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Interferometry for Ellipso-Height-Topometry part 3: Correction of the aspect errors and reduction of the dispersion of the ellipsometric parameters

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ABSTRACT

Ellipso-Height-Topometry, EHT, is an extended optical topometry, where both the topographies of the surface height $H(x,y)$ and the ellipsometric local parameters $\Psi(x,y)$ and $\Delta(x,y)$ of surfaces with locally changing materials are measured on the same pixel raster with high resolution and using the same data sets. Further quantities can be calculated from these measurements on the base of locally confined surface models: the local refractive index, the thickness $t(x,y)$ of overlayers or films, or other parameters of layered systems.

In part 1 of this work a z-scanning interferometric scheme with oblique incidence over the entire object field and very useful coherence properties for practical coherence-scanning have been introduced.

In part 2, the theory of the ellipsometric parameter acquisition in this interferometer has been developed for isotropic surfaces and the theory for the local segmentation of different materials or such materials covered with films was introduced. The results were verified by two sets of topographies for two different kinds of objects: a grid of gold strips on a substrate of quartz glass and an engine cylinder surface featuring silicon crystals in an aluminium matrix.

In this part we deal with the aspect error of the measured profile due to an oblique incidence of the light and the dispersion of the ellipsometric parameters due to the surface roughness and its reduction. The new results are verified by two EHT-sets of topographies for a cast iron surface with graphite laminas.

1. Introduction

Micro topometry (profilometry) is well established in surface measurement tasks. However, if the surface is composed of different materials like crystals in a metal matrix or like structured objects in micro electronics, or like many other technical or biological objects it is important not only to acquire the height or shape distribution $H(x,y)$, but also the material distribution and the topography of layers and their thickness distribution $t(x,y)$.

Moreover, material induced phase changes by reflection enter into the measured phase and lead to errors in the height topography. These errors are more important if the object is covered with irregular overlayers of oxides or lubrication materials or with structured overlayers or systems of thin films [8]. Ellipso-Height-Topometry, EHT, [1,4,7,9], is an extended optical topometry, where both the topographies of the surface height $H(x,y)$ and the ellipsometric local parameters $\Psi(x,y)$ and $\Delta(x,y)$ of surfaces with locally changing materials are measured on the same pixel raster with high resolution.

We showed in parts 1 and 2, [1,4], of this paper how ellipsometric information ($\Delta(x,y)$ and $\Psi(x,y)$) can be obtained in a z-scanning interferometric measuring scheme by introducing oblique incidence of the illuminating light and a fixed imaging relation between the two-dimensional object field and the two dimensional imaging device. We showed that oblique incidence leads to very favourable coherence properties for Z-scanning [4]. Theories for isotropic materials were derived and verified by sets of topographies on various samples [1]. It is of fundamental importance that both the interferometric height information and the ellipsometric information refer to the same point on the surface or to the same pixel of the camera and are calculated from the same data sets using the same algorithms. Further quantities of interest can then be calculated from these data sets on the base of locally confined surface models, the thickness $t(x,y)$ of a thin overlayer of oxides, oil or contaminations or the refractive index $N(x,y)$ of a bare surface. In part 1 and part 2 of this paper

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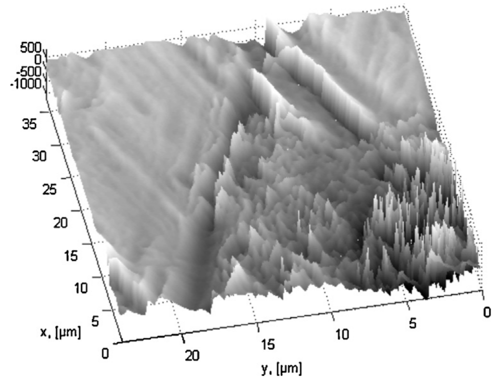

Fig. 1. Aspect error due to oblique incidence. The incident light comes from the left upper side, $\phi_g = 47°$, the camera looks from the right upper side.

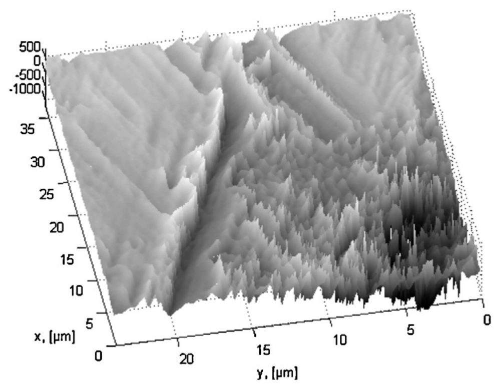

Fig. 2. The same surface detail as in Fig. 1. The incoming light now comes from the right upper side, $\varphi_g = -47°$, The Camera looks from the left upper side.

we described Ellipso-height topometry in Linnik- or Mirau interference microscopes and the modifications which guarantee these strict principles. In the present paper important specific problems are solved and new results are presented.

