Proceedings of the 2005 IEEE
International Conference on Mechatronics
July 10-12, 2005, Taipei, Taiwan

Automatic Probe Alignment for Atomic Force Microscope

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***Abstract* - We built an atomic force microscope (AFM) system in combination with a robotic manipulator to help users in two rigorous tasks: to load the probe and to align the optical detection path. A novel z-tracking optical design, which allows vertical probe scan is also proposed. This method will enhance the scan speed for massive samples.**

Index Terms* - *atomic force microscope, automatic manipulation.

I. INTRODUCTION

The scanning probe microscope (SPM) family was developed with extremely high speed since the scanning tunneling microscope (STM) was invented from 1986. These series of powerful instruments take people to the nanometer scale world that has never been reached before and are widely used to obtain atomic-scale images of metal surfaces. AFM [1] is an important branch of SPM family and becomes the most popular in application because of some kinds of its specific characteristics. It uses a sharp probe to move over the surface of a detected sample, and the probe is a tip at the end of a cantilever that bends in response to the force between the tip and the sample.

To detect the variance of force between the sample and tip, constant height and constant force are usually utilized in AFM. For the former one, the height between the sample base and the probe base is constant. The force between the sample and the probe will make the cantilever bending; therefore we record the sensor signal that detects the light from laser reflected from the probe as the sample's surface profile. In the case of constant force mode, we need an additional vertical scanner to maintain the constant force. Then, we can record the trajectory of z-scanner as the profile of the sample. Notice that if the sample surface is a ramp or too rough, the reflected laser beam will exceed the working range of the photo sensor. Utilizing feedback control techniques, constant force mode will be better than constant height mode.

Optical lever [2] and inteferometry [3] are the two well known techniques in detecting the probe cantilever of AFM. Optical lever technique is preferred because of its high resolution. In the beginning of the detecting operation of the AFM, the most important task is aligning the optical path to guarantee that the light from the laser can be detected precisely from the sensor after it reflected from the probe. In traditional, the moving sample type was widely applied instead of dealing with much more complex design of the mechanism. Unfortunately, how heavy the sample is seriously decides how much the response speed will be decreased. Due to the lightness of the probe and the requirement of high bandwidth in vertical direction, moving probe type will be better [4]. But there still has difficulty to align and assembly for the three dimensional tracking optics [5]. On the other way, even the moving sample type can supply low scanning speed but it prevents trouble in aligning light path during the operation [6]. Therefore, in this paper, we induced a novel design, which called single-axis moving probe type, can include the advantages of the moving sample type and moving probe type without their shortcomings at the same time.

Next section we will introduce the whole system design and focus on the automatic probe replacement and optical path alignment. In section III, we will represent the novel z-tracking optical path arrangement, which has the capability to scan large sample and guarantees the response speed as well. And then, the sample topography with 2D and 3D will be shown to prove the performance of the improved and developed AFM system. Finally, the conclusions will be given in section IV.

II. SYSTEM DESIGN

Figure 1 shows the architecture of our AFM system. The major elements are in combination with a CCD camera used to assist the automatic light path alignment, an aiding 4 degree-of-freedom (DOF) manipulator that has 0.1 mm translational and 0.07 degree rotational resolution, a laser source, a piezoelectric ceramic tube used to scan in the horizontal direction, two refractors, and a position sensitive detector (PSD).

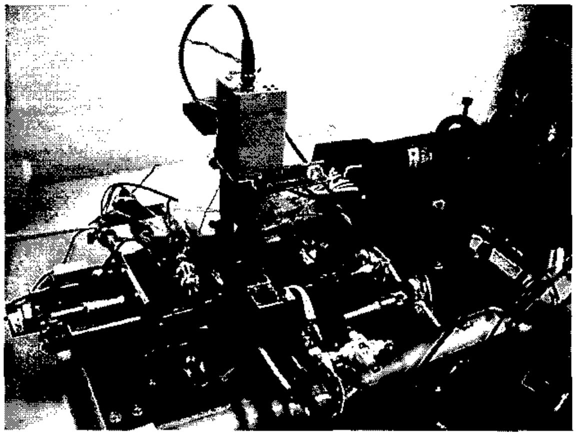


Fig. 1: The architecture of the proposed AFM system.

