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HEIGHT PROFILE MEASUREMENT BY MEANS OF WHITE-LIGHT INTERFEROMETRY

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Summary: *White-light interferometer allows to measure the height profile of smooth as well as of rough surfaces. This feature renders white-light interferometry suitable for height profile measurement in technical practice. Unlike to classical interferometry, the ambiguity problem does not occur, even if the measurement range is greater than that corresponding to one interference fringe. Due to this unambiguity, the measurement range is theoretically unlimited; in practice it amounts to 20 – 50 mm. A very low measurement uncertainty (of about 1 µm) is independent on the measurement range. The height profile is measured in the course of one measurement procedure on a surface area that amounts to 20 × 20 mm.*

1. Introduction

White-light interferometry operates on the same principle as the classical interferometry. The basic difference is that the light source is not a monochromatic laser but a broadband (white-light) source whose spectral width ranges from tens to hundreds of nm (Kino et al., 1990). An example of such a source is a luminescent diode or an incandescent lamp. The reason to use white-light interferometry is that it can also be used for optical measurement on rough surfaces, where the classical interferometry fails (Dresel et al., 1992). Another important advantage of white-light interferometry is its unambiguity. The unambiguity range can be extended over several mm, it is not limited by the motion within one interference fringe (Häusler et al., 1999).

Due to these features, the white-light interferometry is particularly suitable for the height profile measurement of technical surfaces (Koch et al., 1998). The technical surfaces can be classified in their majority into the category of rough surfaces. The height profile of the object is measured in the course of one measuring procedure, the lateral scanning is therefore not necessary. The measurement uncertainty of the height profile measurement is independent on the parameters of the imaging system. Because the illumination and the observation are arranged coaxially, the height profil can be measured also in deep holes and cuts.

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2. Principle

White-light interferometer is in principle a Michelson interferometer. The movable mirror of the interferometer is replaced by the measured object. A luminescent diode with the spectral width of about 30 nm is used as the broadband light source. For comparison, the spectral width of a laser is less than one thousandth of a nanometer. The setup of a Michelson interferometer with the broadband light source is schematically illustrated in Fig. 1 (Pavlíček, 2002).

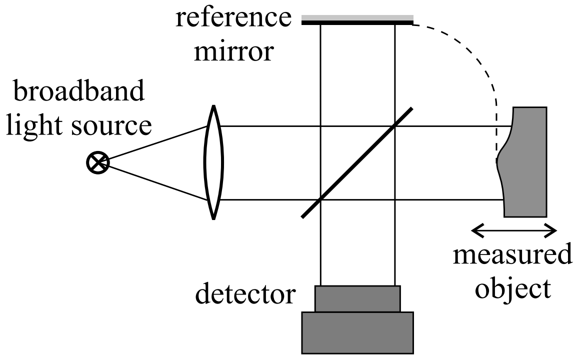

Fig. 1 Setup of the Michelson interferometer

The light from the light source is collimated in a parallel beam which is split into two beams by a beamsplitter. One of the beams reflects off the object and the other the reference mirror. The reflected beams are put together and the resulting beam is brought to the detector. If the object is moved in the direction of the optical axis as signed with the arrow in Fig. 1, the light intensity on the detector varies according to the coherence function of the light source (Larkin, 1996). The dependence of the intensity on the object position is called correlogram and is displayed in Fig. 2.

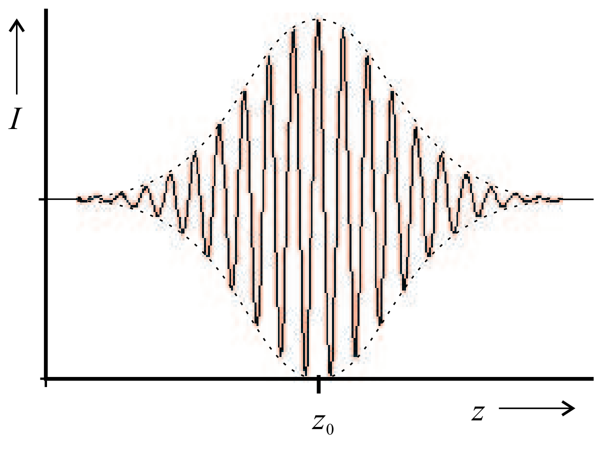

Fig. 2 White-light correlogram

If the object is situated at the position z_0, the both interferometer arms have the same length. The correlogram width is inversely proportional to the spectral width of the light source (Peřina et al., 1994).

In order to measure the height profile on a definite area of the surface, a CCD camera is used as a multiple detector. This arrangement brings the advantage that the hight profile on the illuminated area is measured in the course of one measuring process. The scanning, which is characteristic for mechanical stylus sensors, becomes unnecessary.

