DETECTION SYSTEM FOR ATOMIC FORCE MICROSCOPES

The present invention relates to scanning probe microscopes and, more specifically to scanning force microscopes, sometimes referred to as atomic force microscopes.

BACKGROUND OF THE INVENTION

Scanning force microscopes (SFM), sometimes referred to as atomic force microscopes (AFM) are used to investigate the surfaces of matter in the micrometer, nanometer, and sub-Angstrom scale. Such microscopes operate by positioning a probe, consisting of a cantilever arm with a sharp tip located orthogonally on one end of the cantilever arm, in, or nearly in, contact with the surface to be profiled or otherwise examined.

The cantilever arm has such a small spring constant that typically one nanonewton of force will cause a noticeable deflection. The cantilever arm deflects due to natural forces present between the tip and the sample. The probe may be either attracted to the surface or repelled by the surface depending on the forces at work. When relative motion in the X and Y directions exists between the probe and the sample surface, the cantilever arm will bend as topographical features of the sample move under the tip.

Typical prior art is described in U.S. Pat. Nos. 4,724,318 and 4,800,274. In these patents, microscopes are described in which the detection of cantilever arm bending is accomplished by a second probe which is suspended over the first probe. The second probe detects changes in a tunneling current flowing from the first probe to the second probe. Measurable changes in this tunneling current result when the distance between the first probe and the second probe changes as the cantilever portion of the first probe moves up and down in response to the presence of topographical features of the sample moving under the first probe tip.

Subsequent patents of the prior art describe optical detectors which use only a first probe and use either light interference or light beam deflection (optical lever) to detect the bending of the probe cantilever arm due to the interaction of the forces between the surface and probe tip. The interference method is described by Y. Martin, et al, in the publication, J. Appl. Phys. 61,4723, (1987).

The optical lever method is described by O. Marti, B. Drake, and P. K. Hansma, in the publication Appl. Phys. Letters 51,484 (1984). Further, U. S. Pat. Nos. 4,935,634 and 5,025,658 describe optical detection schemes in which a sample is moved in a rastered motion under the probe.

The optical lever method of detecting the probe deflection utilizes a narrow beam of light directed toward the probe. Probe deflections caused by the changing topography of the sample surface result in changes in the angle of the reflected light beam. This change is detected by means of photo-diodes. The light source may be a laser device. A pair of photo-diodes are placed in close proximity to each other and form a bicell.

As the reflected light from the probe shines on the diodes, and as the probe cantilever arm moves up or down, the proportion of the light on each of the photo-diodes will change. This change is used to determine the amount of bending of the cantilever arm, thus indicating a change in the relative distance or force between the probe tip and the surface being examined.

The prior art also teaches that the sample, whose surface is to be examined, may be attached to a motion controlling device, typically a piezoelectric cylinder, the end of which moves the sample back and forth in both the X and Y directions in a rastering motion underneath the probe. Further, using the signals generated by the photo-diodes, the device moving the sample in X and Y may also control the Z direction, or height.

The photo-diode signals are typically subtracted to create a difference signal. The set-point value will then establish a constant probe deflection value. The subtraction of the difference signal from the set-point value results in an error signal. This signal is routed through feedback conditioning means to create a correction signal.

The feedback conditioning means may be either an analog circuit or a digital circuit using computing means such as is described by Hanselmann in "Implementation of Digital Controllers—A Survey" Automatica, Vol. 23 No 1, 1987. Digital control also is described in U.S. Pat. No. 4,889,988 dated Dec. 26, 1989, reissued as U.S. Pat. No. RE 34,331 on Aug. 3, 1993.

The correction signal is, in turn, routed to the motion control device such that the control device keeps the cantilever arm at a constant bend angle. Consequently, the force between the probe tip and the sample surface remains essentially constant even though the topography of the sample is changing under the probe tip.

Stated differently, the probe cantilever arm is maintained at a constant deflection. The correction signal is then an indication of the surface profile. The correction signal may also be filtered or conditioned to produce a second signal which can enhance certain surface profile features.

The prior art system thus described provides X and Y raster signals and a Z signal indicating the surface profile. These three signals are sufficient to give surface topographical information. Persons skilled in the art recognize that the signals thus generated can be digitized and displayed by a computer with the topography displayed in various representations.

Certain distortions in the image can be corrected in computer software. Software algorithms can be employed to correct curvature in the image caused by the arc traced by the probe as it swings from side to side instead of traversing the surface of the sample in a flat plane, as would be the ideal case.

The prior art system thus described has several shortcomings. Since the sample is moved, and as each sample may have a different mass, it may be necessary to change the feedback loop parameters, or the raster speed, or both with changes of sample in order to preserve loop stability. Also the motion producing device has only limited available force to move the sample. Therefore, large samples can only be examined when cut or broken into smaller fragments.

It would, therefore, be desirable to have the probe move over the sample in a rastering fashion, rather than moving the sample under the probe. As the probe moves in X and Y directions, it will be deflected in the Z (vertical) direction as it passes over the surface features. With prior art beam deflection (optical lever) systems this is not possible, since the raster motion of the probe moves the probe away from (out of) the light path thereby depriving the photo-diodes of information