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DIFFERENTIAL POLARIZATION INTERFEROMETER FOR MEASURING SURFACE PROFILES

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Abstract. A differential interferometer based on the Nomarski microscope principle for measuring surface profiles is described in the paper. It is an instrument measuring surface profiles in a line with accuracy of better than 5 A. A scan of more than 25 mm in steps of 10 μm can be performed and the output data are in analog form which can be digitized and stored in a computer or displayed on a z-y plotter. The lateral resolution is determined by the used objective and the translation stage and in our case is 10 μm, and the maximum vertical measurement range is 1 μm.

Резюме. Создан дифференциальный интерферометр на основе интерферометра Номарского. Интерферометр предназначен для измерения шероховатости отражательных поверхностей с точностью 5 Å и протяжения сканирования больше 25 mm. Разрешающая способность в горизонтальном направлении лучше чем 10 μm.

1.Introduction

Surface profiles play an important role in the production of mechanical, electronic and optical elements. For example the surface roughness of a computer magnetic hard disc should be adequately controlled to a value determining the disc memory capacity. The surface roughness of optical components is most important to avoid scattering and to ensure its quality especially when the components are used in interferometers or in high power laser systems.

The most used method for measuring the surface roughness in the range 1–100 Å is the stylus instrument. The instrument uses a sharp diamond stylus the vertical motions of which are transferred to electrical signal by electromechanical or capacitance transducer. The disadvantage of these instruments is that usually after measurement the soft samples are destroyed by the hard edge of the stylus. The instrument also requires a vibrationally isolated table. Another surface profiles used in the practice are the electron microscopy and microinterferometry. The first one requires a long time to prepare the sample, while the second is more used. The multibeam interferometers of Fizeau and Mirau have a lateral resolution of some microns and height resolution of 1 **Å.** These instruments need a good camera interfaced to a computer, excellent optics and in some cases covering the samples with reflection coatings which makes the methods much expensive.

The differential iterferometers baaed on the Nomarski contrast microscope are with the same capabilities as the other interferometers, but require less expensive optical components, do not require test samples for quantitative measurements and very important is its vibrational insensitivity.

The instrument described in this paper uses a simple wedge made from calcite as a polarizing element which allows us different focusing objectives to be used, and different lateral resolution together with different object/sample distances to be obtained. The lateral resolution is determined by the objective and the z-y scanning stage. In our case the diffraction limited focal spot is down to $3–4\,\mu m$, but the stage used in the experiments is with a readout resolution $10\,\mu m$. That is why we changed the objective to obtain the same resolution.

2. Principle of Operation and Optical Configuration of the System

The optical configuration of the system is shown in Fig. 1. It is similar to those described in the literature [1, 2] with some differences. The beam from a standard He-Ne laser is passed through a X/4 plate to obtain a circular polarized beam in order to avoid the noise in the beam polarization. The beam passes through an ex-

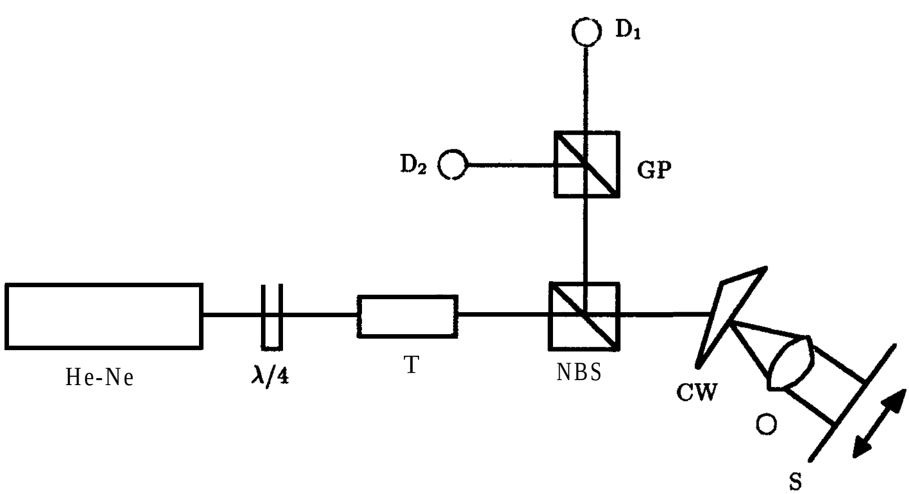

Fig. 1. Optical configuration of the interferometer. D1,D2 pi-n photodiodes,T—telescope, NBS-nonpolarizing beamsplitter, CW—calcite wedge, O-objective, S—sample, GP-Glan-Taylor air-spaced polarization prism

pander **"T"** and a nonpolarizing beamsplitter "NBS". Next there is a calcite wedge **"CW"** and an objective "0". The two orthogonally polarized beams with equal intensities are focused on the sample "S". The beams on the sample are separated by a distance determined by the wedge and objective. The best situation is when the distance is equal to the spot diameters in order not to lose a lateral resolution. In Fig. 2 are shown the spots on the samples. The intensity distribution is measured