The operation principle is according to the force reacts between the sample and the probe. Through detecting the quantity of bending of the probe, it can reveal ultra-little difference of the sample surface. To have good performance it needs a probe with tiny and sharp tip. This means such probe would be probably wasted after operating again and again. It often spends the engineers a lot of time to replace this probe especially the uninitiated. The most difficult is to replace intact and to align the light path precisely, because the effective area (20mm × 20mm) that can be used to reflect the laser light is extremely small. In this section, we will discuss first about the division of aligning light path and replacing the probe automatically.

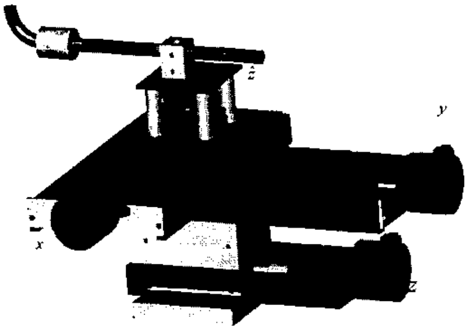


Fig. 2. 4-DOF manipulator has 0.1 μm translational and 0.07 degree rotational resolution; (b)End-effector.

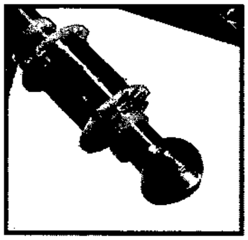


Fig. 3. The electromagnetic chuck, the end-effector of the 4-DOF manipulator.

Fig. 2 shows the 4-DOF manipulator, which is actuated by 4 stepping motors, can move in x-, y- and z-direction and perform the rotational motion. In Fig. 3, the probe, which is glued to a steel plate, can be placed at the end-effector, and further it can be caught solidly with additional electromagnetic force. On the other hand, there is another magnet set in the platform of the AFM. As long as the probe enters the exact position, the current will be drawn out from coil and the probe will be loaded to the AFM system with the aid of CCD camera monitoring. The strongest reflective intensity can be received when the probe is located at the focus of the object lens. The procedure is automated by a program.

It is challenging for human beings to load the probe, because the effective area is extremely small. If we want to automate this procedure, it is necessary to know where is the exact position or the effective area. The traditional microscopy is useful to detect the effective area. Here, we apply a CCD camera for assisting to decide the effective area. From the view of the camera, it is easy to see the variance of the quantity of the light, and through tracing this information it will be not difficult to enter the effective area by using the high-resolution 4-DOFs manipulator. Furthermore, the PSD is another important device for measuring and detecting. It is separated into 4 divisions. Based on the detected signal in each division we can derive the position of the reflected laser spot, which represents the deflection status of the probe. By Hooke's Law, this signal also represents the interaction force between the probe and the sample. It is a crucial signal that decides the performance of the AFM system. High quality pre-amplifier and signal conditioning should be implemented to deal with this slight photocurrent signal.

At the same way, the detected signal in these 4 divisions can be summed to decide the exact position. The CCD camera can view the larger region than the PSD can detect, therefore, we can use the camera to pre-check the position of the probe until the signal drops into the region that the PSD can detect. There are two stepping motors to drive a 2D linear stage, which carries the PSD. The four signals are equal to each other when the reflective laser spot points at the center of the PSD. This procedure is also automated by a program. After that, all of the procedures can transfer to the auto-mode. The manipulator can carry the probe moving in the effective area automatically and the PSD will start scanning and recording the energy and its axis, then, by comparing and finding out the largest energy the probe can be successfully placed to the exact position. The whole procedure will save the time wasting enormously and decrease the probability in probe wearing during the replacement.

