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SURFACE ROUGHNESS OF FLAT AND CURVED OPTICAL SURFACES

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ABSTRACT

A profilometer has been fabricated based on optical heterodyne detection technique. The vertical height sensitivity of the technique has been improved to much better than 10Å rms. The surface roughness of several coated and uncoated samples has been measured. A typical surface profile and surface characterization plots are also shown.

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Introduction

Surface roughness measurement has several applications. Even a few Å roughness will cause scattered light in optical systems. Smooth surfaces are required in a wide variety of instruments. For example, the outputs of the high power lasers are limited by the surface roughness of mirrors and windows. Similarly, the information storage capacity of magnetic media is limited by the roughness of the surface. Roughness reduces the resolving power of optics and distorts images. The performance of certain thin film components in electronic industries is affected by the roughness on the film surface. X-ray astronomical telescopes require smooth curved surfaces. To improve the surface quality, super sensitive detection methods are required. Wide ranging measurement techniques are developed based on interferometry, electron microscopy, X-rays, ellipsometry, light scattering, and using mechanical stylus, etc. Though there are several techniques[1,2] available for measurement and evaluation of the surfaces, no single technique is fully adequate. Also, the technique used should be nondestructive and highly sensitive. So, we fabricated an optical heterodyne profilometer[3] and its current sensitivity is much better than 10Å rms. It is a noncontact and nondestructive technique. The instrument can be operated even by unskilled personnel for routine measurements.

Principle

The principle[4] behind the technique is simple and elegant. Briefly, in this experiment, a laser beam is split into two parts and focused at two different points on the surface under investigation, and then the phase variation of the reflected beams is measured, which directly relates to the height difference between the two points. A brief description of its theoretical background is given elsewhere[4].

Experimental

A block diagram of the experimental setup is shown in Fig. 1. The experiment uses a 1mW Zeeman split (Δw = 1.5 MHz) He Ne laser (HP 5501A) whose frequencies are collinear but orthogonally polarized. The laser output is passed through a spatial filter/telescope combination to reduce the spatial noise and the beam size to ~0.5 mm. The laser beam is split into two parts of unequal intensities, but both parts contain the two Zeeman components. One part is detected by a receiver (HP 10780B) whose output is hereafter called reference signal and the other part is directed vertically upwards to the surface mounted on an airbearing rotary table (Dover Instruments). Before falling on the sample, the beam passes through a wollaston prism and on exit the two frequencies are spatially separated and then focused at two different points on the surface of the sample. The beam path is arranged such that one of them falls at the axis of rotation of the table and the other is separated from it by only a fraction of a millimeter. The reflected beams are recombined by the wollaston prism and then directed to another identical receiver (HP 10780B) whose output is hereafter called measurement signal. Whenever two different frequency signals fall on a detector its output is an average dc current proportional to the