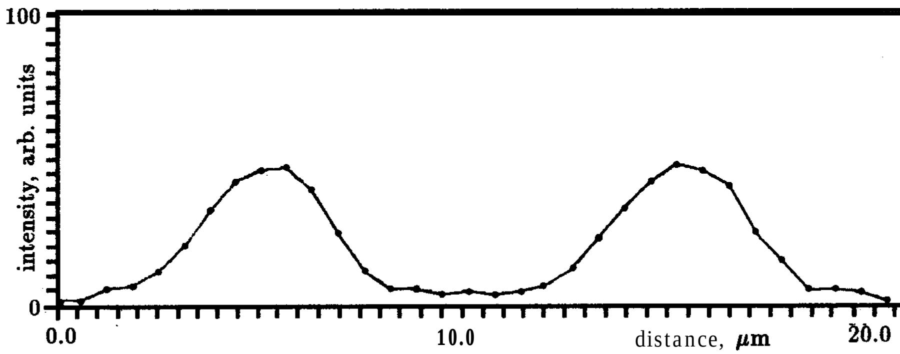

Fig. **2.** Distribution of the intensity at the focal spots

by a sharp edge translated in the x direction with a resolution of $1.25\,\mu m$. The objective is with focal length of 5mm. After reflection from the sample surface the two beams spatially recombine at the calcite wedge. The beams which retain their polarization identities are partially reflected from the beamsplitter and enter the polarization beamsplitter — a Glan-Taylor "GP" prism. Both polarization components are directed to the pi-n photodetectors D1 and D2. This differential scheme allows to exclude the reflectance of the sample and to take into account only the sum and different signals of the detectors. The sum and the difference of the signals from both photodiodes are measured as functions from the translation of the sample. The sample is translated in a line colinear with the line connecting the focal spots.

The intensity of the interfering beams is related to the surface height differential h at the two focal spots [1, 3]. If the birefrigent prism and the polarization beamsplitter are properly adjusted, the intensities on each photodetector are linearly proportional to the slope of the surface between the two focal spots. This is strictly true only if the height variations in the spots are small in comparison with the wavelength. Following the ABCD matrix method of Jones (1941) [4] in a plane after the $\lambda/4$ plate which "fast" axes are approximately $45°$ to the plane of polarization of the laser beam the vector is

$$\frac{A}{\sqrt{2}}\begin{pmatrix} e^{i(\pi/2+\varepsilon_y)} \\ e^{i\varepsilon_y} \end{pmatrix} \tag{1}$$

where A is the amplitude of the electrical vector, ε is the initial phase. The component refering the time evolution of the signal is neglected. The birefrigerent wedge can be expressed as two orthogonally placed polarizers. Each of them gives a linear polarized beam, as the other does not exist. Both beams are with equal amplitudes. For the first

$$\begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix}\frac{A}{\sqrt{2}}\begin{pmatrix} e^{i(\pi/2+\varepsilon_y)} \\ 0 \end{pmatrix} \tag{2}$$

and for the second

$$\begin{pmatrix} 0 & 0 \\ 0 & 1 \end{pmatrix} \frac{A}{\sqrt{2}} \begin{pmatrix} 0 \\ e^{i\varepsilon_y} \end{pmatrix}.$$

After reflection the second beam (for example) acquires an additional phase change and it can be expressed

$$\frac{A}{\sqrt{2}} \begin{pmatrix} 0 \\ e^{i(\varepsilon_y+\Delta)} \end{pmatrix}. \tag{3}$$

After passing back through the wedge both beams do not acquire any additional polarization changes [1,5] and the resultant beam is

$$\frac{A}{\sqrt{2}} \begin{pmatrix} e^{i(\pi/2+\varepsilon_y)} \\ e^{i(\Delta+\varepsilon_y)} \end{pmatrix}. \tag{4}$$

