DOI 10.5162/SMSI2020/C6.3

Investigation of a metrological atomic force microscope system with a combined cantilever position, bending and torsion detection system

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Summary:
This article presents a new metrological atomic force microscope (MAFM) with adjustable beam position and direction of the cantilever measuring system. An interferometric measurement system measures the position of the cantilever and a quadrant photodiode detects the bending and torsion of the cantilever. To improve the signal quality and reduce disturbing interferences, the optical design was changed in comparison to the system of [3, 4]. The integration of the MAFM in the nanomeasuring machine (NMM-1) offers the possibility of large-scale measurements over a range of 25 mm × 25 mm × 5 mm with subnanometre resolution. A large number of measurements have been performed by this MAFM in combination with the NMM-1. In this short paper, examples of these measurements for determination of step height and pitch and the measurement of an area are demonstrated.

Keywords: metrological atomic force microscope, nanomeasuring machine,

Introduction

Today's progress in areas like nanotechnology and electronics requires metrological accurate object positioning and measurement with a high resolution and high accuracy. Decreasing structural sizes and at the same time feature miniaturization with increasing component dimensions characterize the measurement tasks for micro- and nanomeasuring systems. Since its invention in 1986 [1], the atomic force microscope (AFM) has been widely used in the precision engineering as well as in the micro- and nanotechnology. Currently, optical beam deflection (OBD) systems are mainly used to detect the bending and torsion of cantilevers [2]. Instead, focus sensor detection systems and interferometric detection systems measure the position of the cantilever. Measurements using laser interferometer can be over the laser wavelength directly traceable to the metre definition.

A new version of a metrological laser interferometer-based AFM head has been developed at the Institute of Manufacturing Metrology (FMT). The measuring head was first developed to enable exact interferometric position measurement, performed directly on the reflecting backside of the probe and simultaneous measurement of the position, bending and torsion of the backside of the probe [3]. During the measurement with the AFM, the cantilever is usually slightly tilted (in our system 8°) in order to avoid contact of the clamping chip with the surface of the measured object. Two tiltable plane mirrors are used as an adjustment unit to adjust both the direction and the position of the focused laser beam. Consequently, the optical axis of the focusing lens in the measuring arm can be perpendicular to the reflecting backside of the cantilever. This adjustment unit is also very useful for adapting the system after exchanging the cantilever or the complete cantilever unit even in case of different tilt angles or lengths of the cantilever. The MAFM has been integrated in the NMM-1 as a probe system and therefore a large area measurement of a range over 25 mm × 25 mm × 5 mm and a resolution of 0.1 nm is realizable.

This short paper reports the design and implementation of the MAFM. Results of step height and pitch determination and areal measurements on different samples are given.

System setup

The measuring head combines a homodyne interferometer and a tilt measuring system, which allows the simultaneous detection of position, bending and torsion of the reflecting surface with one focused beam [4]. A single laser beam is utilized in this measuring head. This results in an advantage of a compact, small measuring head with total dimension of about 110 mm x 130 mm x 40 mm (including reference arm). Two wedge plates are integrated to minimize disturbing interferences on the position sensitive device (PSD) caused by multiple reflections on the quarter wave plate [4]. While one tiltable plane mirror is fixed, the other tiltable plane mirror can realize an adjustable angle of ±3°. Accordingly, the adjustable displacement is approximately 250 µm – 290 µm. The new system design is shown in Fig. 1

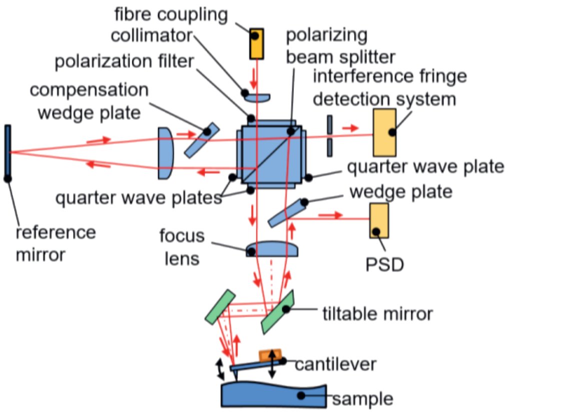

Fig. 1 Functional principle of the metrological AFM system

Measurement Results

In order to carry out measurements correctly, the MAFM was calibrated by the NMM-1. Different measurement tasks were carried out. In the following, exemplary measurements in contact mode with the cantilever PPP-CONTSCR from the company Nanosensors are illustrated. The profile height (z-direction) is the difference between the calibrated AFM bending signal and the z-axis position data of the NMM-1. Fig. 2 shows the measurement on a step height TGZ1 from company NT-MDT with a step height of (21.4 ±1.5) nm. With a scan speed of 1.5 µm/s and a point distance of 1 nm the lateral mean mismatch between forward and backward scan is about 15 nm. The step height was calculated according to DIN EN ISO 5436-1. The measured step height is 20.66 nm with a standard deviation of 1.8 nm. This result agrees with the nominal value.

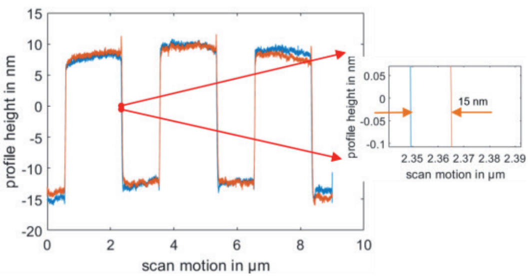

Fig. 2 Step height measured forwards and backward

In order to determine the pitch, the measurements are conducted perpendicular to the gratings TGZ2 with a step height of (108 ±2) nm and a period of (3 ±0.01) µm. A scan length of 600 µm was repeated 10 times. Fig. 3 illustrates a section from one repeated measured profile. The mean pitch was calculated using the Fourier transform method [5]. The determined mean pitch is 3.007254 µm with a standard deviation of 61 pm.

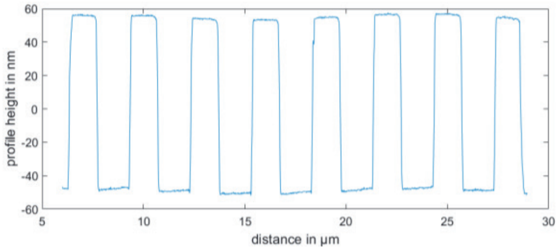

Fig. 3 Measurement on calibration grating (one scanned line)

Finally, an exemplary areal topography scan in macroscopic range is shown in Fig. 4. A 1 mm × 70 µm area of TGZ2 was measured with 10000 × 14 pixels. Commercial AFMs have a limited scanning range of less than 200 µm. Due to the integration of the MAFM in NMM-1 a scan area of 25 mm × 25 mm can be achieved.

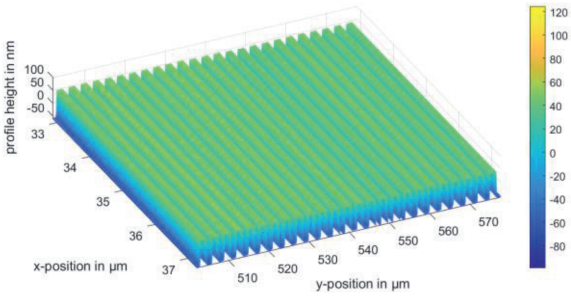

Fig. 4 Section from the scanned area of TGZ2

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