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Metrological atomic force microscope with self-sensing measuring head

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ABSTRACT

A metrological atomic force microscope (AFM) adapting compact measuring head for the micro-nano dimensional measurement is introduced in this paper. Based on a novel self-sensing probe the head does not need any optical detector to measure the bending of the cantilever, significantly saving the working space to integrate with other measuring methods. This AFM operates in tapping mode and adapts frequency modulation (FM) mode to enhance measuring speed. A *z*-axis piezoelectric positioning stage (compact *z*-stage), with high resonant frequency, is responsible for the rapid motion of the sample in *z*-direction. A high-end digital signal processing (DSP) servo control system further guarantees high measurement speed. A nano-measuring machine (NMM) is equipped as the lateral moving stage to realize three-dimensional measurement. Three interferometers in the NMM enable the measurement to be traced to the meter definition. After calibration, the measurement of one-dimensional grating has been made. According to experimental results, the resolution of the AFM can reach nanometer level.

1. Introduction

With the development of nanotechnology, various metrological techniques are used for nanoscale dimensional measurements such as optical microscope, stylus profilometer and scanning probe microscope (SPM) [1]. The SPM is a technique that can directly manipulate, image and measure properties of nanoscale structure. Compared with other two techniques, SPM has higher resolution, particularly in lateral direction [2]. Atomic force microscope (AFM), one common type of SPM, was invented in 1986 to provide nanometer resolution imaging of insulating as well as conducting surface [3].

However, nowadays, the capabilities of AFM are still insufficient. To assure the demanded measurement quality, the AFM is usually calibrated to transfer standards. This process is indirectly because the transfer standards must be calibrated using metrological instruments prior to their usage. Besides, to measure the bending of cantilever, most AFMs always need optical signal detectors which increase complexity of system and occupy lots of working space [4].

Cantilevers with integrated sensing elements do not require alignment of an external laser and optical detectors. The defection of the cantilever is converted into an electric output signal, which is proportional to the applied strain. Such self-sensing cantilever probes, including capacitive [5], piezoresistive [6] and piezoelectric [7] probes, make more compact systems possible. Piezoelectric probes have a simpler design than capacitive probes and consume less power than piezoresistive probes. Besides, they can simultaneously sense and actuate. As one kind of piezoelectric probes, tip or cantilever is fixed on one beam of a tuning fork, which is a strong candidate for the AFM because of its high-frequency stability. The tuning fork probes are usually used in the non-contact AFM (NC AFM) [8–10], since the high spring constant of probe determined by the tuning fork can enable a stable tip vibration with small amplitude (several nanometers or even smaller) which prevents the tip from being captured by the surface. However, for contact mode or tapping (intermittent contact) mode AFM [11], the stiff cantilever creates higher tip-sample force including lateral force which may cause damage to the sample and is not suitable for the measurement of soft material.

In this paper, a metrological atomic force microscope (AFM) adapting compact measuring head is introduced. In the purpose of dimensional measurements, the AFM is operated in tapping mode. A self-sensing tuning fork probe [12] with novel structure is integrated in the measuring head which does not need any optical detectors. By means of the laser interferometers, traceable characterizations can be realized. To avoid measuring speed limitation caused by high quality factor [13], the frequency modulation (FM) technique is adopted.

2. Systemation

2.1. Schematic structure and operating principle

Fig. 1 shows the schematic diagram of the AFM system, which consists of six main blocks. Block I is the signal detecting module