Therefore the parameter tg $\beta = \frac{b}{a}$ describing the elepticity of the polarization [3] is

$$\beta = \frac{1}{2}(\Delta + \frac{\pi}{2}) \tag{5}$$

where we have assumed that the phase difference A is smaller than $\frac{\pi}{2}$. After simple transformations of the matrices the intensities of the beams after the polarization cube "GP" are

$$I_{D1} = I_0 \cos^2(\frac{\Delta}{2} + \frac{\pi}{4})$$

$$I_{D2} = I_0 \sin^2(\frac{\Delta}{2} + \frac{\pi}{4}). \tag{6}$$

It is seen that the intensities detected by the photodetectors are changed by $\sin^2$ and $\cos^2$ in comparison with the whole phase change (in the birefrigerent wedge and from the height between the two focal spots). The phase change due to the wedge can be compensated in the double pass through it or can be tuned to be $\frac{\pi}{2}$. So the differential signal is

$$I = I_{D2} - I_{D1} = -I_0 \cos[2(\frac{\Delta}{2} + \frac{\pi}{4})], \tag{7}$$

i.e.

$$I = I_0 \sin \text{A}.$$

When the phase shift A is small

$$I = I_0\Delta \tag{8}$$

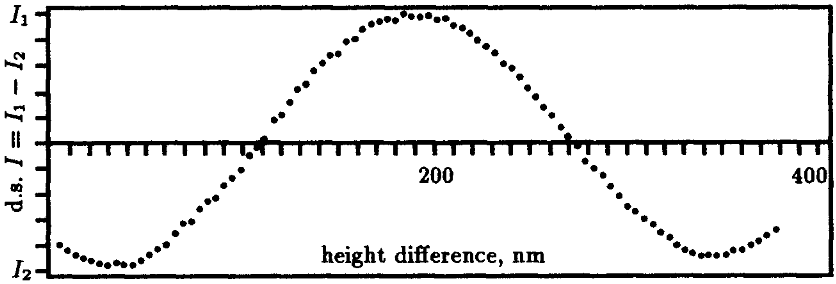

Fig. 3. Differential signal v.s. height difference between the focal spots

and the height h is smaller than the wavelength λ, i.e. the measurements are carried in the slope of the function shown in Fig. 3

$$\Delta = 4\pi \frac{h}{\lambda}$$

$$h = \frac{\lambda}{4\pi} \frac{I_{D1} - I_{D2}}{I_{D1} + I_{D2}}. \tag{9}$$

In Fig. 3 the differential signal ($I_{D1} - I_{D2}$) is shown in comparison with the height h between the two focal spots. This is derived when the stage where the sample is located is tilted to the line connecting both spots. From the angle of rotation this height is determined. The sensitivity of measuring the height (or the slope between the focal spots) is determined by the amplification of the electronic circuit and the accuracy of measuring the differential signal. In our case for an Al mirror the sensitivity gives a minimum detectability of less than 0.5 Å. The upper limit of the height difference between the focal spots measurements is determined by (7) and is chosen to be less than 100 nm, while the vertical measurement range is determined by the focal depth of the objective and is measured to be more than 1 μm.

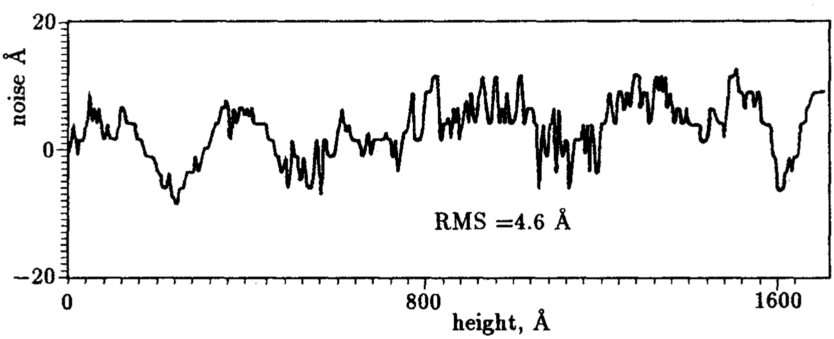

Fig. 4. Evolution of the signal without integration, i.e. noise due to vibrations

The final sensitivity is determined by the quality of the optical components and the mechanical stability of the construction. We should admit that there has been paid no attention to these requirements at all. The final sensitivity of

the instrument is checked by following the time evolution of the signal without translation and without any integration period. The points in Fig.4 are taken every 5 seconds. The RMS of the error caused by these fluctuations is smaller than 4.6 Å. The other most important error cornea from the nonlinearity of the translation stage. This error is measured to be less than 2 Å. The repetability of the measurements is determined by the accuracy of the translation stage and is down to 1 μm.

