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Simultaneous spatial and angular positioning of plane specular samples by a novel double beam triangulation probe with full auto-compensation

Janos P. Makai *

Hungarian Academy of Sciences, Centre for Energy Research Institute of Technical Physics and Material Science, Konkoly Th. u. 29-33, H-1121 Budapest, Hungary

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ABSTRACT

The positioning of a plane specular sample to be measured or processed is an important requirement in many fields of research and industry. Where a sample is to be processed either by electromagnetic waves or a particle beam of higher numerical aperture the irradiance or the particle number over unit area is position and angle dependent. Where optical properties of a sample are to be measured, such as in spectrophotometry, these parameters can depend on the angle of incidence and on the value of the irradiance, i.e. on the angular and spatial position of the sample. In some cases parameters of many samples have to be compared among each other or to those of a standard, this also requires the highly accurate positioning of each sample to the same position. This paper describes a method that is suitable for high accuracy alignment of specular plane samples both angularly and spatially. It applies a double beam triangulation probe, where the second beam serves not only as a reference beam to compensate for any changes of the transmitting media and that of the laser but also doubles the sensitivity of the probe. The method does not compete with interferometric methods, it is required only in special applications, but provides an absolute uncertainty for spatial positioning in the sub-micrometer range and an angular one in the 0.0003° range. Furthermore, the accuracy is tunable by the parameters of the setup.

1. Introduction

In many fields of research and industry it is important to position a sample accurately both spatially and angularly so that it can be measured or processed. Small sized samples or samples having a sensitive surface area must not be brought into contact with a reference surface therefore only non-contact, usually optical methods, should be used. In the spectrophotometry of small samples when a converging/diverging beam is used in underfilled mode each sample has to be in the same position as the standard. In carrying out comparisons among samples, the same requirement exists. To achieve repeatable conditions during the processing of a sample, for example a wafer by a high numerical aperture ion- or electron beam, where the particle irradiance is a function of position, accurate positioning is again essential. The same requirement holds for optical irradiances at high precision curing. In most cases, the irradiating source must be positioned perpendicular to the sample, sometimes they have small working distances therefore only grazing incidence beams can be applied for positioning.

Autocollimation [1] provides only an angular positioning and not a spatial one and it irradiates the sample perpendicularly. Interferometric methods [2,3] provide high accuracy, but are limited in that the surface of the sample must be suitable for the interferometry. As regards laser distance measurement, the triangulation method serves either for a diffuse surface [4], or for specular one [5], but the accuracy of this last one can be significantly improved by the optical arrangement described in this paper. Interferometric methods provide a very high accuracy that is not required in many fields, furthermore, their realization is costly. This paper describes a novel double beam triangulation method with full auto-compensation for any changes of the transmitting media and that of the laser. It is simple, easy to realize and provides an absolute spatial uncertainty in the sub-micrometer range and an angular one in the 0.0003° range; furthermore the accuracy is tunable by the parameters of the setup.

2. Theory

The triangulation method is used, independent of the tilt of the sample, for the distance measurement of specular surfaces in [5]. In this setup, two light sources and two detectors are used. The

* Tel.: +36 1 392 2222/3267.
E-mail address: makaij@mfa.kfki.hu

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beams from the sources are reflected to the corresponding detectors from the specular surface of the sample (see Fig. 1) where S denotes the plane mirror like sample, B_1 and B_2 the two beams, β_1 and β_2 the two incident angles, D_1 and D_2 the two detectors, P the incident point of the beams, L_1 and L_2 the distances between the incident point P and the detectors, i.e. two triangulation probes are mounted in opposite directions. Arrowheads on the lines show the propagation direction of the beams. The spatially displaced position of the sample is also drawn on the figure marked by dotted lines, where d denotes the spatial displacement. For clarity of the figure the angular displacement α_1 is shown in Fig. 2. It is assumed that the surfaces of the detectors are perpendicular to the beam in the nominal position. The figure shows that the two beams do not cover the same path in the setup, they cannot serve as reference beams for each other [6], that would compensate for the instability of the medium. Furthermore, the two light sources drift independently from one another resulting in another uncertainty component.

Considering only a subportion of Fig. 1 the elements denoted by subscript 1 or without subscript show a single beam triangulation setup that cannot distinguish between a displacement d of the sample perpendicular to its surface and a tilt α_1 of the sample around the axis through P and perpendicular to the plane of the incident and reflected beams. If the tilt α_1 is applied, the displacement of the beam on the detector is $D=L_1{}^*\tan 2\alpha_1$ in the plane of the incident and reflected beams. If the sample is displaced by a distance d perpendicular to its surface then the displacement of the beam on the detector is $D=2{}^*d{}^*\sin\beta_1$ again in the plane of the incident and reflected beams. The simultaneous tilt and displacement of the sample described above results in a displacement of the beam on the same line of the detector, making the distinction between tilt and displacement impossible. Similarly, if a tilt of α_2 around the axis perpendicular to the previous one and defined by the section line of the plane of the incident and reflected beams and that of the sample takes place the beam displacement on the detector will be $D=L_1{}^*\tan 2\alpha_2$.

