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Advanced nanoscale metrology of pole-tip recession with AFM

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Abstract

Atomic force microscopes (AFM) have been widely used for precision metrology. However, most conventional AFM revealed their limits in accuracy due to the inferior characteristics of piezoelectric tube scanner. In order to overcome these limits, we introduced the new XE AFM, which has a *z*-scanner separated from the *x–y* scanner. With the new XE AFM, we were able to successfully measure dimensions of pole-tip recession (PTR) in magneto-resistance (MR) head, which had been difficult to be measured by conventional AFM. In addition, we found that it is important to use non-contact AFM, not tapping mode AFM for accurate measurement of PTR since the tapping force can depress the pole-tip region and make the PTR value appear larger than it actually is. In order to confirm this phenomenon, we performed force modulation microscopy and contact mode AFM at various force set points.

Keywords: AFM; PTR; Non-contact AFM; Tapping mode AFM; FMM

1. Introduction

As the design rule becomes smaller, meeting the precision metrology demands from industries is becoming more difficult. Traditional tools, such as stylus profiler, optical microscope, and CD–SEM are proving to have insufficient resolution. Atomic force microscopes (AFM) have gained attention as a new candidate for nanoscale metrology tool. However, most conventional AFM systems used a piezoelectric tube actuator, which has significant background curvature and crosstalk between the *x–y–z* axes, making them unsuitable for metrology applications.

To address this problem, we have developed a new AFM, where the *z* scanner is separated from the *x–y* scanner [1]. The *x–y* scanner scans the sample in *x–y* plane, while the *z* scanner scans the probe in *z*-axis. For the *x–y* scanner, we used a single module parallel-kinematic flexure stage, which has high orthogonality and minimum out-of-plane motion. With this new AFM, we were

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able to measure extreme features, which have been very difficult or impossible to measure with conventional AFM.

The pole-tip recession (PTR) in magneto-resistance (MR) head is a prime example. PTR, depicted in Fig. 1, refers to the difference in height between the pole-tip material and the air-bearing surface (ABS). As one way of increasing the storage density in rigid disk drives, many efforts were taken to minimize the head–media gap, and consequently the signal loss [2,3]; the pole-tip had to be recessed as little as possible, only to the point of preventing damage by contact with the disk. For this reason, PTR has been only a few nanometers and the metrology of PTR has remained a demanding task [4], in spite of its economical importance [5,6].

As an alternative to optical interferometry, which had a major problem of convoluted data owing to the effect of different refractive indices of various materials used for PTR [7], people tried to take advantage of the superior spatial resolution of AFM. However, the performance of conventional AFM in PTR metrology was disappointing due to the poor behavior of piezoelectric tube scanner [4,8]. Since the reference plane (ABS) is far from the pole-tip, the small height of PTR is easily buried in the background curvature of the tube scanner, which is a couple dozen times larger than the PTR height. The images taken with conventional AFM are often flattened with polynomial fitting before analysis. However, it is not easy to realize how much of the data is lost during this post-image processing. There have been efforts to reduce the background curvature by modifying the electrode design of the piezo tube, but the fundamental problems of piezo tube scanner could not be eliminated [9,10].

Besides the problems originating from the tube scanner, we have found that the tapping mode AFM can cause serious artifacts due to the tapping force when the sample is composed of various materials as in the case of PTR. Since the pole-tip is made of softer materials, the tapping force depresses the pole-tip more than its surroundings and makes PTR value appear larger than actual.

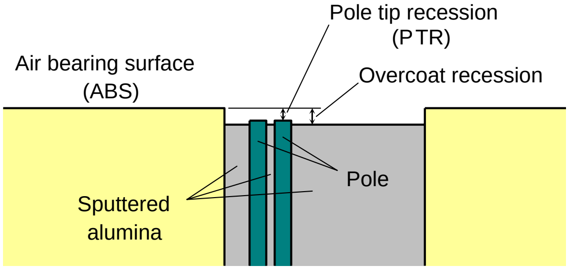

Fig. 1. Cross-section of a typical thin film head showing the pole-tips, undercoat/overcoat, gap, and the air bearing surface (ABS).

2. Advanced metrology of PTR with improved XE scan system

We have developed a new AFM with the concept of cross-talk elimination (XE) [1]. The key point is to separate the z scanner from the xy scanner. We used a 2-dimensional flexure stage to scan the sample only in the xy directions, and a stacked piezoelectric actuator to control the cantilever position along z-axis. This configuration, shown in the conceptual diagram of Fig. 2, allows improved scan accuracy and increased z-servo performance.

This design practically eliminates the cross coupling between xy and z directions, hence the background curvature artifacts common in AFM

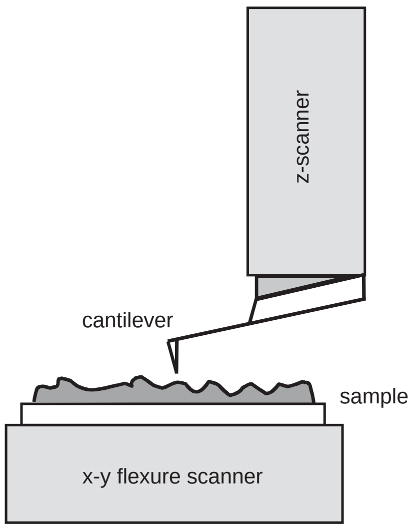

Fig. 2. Conceptual diagram of the new XE AFM.