Optical encoder measurement technology

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ABSTRACT

A new approach to metrology for the range below 100 nm is based on large fiducial grids optical encoders produced by interference / lithography. Since the encoder can only be as accurate as the grating scale, advance in this area depends on the availability of encoder plates of nanometer accuracy. Various commercially available or home made holographic gratings were checked using interferometric methods and compared with the AFM device results. The budget of errors was analyzed and the necessary improvements of measuring technology are presented.

Keywords: interferometry, nanometrology

1. INTRODUCTION

Nanometrology (the science of measurement at the nanoscale) is concerned with dimensional measurements of very small objects in micro, semi-conductor and nano technologies. Nanometrology involves the measurement of geometrical features of size, shape and roughness at the nanoscale. Measurement accuracy is also important for microscopy. As dimensional tolerances for such applications as semiconductors and optical discs get tighter, the need for precision length standards at the nanometer length scales becomes more important [1]. The sophisticated measuring tools used to measure these features, such as Atomic Force Microscopes (AFM) and Scanning Electron Microscopes (SEM), require periodic calibration to produce accurate results [2,3]. Calibration specimens [4-7] with feature sizes or positions directly traceable to international length standards are key tools to producing accurate and reliable results. The recommended practical international length standards (definition of meter) are vacuum wavelengths of a number of standard reference radiations determined from interferential frequency measurements that are listed in Table 1.

Table 1. Vacuum wavelengths recommended for international length standard

Spectrum domain	Green	Red	Infrared
Wavelength (nm)	543.515077	633.96139822	780.24629163

Thus interferometry, having the wavelength of light as a physical measuring unit, is a *de facto* length scale. If the light source for a two-beam interferometer is one of the recommended laser wavelengths we can use that interferometer to measure some artifacts with sufficient precision to warrant their use in microscope calibration. Generally such artifacts are diffraction gratings. They are characterized by their pitch and the height of the lines. The calibration of a scanning microscope has to be done on 3 axes: 2 axes perpendicular to the optic or sensing axis meaning lateral calibration and 1 axis along the sensing direction or vertical calibration. As a consequence measuring interferometrically the pitch [6] and the height of the grating choose as calibrating artifacts we can obtain a traceable way to calibrate a scanning probe microscope.

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2. VERTICAL CALIBRATION

2.1 The Linnik interferometer

The Linnik interferometer [8] utilizes a high magnification 490X objective lens for observation of minute details. The Linnik interferometer is at core a Michelson interferometer. Fig. 1 presents the basic arrangement comprising a light source, a collimator, a beam-splitting prism, an eyepiece, uniform objective lenses with completely identical optical distances, a specimen surface, which gives rise to an image, and a reference mirror, which gives rise to a reflection image. We used a Linnik Interferometer type MIN-4 produced by LOMO Sankt Petersburg Industries.

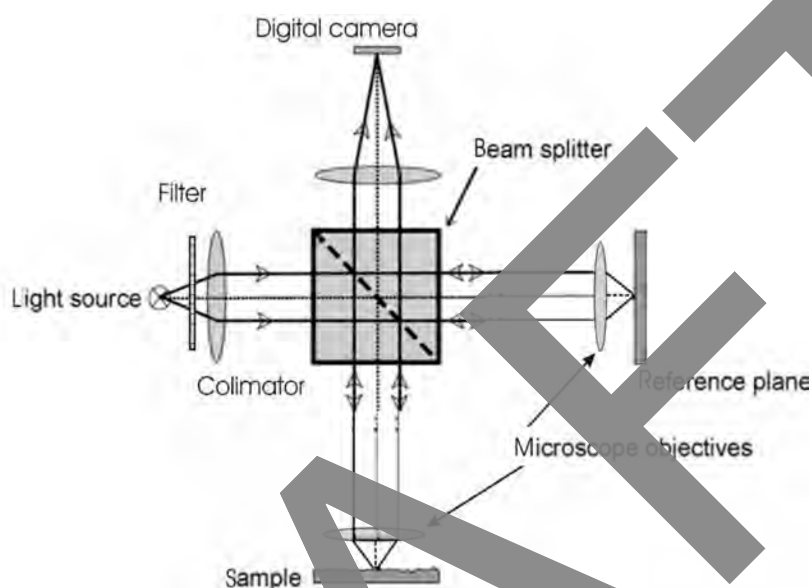

Fig. 1. The Linnik interferometer optical scheme.Technical data regarding the interferometer, concerning the measurements taken by us, are the following: the interferometer has an optical power of 490X, two optical filters, for 533 and 586 nm, both of 10 nm spectral width. Also, the optical field of the interferometer is 320 μm.