It can be seen that at a tilt of α_1, D will be proportional to the distance of the detector L_1 and the tangent of the tilt angle. Usually, this tangent is very small. For the displacement of the sample $\sin\beta_1$ can be chosen to be relatively high at a high incidence angle. If both tilts and the displacement simultaneously take effect, and assuming that the tilt angle is negligible compared to the incidence angle, the resulting beam displacement on the detector will be

$$D = \sqrt{\left(L_1 \tan 2\alpha_1 + 2d \sin\beta_1\right)^2 + \left(L_1 \tan 2\alpha_2\right)^2} \qquad (1)$$

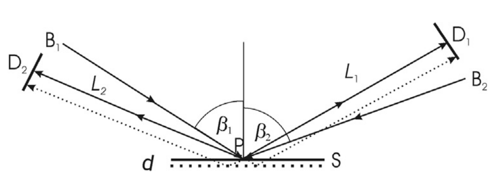

Fig. 1. Double beam triangulation arrangement.

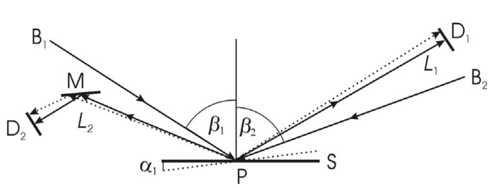

Fig.2. Double beam triangulation arrangement with turning mirror in one of the detection arms.

The setup of [5] makes the tilt from the displacement of the sample discernible by using a second triangulation probe. A counterclockwise tilt α_1 of the sample results in a counterclockwise displacement D of the beams on both detectors, but a displacement d of the sample results in one detector having a clockwise and on the other one in a counterclockwise beam displacement (see Fig. 1). This difference allows the distinction between tilt and displacement of the sample. If a turning mirror as in Fig. 2 is placed in the path of one of the beams B_1 or B_2 after P, contrary to the previous setup a counterclockwise tilt α_1 of the sample results in one detector showing a clockwise and on the other one a counterclockwise beam displacement. The turning mirror also changes the effect of a displacement d of the sample; it results in both detectors showing a beam displacement in the same direction. It means that the turning mirror reverses the displacement of the beam on the detector D_2 for both tilt and displacement of the sample from clockwise to counterclockwise or vice versa. If $L_1=L_2$ then on both detectors the value of the beam displacement D is identical for the same displacement and tilt of the sample.

The useable range of the displacement of the sample is determined by the incidence angle β, the beam diameter and the sizes of sample and detector. The beam diameter should be as small as possible because at higher beam diameters at a given sample size a part of the beam might miss the sample, making the evaluation tedious. On the other hand a small diaphragm increases interference therefore a compromise should be found. If the detector is small at high tilt or displacement of the sample, the beam might miss the detector. At high β and small sample size values the beams will miss the sample after a given sample displacement and tilt value. For the same sample at a decreasing β a higher sample displacement or tilt can be measured, but the resolution of the measurement will be lower.

It is preferable not to use two sources nor two detection systems. If both beams originate from a single source then the drift of the source affects both beams identically. The evaluation is much easier and the uncertainty is lower if only a single detector catches both beams for the setup of Figs. 1 and 2.

It should be noted, that in the above setups for a tilt of the sample around the section line of the plane of the incident and reflected beams and that of the sample produces the same beam displacement direction for both beams, i.e. they roll away from the nominal position in the same direction.

3. Experimental setup

In displacement measurements it is usual to apply a reference beam to compensate for the angular drift of the laser beam resulting from the fluctuations of the local temperature, humidity, pressure, etc. of the transmitting media, in our case air. It has been shown that even at constant temperature, vibration isolation and beam path shielding the angular drift resulting from the instability of air medium can be 0.02 arcsec ($5.55{}^*10^{-6\circ}$). The application of the reference beam follows the common-path principle so that the drifts resulting from laser generation mechanism and instability of beam transmission medium can be accurately detected and compensated for, especially over a long measurement distance. [6].

Fig. 3a and b shows the experimental layouts. As a source, a collimated beam semiconductor laser L was used with a diaphragm. A 50/50 beam splitter BS1 provides the two beams then the two split beams follow the same path but in opposite directions. The drift of the laser beam originating from the laser generation and the change of the transmitting media therefore affects both beams simultaneously and to the same extent [6]. Mirrors M1 and M2 reflect the entering two split beams towards the sample