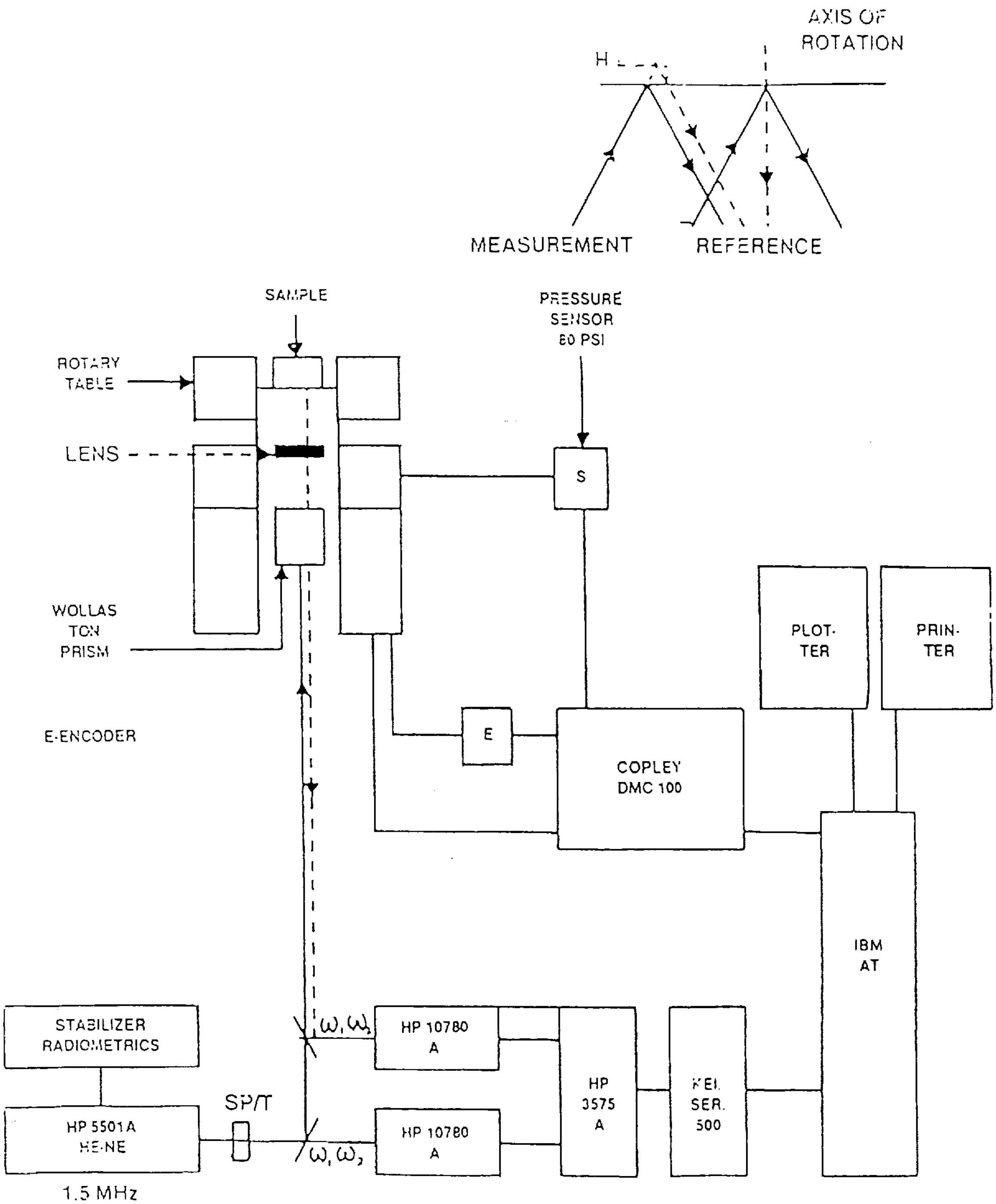

Figure 1. Block Diagram of the Experimental Set Up.

