Featured Articles

Measurement of Microscopic Three-dimensional Profiles with High Accuracy and Simple Operation

—AFM5500M Scanning Probe Microscope—

Satoshi Hasumura
Shigeru Wakiyama
Masato Iyoki
Kazunori Ando

OVERVIEW: SPMs are able to measure the surface profile of a sample and its mechanical and electrical characteristics with sub-nanometer resolution. Hitachi High-Tech Science developed the AFM5500M SPM, which can accurately measure three-dimensional profiles, to meet demand from industrial measurement applications. Its simple operation reduces the operator's workload by providing features such as an automatic adjustment mechanism for the optical axis of the cantilever and automatic adjustment of measurement parameters. It also has a linkage function for correlation with an SEM or a CSI to enable complementary observation and measurement, and measurement of physical properties of the same area on the sample. This article describes the AFM5500M and its linkage function together with example measurements.

INTRODUCTION

A scanning probe microscope (SPM) is a type of microscope that obtains an image by tracing a needle-sharp tip (probe) over the surface of the object being observed or measured. Fig. 1 shows images obtained by an SPM. An SPM can scan areas with sizes ranging from several hundred microns to several nanometers, and can observe surface profiles with sub-nanometer resolution when scanning small areas. Typically, the resulting images are displayed on a personal computer (PC) monitor, with magnification reaching more than 10 million times when the images are displayed 10-cm square.

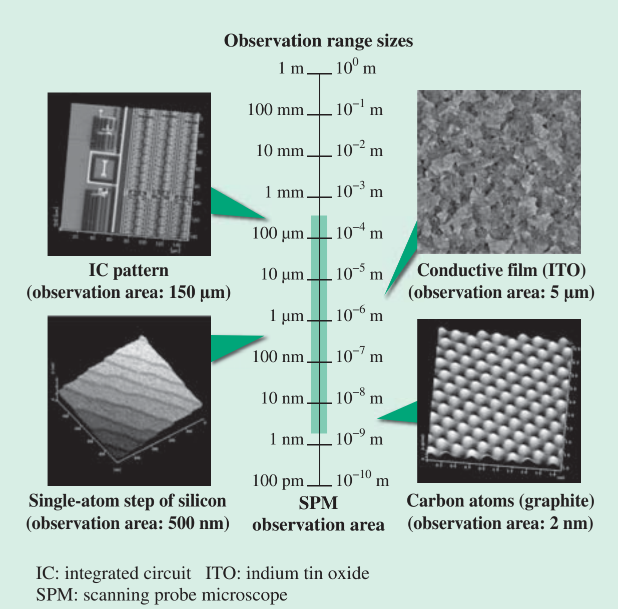


Fig. 1—Example Images Taken by an SPM.
The figure shows the observation range of an SPM and various example images. An SPM has the resolution for atomic imaging.

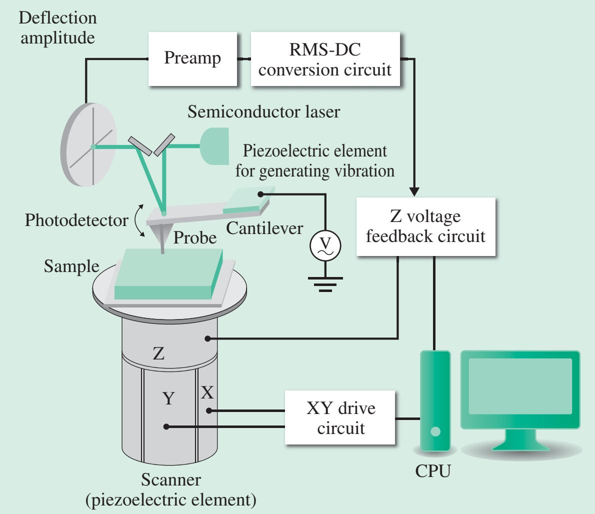
Other microscopes used for observing surface profiles include scanning electron microscopes (SEMs) and coherence scanning interferometers (CSIs). These other microscopes can obtain images of a large area more quickly than an SPM. However, an SPM has superior resolution, both horizontal and vertical, and can measure length and other physical properties in three-dimensions. This means that the ability to correlatively use these different types of microscopes enables complementary observation and measurement that takes advantage of their respective capabilities.