III. OPTICAL PATH DESIGN

Two ways in implementing AFM are moving sample and moving probe. In the case of moving sample, the probe will be fixed and it is contrary for moving probe. Take the moving sample type as an example; due to the probe is stationary the entire light path system will be also stationary, and it reveals that such system will supply high-precision sensitivity and high-resolution ability in detecting. But, it causes the bandwidth reduction for the piezo-scanner to carry a heavy sample. Even though the moving probe type has the better ability to bear the sample size, it usually needs complex design to track the moving of the probe for the detecting spot.

A novel light path design, which called single-axis moving probe type, was proposed to integrate the advantages of these two scanning types. Moreover, from anglicizing these two scanning types, it was found that vertical detecting usually requires higher bandwidth (≈1kHz) than the horizontal one (<10Hz) and it was more complex for the spot to track the probe in x- and y-axis than that in z-axis. In order to improve the traditional architecture but not to raise too much complexity, we apply the spot tracking only in z-direction and for the low-bandwidth requirement the moving sample type was utilized in x- and y-axis.

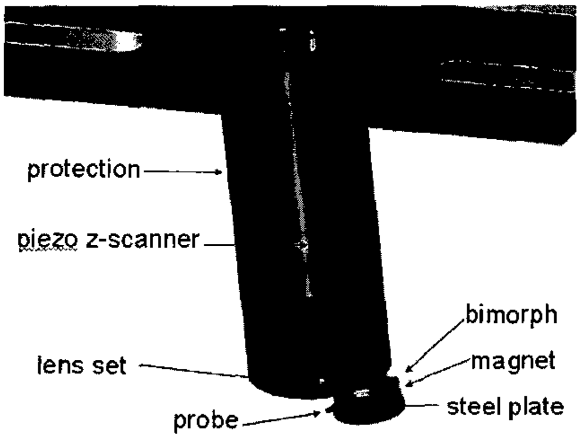
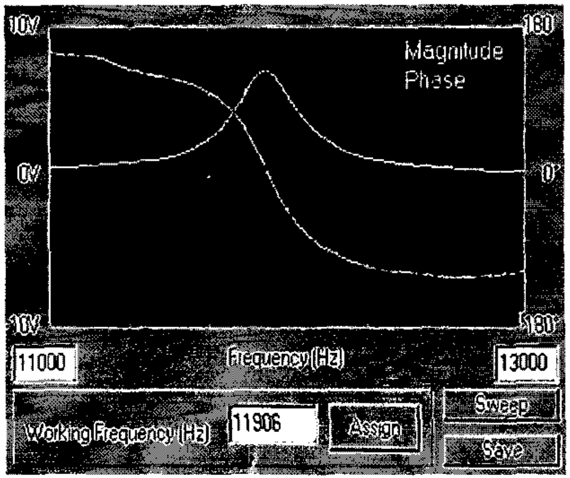


Fig. 4. Z-scanner module.

Fig. 4 depicts how the probe to be installed. The probe, which is glued to a steel plate, is caught solidly by the magnet after the 4-DOF manipulator transferring it to the focus of the lens. The piezoelectric z-scanner will carry the probe and the lens synchronously so that the probe can be maintained at the focus of the lens. The detective optical path keeps invariant via this synchronized manner. This novel z-tracking optical design can enhance the scanning speed because the moving part is the light probe but not the massive sample. In addition, the bimorph is a bedded piezoelectric material. It oscillates the cantilever of the probe when we operate the AFM system in tapping mode. Utilizing the automatic system identification procedure, the spectrum can be obtained in Fig. 5. The surrounding tube not only protects the z-scanner module but also blocks the disturbance light from the environment.



Working Frequency (Hz) 11906

Fig. 5. The spectrum of the cantilever when the AFM system is operated in tapping mode.

The entire conceptual drawing of our AFM system is shown in Fig. 6. According to this design the z-scanner carries the probe with the lens in the vertical direction, therefore, no matter when it moves up or down to track the sample surface the optical configuration can be always maintained.

