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Application News

No. S49

Scanning Probe Microscope / Atomic Force Microscope

Visualization of Spatial Distribution of Magnetic Force by ZXY Measurement

Introduction

Our everyday environment includes many products using magnetic materials, such as motors and memory devices, and in recent years, nano magnetic materials have been applied in drug discovery research. Although magnetic force microscopy (MFM) employing the scanning probe microscope (SPM) is used in research and development of these materials, conventional MFM was "constant height scanning," in which the probe (cantilever) was kept at a constant distance from the sample. As reported in this article, we carried out measurements applying the new "ZXY measurement" technique (Application News No. S47) and succeeded in visualization of the 3-dimensional distribution of magnetic force, which could not be obtained by conventional techniques.

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Magnetic Thin Film: Magnetic Force Distribution in XY Direction

MFM measurements by the conventional method and ZXY measurement were compared using a commercially-available magnetic thin film sample (Fig. 1). Because the MFM image by the conventional method is a "constant height scan," in which the probe is separated from the sample surface by a constant distance, the obtained image is limited to the distribution of magnetic force in the XY direction at a predetermined vertical distance from the sample surface. In contrast, with the new ZXY measurement technique, the XY image can be redrawn at any desired vertical distance using the 3-dimensional data obtained by the ZXY measurement. The MFM image shown here is positioned 20 nm from the surface.

Although the parts of a sample measured by the conventional method and the ZXY measurement technique are different, the surface height image and MFM images (top and bottom rows in the figure, respectively) by these measuring methods show the same field of view. The patterns in the MFM images represent the magnetic domain/magnetic wall distribution. Areas of weak magnetic force are shown in red, and areas of strong magnetic force are shown in blue.

The height image differ due to differences in the measured parts. However, in the MFM images, a fingerprint-like magnetic domain/magnetic wall structure with a width of approximately 100 nm can be obtained by both the conventional and the ZXY measurement techniques.

Magnetic Thin Film: Magnetic Force Distribution in Z Direction

Fig. 2 (a) shows a ZX image of the magnetic force in a ZXY measurement. This ZX image is the data for the first scanning line of the MFM image shown at the lower right in Fig. 1. In this image, the sample is viewed from the cross-sectional direction, where the upper side of the figure is the space above the sample, and the white dotted line in the lower part of the figure shows the sample surface.

The alternating pattern of red and blue near the sample surface, indicated by the black arrows in the figure, shows the distribution of magnetic force extending into space. This magnetic force can be observed in a spatial region with a height of about 100 nm.

Fig. 2 (b) and (c) show the comparison of the ZX image and XY image. The patterns of red and blue, that is, the X direction patterns of magnetic force, are in good agreement.

As this ZXY scan example demonstrates, spatial information concerning a sample surface can be visualized by viewing the sample from the cross-sectional direction.

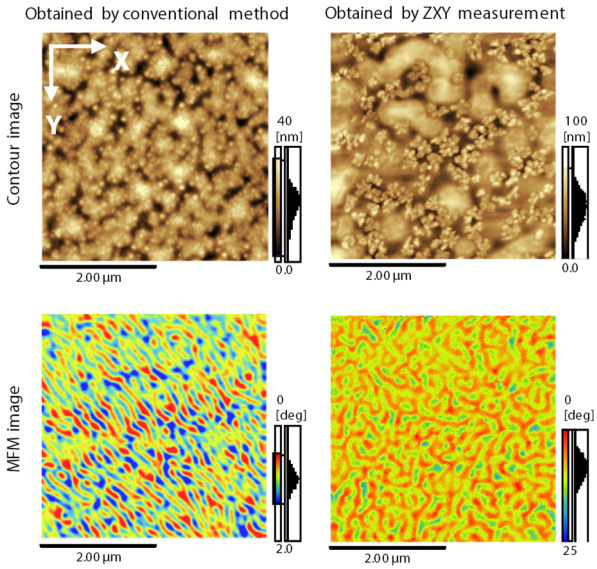

Fig. 1 Height Image and MFM Images of Magnetic Thin Film

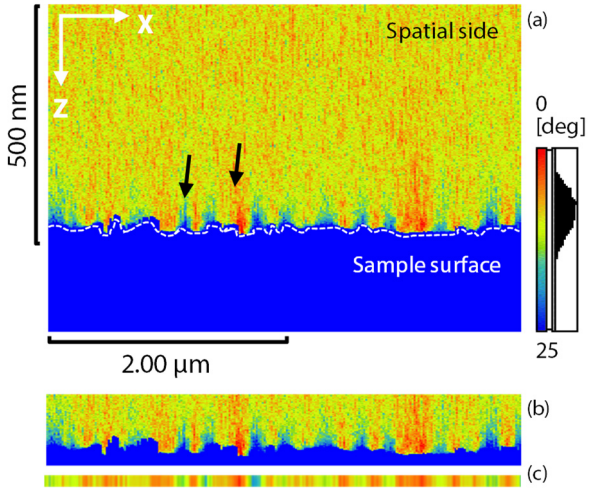

**Fig. 2 (a) ZX Image of Magnetic Thin Film,
(b) Trimmed Version of ZX Image,
(c) Enlarged View of First Line of XY Image.
The red and blue magnetic force distribution is in good agreement.**

Visualization of Spatial Distribution of Magnetic Force

Because 3-dimensional values are stored as data in ZXY measurement, arbitrary XY planes and ZX planes can be drawn after a scan. Fig. 3 shows XY-axis MFM images drawn a Z positions 1.5 nm, 2 nm, 5 nm, 10 nm, 20 nm, 30 nm, and 40 nm from the sample surface. The magnetic force contrast is strong until the 10 nm Z position, and becomes weak at the 40 nm Z position. These results also revealed that the same magnetic structure as at the 5 nm Z position continues to exist without change until the 40 nm Z position.