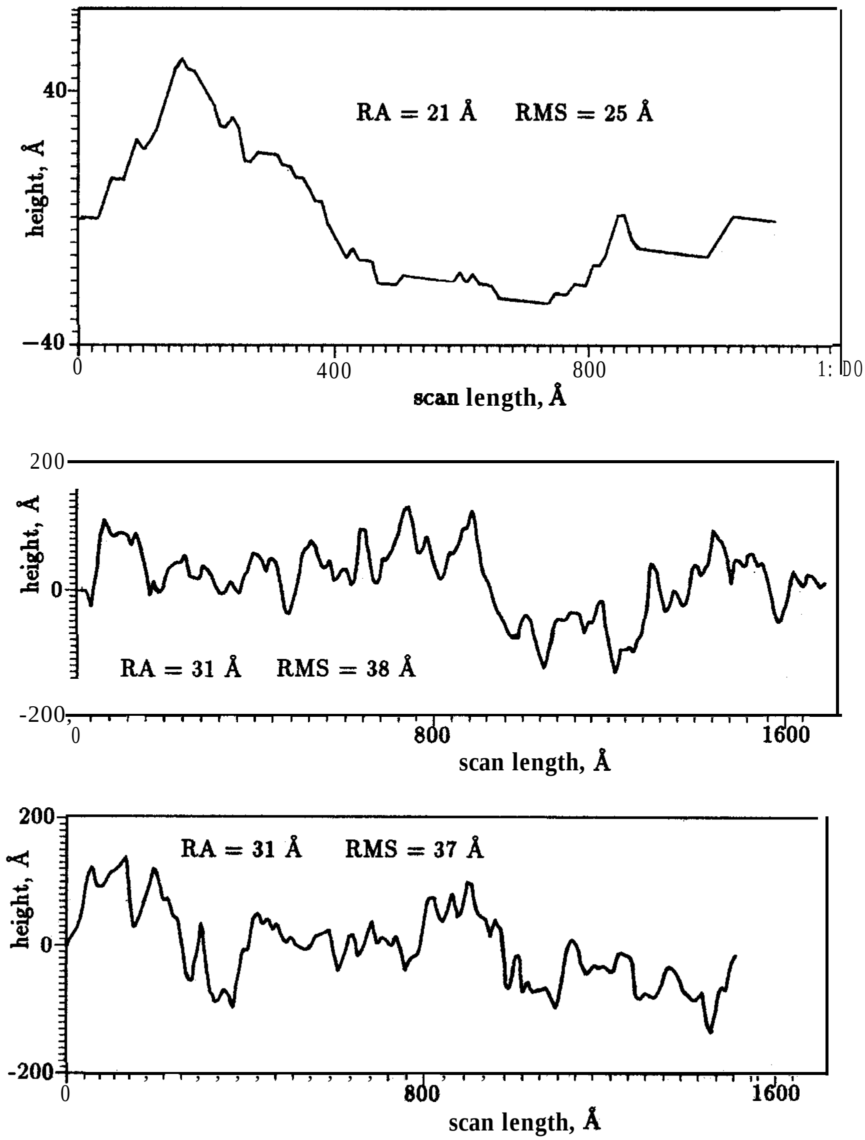

Fig. 5. Surface profiles **of:a)high** power eximer laser Al mirror; b)computer hard disc; c) computer hard disc

3. Results

Several types of surfaces were measured using the surface profiler. They are shown in Fig.5a, b, c. The profiles are taken by translation of, the stage where the samples are mounted in steps equal to the distance separation between the spots, in our case 10 μm. The slope is calculated at each sampling point, and then the data are numerically integrated to yield the surface profile. In this case no reference sample is needed.

With RA the average arithmetic deviation from the zero points line, and with RMS the standard deviations are noted. In Fig. 5a a high power excimer laser Al mirror is measured. Here the parameter RA is 21 band RMS = 25 Å. Two kinds of roughness can be seen. The “fast” has a smaller RA while the “slow” one is deeper. The “slow” one is due probably to vibrations in the polishing machine. In Fig. 5b, c the profiles of computer 20 Mbyte hard discs are shown. Their surfaces are diamond polished and after that they are covered with a Ni7P alloy. Then again they are polished. These results are the same as those obtained from measurements with stylus instruments (Taylor-Hobson) where RA= 30-35 Å.

References

1 J. Hartman, R.L. Gordon, D.L. Lessor. *J. Opt. Soc. of Am. 69* (1979) 357; *Appl. Optics* **19** (1980) *2998; Appl. Optics 20* (1981) 2665.

2 J.M. Eastman, J.M. Zavislan. *Proc. SPIE 429* (1983) 56.

3 M. Ivanov. Diploma work, ILT, Sofia Univ., June 1990.

4 W.A. Shurcliff. *Polarized* Light (Mir, Moskow 1965).

5 T.C. Bristow, K. Arackellian. *Proc. SPIE 749* (1987).