Nonconfocal Differential Interferometry Sensing Scheme for Scanning Probe Microscopy

Nonconfocal Differential Interferometry Sensing Scheme for Scanning Probe Microscopy

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In this work, we describe a nonconfocal differential interferometer to detect the cantilever vibration for a scanning probe microscope. Capable of focusing the beams on the different height surfaces of a cantilever to adapt the length of commercially available cantilever chips, the proposed two-beam interferometer can maintain the sensitivity by placing a glass slip for an object beam to extend the focal length to the cantilever. An experiment involving a scanning force microscope is performed in static mode operation for applications where topography and magnetic images are presented. © 2011 The Japan Society of Applied Physics

Developing a force microscope to monitor the deflection of the cantilever consists of using optical interferometry,[1–6] capacitance,[7,8] point-contact current-imaging,[9] beam deflection,[10–14] and magnetoresistive head.[15] Constructing the force-sensing cantilever/tip device is a major task for the force microscope. Many chemistries and metallic modified commercially available atomic force microscope (AFM) probes are powerful tools for nanoscale research.[12,16–19] A two-beam interferometry system normally focus the laser spots on the same plane of a cantilever to obtain interference signals.[2] However, the commercial cantilevers used in the system have a maximum length of only 100 μm to 200 μm. In this case, the focusing point of a reference beam and object beam has difficulty in lying on the cantilever. This work demonstrates that a simple glass slip enhances the sensitivity of a differential interferometer with two beams focused on a different plane, and completely with the application of instruments for various samples to investigate the topography of specimens and the magnetic patterns. Previous efforts have confirmed that the use of a differential optical interferometer in scanning force microscope systems provides better DC stability and less optical path perturbation than other methods.[2,3] These features are important when using the force microscope in its static mode of operation. Figure 1 schematically depicts a scanning force microscope system. This instrument is based on the differential interferometer to detect the deflection of a cantilever. A 3 mW, 670 nm wavelength diode laser beam with plane-polarization at 45° passes through a polarizer with its transmission axis set to 45°. The laser beam is partially transmitted by a nonpolarized beam splitter (NPBS). The other portion of the light is coupled with the beam splitter and is blocked with a black card. The transmitted light passes through a Wollaston prism (Wp1) that splits the beam into an object beam and a reference beam. These beams are orthogonally plane polarized mutually. Owing to the birefringence of the Wollaston prism, a phase shift can be introduced between the object and the reference beams by shifting the prism perpendicular to the incoming beam. Several modifications have been made to cope with the commercially available cantilever used in the system. These modifications focus mainly on adapting to the cantilever shapes. For the commercial cantilever stylus, the cantilever has a maximum length of only 200 μm, which is insignificant compared with the range of Wp1's deviation distance, 2 mm. The solution is achieved
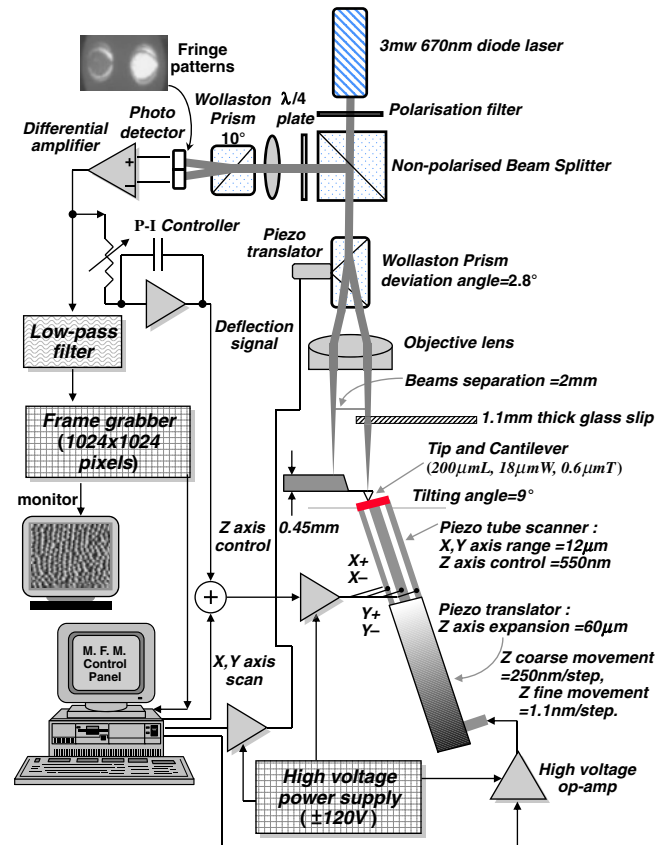

Fig. 1. (Color online) Schematic diagram of the scanning force microscope system based on the nonconfocal interferometric deflection sensor.

by focusing the object beam on the tip and then focusing the reference beam somewhere else on the same altitude. Despite attempts to focus the reference beam on an independent tiny mirror close to the cantilever, widely fluctuating signals were produced that were impractical and possibly obstructed the sample. This limitation is due to the fact that the two reflection planes are not rigidly connected, subsequently inducing vibration between them. The only position that the reference beam can point to is the cantilever's base plateau, which is coated with gold.

