The interference Linnik type microscope (IM) developed at Inmetro

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Abstract. The interference Linnik type microscope was developed and it design was modernized to provide high resolution nanometrology facility. This microscope can perform length measurement directly relative to wavelength standards such as the frequency stabilized lasers. Thus, one can use interference microscope for primary calibration of the step heights. These step heights can be used to calibrate vertical axis of the other instruments like optical coherence tomography, atomic force microscope, confocal microscope, etc. In all cases the traceability to the National Institute of Metrology, Quality and Technology length primary standards was attempted to be established.

1. Introduction

Nano-metrology is the science and technology of measurements of the artifacts with nano-meter or sub-nanometer accuracy. In order to make such high level scientific measurements it is important to establish the chain traceability to the International System SI meter unit in this area. In this respect, INMETRO have been actively involved in this area of metrological research since 1997 [1-4] when we created new automatic type of Gauge Block Interferometer (GBI). This study has resulted in characterization of the high resolution primary GBI down to sub-nanometer level. We applied a similar methodology to measure other smaller objects, such as nanometrology secondary standards, or so called step-heights.

2. Experimental Set-up

A new primary interferometric microscope (IM) developed is based on the Linnik type interferometer [3], modernized and fully automated and with full digital processing. The light source used is the frequency stabilized He-Ne laser, calibrated against primary length. As the secondary step height standards we have used the step height triple gauge block from Mitutoyo of 2 µm and 10 µm and the step height of 100 nm, produced at Materials Metrology Division. The schematic of the Linnik type of IM is shown in Figure 1.
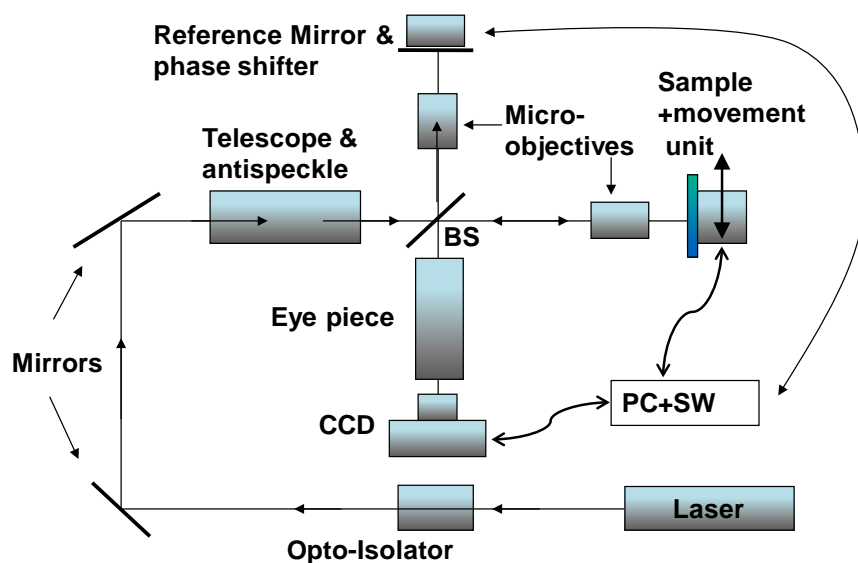
Figure 1. Set up of Linnik type interferometer

The frequency stabilized 633 nm He-Ne laser beam light is directed through a speckle removal unit consisting of two lenses of 100 mm focal length and a rotating diffuser plate. The emerging light is divided by a 50/50 beam splitter and directed into the sample and reference arms. Two identical microscope objectives (10x) are located with equal optical path length to the step height block sample and to the flat reference mirror (λ/20). The reflected beams from sample and reference are recombined at the beam splitter, passed x20 variable zoom eye-piece from HIROX and fringe is directed as image plane to the CCD camera. The CCD image is analysed using in-house developed software for evaluating the fringe fraction of the nominal step height. The interferometric frames are taken from CDD by PC and processed with specially developed and tested dedicated fringe pattern processor software (SW). The sample itself can be moved relative to the optical axis of the interferometer by motorized micrometer in X or Y directions in perpendicular to the axis direction.

3. Experimental Results
We have developed a set of hard-ware and software tools suitable for fringe image processing, phase shifting interferometry and post processing data visualization. The main fringe-pattern processing software (SW) module is based on multi-parameter iterative fit of the digitized pattern along the vertical line (or several neighbouring lines). Prior to the fit it is also possible to perform direct / reverse FFT with gaussian filter. This filter is known for not to perturbing the phase and it is used to remove pixel noise from the interferometric pattern. Additionally pixel noise was removed by averaging several frames to produce the final master interferogram used for processing. The quality of the measured fringe and the theoretical fit are in very good agreement. The minimization criterion is the least square difference between measured data and the model function. It is possible to analyze the fringe pattern along multiple lines, so that we can figure out the topography of the measured artifact. It has been previously shown that using our fringe processing algorithm the resolution of the interferometer can be as high as 0.1 nm or better. The accuracy of the measurement is determined mainly by the quality of the artifact GB and it might be as good as 1 nm the resolution of the method is well below 1 nm. One of the most serious systematic errors of IM is known to be the misalignment of the reference and measuring shoulders. While our interferometer software permits to control misalignments we have developed simple but very efficient self-calibration procedure. In this procedure we measure standard and immediately after that, we calibrate the fringe pattern on reference flat surface of the gauge block. We can optionally use flat surfaces of both GB in the master standard