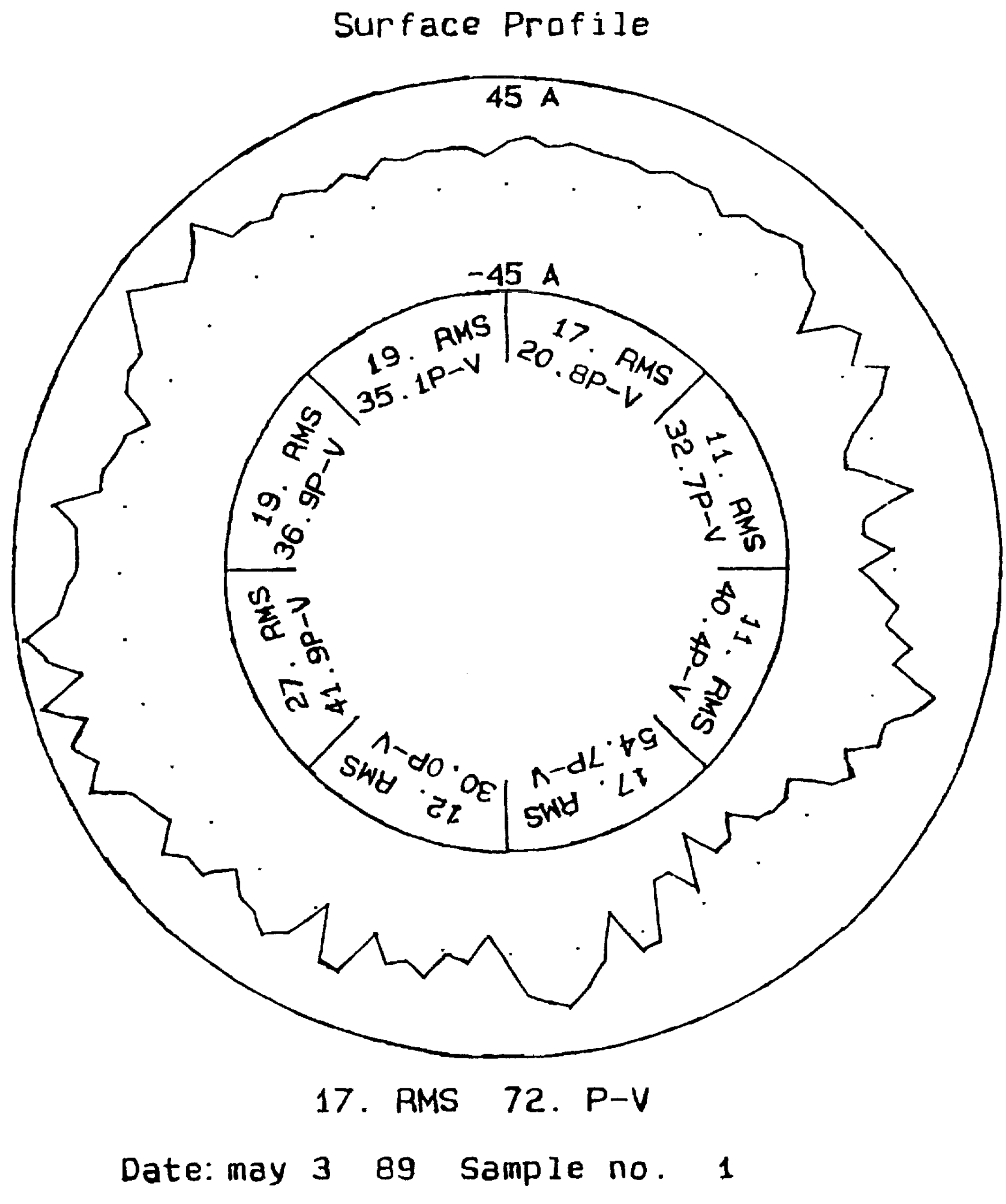

Figure 2. Surface Profile of a GaAs Wafer.

intensity plus an rf signal at the beat frequency (Δw). The dc part is elemented by a preamplifier built into the reciever (HP 10780B). The outputs of the two receivers are rf signals at 1.5 MHz (Δw), but the phase of the measurement signal varies due to roughness. The two rf outputs are given to the two inputs of a phasemeter (HP 3575A) whose output is an analog signal and its amplitude is proportional to the phase difference between the two inputs (10 mV/degree). The analog output of the phasemeter is interfaced with an IBM-AT computer using a 14 bit-A/D converter (Keithley series 500). A dc motor is attached to the table and its motion is controlled by a DMC 100 controller (Copley controls), and a two channel incremental encoder (Teledyne Gurley) provides feedback from the motor to the controller. There is one general program in BASIC that triggers DMC 100 for table rotation and initiates Keithley module for online data acquisition. The sample/table is rotated at the rate of one revolution per two minutes and data are acquired at the rate of 128 samples per revolution or an integral multiple of it. During table motion one of the spots is stationary and the other encounters different points in a circular path and so the measured signals are plotted in circular format.

Results and Discussion

The measured phase difference $\Delta\phi$ and the surface height variation or roughness ΔH ($\Delta H \approx \frac{\Delta Z}{2}$) are related by $\Delta\phi \approx \frac{2\pi}{\lambda}\Delta z$ where Δz is the extra pathlength traveled by one of the beams due to roughness. A typical surface profile of a GaAs wafer is shown in Fig. 2. The rms values of the roughness and peak-to-valley (P-V) values are calculated for eight different segments and the entire profile and are printed in the same figure. A number of functions are used to characterize the surfaces like autocovariance, spectral density, height and slope distribution functions. Autocovariance function refers to the distribution of correlation lengths, which are separations between similar topographic features. The spectral density function describes the angular distribution of the scattered light. Classical scattering theories were based on the assumption that the autocovariance and height distribution functions are gaussian which may not be true for every surface. All these functions have been calculated using the formulas given in reference 4 and are plotted in Fig. 3. Obviously, the autocovariance function deviates from gaussian distribution.

