. Figure 4(b) is the analysis on the bottom of the film surface. The signals of the bottom surface of the film are much improved as the interference occurs within the coherence length of the system.



(a) (b)

Fig. 5. (a) measured image of the film on glass substrate by a commercial white light scanning interferometer; (b) step height analysis of the measured step height.

The same sample was also measured by a commercial vertical scanning white interferometer (VSWLI) and a stylus instrument. The measured step heights of the film are 10.23 µm and 10.42 µm respectively. The result for the commercial VSWLI and the subsequent step analysis are show in figure 5. The variation of the measured value of the film thicknesses may be caused due to sampled areas being slightly different for each of the measurements.

The above measurement on Parylene N film by WSI is a feasibility study that demonstrates WSI is able to measure both top and bottom surfaces of a transparent film as well as the film thickness with the condition that the refractive index is known a priori. It provides a method that could quickly evaluate the surface form errors, surface roughness as well as film thickness in many applications, including the manufacture of cryogenic target capsules for HiPER.

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