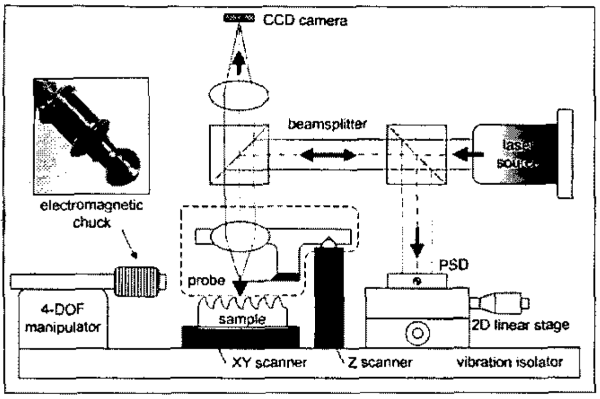
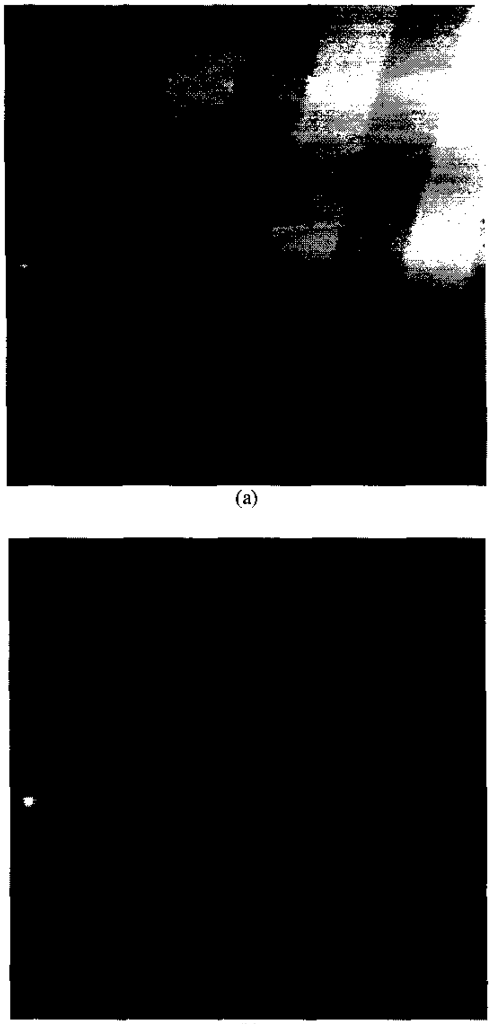


Fig. 6. The schematic drawing of the optical path design.

IV. EXPERIMENTS

AFM is a kind of precise and sensitive microscopy. In this section, we will show some images to prove this AFM system not only can work but also has good performance with the novel design and satisfies the serious requirement.



(a)

(b)

Fig. 7. (a) Original image; (b) flattened image.

Fig. 7(a) shows the original topography of a standard silicon grating scanned by our AFM system directly and Fig. 7(b) depicts the flattened image that is processed by software in order to reject the ultra-low frequency disturbance from the environment. The image illustrates a 10mm × 10mm area. The depth of the trenches is 26 nm.

Fig. 8. A virtual 3D view.

Fig. 8 shows a virtual 3D image that is transferred from Fig. 6(b). It is evident to see that there are some peaks in this graph, and it reveals that there are some particles on the surface. The diameter of the particles is at 100nm.

V. CONCLUSIONS

We built a 4-DOF robotic manipulator to exchange the worn probes of AFM. The manipulator has 0.1 μm translational and 0.07 degree rotational resolution. Using visual servo techniques, it owns the ability to load the probe at the focus of the laser measurement system of the AFM. The other motored stage aligns the reflected laser spot to the center of the PSD. The whole delicate procedure is not easy for human hands to do but now can be implemented by the proposed robotic manipulator.

If the sample is massive, it is hard for the piezoelectric scanner to drive the sample up-and-down and the bandwidth is hence reduced. A novel optical arrangement is also proposed in this paper. It allows the probe to track the sample surface in z-direction. This feature can improve the scanning speed of AFM especially when the sample is heavy or not suitable to be moved.

Experiment results prove the functionality of our AFM system. Accurate topography images can be obtained by our hands-on instrument.

ACKNOWLEDGMENT

The authors would like to thank the AngsNanoTek Co. who supplied the piezoelectric xy-scanner to establish this research.

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