2.2 White light measurement principles

White light fringes give the integer number of $\lambda/2$, the step unit (pitch) while the monochromatic light fringes provide the fractional part of $\lambda/2$. Their sum gives the height. This measurement principle is illustrated in Fig. 2. Using white light we cannot assure the traceability of the measurement. Monochromatic light is insured by the use of 2 filters - red and green – of only 10 nm spectral width. With such spectral width we cannot insure the traceability. Introducing coherent light of the recommended laser in a limited aperture optical system means a lot of high size speckle. The solution we found out was to use a Pohl light source, source of variable spatial coherence [9].

Using the Linnik interferometer we measured the height of a grating with 48 nm pitch and obtained h = 1004 ± 27 nm. As a light source for Pohl variable spatial coherent light we used a frequency stabilized laser produced by Spectra Physics, Model 117 (frequency 473.61254 THz), a red monochromatic light.

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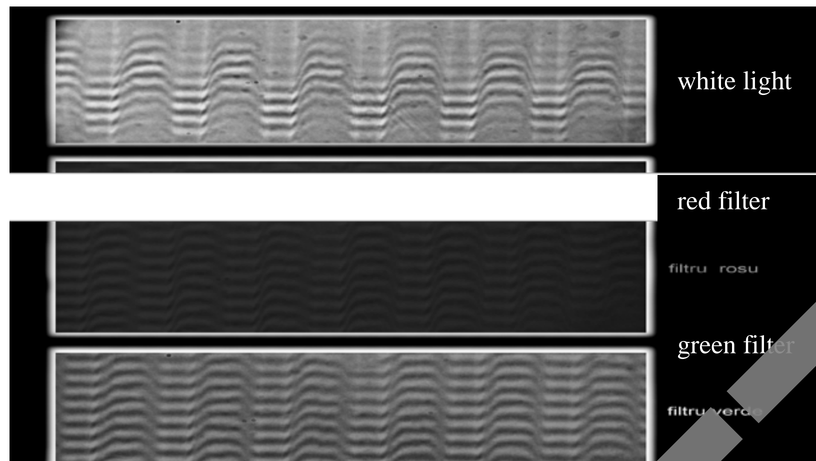
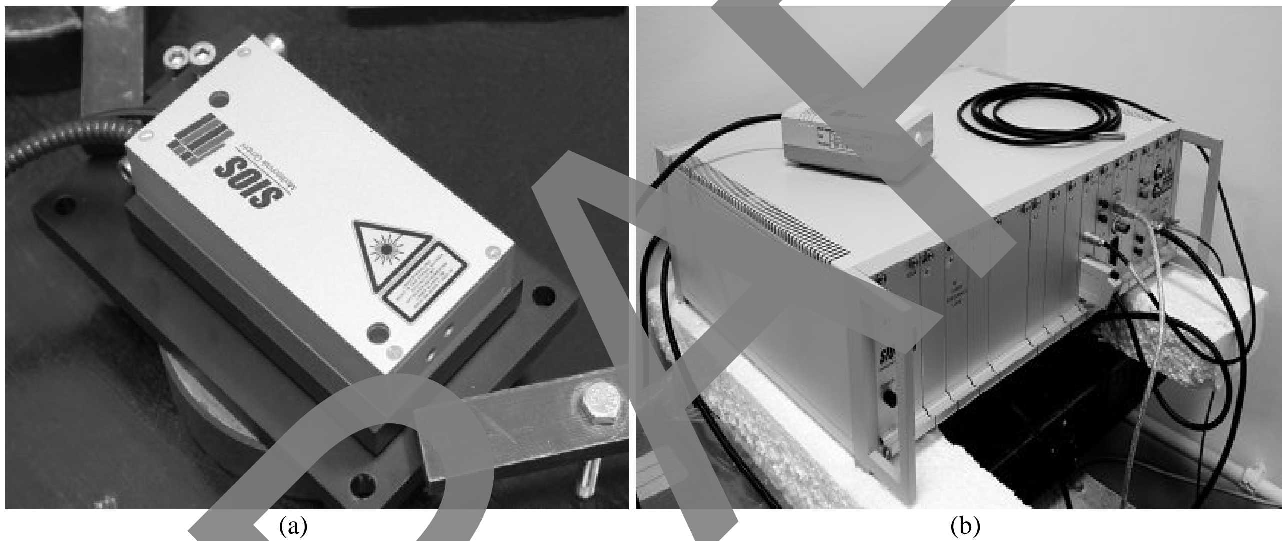


Fig.2. Fringe pattern for white, red and green light source, obtained for imaging a diffraction grating of 48 µm pitch with the Linnik interferential microscope



(a) (b)

Fig. 3. Laser length measurement interferometer produced by SIOS: (a) the head of the unit and (b) the controller. Technical data regarding the interferometer, concerning the measurements taken by us, are the following. The light source is a He-Ne laser (632.8 nm wavelength) of 2 mW output power, the measurement range 5000 nm, the metric resolution 0.1 nm, the physical resolution λ / 512 (about 1.24 nm), laser frequency stability 2 10^{-8} Hz, and maximum retro reflector translation rate 600 mm/s.