The height profile measurement proceeds so that the measured object is moved along the optical axis. The image of the object is formed on the CCD camera and is superimposed with the reference wave. The maximum of the correlogram is acquired for each pixel of the CCD camera. This maximum determines the height of the corresponding point on the object's surface. It means that the phase is not evaluated in white-light interferometry but only the maximum of the correlogram is searched. In this way the ambiguity of classical interferometry is overcome.

3. Measurement of the height profile

The experimental setup is displayed in Fig. 3. The measured object is fastened on a linear

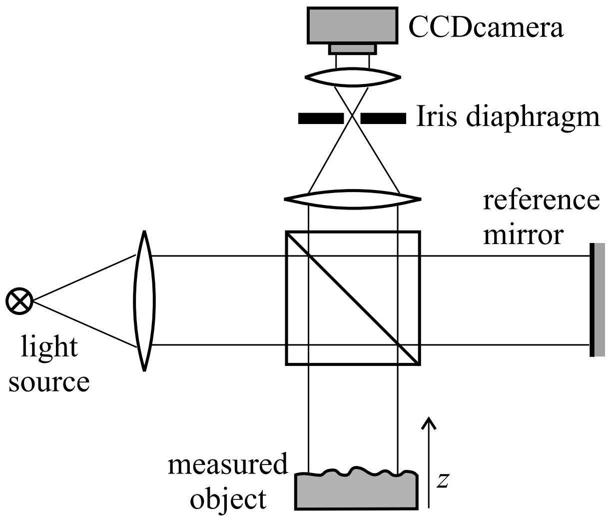

Fig. 3 Experimental setup for the height profile measurement

positioner and creates one arm of the Michelson interferometer. The light source is an infrared LED with central wavelength of 875 nm and the spectral width of 30 nm. The light from the light source is collimated in a parallel beam so that the measured object is uniformly illuminated. A CCD camera is used as a multiple detector. The height profile of the measured object is acquired from evaluation of the individual correlograms.

4. Results of the measurement

Some results of the height profile measurement are shown in this section. The height profile is expressed using grey scales so that the higher parts of the surface are brighter. Each height profile is completed by a cross section along a horizontal line. The cross section enables an easy reading of the height profile. The height data are given in μm. The measurement uncertainty depends on the surface roughness of the measured object and amounts to approximately 1 μm.

Figure 4 shows the measured height profile of a mirror. This height profile shows rather the abilities of the measurement methos than the real height profile of the mirror. The height deviation are smaller than the measuring step which amounts to 0.18 μm. Therefore the measured height profile takes a form of a plane.

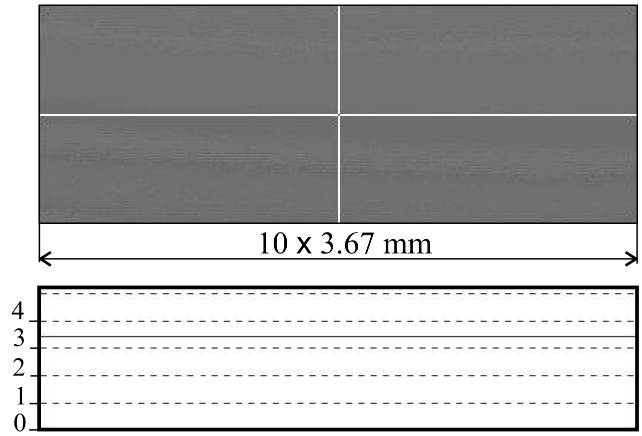

Fig. 4 Measured height profile of a mirror expressed using gray scales and the cross section of the height profile along the horizontal line. The height data are given in μm

Figure 5 shows the measured profile of a properly cut silicon wafer.

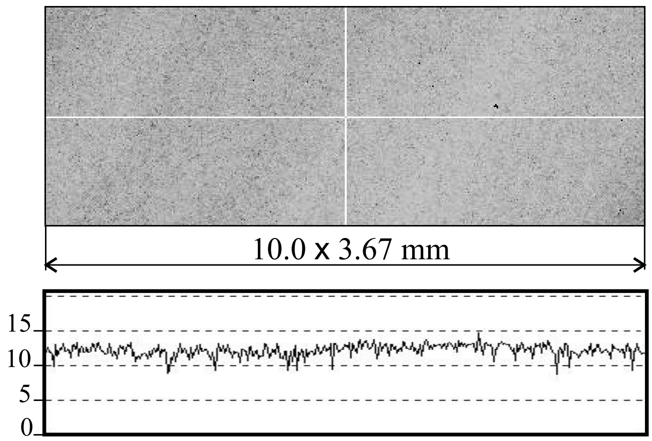

Fig. 5 Measured height profile of a properly cut silicon wafer expressed using gray scales and the cross section of the height profile along the horizontal line. The height data are given in μm

The measurement of the height profile shows that the silicon wafer exhibits an average roughness amplitude of 0.7 μm. Thus the white-light interferometer can be used for the measurement of roughness analogous to the mechanical stylus sensor.