This article describes the measurement principles and configuration of an SPM, and introduces the AFM5500M SPM released in March of 2016.

SPM MEASUREMENT PRINCIPLES

Principles of Measurement

Fig. 2 shows how SPM measurement works. It uses a needle-sharp tip (probe) on the end of a cantilever.



RMS–DC: root mean square value – direct current
CPU: central processing unit

Fig. 2—Principles of SPM Measurement.
The force between the cantilever and the sample causes deformation of the cantilever (deflection amplitude of the lever in the case of a repulsive force). The deformation of the cantilever is detected optically.

When the cantilever is made to vibrate, causing the probe to approach the sample, the resulting physical force between probe and sample causes a change in the cantilever vibration amplitude. This amplitude is detected by shining light on the back of the cantilever.

The sample is place on top of a scanner that is able to move very short distances in the horizontal (X and Y) and vertical (Z) directions. As the scanner scans horizontally with the probe close to the sample, the distance between the probe and the sample varies depending on the surface profile of the sample, causing the cantilever amplitude to vary. This allows the surface profile of the sample to be determined by controlling the vertical position of the scanner so as to keep the cantilever amplitude constant and converting this movement into a three-dimensional image.

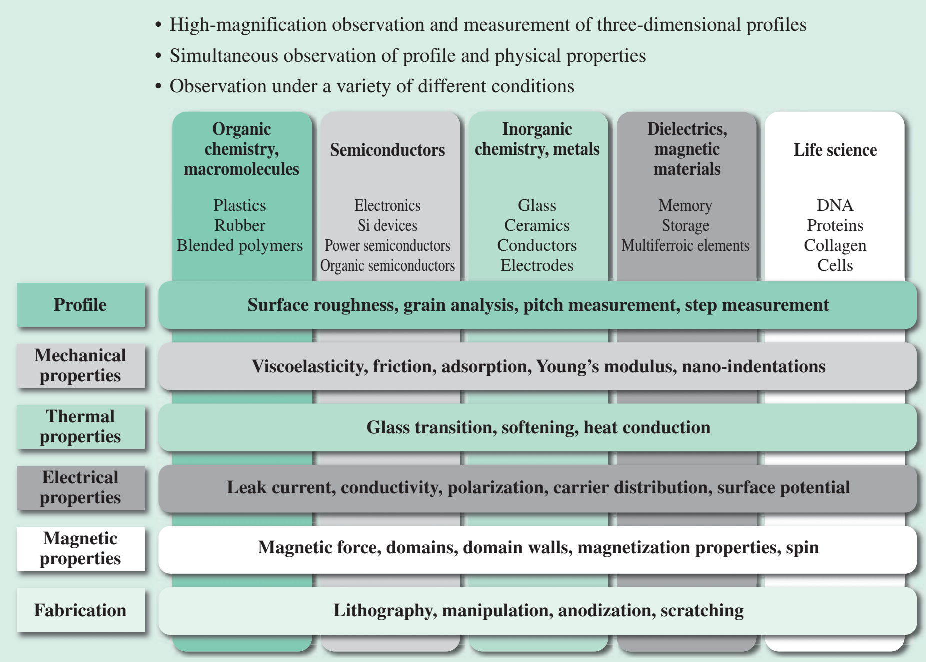
Features and Applications

Fig. 3 shows the features and applications of SPMs. Along with high-magnification observation and measurement of three-dimensional profiles, an SPM can also obtain information about the physical properties of the sample surface through techniques such as using a coated cantilever or causing the scanner and cantilever to vibrate. Together with the ability to perform measurements in atmosphere, vacuum, or liquid, the technology is being adopted in a wide variety of fields.

AFM5500M SPM

AFM5500M Precision Probe Microscope

In applications such as electronic components where progress on scaling continues to be made, and for



Si: silicon DNA: deoxyribonucleic acid

Fig. 3—SPM Features and Applications.
SPMs are used for observation and measurement in a large number of different fields.

