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Development of a multiprobe instrument for measuring microstructure surface topography

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ABSTRACT

This paper presents a multiprobe instrument for measuring the surface topography of microstructures. The instrument consists of a white light interference (WLI) microscope and an atomic force microscope (AFM), which work in conjunction with a precise positioning platform and can be switched freely by using a large-range kinematic axis mounted on the crossbeam of the supporting framework. To verify the performance of the instrument, a calibrated nanodimensional standard was measured. The results are given for the instrument and show good accuracy. To demonstrate the instrument's ease of use, a suspension spring in a microcapacitive sensor was measured and characterized by using the two probes interactively.

1. Introduction

Surface topography plays a vital role in the functionality of a component; therefore, controlling surface topography is crucial in manufacturing and many engineering and scientific disciplines. The dimensional accuracy of a micro-structure is also essential because it assures the quality and interchangeability of a device. The modern manufacturing industry is beginning to benefit greatly from the ability to control the three-dimensional, or areal, structure of a surface [1,2]. Measurement technology for large areas and microsurfaces are necessary in the inspection process of semiconductors, microelectromechanical systems (MEMS), optical components, and plasma displays [3].

To obtain the surface dimensional information of a microdevice, numerous high precision instruments have been developed, including the SIOS NMM-1, Zeiss F25, and IBSPE Isara400 [4–7]. Both contact and noncontact methods have been used in such measuring machines with interchangeable probes. Nanoprobes such as laser focus sensors, atomic force microscopes (AFMs), white light interference (WLI) microscopes, and micro tactile probes have been developed and integrated into measuring platforms [8–11]. These probes enable the measurement of diverse specimens. Features including step height, line width, 1D and 2D gratings, and many other microstructures can be measured and characterized accurately.

However, it is not always convenient to change between the different types of probes in some of these machines. Moreover, when one probe is replaced by another, the feature regions to be measured are difficult to track again. Attempts have been made to solve this problem by using a nose wheel to switch between the probes [5], but not all kinds of probes are suitable for mounting on a nose wheel.

This paper presents a multiprobe instrument that was developed to overcome such problems, using a WLI microscope and an AFM. By arranging the two probe types and leveraging a large-range kinematic axis, the sample being measured can be switched freely to the targeted probe. The two probes use the same positioning stage, and the distance between the two probes is calibrated before measurement.

2. Overview of instrument design

The multiprobe instrument is designed to perform surface topography measurements at the micro- and nanoscale. As shown in Fig. 1, it comprises a large granite base to support the structure of the instrument, two probes, a positioning stage, and a large-range kinematic axis to move the probes. To decrease the influence of environmental vibrations, the granite base [Fig. 1(a)] is mounted on a passive vibration isolation platform whose vibration isolation

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frequency is 2.77 Hz. The large-range kinematic axis [Fig. 1(j)] is mounted on the crossbeam of the structure and has a travel range of 300 mm with a positioning repeatability of 0.4 μm. A step motor is used to drive the axis.

The positioning stage is bolted rigidly onto the granite table. It is designed in a two-grade actuating style, driven by a combination of coarse driving [Fig. 1(b)] and fine driving [Fig. 1(e)] to achieve nanometer resolution. The coarse driving, which has a movement range of 300 × 300 mm in the x–y plane with a positioning accuracy of ±2 μm and resolution of 20 nm, is driven by two linear motors arranged orthogonally on the bottom of the stage. Each of the axes uses a Renishaw grating ruler to record the feedback data. The movement of the fine driving is provided by a two-axis piezoelectric transducer (PZT) with capacitive sensors as feedback. The travel range of the fine driving is 100 × 100 μm with a resolution of 0.6 nm.

Moreover, a rotating table [Fig. 1(c)] and a tilting table [Fig. 1(d)] are also used in the positioning stage to adjust the sample to an appropriate attitude. The specimens to be measured are positioned on a 300 mm diameter plate [Fig. 1(f)], which can support a 12-in. silicon wafer; this supports the needs of the semiconductor industry. The distributions of the AFM and WLI microscope are shown, respectively, in Fig. 1(g) and (h). They are kinematically mounted onto the crossbeam by two motion spindles [Fig. 1(i)], which are utilized to bring the probes close to the specimens. Fig. 2 shows the structure of the kinematic axis and two motion spindles.

3. Probing system

3.1. WLI microscope

The WLI method is a powerful optical measurement scheme that enables an entire surface to be captured with very high precision within a few seconds, depending on the topology of the measuring probe [12]. The basic form of this method relies on optical coherence. Fig. 3 shows the optical structure of the WLI microscope. Light is collimated and passed through a beam splitter; subsequently, interference occurs as the light reaches a Mirau interference objective. The interference pattern, which varies with the optical path difference, is finally captured by a charge-coupled device (CCD) camera. The CCD camera has a resolution of 1936 × 1216, with 5.86-μm square pixels.

