Scanned-cantilever atomic force microscope with large scanning range

Jintao Yang (杨金涛) and Wendong Xu (徐文东)

Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, Shanghai 201800

Received April 12, 2006

A scanned-cantilever atomic force microscope (AFM) with large scanning range is proposed, which adopts a new design named laser spot tracking. The scanned-cantilever AFM uses the separate flexure x-y scanner and z scanner instead of the conventional piezoelectric tube scanner. The closed-loop control and integrated capacitive sensors of these scanners can insure that the images of samples have excellent linearity and stability. According to the experimental results, the scanned-cantilever AFM can realize maximal 100×100 (μm) scanning range, and 1-nm resolution in z direction, which can meet the requirements of large scale sample testing.

OCIS codes: 180.0180, 110.0180, 180.5810.

Since the invention of atomic force microscope (AFM)[1] in 1986,it has been widely applied in the field of nanotechnology. Now it has actually become an indispensable instrument for nano-scientists and engineers. Most of AFMs scan the sample instead of the cantilever. AFMs in which the cantilever is stationary with respect to the photodetector and the sample moves only are effective for small sample. The size of sample is restricted by the end of the piezoelectric tube scanner in these AFMs; moreover, massive samples will drop the natural resonant frequency of the piezoelectric tube scanner and affect the performance of AFMs. So, a few AFMs in which the cantilever scans and the sample is stationary have been developed[2−7]. A solution to scanned-cantilever AFM was described, but it can only gain good performance in 3.6×3.6 (μm) scanning range[2]. A method to obtain large scanning range is to scan the laser and laser positioning system with the cantilever[3]. But for this design, the laser and laser positioning system should be light, which means that ease of use and accuracy of laser positioning must be compromised[4]. The Dimension 3000 series scanned-cantilever AFMs of Veeco Instruments Inc. can easily realize large scanning range, but the design of these AFM heads is comparatively complicated[8]. In order to remove these restrictions, we developed a scanned-cantilever AFM which only scans cantilever, the laser and the detection apparatus are stationary. This new AFM can scan in a wide range of sample (100×100 (μm)) without restrictions of its size and weight. In addition, we adopt a separate x-y scanner and a separate z scanner instead of the conventional piezoelectric tube scanner. The x-y scanner and z scanner can scan in closed loop mode, so the topography images of the sample have almost perfect linearity and good repeatability.

There are two key points to realize a scanner-cantilever AFM, one is to keep the focused spot on the back of cantilever to track the scan motion of the cantilever, the other is that the convergent light spot on 4-segment photodetector (PSD) of the optical-lever detection system can keep relatively stationary with the PSD when AFM scans without sample. Here we introduce a new design named laser spot tracking that can resolve these problems, as shown in Fig. 1. The scanner is composed of an x-y scanner and a z scanner. The first lens is fixed on the z scanner and the cantilever is fixed on the x-y scanner. Both the second lens and the PSD are stationary. The parallel beam from the laser passes the first lens and forms a focused spot on the back of the cantilever. Because the end of the cantilever locates at the focus position of the first lens and they can keep relatively stationary at any time, the focused light spot always accurately tracks the cantilever. This resolves the first problem of the laser spot tracking.

The PSD shown in Fig. 1 does not move with the scanner. If it is optionally placed at a certain position, the reflection from the back of scanning cantilever will move with respect to the fixed PSD, even the cantilever does not actually bend. The result is that the relative movement between the reflection and the PSD will result in false deflections of the cantilever, which can induce spurious information at the image of samples. In order to resolve this problem, we design the second lens and the PSD is placed at a special location behind the second lens. As we know, the axis of the reflection from the cantilever is corresponding to the center of the convergent light spot on PSD. If all axes of the reflected beam can converge to a spot on the PSD when the cantilever scans, the convergent light spot on the PSD can keep

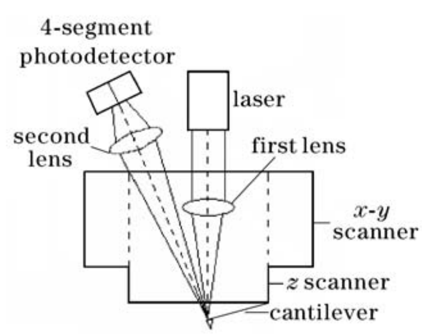

Fig. 1. Schematic diagram of the scanned-cantilever, optical-lever AFM.

relatively stationary with PSD. In fact, the axes of all the reflected beams will converge to a virtual spot after being extended in opposite direction when the cantilever scans. The existence of the virtual spot can be proved by geometry optics and calculated using MATLAB. So, we place the PSD at the position of the virtual image formed by the second lens, which is the image of the virtual spot. This position is desirable, because it can satisfy the second key point of scanned-cantilever AFM. Calculated by MATLAB, the virtual spot actually is a square of 27 × 27 (nm) over 100 × 100 (μm) scanning range.