Fig. 4—AFM5500M SPM.
Designed as an SPM with a high level of precision and automation, the AFM5500M went on sale in March of 2016.

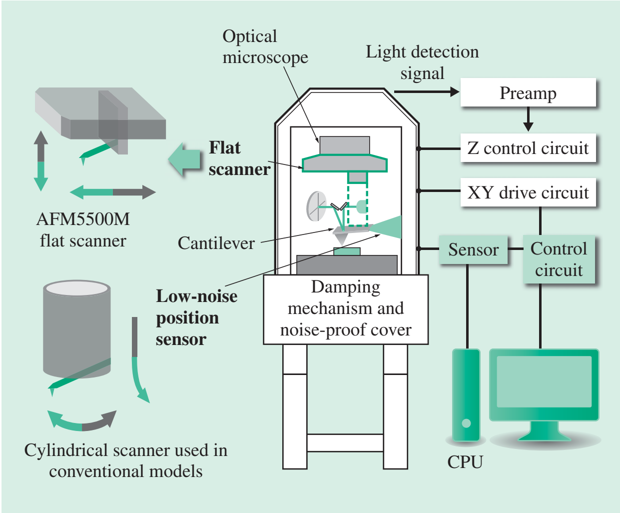


Fig. 5—Configuration of AFM5500M.
A low-noise position sensor and a newly developed flat scanner with high orthogonality and a wide 200-μm range are located near the cantilever.

highly functional materials and precision parts, there is growing demand for SPMs that can measure at even higher resolution for use in development, manufacturing, and quality management. Hitachi High-Tech Science Corporation developed the AFM5500M SPM in response to this demand, designing it for greater precision and automation. Fig. 4 shows a photograph of an AFM5500M and Table 1 lists its main specifications.

Achieving Superior Measurement Precision

To combine high measurement precision and sensitivity with a wide scanning range, the AFM5500M has adopted a technique not used on conventional SPMs. The AFM5500M has a wide-area flat scanner that incorporates a piezoelectric element in the parallel spring mechanism of the cantilever, and Low-noise position sensor for the three axes (horizontal and vertical) located near the cantilever (see Fig. 5). Whereas previous scanners have had problems with arc error and Z-axis orthogonality due to use of a cylindrical piezoelectric element, the AFM5500M is able to obtain distortion-free three-dimensional images by using a flat scanner and reading the vertical sensor while using a sensor to control horizontal scanner movement.

Fig. 6 shows a measurement by the AFM5500M of a step in an amorphous silicon film on a silicon substrate. Whereas conventional scanners introduced arc error into measurement data, the AFM5500M is capable of performing measurements with good uniformity over a wide 200-μm range.

Fig. 7 shows a measurement by the AFM5500M of the texture of a photovoltaic cell. The poor Z-axis orthogonality of conventional scanners results in asymmetrical measurement of the left and right angles. The AFM5500M, however, is able to accurately

Table 1. AFM5500M Main Specifications
The wide-area flat scanner is on the cantilever side and the automatic XY stage is on the sample side. The AFM5500M features a wide scanning range, measurement precision, and ease of use (automation).

Parameter	Value
Scanner range (observation range)	XY: 200 μm Z: 15 μm
Nonlinearity	<0.2% (X,Y,Z)
XY orthogonality	<0.5°
Bow	2 nm (50-μm area)
Maximum sample size	ϕ: 100 mm, thickness: 20 mm

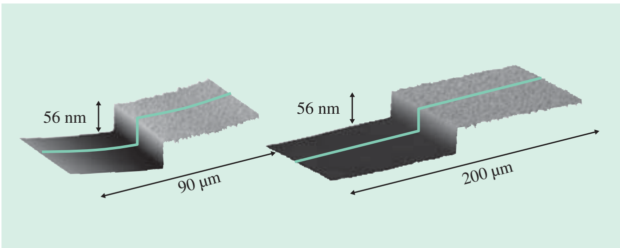


Fig. 6—Step Measurement of Amorphous Silicon Thin Film.
A measurement performed using a conventional model is shown on the left and the AFM5500M measurement is on the right. This demonstrates the uniformity of measurement over a wide area.

