Abstract—A scanning tunneling microscope (STM) for surface magnetic force measurements on thin-film longitudinal magnetic storage media has been adapted. The usual rigid PtIr tip of the STM was replaced by a flexible Fe film tip. Images of a hard disk showing bit tracks written by a ferrite head in a computer disk drive are presented. The images shown are comparable to images of the bit tracks on textured surfaces using either ferrofluid decoration or other magnetic force microscopy (MFM) imaging techniques. The sensitivity of the Fe film tip was such that the influence on the image due to magnetic forces was larger than the influence due to sample topography.

Microscopic images of surface magnetic fields and forces can be obtained in several ways. Bitter patterns are created using a fluid dispersion of fine magnetic particles [1]. When the dispersion is applied to a magnetic surface the particles coalesce near regions of high field divergence. The surface is then viewed with an optical microscope. Lorentz microscopy and electron holography detect the deflection of electrons in a scanning electron microscope (SEM) to produce an image showing variations in the magnetic fields [2]. SEM with polarization analysis (SEMPA) is used to determine the magnetization of a sample surface by detecting electron polarization [3]. A more recent method detects the change in frequency of a vibrating magnetic probe in response to changes in magnetic fields [4]–[6]. This method is based on optical interferometer detection of tip motion using a piezoelectric scanner, like that used in a scanning tunneling microscope (STM), to move the probe over the surface of a sample.

In this paper we present images of bit tracks on a hard disk obtained using an unconventional magnetic force microscope (MFM). This MFM, described in a previous paper [7], uses a STM to position, in a dc mode, a flexible Fe tunneling tip above the surface of a CoCrTa thin-film hard disk. We call this process tunneling-stabilized magnetic force microscopy (TSMFM). This is in contrast to the vibrating magnetic probe MFM technique mentioned above. The tip position is stabilized near the surface of the sample using the STM feedback system as tunneling occurs between the tip and sample surface. With this method we have imaged 5 μm × 30 μm magnetic “bits” on a hard disk.

In earlier experiments by Allenspach et al. [8], STM images believed to be magnetic features on an Fe polycrystal were obtained with a rigid silicon tip coated with a thin magnetic film of CoCr. The CoCr film was used as a magnetic tunneling contact. The authors speculated that the CoCr film might have been elastically deformed in some fashion by fringe fields of the sample. We have proven independently and purposefully that when using a free-standing flexible ferromagnetic tip with the proper spring constant that images can be made of submicron surface magnetic fields. In particular, we have made progress towards reducing the TSMFM method to a practical diagnostic tool for applications in the magnetic recording industry.

We studied sections of a thin-film hard disk removed from a computer disk drive. The hard disk consisted of multilayer sputter-deposited films on an aluminum disk including a NiP base layer, a 1-μm magnetic CoCrTa layer, and a thin lubricating C surface layer [9]. Typical coercivity for reversing the CoCrTa film magnetization is 48 kA/m (600 Oe) [2]. As observed using standard STM techniques, disk surface features due to manufacturing surface preparations were in the range of 20–40 nm.

The flexible tip was constructed of a 5-μm-thick triangular thin film of Fe. A sharp tip was obtained by cutting the Fe film with scissors in the shape of a triangle with a base of 1 mm and height of 3 mm. The tearing action of the scissors left a sharp tip suitable for high resolution STM imaging. Fig. 1(a) shows an SEM micrograph of the end of the Fe tip. This triangle was attached at an angle to a support wire with silver paint (see Fig. 1(b)). After the tip was cut and mounted onto the support wire, it was coated with 100 nm of thermally evaporated Au (99.99% pure). The Fe film tip assembly was then fastened to the piezotube translation stage of the STM.

While scanning, we used a tunneling bias voltage of 1.611 V and a tunneling current setpoint of 0.49 nA. The STM was used in a constant-height mode to position the tip relative to the surface to be imaged. As the tip is scanned over the sample, it is deflect by changes in the magnetic force. If the force is repulsive, the STM extends toward the surface keeping the tunneling current constant. Conversely, if the magnetic force is an attractive force, the tip is pulled toward the surface and the STM retracts to keep the tunneling current constant.

The TSMFM image (raw data) shown in Fig. 2(a) is a combination of disk surface topography and magnetic field...
Fig. 1. (a) SEM micrograph of the end of the flexible Fe STM tip used for tunneling-stabilized magnetic force microscopy (TSMFM). (b) SEM micrograph of support wire and triangular Fe film assembly. The tunneling point is in the lower right corner.

Fig. 2. (a) TSMFM image of a bit track recorded on the surface of a hard disk. The arrows indicate bit track separations. (b) Cross section showing the STM piezoelectric Z motion in response to magnetic forces on the flexible Fe tip.

Rugar et al. [11], may explain the difference in the appearance of the two track separations.

The distance traveled by the STM piezotube was greater for magnetic forces than for tunneling current adjustments due to surface features. We assume that the disk, in general, had an attractive force on the Fe tip. The relative magnetic force from the sample on the Fe film tip can be calculated by multiplying the distance traveled by the STM (as it withdraws to keep the tip height constant) times the spring constant of the triangular Fe film. From a cross section of our TSMFM image (Fig. 2(b)) we measure a 20-nm magnetic displacement from the base attractive force. This multiplied by our estimate for the spring constant of 0.1 N/m gives a relative force of $2 \times 10^{-9}$ N.

An interesting effect was also observed while we were imaging disks with Fe film tips without an Au coating. When the tunneling current was increased, we found that these tips changed the magnetization of the disk. We have shown previously that if the Fe tip is magnetized with a small magnet glued to the Fe film, it is then possible to write as well as image magnetic spots on hard disk surfaces. This process overwrites existing magnetization on the disk. This is a disadvantage if the goal is to nondestructively image existing magnetization on the disk surface. However, as we have shown in this paper, when an unmagnetized Au-coated Fe film tip is used for TSMFM imaging there is minimal disturbance of the magnetic bit tracks on the hard disk.

Presently we are investigating the effect of tip geometry and composition on TSMFM imaging. We believe that in order to obtain good TSMFM images, the Fe films should be slightly magnetized and the fringe fields of the Fe film should be small enough to avoid affecting the magnetization during the imaging process. Either reducing the quantity of magnetic material near the disk surface or increasing the distance of the magnetic material from the disk surface should enhance TSMFM capabilities. These modifications include nonmagnetic thin-film tips with very...
thin magnetic coatings and magnetic films with relatively thick (200 nm) nonmagnetic coatings. Studies of Permalloy films by Mamin et al. [12] have shown that magnetic tips change the magnetization when the tip is approximately 220 nm from the sample surface. Tunneling-stabilized probes minimize probe lift-off. The potential for nanometer resolution of surface magnetization using TSMFM may be possible. The modifications to a standard STM to do TSMFM imaging are minimal and the combination force/topography images can offer dual analysis of a surface with one scan.

REFERENCES


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