The schematic diagram of the scanned-cantilever AFM system is shown in Fig. 2. It is composed of the main AFM part and its control system. The AFM part mainly includes linear positioning stage, sample holder, scanners, probe of AFM, optical-lever system and an optical microscope. The control system of AFM is constituted by computer system, digital signal processing (DSP) card, interface circuit, AD/DA, preamplifier and closed-loop control of the scanner.

The working mode of the scanned-cantilever AFM is contact-mode. The linear positioning stage and the z scanner realize the light contact of sample and probe. The optical microscope can provide real-time observation for sample and probe in micron resolution. When the x-y scanner drags the probe on samples, the deflection of the cantilever will cause the variation of the PSD's output current. After the DSP card collecting this variation, the proportional-integral-differential (PID) algorithm (digital PID feedback) in DSP card will control the movement of the z scanner in order to keep the force between the sample and the probe to be constant. Finally, the computer traces out the images of samples according to the feedback voltage on z scanner.

The closed-loop control of these scanners mainly includes a high-voltage amplifier and an analog PID feedback circuit. In addition, it has three signal ports: the first is the input voltage signal from DA which controls the final position of these scanners in closed-loop working mode; the second is the output high-voltage signal to these scanners which can drive them; the last is the input sensor signal from these scanners. Each scanner has a flat air-capacitor sensor which is composed of the scanner's moving part and base part. In closed-loop working mode, the analog PID feedback circuit compares the input control voltage signal with the output sensor signal from scanners, generates a positive or negative voltage signal for the high-voltage amplifier to drive the scanner to a right position. The closed-loop control and the

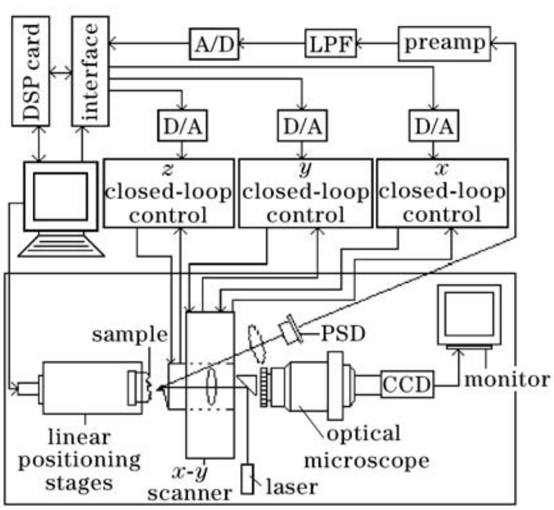

Fig. 2. Schematic diagram of the scanned-cantilever, optical-lever AFM system. LPF: low-pass filter.

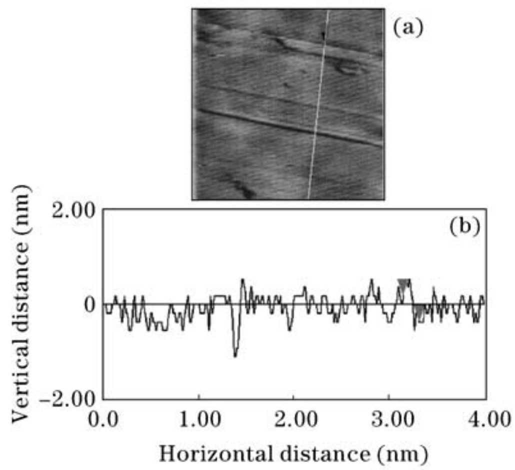

Fig. 3. (a) AFM image of the graphite surface and (b) profile along the line in (a). The maximal vertical distance is 0.916 nm.