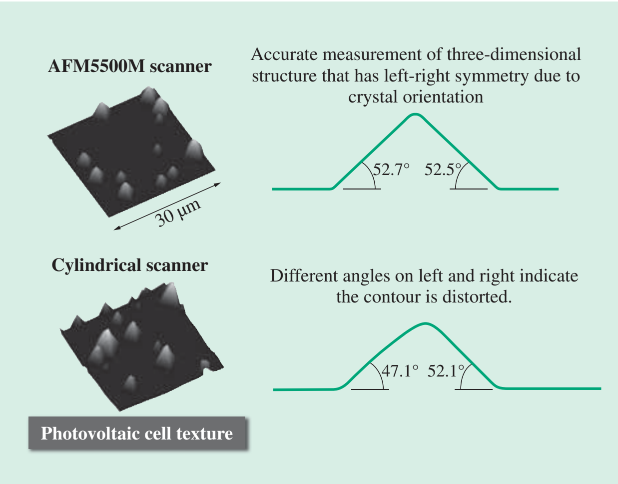


Fig. 7—Measurement of Photovoltaic Cell Texture.
The AFM5500M measurement is shown on the top and the measurement performed using a conventional model is on the bottom. This demonstrates the underlying superior performance of the AFM5500M in terms of things like Z-axis orthogonality and horizontal nonlinearity.

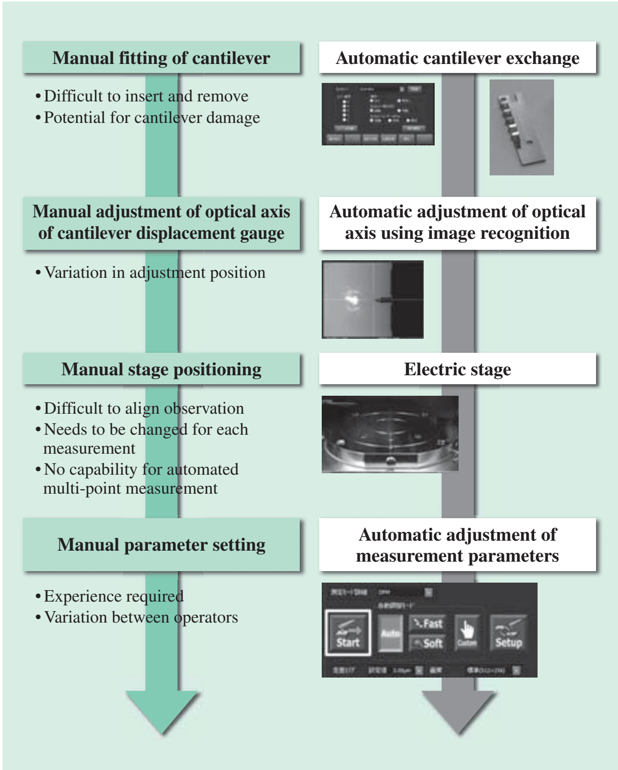


Fig. 8—SPM Measurement Procedure.
The conventional measurement procedure is shown on the left and the procedure for the AFM5500M is on the right. Automation has significantly simplified the procedure.

measure this three-dimensional structure, which has left-right symmetry due to the crystal orientation. This demonstrates how the AFM5500M is capable of highly precise profile measurement, without the profile distortion and asymmetry that have been problems for SPM measurement.

Improved Operation through Measurement Automation

Fig. 8 shows a flowchart of the operator's procedure when making an observation or measurement. The AFM5500M uses pattern matching and other techniques to automate the insertion of the cantilever and adjustment of the optical axis, and is equipped with functions for automatically adjusting the cantilever amplitude and feedback parameters. These functions make it easy for the operator to perform observation and measurement without the need for complicated procedures, they also eliminate measurement errors due to the operator.