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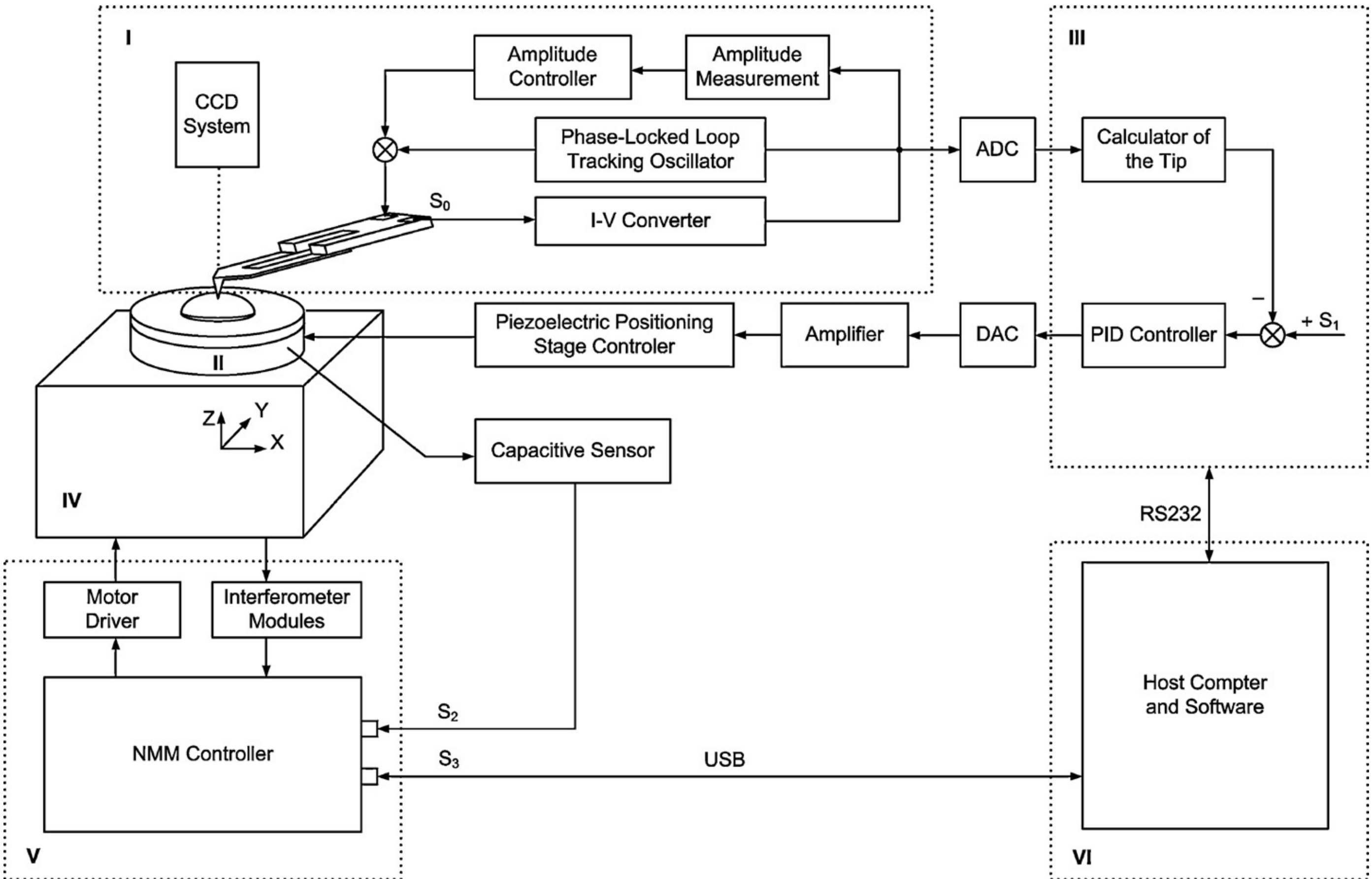

Fig. 1. The schematic diagram of system. The system includes six parts: (I) signal detecting module; (II) z-axis piezoelectric positioning stage; (III) DSP control system; (IV) NMM; (V) NMM controller and interferometers; (VI) host PC with measurement software.

including the measuring head with self-sensing probe, FM module and CCD system. Block II is a fast z-axis piezoelectric positioning stage (compact z-stage) with an internal capacitive sensor. Block III is a high-end digital signal processing (DSP) serve control system. Block IV is a positioning system with a motion range of 25 mm × 25 mm × 5 mm in x-, y- and z-directions, referred to as a nano measuring machine (NMM) [14]. Block V controls the motion of the NMM and includes three interferometers. Block VI is the host computer with measurement software.

After successful tip approach, the sample surface is detected using the self-sensing probe in tapping mode by monitoring the vibration of cantilever. The measuring head signal is sent to DSP control system which maintains the vibrating state of the cantilever constant by moving the compact z-stage with the sample in z-direction. Simultaneously, the NMM can detect the extension of compact z-stage by sampling the voltage output of capacitance sensor.

2.2. Measuring head

Fig. 2(a) shows the AFM measuring head structure including self-sensing probe, weak signal amplification circuit and mechanical package structure. The self-sensing probe is hold by grippers on the circuit board. Compact structure makes it convenient to mount

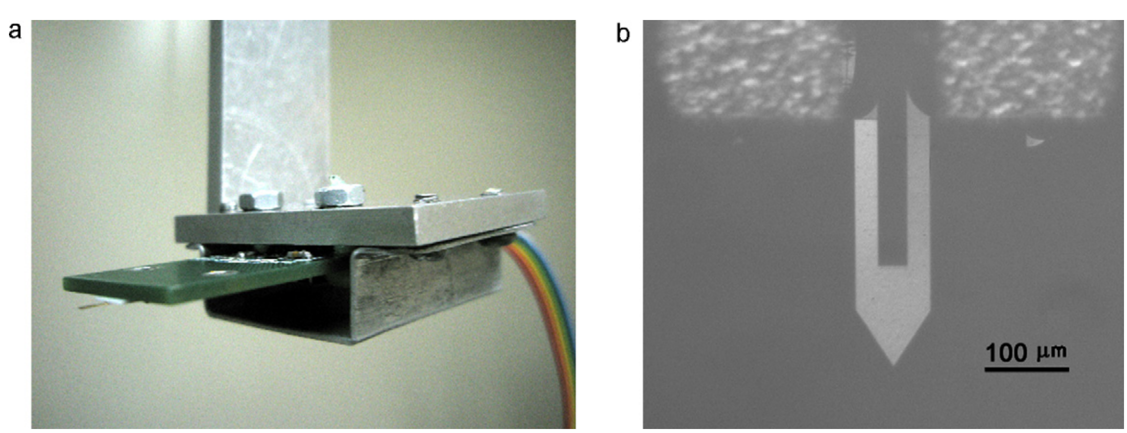

Fig. 2. Measuring head structure (a) and probe image in CCD system (b).