3. LATERAL CALIBRATION

In Fig.3. is shown the SIOS Interferometer from our lab. SIOS is a precision laser interferometric length measurement instrument, equipped with triple-faceted retro-reflectors [10]. The miniaturized sensor head and triple-faceted retro-reflector allow for its employment as permanently installed metrological system. The miniature interferometer converts motions of the triple-faceted retro reflector into optical interference signals that are transmitted to the optoelectronic signal power supply unit (Fig. 3 b) for processing and conversion into lengths. A He-Ne laser serves as the light source for the miniature interferometer, and the fact that it is frequency stabilized allows for a large dynamic range. Compensation of environmental influences form the basis for high metric precisions and are achieved through the correction of laser wavelengths.

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Vertical calibration is achieved by pitch measuring of the grating. Many gratings lines are included in a measuring range so the pitch value is a medium size. The gratings are visualized by an optical microscope (AxioImager, Zeiss); the grating is moved by a mechanical table from Luminous Instruments Ltd. with the retro-reflector on the table. The experimental results obtained using the SIOS interferometer are displayed as a statistical distribution in Fig. 4.

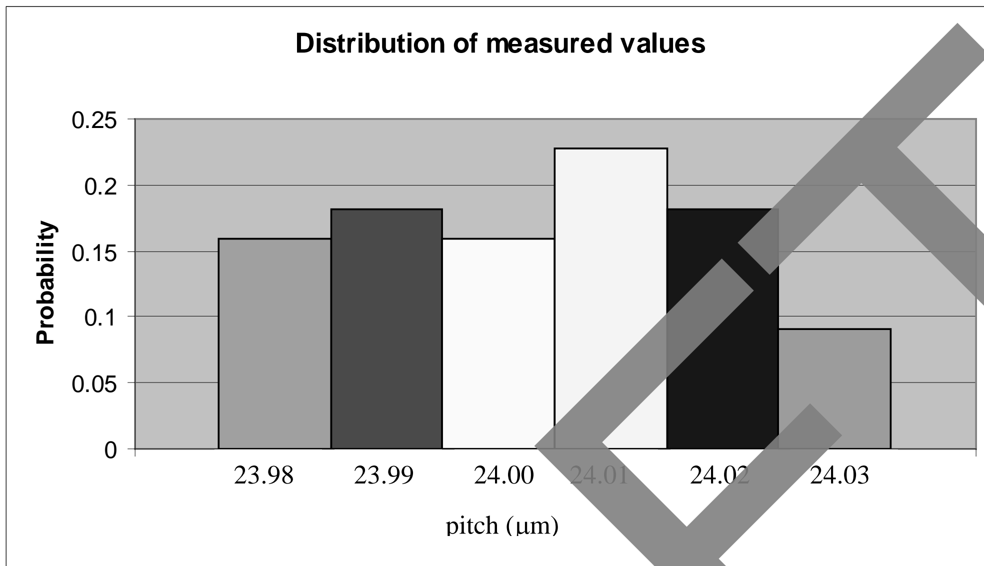

Fig. 4. Distribution of pitch measured values obtained using the SIOS interferometer.

4. AFM CALIBRATION

Atomic Force Microscopy (AFM) is based on the measurement of the interaction forces between a very sharp tip and the surface material. The tip, mounted on a flexible cantilever, is brought into close vicinity of the surface, while monitoring the vertical bending of the cantilever due to the interaction forces between the tip and the surface. In order to acquire an AFM image, the tip is raster-scanned over the surface, while measuring the bending of the cantilever. The result will be a three-dimensional image of the surface.

The first AFM microscope labeled "1" has the capability to scan the samples in contact mode, non-contact mode and intermittent contact mode. The maximum horizontal scan range is about 44×44 μm^2 and the maximum vertical movement is 3.85μm. Depending on the scanning mode, on the nature of the surface and on the tips we use, a lateral resolution of tens of nanometers can be achieved. The AFM is also equipped with a 200X magnification video microscope, which allows good sample and probe viewing and positioning. The microscope labeled "2" has similar characteristic but the horizontal range is even smaller.

For comparison purposes the experimental results for two gratings obtained using the two AFM devices are displayed together with the experimental results obtained using the SIOS interferometer in Tables 2 and 3. The nominal values of the gratings are also displayed. The first one is a photoresist quasi-sinusoidal grating and the second one is a step-like structure of chromium deposited on glass. One may notice the excellent relative error for the pitch measurement that we obtained using the SIOS interferometer, namely 2.0 10^{-4} for the first grating and 4.0 10^{-4} for the second grating respectively.