TRIAL CORRELATION BETWEEN OBSERVATION EQUIPMENT

As noted in the introduction, the ability to correlatively use different types of microscopes enables complementary observation and measurement that takes advantage of their respective capabilities. To achieve this, Hitachi High-Tech Science has developed quick and simple observation techniques that use a number of different microscopes to image the same location by using a shared alignment sample holder and a coordinate linkage function (see Fig. 9).

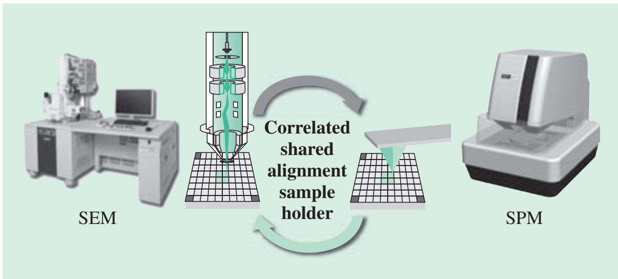
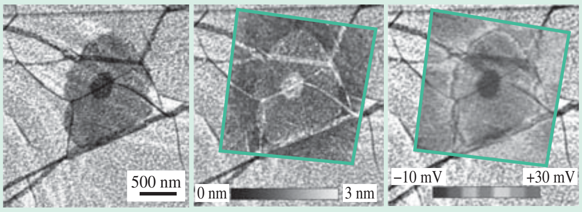


Fig. 9—Concept of Correlation between Instruments.
By using a shared alignment sample holder and sharing the alignment marks and measurement coordinates, it is possible for different instruments to observe the same area of the sample.

Fig. 10 shows images acquired from the same location on monophase graphene/silicon dioxide (SiO_2) grown by chemical vapor deposition (CVD) using both an SEM and an SPM. To investigate the cause of contrasts present in the SEM image, the image was overlaid with SPM images of topography and surface potential. This showed that the difference in contrasts on the SEM image correspond to the height



SiO_2: silicon dioxide CVD: chemical vapor deposition

Fig. 10—Monophase Graphene/SiO_2 grown by CVD.
The initial SEM image is shown on the left, overlaid with the SPM topography in the center, and overlaid with the SPM surface potential image on the right.

of one layer of graphene observed by the SPM, and that the surface potential varies with factors such as the number of layers of graphene[1].

CONCLUSIONS

This article has described the principles and features of an SPM. It has also described the AFM5500M, an SPM suitable for applications ranging from nano-scale research and development to industrial measurement and quality management.

Along with a high level of measurement precision thanks to features that include a newly developed scanner and low-noise sensors, this latest SPM also features significant improvements in ease-of-use, including automation of cantilever exchange and optical axis adjustment. And, as a new trial, the article also presents an example of its use in observing and measuring the same location with a number of different microscopes.

In anticipation of the growth in demand for nano-scale measurement in industry, Hitachi High-Tech Science intends to continue developing the instrument with the aim of improving precision, speed, and resolution. Hitachi High-Tech Science also intends to supply customers with total solutions that correlate a number of different microscopes together to make it easy to perform the steps from observation to analysis and measurement.

REFERENCE

(1) Y. Hashimoto et al., “Correlative Characterization of Graphene with the Linkage of SEM and KFM,” Proceedings of Microscopy & Microanalysis 2016 Meeting (Jul. 2016).

ABOUT THE AUTHORS

Satoshi Hasumura

Analytical Instruments Design Group 2, Analytical Instruments Design Department, Hitachi High-Tech Science Corporation. He is currently engaged in the management and development of a scanning probe microscope.

Shigeru Wakiyama

Analytical Instruments Design Group 2, Analytical Instruments Design Department, Hitachi High-Tech Science Corporation. He is currently engaged in the development of a scanning probe microscope.

Masato Iyoki

Application Engineering Section Tokyo 2, Hitachi High-Tech Science Corporation. He is currently engaged in the application development of a scanning probe microscope.

Kazunori Ando

Analytical Instruments Design Group 2, Analytical Instruments Design Department, Hitachi High-Tech Science Corporation. He is currently engaged in the development of a scanning probe microscope.