SCANNING FORCE MICROSCOPE

BACKGROUND—FIELD OF THE INVENTION

This invention relates to scanning force microscopes, sometimes referred to as atomic force microscopes, using light beam detection schemes.

BACKGROUND—DESCRIPTION OF PRIOR ART

Conventional optical microscopes used to observe the surface features of materials begin to lose resolution when the dimensions of the surface features approach one half the wavelength of visible light. Alternate types of microscopes have been developed to overcome this limit. Confocal microscopes, for example, can improve on conventional optical limits. Scanning electron microscopes image small surface features by the use of energized electrons that have wavelengths shorter than photons. However, many of these alternate techniques have limits of their own and may have other disadvantages in implementation such as a need to place the sample in a vacuum chamber.

A new class of microscopes overcomes the resolution limits of previous techniques in a fairly simple manner. Microscopes in this class are referred to as probe microscopes. The topographical version of these new microscopes uses a fine pointed stylus to interact with some parameter of the sample surface. A scanning mechanism creates relative motion between the stylus and the sample surface. When a measurement is made of this interaction, the surface topography of the sample can be imaged with height as well as lateral detail. One of the more commercially successful microscopes in this class is the scanning force microscope also referred to as a scanning force microscope. Sample features other than topography can be measured with probe microscopes. For example, when measuring the interaction of a magnetic probe with the magnetic fields of the sample, an image of the magnetic domains of the sample can be created.

For topographical operation the stylus is mounted orthogonally to the longer dimension of a cantilever such that the cantilever acts as a bending lever. A cantilever is a lever with a constrained end and a free end. The stylus is mounted near the free end. The cantilever deflects due to the force applied to the stylus as the stylus interacts with the sample surface. The combination of a stylus and cantilever are referred to as a probe assembly. The cantilever has a very weak spring constant and may noticeably deflect when a force as small as one nanonewton is applied to its free end. A detection mechanism provides a signal to a feedback loop when the cantilever deflects. When relative lateral motion exists between the stylus and the sample surface, the changing topography under the stylus creates a force on the stylus which the stylus transmits to the free end of the cantilever. This results in a slight change in the angle of the free end of the cantilever. A lateral drive mechanism creates relative lateral motion between the stylus and sample. The feedback loop controls a vertical drive mechanism which moves the fixed end of the cantilever toward and away from the sample surface. Consequently, the free end of the cantilever surface is held at a nearly constant bend angle. The lateral and vertical drive mechanisms are referred to as a scanning mechanism.

By measuring the vertical drive signal and the lateral position of the stylus over the sample, a matrix of x, y and z values may be created. This matrix describes the surface topography of the sample.

The surface of the cantilever is at least partially reflecting. The deflection of the free end of the cantilever is measured by directing a laser beam onto the free end, and by measuring the position of the reflected beam. The stylus is mounted on the surface opposite the reflecting surface of the cantilever. Further, an array of two or more light-sensitive devices may be used to detect the position of the reflected beam. These devices then produce electrical signals which are related to the cantilever deflection. The difference of the two signals is proportional to the amount of the cantilever deflection in one direction. Four light-sensitive devices arrayed in a quadrant can measure the amount of cantilever deflection in two orthogonal directions. The vertical drive mechanism receives signals processed from the output of the light-sensitive devices. This creates the feedback loop that controls the bend angle of the cantilever.

Prior art devices constructed as described above are shown in U.S. Pat. Nos. 4,935,634 to Hansma et al, and U.S. Pat. No. 5,144,833 to Amer et. al. These prior art devices move the sample laterally and vertically under a stationary stylus while detecting the cantilever deflection with the laser beam apparatus described above. This method has a disadvantage stemming from the limited force capability of the lateral and vertical drive mechanisms. The sample mass may be large compared to the force created by the drive mechanisms. In such cases the sample may either move very slowly or not move at all under the stylus.

Prior art microscopes described in U.S. Pat. No. 5,481,908 and its continuation U.S. Pat. No. 5,625,142 to Gamble maintain a fixed sample and move the laser, the cantilever, and all of the associated mechanisms that are necessary to make initial adjustment of the laser beam. Since the laser moves with the cantilever, the laser beam follows the motion of the cantilever during scanning. The mass associated with moving part of such microscopes limits the speed at which the image data can be taken.

Other prior art microscopes attempt to overcome the disadvantage of moving the sample by using an interferometric method to track a moving cantilever. These microscopes are described in U.S. Pat. Nos. 5,025,658 and its continuation U.S. Pat. No. 5,189,906 to Elings et al. Further, prior art microscopes use moving beam steering optics with a stationary laser source as described in U.S. Pat. Nos. 5,524,479 which is a continuation of U.S. Pat. No. 5,388,452 to Harp and Ray and in U.S. Pat. No. 5,463,897 with associated continuation U.S. Pat. No. 5,560,244 to Prater et al as well as U.S. Pat. Nos. 5,440,920 and its continuation 5,587,523 to Jung et. al. These techniques employ a fixed position laser and moving optical elements. The optical elements move with the moving probe assembly. The result is a lateral redirecting of the laser beam which then follows the moving surface of the cantilever.

These systems must move optical components with the cantilever. This adds mass to the moving part of the system. These systems also position the laser in a location above the cantilever. This position may preclude simultaneous optimum optical viewing from positions above the cantilever and sample. The lateral and vertical drive mechanisms must accommodate the potentially significant added mass of the moving optical devices by providing additional force. The result is a significant limit to the velocity of the stylus over the sample. In addition, if one wishes to optically observe the probe assembly from certain angles it may be necessary to place additional mirrors or other optical devices on the moving part of the microscope. Further, mechanisms often are needed to adjust the laser over a range of angles, in order to initially bring the beam onto the reflecting surface of the cantilever.