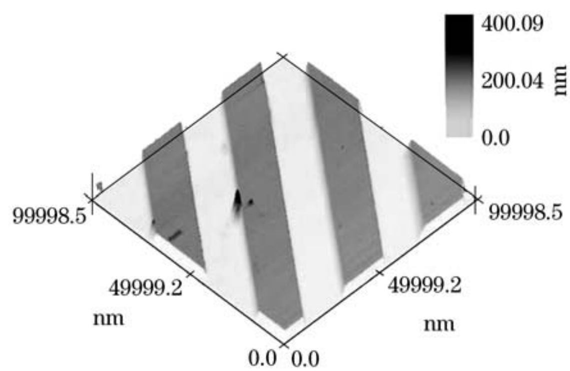

Fig. 4. AFM image of the 31-μm raster, the scanning range is 100 × 100 (μm).

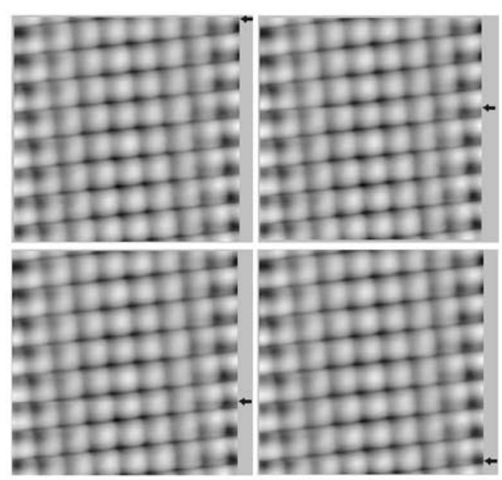

Fig. 5. Comparative experiments for the same area of the same 500-nm raster sample at different time, the scanning range is 5 × 5 (μm).

capacitor sensor integrated in scanners insure the excellent linearity when these scanners scan.

In order to check up the capability of the scanned-cantilever AFM, some experiments were carried out at the contact working mode. Figure 3 shows the AFM image of the graphite surface. The experiment data reveal that the scanned-cantilever AFM can distinguish 1 nm at z direction. Figure 4 shows the AFM image of the 31-μm raster. The scanning range of Fig. 4 is 100×100 (μm). The series of images in Fig. 5 show the comparative experiments for the same area of the same 500-nm raster sample at different time. In the process of repeating scanning, the new image fits very well with the old one. This demonstrates that the scanning movement of the x-y scanner is stable.

In summary, we describe a new scanned-cantilever AFM operating in the contact working mode which employs the laser spot tracking method. The configuration of scanning cantilever instead of scanning sample has no restriction on the sample's size and weight. Testing experiments show that the performance of this AFM, such as the resolution at z direction, repeatability and stability can satisfy the requirements of measuring large samples in nanometer scale.

This work was supported by the Nanometer Technology Project of Shanghai Science and Technology Committee under Grant No. 0359nm003. J. Yang's e-mail address is y_800210@etang.com.

References

1. G. Binnig, C. F. Quate, and Ch. Gerber, Phys. Rev. Lett. **56,** 930 (1986).
2. D. R. Baselt and J. D. Baldeschwieler, Rev. Sci. Instrum. **64,** 908 (1993).
3. B. G. de Grooth, C. A. Putman, K. O. van der Werf, N. F. van Hulst, G. van Oort, and J. Greve, Proc. SPIE **1639,** 205 (1992).
4. P. K. Hansma, B. Drake, D. Grigg, C. B. Prater, F. Yashar, G. Gurley, V. Elings, S. Feinstein, and R. Lal, J. Appl. Phys. **76,** 796 (1994).
5. D. Sarid, P. Pax, L. Yi, S. Howells, M. Gallagher, T. Chen, V. Elings, and D. Bocek, Rev. Sci. Instrum. **63,** 3905 (1992).
6. G. Meyer and N. M. Amer, Appl. Phys. Lett. **56,** 2100 (1990).
7. M. Hipp, H. Bielefeldt, J. Colchero, O. Marti, and J. Mlynek, Ultramicroscopy **42-44,** 1498 (1992).
8. C. B. Prater, J. Massie, D. A. Grigg, V. B. Elings, P. K. Hansma, and B. Drake, *Scanning stylus atomic force microscope with cantilever tracking and optical access* US Patent 5560244 (1996).