2. Correction of the aspect error of the topographies under oblique incidence

In Ellipso-height topometry oblique incidence is needed for the determination of the ellipsometric parameters. A global angle of incidence ϕ_g is effective over the entire object field [4,7]. However, the profile of the measured height $H(x,y)$ in the direction of the oblique incidence is distorted as can be seen by comparing Fig. 1 with Fig. 2. For the simple case of an oblique incidence on plane parallel surfaces with local inclination angle $\alpha(x,y) = 0$ the topographic height can be calculated from the path length difference $G(x,y)$ of the interfering beams by

$$H(x, y) = \frac{G(x, y)H_{2\pi}}{\lambda} \tag{1}$$

where λ is the wavelength and $H_{2\pi}$ is the height resulting from one fringe period. For angle of incidence $\phi_g = 0$ the period $H_{2\pi}$ = is $\lambda/2$. For $\phi_g \neq 0$ and $\alpha = 0$ the height of one fringe period is

$$H_{2\pi} = \frac{\lambda}{2\,\cos(\phi_g)} \tag{2}$$

For plane parallel surfaces $\alpha(x,y) = 0$, this results in the widely used formula of interferometric height evaluation under oblique incidence:

$$H(x, y) = \frac{G(x, y)}{2\cos(\phi_g)} \tag{3}$$

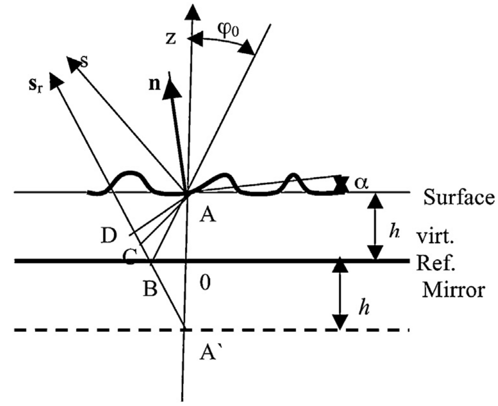

Fig. 3. Path length difference of a tilted surface element of height h, inclination angle α and oblique incidence of angle ϕ_0. The local normal vector is **n**.

For small inclination angles $\alpha(x,y)$ this formula can be used to calculate the topographic height from the interference phase but for rough and structured surfaces we have to be aware of aspect errors.

In Fig. 3 the path length difference G for angles of incidence $\varphi_g \neq 0$ and $\alpha \neq 0$ and a given topographic height h is given as:

$$G = \overline{DA'} - \overline{DC} \tag{4}$$

where $\overline{DA}$ is perpendicular to the direction given by the unit vector $\mathbf{s_r}$ of the reflected beam on the tilted surface element of true height h, and $\overline{CA}$ is perpendicular to the corresponding wave of direction **s** reflected on the virtual reference mirror with $h = 0$ and $\alpha = 0°$:

$$\overline{DA'} = 2h\cos(\phi_0) \tag{5}$$

$$\overline{DC} = \overline{AD}\,\tan(\alpha). \tag{6}$$

(5) and (6) in (4) results in

$$G = 2\,h\cos(\phi_0)(1 - \tan(2\phi_0)\,\tan(2\alpha) \tag{7}$$

and with (7) in (3)

$$H(x, y) = h(x, y)\,[1 - \tan(2\alpha(x, y))\tan(\phi_0)] \tag{8}$$

where as stated above $h(x,y)$ is the true local height and $H(x,y)$ is the height resulting from an evaluation on basis of Eq. (3). Eq. (8) is independent of the wavelength of the light and therefore Eq. (8) is true also for polychromatic light. Thus, if the angle $\alpha(x,y)$ was known initially, $H(x,y)$ could be easily corrected:

$$h(x, y) = \frac{H(x, y)}{1 - \tan(2\alpha(x, y)tan(\phi_0)} \tag{9}$$

For rough surfaces as in the application above, the angle of the inclination of the surface element α is not known initially. For further theoretical work the fact could be used that $\tan(\alpha(x, y)) = \partial h(x, y)/\partial(y)$. But the true topography $h(x,y)$ is initially also unknown. Starting an iterative process for α with a measured topography $H_1(x,y)$ using Eq. (3) and calculating as an approximation $\tan(\alpha'(x, y)) = \partial H_1(x, y)/\partial(y)$ for Eq. (9) is not trivial because of noise and discontinuities of the measured profile.

A much more elegant and practical solution is the superposition of two measurements of the height fields $Hr(x,y)$ and $Hl(x,y)$ taken from two equal, but opposite angles of incidence, $\phi_{gr} = +|\phi_g|$and