According to Fig. 2, the cantilever and the base plateau surface differ by a level of 0.45 mm, subsequently incurring a focusing problem of the two beams. The solution extends the focal length of the object beam leading to a situation in which the reference beam focuses on the chip base and the object beam focuses on the cantilever. Notably, the method
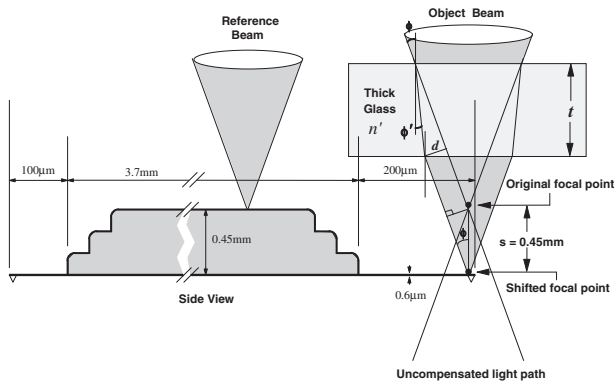
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Fig. 2. Adjusting the focal length of the two-beam differential interferometer, which focuses on the cantilever and the chip.

(a)

(b)

Fig. 3. (a) Magnetic and topographical images of an M–R sensor. Starting from the magnetic force scanning, the tip finally lands onto the surface of the sample at the bottom of scanning, as well as reveals the topographical image. (b) With a line scan across a single magnetic domain in (a) showing the profile of the 24 nm transition of the domain wall.
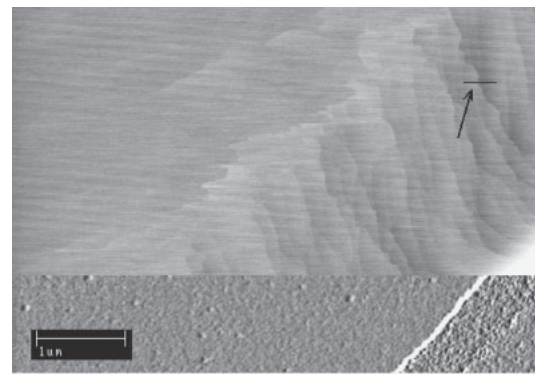
to expand the focal length of object beam is rather simple. When a laser beam travers a glass plate with plane surfaces that are parallel to each other, a ray emerges parallel to its original direction but with a lateral displacement d, subsequently increasing with the angle of incidence ϕ. By using the notations in Fig. 2 and applying the law of refraction with some simple trigonometry, the thickness of glass t can be found as follows:

$$t = \frac{s}{\left(1 - \frac{n}{n'} \cdot \frac{\cos\phi}{\cos\phi'}\right)} = 1.091 \, \text{mm},$$
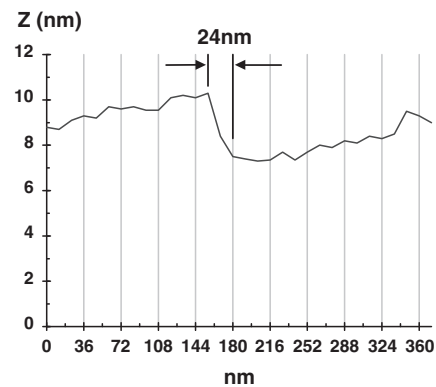
where $n = 1$, $n' = 1.7$, $s = 0.45 \, \text{mm}$, $\cos\phi = 0.998$, and $\cos\phi' = 0.999$. Moreover, using the above relationship and carefully selecting the glass thickness, we can stretch the focusing point to the plane of the cantilever. A 1.1-mm-thick glass cover slip yields a satisfactory outcome. Adding the glass between the objective lens and the cantilever to extend the focal point of the objective beam allows us to clearly observe the interference fringes in the output, whereas none were visible before adding the glass.

By coating the tip with a magnetic material (PtCo) to magnetise the tip, this scanning force microscope can work in noncontact mode scanning to obtain the magnetic force image. Figure 3 illustrates the ripple distribution of a magnetic stray field and the surface microstructure of a magnetoresistive sensor that is fabricated from NiFeCo alloy layers. While the tip is scanned in the lift mode from top to bottom and displays a magnetic image, the tip is attracted to the sample's surface and the scanned image is changed from a magnetic image to a topographical image. The topography exhibits a step edge, which has separated conduction layers. The line scan in Fig. 3(a) (black line) draws across a single magnetic domain, while the line profile in Fig. 3(b) shows the 24 nm transition of a domain wall. The minimum detectable vertical displacement of the cantilever is about 0.1 nm.

In this works, we have presented a scanning force microscope system based on a nonconfocal differential interferometry sensing scheme. The differential optical detection scheme with a simple glass slip can focus its two beams to different levels of height to adapt to an extremely small microfabricated cantilever. Experimental results demonstrate the effectiveness of the proposed system by imaging the grooves grating, as well as the domain wall of a magnetoresistive sensor. The magnetic image indicates that the differential interferometer principle for measuring cantilever deflection can be used with rather short cantilevers, if modified in the manner described, to investigate extremely small magnetic features.

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