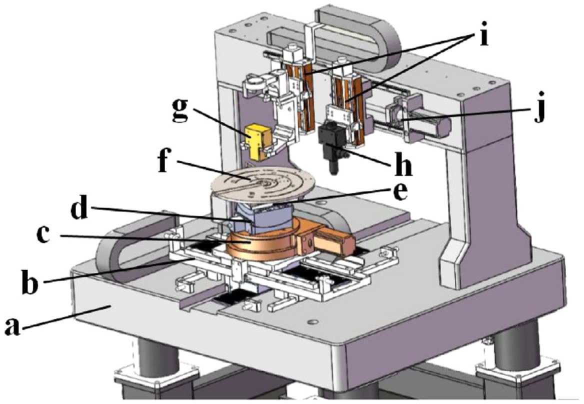

Fig. 1. Structure of the multiprobe instrument. (a) Granite base. (b) Coarse driving. (c) Rotating table. (d) Tilting table. (e) Fine driving. (f) Carrier plate. (g) AFM. (h) WLI microscope. (i) Motion spindles. (j) Large range kinematic axis.

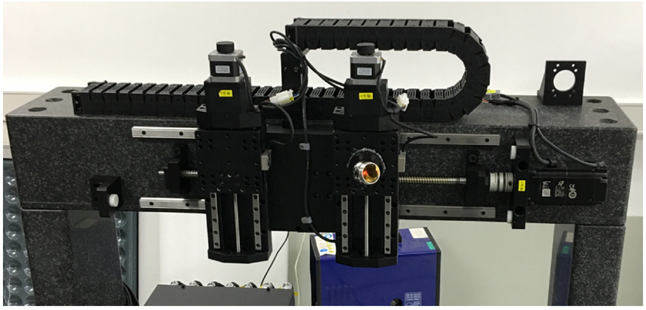

Fig. 2. Structure of the kinematic axis and two motion spindles.

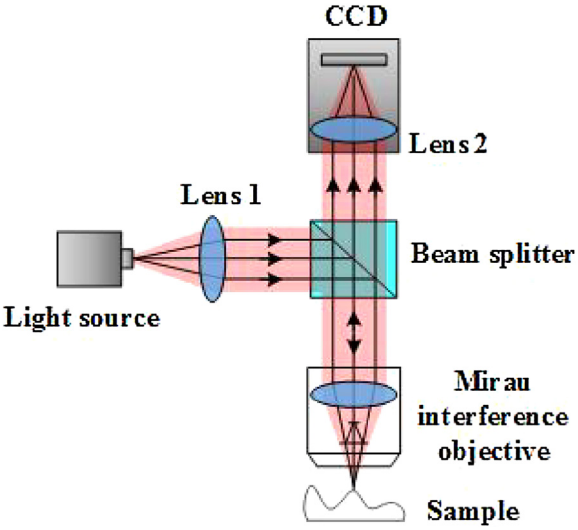

Fig. 3. Optical structure of WLI microscope.

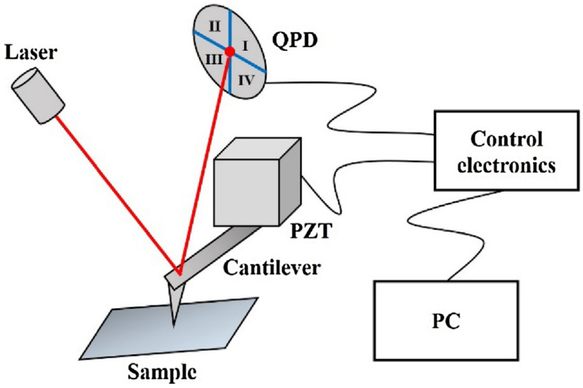

Fig. 4. Schematic of the AFM.

The variation of the optical path difference is generated when the objective moves. The objective is driven by a uniaxial PZT, the range of which is 250 μm with an open loop resolution of 0.4 nm. The illumination is provided by a cold white LED, which has a short coherence length in contrast to laser light. The magnification of the Mirau interference objective is 20 × and the numeric aperture is 0.40.

3.2. AFM

Compared with the optical method, as a scanning probe technique, AFM is usually slow and suffers from the limited measurement range. However, it has a relatively high lateral resolution and is nonselective to samples. The AFM and the WLI microscope are thus complementary in how they measure different types of samples. In the multiprobe system, a Nanosurf NaniteAFM is used, which can achieve lateral resolution of 1 nm. Fig. 4 is a schematic diagram of this AFM.