5. COMMENTS / OBSERVATIONS

Prior to conclusions some remarks are to be made. Regarding lateral calibration, one of the most difficult problems for such measurement is connected to vibration influence on the measurements. The heavy optical table was not enough to reduce the amplitude of vibrations to one nanometer. The large uncertainty is mostly the result of the vibrations. Regarding vertical calibration, our artifacts are not good for calibration because they are not uniform; as one can observe from the lower part of Fig. 5 adjacent lines have different height so we can have different results depending on the area

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we are measuring on. It is necessary to have first very good quality artifacts. To check the uniformity of the grating lines height we need an AFM scanning on long distance [11]. Unfortunately our AFM devices are unable to measure a length of 48µm, as the pitch of the first grating, because of their limited range of 44µm. This is also the reason we have not a statistical analysis of the AFM measurements. The uncertainty for the calibration is not the uncertainty of the measuring devices but the imprecision of the artifact itself, and it is reasonable to consider the uncertainty of the AFM much better than that of the grating. We came to the conclusion that the Linnik interferometer is a good reliable instrument and its compatibility to the definition of traceability in height measurement is demonstrated.

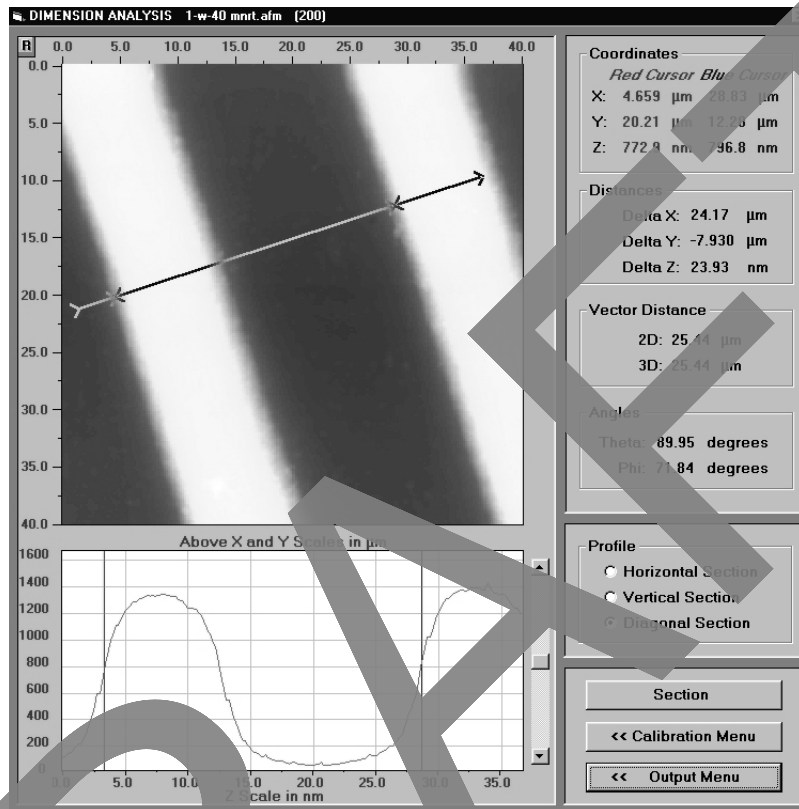

Fig.5 AFM image of a square shaped grating. The upper part is a view from the top while the lower part is a lateral view (section) of the grating structure.

Table 2 Values of the gratings heights obtained using different methods and instruments.

Grating	Nominal pitch (µm)	Linnik	SIOS	AFM 1	AFM 2
1	48µm	1004 ± 27 nm	–	1024 nm	700 nm
2	24µm	1240 ± 30 nm	–	1300 nm	1090nm

Table 3 Values of the gratings pitches obtained using different methods and instruments.

Grating	Linnik	SIOS	AFM 1	AFM 2
1	–	48007 ± 10 nm	–	–
2	–	24 003 ± 10 nm	25620 nm	2401 nm

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6. CONCLUSIONS

We developed a system of measurement for pitch and height lines of 1D gratings that we applied for the case of 2 gratings with nominal values of the pitch of 24 μm and 48 μm respectively. Both of them are intended to be used as standards for scanning microscope calibration in two different laboratories.

First of all we are interested in developing calibration traceable methods. For this reason we used interferometers as transducers from meter definition to real length measurement and frequency stabilized He-Ne lasers. Different interferometers and methods were used to measure pitch and height of the grating lines. Linnik white light interferometer and He-Ne frequency stabilized laser where used to measure height of lines and length measurement. Twyman-Green laser interferometer was used for pitch measurement.

Two commercially available AFM data were compared with our results from interferometry measurements. As far as our frequency stabilized lasers are not calibrated to standard iodine He-Ne laser our measurements are not fully traceable.

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