to perform such self-calibration. If the surface of the GB is assumed to be flat then we can remove misalignment error, by appropriate correction. Our IM instrument of the design used in set-up permits both pattern processing and phase shifting to be performed. We have developed and applied the software (SW) procedures suitable for detailed analysis of phase shifting technique. Our phase shifting unit is based on quite sophisticated 3 degree of freedom tilt-move stage. At each point the full interferogram is taken and saved into memory of the PC. After the procedure is done, it is possible to process its image stack at each position vs. distance of movement such as to reconstruct the phase for the whole measured surface. Further, to remove vibration related noise, we normally take several interferograms, averaging at each position of phase-shifter. To improve exactness of the phase stepper we can optionally make several back-forward positioning at each Z position averaging interferograms. Each individual scan produces interferometric fringe line of about 5-6 fringes at each pixel of the field of view. Each line can be Sin function fitted with an algorithm similar to the one described before. Normally we use no single pixel, but some neighbouring pixel area to average out the pixel-to-pixel noise. It is possible to process individual interferograms the way described above, something we do simultaneously with phase shifting. Thus, we have an opportunity to compare both algorithms: fringe pattern and pure phase shifting method. The experience shows that after all above precautions the signal to nose ratio permits some 0.1 nm resolution (or better) of the system. This has been confirmed by multiple repeatability testes. See example in Figure 2.
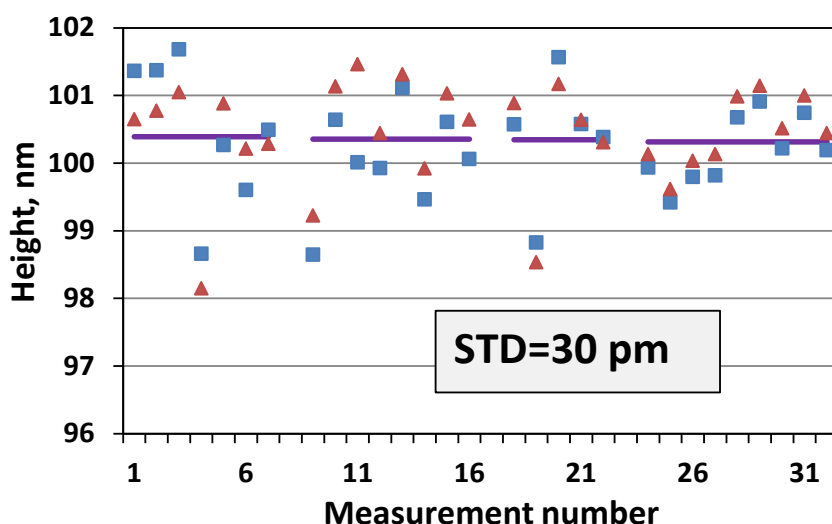

Figure 2. Reproducibility of 100 nm step height measurements taken by phase shifting technique method and corrected on field error.

Our estimation of the uncertainty of primary Linnik IM was made from the results of multiple measurements. The uncertainty budget of Linnik IM is shown in table 1. While single measurement presents relatively big phase noise, using automated system it is possible to average multiple readings at the same conditions (and positions). Next step was to apply adequate correction to the field. To do this we added vertically movable automated stage that was useful for on-flight calibration flat area of the sample. Exactness of correction is estimated to be about 2 nm. The obliquity or aperture error was theoretically estimated from the geometry of the optical Set-Up of our IM. With NIKON PLAN x10 long focus microscopic objectives the maximum incidence angle on sample is about 20 angular degrees that is significantly decreased by camera lens x20 eye-piece. The eye-piece restricts the angles, and at the end effective incident angle is about 3-4 angular degrees by estimation. This means that the possible obliquity error is about 80-90 pm on 100 nm step. To check it, we have restricted the entrance aperture of the IM down to about 2.5 The result was that the obliquity error is non-detectable

within 100-200 pm uncertainty. So, we consider that at k=2 nm the uncertainty, associated to this particular error type, is no more than 0.5 nm. This is well within our target final IM uncertainty.

Table 1. Uncertainty Budget for IM.

Source of uncertainty	Uncertainty
Alignment, corrected	0.5 nm
Fringe fraction	0.3 nm
Phase noise after 20 measurements average	0.3 nm
Repeatability after 10 measurements average	0.1 nm
Reproducibility after 10 measurements average	0.8 nm
Flatness of the artefact (exactness of field correction)	2 nm
Laser Wavelength	< 0.1 nm
Combined standard uncertainty	2 nm

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4. Final Results and Discussion
An important problem of traceability to SI unit in nanotechnology and nano-production has been discussed in several institutes and new methods were developed and applied, for example, in dimensional nanometrology. In our work we use IM Linnik using step heights to give traceability to AFM, CM, etc. Nowadays INMETRO is developing and characterizing their own step heights in sub-micrometer scale. Satisfactory results were obtained in the first artifacts but we need to improve the method of preparing and test different material to produce these secondary standards.

We have created a new interferometric microscope for primary measurements. The instrument has been shown as a powerful tool to provide the traceability for the SI meter unit length scale for several optical and opto-mechanical instruments such as AFM, CM, TEM, etc. The limits of the reproducibility of Linnik Interferometer are shown to be as high as a few tens of pico-meters. The primary measurement system for nanometrology was created and certified, so we are ready to participate in a key comparison in this area.

Acknowledgments

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