Figure 6 shows the measured height profile of a silicon wafer with an imperfection. The measured height profile enables to determine the form and the dimensions of the imperfection. In this case, cross sections along two horizontal lines with mutual distance of 0.5 mm are displayed. One can see in Fig. 6 that the both cross sections differ only slightly.

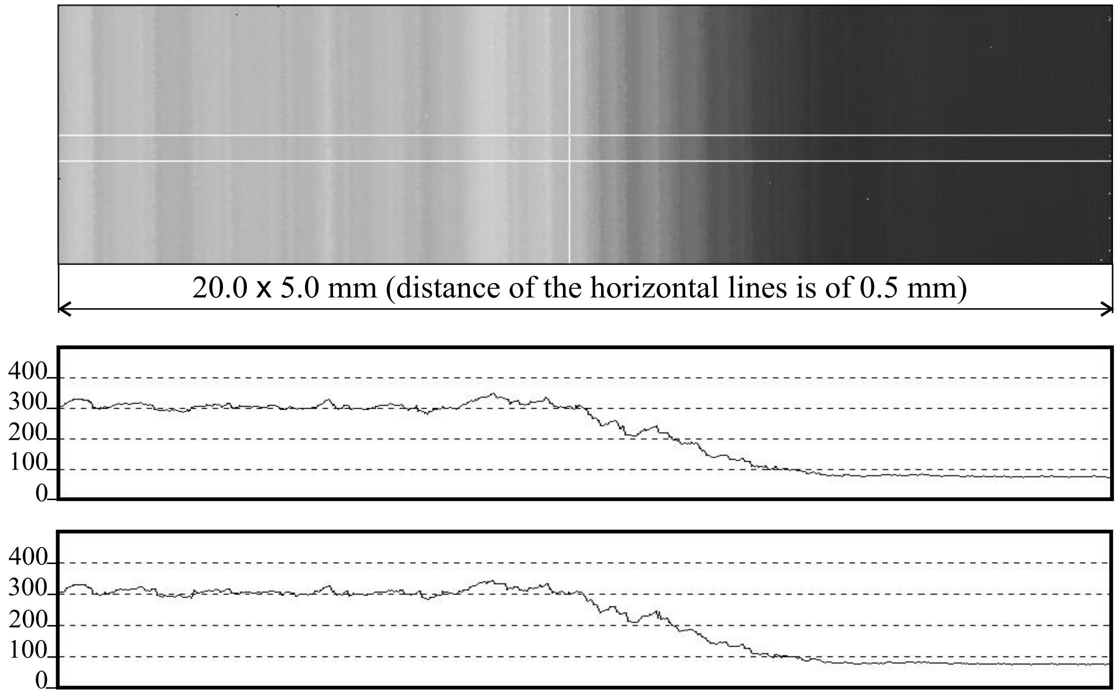

Fig. 6 Measured height profile of a silicon wafer with an imperfection expressed using gray scales and the cross section of the height profile along the horizontal line. The height data are given in μm

In the shown height profiles (Figs. 4 – 6), some black or white dots arise. The height of these points is wrongly determined. The origin of these errors is the low dynamic range of the CCD camera, the correlograms cannot be properly recorded and evaluated. Especially the measurement on metallic surfaces puts high demands on the dynamic range of the measurement method. The dynamic range of this method is substantially reduced by the relatively low dynamic range of the standard CCD camera.

4. Conclusion

White-light interferometry is proved as a contactless method for height profile measurement. It can measure height profile of a rough as well as of smooth surface which makes this method suitable for industrial use. Due to the interferometric principle, the accuracy of the method is high and independent on the measurement range. The measurement uncertainty does not depend on the optical setup parameters, e.g., wavelength or the observation aperture (Häusler & Leuchs, 1997). The measurement range is theoretically unlimited, practically it is limited by the range of the positioner. The coaxial arrangement of illumination and observation avoid creation of shadows and allows measurement in deep cuts and holes.

A disadvantage of this method is that the area on which the height profile is measured is limited by the size of the beamsplitter. In order to measure the height profile, the object must be translated which renders the measurement slow.

5. Acknowledgments

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