Sensitivity

Sensitivity of the technique is determined from the relation $\Delta\phi \approx \frac{4\pi}{\lambda}\Delta H$. Roughness ($\Delta H$) ≈ 1Å will cause a phase change of $\sim 0.1°$ which is the resolution of the phasemeter. A severe limitation to the sensitivity is set by improper alignment of the optical beams. Some of the important criteria to be fulfilled are (1) one of the spots has to fall at the axis of rotation, (2) the surface normal has to be parallel to the axis of rotation and (3) the contact area between the table top and the sample are to be free from dust. When all these criteria are fulfilled the sensitivity of the instrument will be improved to the theoretical limit ~ 1Å, because the noise from other sources is insignificant.

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References

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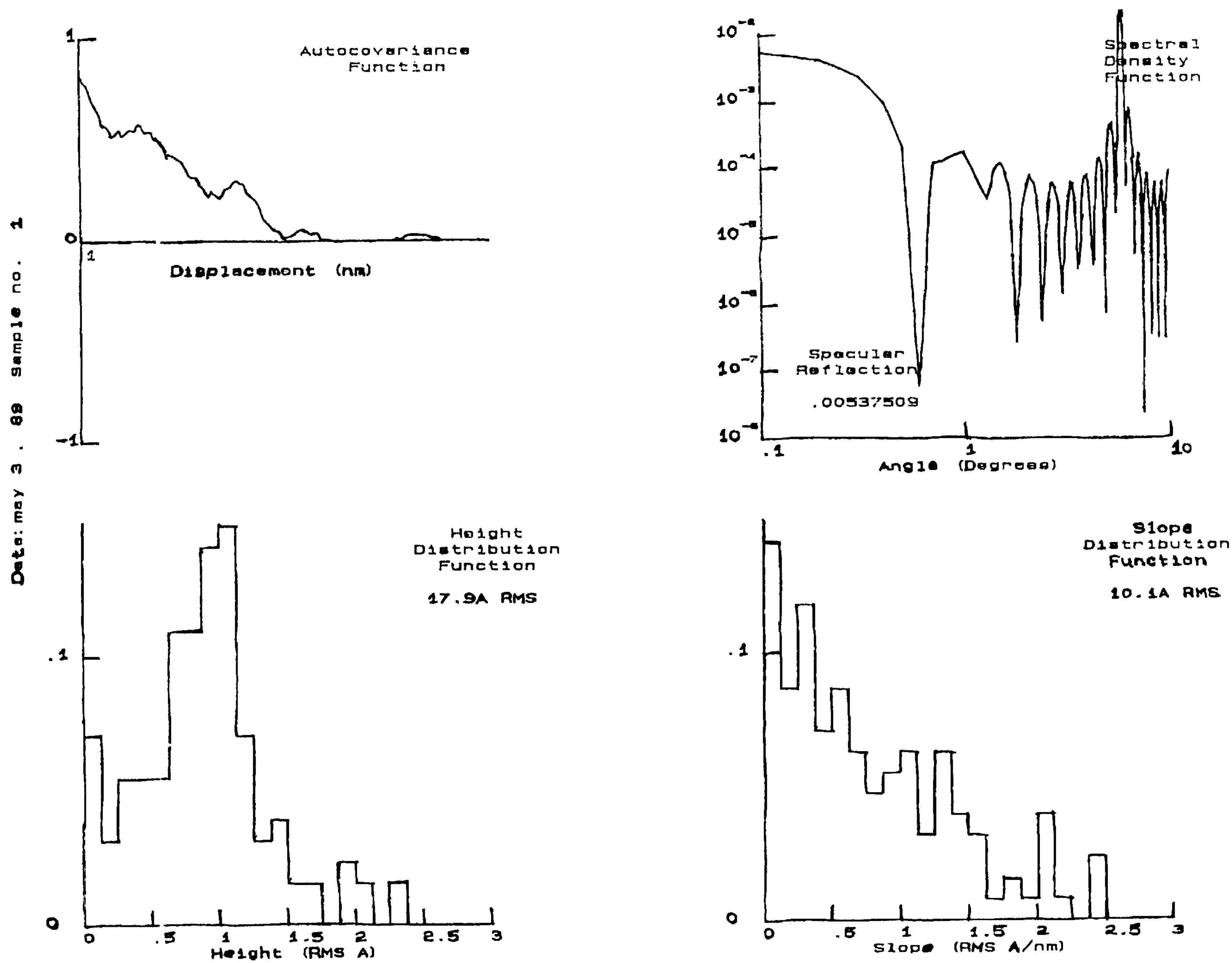

Figure 3. Surface Characterzation Plots.