Absolute Surface Topography Measurement of Composite Structures Using Coherence Scanning Interferometry

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Abstract

Coherence scanning interferometry (CSI) is an increasingly popular method to measure the surface topography of engineering components. CSI measures the phase of the white light fringe pattern generated by scanning the sample surface. The phase of the fringes depends, however, on the complex refractive index of the material being measured and for the topography of a composite structure, the resultant phase changes can cause significant errors (10 nm to 100 nm). This paper discusses the measurement of the complex refractive index of a surface, in order to compensate for this error. First, a microellipsometric set-up using a high magnification objective of large numerical aperture is used to illustrate the measurement problem. A modified CSI with this capability is then proposed to measure absolute surface topography.

1 Introduction

Coherence scanning interferometry (CSI) provides measurements of surface topography from the white light fringe generated by a Mirau objective. The phase of the scattered components will depend on both the surface height and its optical properties. For homogenous materials, the error due to the phase change caused by the optical properties of the material under test does not affect the measurement since the effect leads to a small axial displacement of the entire measured surface. For composite surfaces of conducting and non-conducting media, such as metal tracks deposited on a glass substrate, however, an additional phase change will be interpreted as a change in surface height, resulting in an error in the measured surface topography. At a wavelength of 633 nm, for example, reflection at normal incidence results in phase changes of 14.6^{o}, 28.1^{o} and 35.7^{o}, for aluminium, silver and gold, and corresponds to surface height errors of approximately 12 nm, 24 nm and 31 nm, respectively.

2 Microellipsometry

Microellipsometry [2-3] is a variant of traditional ellipsometry [1] and is used to determine the optical properties of bulk materials from measurements of the polarization state at the back-focal plane of a large aperture objective lens. The set-up is shown in fig. 1. A polariser (P) and half-wave plate ($\lambda/2$) control the intensity and the plane of polarization of the He-Ne laser.

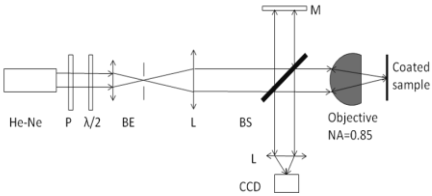

Figure 1(a): Microellipsometric set-up with an objective of NA = 0.85

The objective re-collimates the reflected field and this interferes with a tilted plane wave from mirror (M). Accordingly, the interference at the CCD camera (240 by 320 pixels) is a carrier modulated recording of the field in the back focal plane [4]. By adjusting the $\lambda/2$-plate two interferograms are taken with orthogonal polarizations. After the interferogram is demodulated a transverse modulation with a period of two cycles per revolution along the transverse θ-direction is evident as the radial (r) co-ordinate increases. The ratio of the electric fields E_0 and E_{90}, obtained at $\theta = 0^o$ and 90^o respectively, is estimated by filtering at two cycles in the transverse direction and fitting a second order polynomial in the radial direction to remove all other noise.

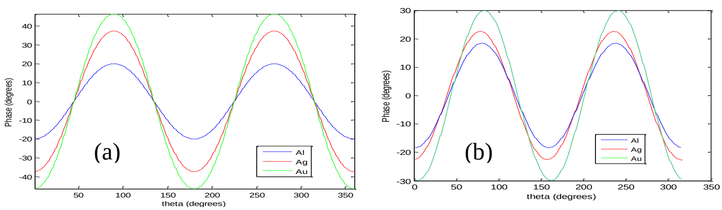

Figure 2: Phase difference at the outermost aperture for NA = 0.85 a) theoretical; b) experimental

Comparison of the experimental data with theoretical predictions for the phase difference of two orthogonal polarization components at extremes of the aperture is shown in fig. 2(a) and fig. 2(b). This figure illustrates that the relative phase change of the experimental data is in close agreement with the theoretical data but, has slightly less modulation depth. This can be explained if the entire aperture is not completely filled by the reflected light and in this case, the results more closely fit an objective of NA = 0.76.

The amplitude and phase pattern obtained from the ratio of the electric fields can be directly related to the ellipsometric parameters, tan ψ and Δ. For orthogonal polarization components, the amplitude ratio of the two reflection coefficients is expressed as tan ψ, with Δ being the phase difference between them. From these values the complex refractive indices (**n**) for aluminium, silver and gold are calculated. Assuming NA = 0.76, measured values of complex refractive indices from the above experiment are shown in the Table 1.

Table1: Refractive indices calculated from microellipsometry experiment

Sample surface materials	tan ψ (calculated)	Δ in degrees (calculated)	Refractive index (measured for 633 nm,)	Refractive index (ideal value at 633 nm)
Au	1.09	29.87	0.56 + 3.24j	0.19 + 3.09j
Ag	1.19	22.53	1.70 + 3.72j	0.13 + 3.98j
Al	1.17	18.36	2.22 + 4.43j	1.44 + 7.53j

From the Table 1 it can be infered that the imaginary parts of **n** for gold and silver, are close to their tabulated values, a fact confirmed by the phase plots of fig. 2(b) [5]. The real parts of **n** for gold and silver are not close to their tabulated values due to the intensity variation between the two interferograms. Finally, the discrepancy in both real and imaginary parts of complex refractive index for the aluminium sample could be due to a surface oxide layer.

3 CSI Implementation

The advantage of microellipsometry over its traditional counterpart is its ability to measure the optical parameters at a single point on the surface. Using a CSI configuration with large NA, it should be possible to make a whole-field map of the optical properties of the surface. The configuration shown in fig. 3(a) retains the focused illumination that defines the single point on the sample but the phase and amplitude of only a single, oblique plane wave component of the scattered field is measured. To provide a whole-field measurement, the configuration in fig. 3(b) is proposed. Here, the sample is illuminated by an oblique plane wave and the phase and amplitude of the scattered field is measured in the back focal plane. It can be shown that exactly the same information can be obtained with this new configuration (fig. 3(b)) [6]. By measuring the field using illumination with orthogonal polarisation states the complex refractive index of the sample surface at different points can be calculated. Using this information the errors due to the additional phase generated by

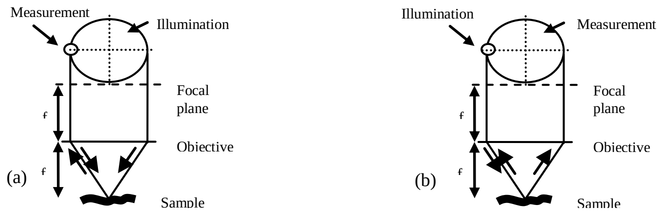

Figure 3: Simplified configuration a) single-point, b) whole-field measurement

variations in the complex refractive index can be compensated and the absolute surface topography for composite surfaces can be measured.

4 Conclusion

In this paper a microellipsometer that can be used to measure complex refractive index has been described and the similarities between microellipsometry and CSI have been highlighted. A CSI system with this capability to measure the surface topography of composite surfaces or varying complex refractive index is currently under construction.

Acknowledgements

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