The ability to visualize the spatial distribution of magnetic force in this manner will make it possible to acquire new physical information.

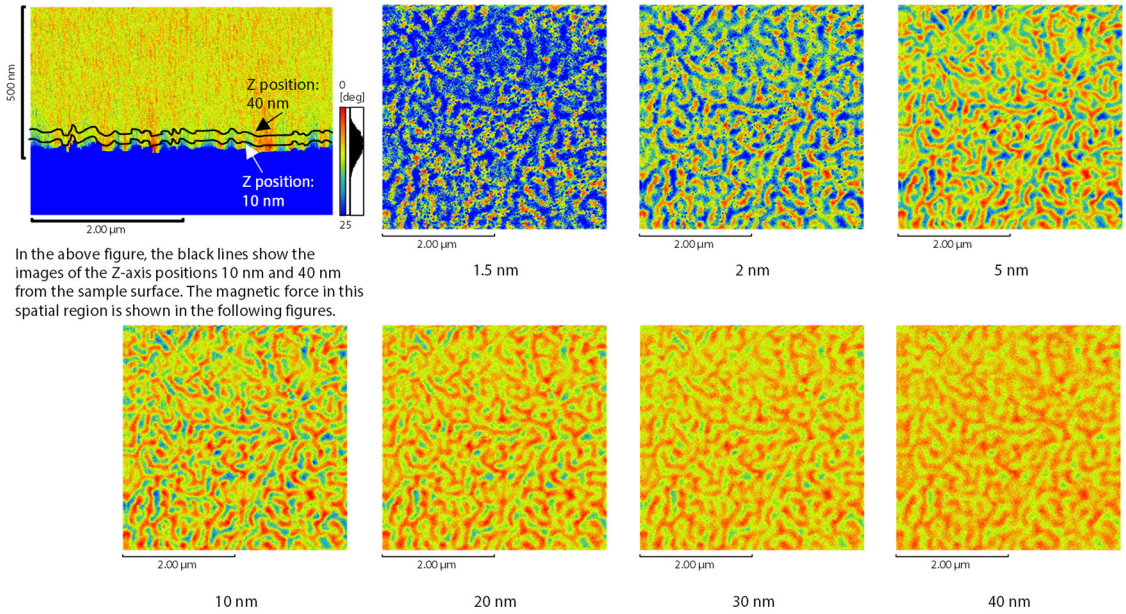

Fig. 3 ZX Image and XY-MFM Images at Various Spatial Positions

Outline of ZXY Measurement Technique

Fig. 4 shows a schematic diagram of ZXY measurement. The basis of ZXY measurement is force curve measurement. A force curve is measured while greatly changing vertical distance (Z-axis) between the cantilever and the sample (approach and release). At that time, the force received by the cantilever is measured. In this process, the phase lag due to magnetic force is detected. Scanning is conducted continuously in the X-axis direction, and a ZX measurement plane is created. Next, a ZXY measurement plane with 3-dimensional (Z, X, Y) information is created by continuously scanning this ZX measurement plane in the Y-axis direction. Any desired XY plane can be redrawn from the 3-dimensional information obtained by ZXY measurement.

Details are described in Application News No. S47.

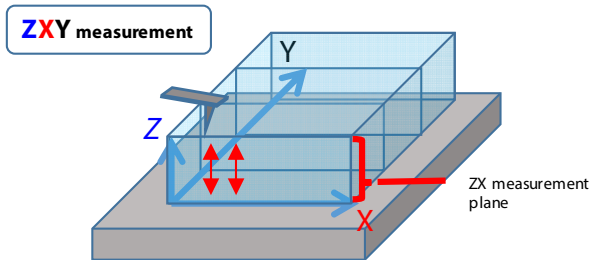

Fig. 4 Schematic Diagram of ZXY Measurement

Instrument Composition

Fig. 5 shows the instrument composition and the connection diagram for this measurement. In this instrument composition, a high performance, wideband digital lock-in amplifier (LI5660, NF Corporation) was connected externally to a Shimadzu SPM-8100FM high resolution scanning probe microscope.

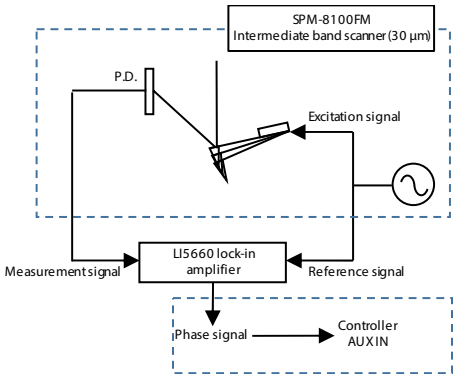

Fig. 5 Connection Diagram of SPM and Lock-In Amplifier (Areas Within Dotted Lines: Standard Instrument Composition of SPM-8100FM)

Conclusion

Magnetic force measurements by ZXY measurement made it possible to visualize the distribution of magnetic force in the ZX plane and at arbitrary Z positions, which could not be obtained by conventional techniques.

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