SCANNING MAGNETIC FORCE MICROSCOPY ON Co/Pt MAGNETO-OPTICAL DISKS

H.W. van KESTEREN, A.J. den BOEF, W.B. ZEPER, J.H.M. SPRUIT,
B.A.J. JACOBS and P.F. CARCIA*

Philips Research Laboratories, P.O. Box 80.000, 5600 JA Eindhoven, The Netherlands

**Central Research Development Department, E.I. du Pont de Nemours and Company, Experimental Station, Wilmington, DE 19880, USA*

Abstract- The key advantage of scanning magnetic force microscopy compared to electron microscopy techniques is that regular MO disks can be investigated. This enables one to relate the writing conditions and carrier and noise levels of the read-out signal directly to the magnetic microstructure of the domains on the disk. High resolution images are shown of domains on Co/Pt multilayer MO disks. Marks were written with both laser and magnetic field modulation and tracks were erased under different conditions. The influence of the Co and Pt layer thicknesses is briefly discussed.

KEYWORDS: SCANNING MAGNETIC FORCE MICROSCOPY, Co/Pt MULTILAYERS, RECORDING

INTRODUCTION

In Scanning Magnetic Force Microscopy (SMFM) a ferromagnetic tip is scanned across the object surface and its deflection is detected to obtain an image of the magnetization pattern. In contrast to electron-optical techniques such as Lorentz TEM, Differential Phase Contrast STEM (DPC), and Scanning Electron Microscopy with Polarization Analysis (SEMPA), SMFM does not require a vacuum environment and specially thinned (TEM and DPC) or sputter-cleaned (SEMPA) specimens. The current resolution obtained with SMFM of about 50 nm is comparable to or even better than that of the other techniques. The first images of thermomagnetically written domains in a TbFe layer were reported by Martin et al. [1]. The fact that SMFM does not require special samples, opened the possibility to study for the first time the domain structure on regular MO disks. This has the key advantage that we can directly relate the writing, overwriting and erasure conditions, as well as the carrier and noise levels of the read-out signal, to the magnetic microstructure of the domains on the disk. Further, SMFM enables study of the influence of pregrooves and dielectric base layers on the magnetic microstructure.

The force microscope, as earlier described by Den Boef [2], uses an interferometer to detect the vibration of a tungsten tip coated with a thin magnetic Co layer [3]. The force gradient acting on the tip affects the phase of the vibration, which is detected and used in a feedback loop to control the object-tip distance with a piezo and thereby maintain a constant force

gradient. To ensure an attractive force during imaging, a small voltage is applied between the tip and object. As a consequence of the resulting electrostatic force gradient, the SMFM images show some surface topography (e.g. grooves) as well. If desired, a topography image can be obtained with the same tip by using a larger voltage and adjusting the control loop to a larger force gradient.

For the present SMFM study we used disks with Co/Pt multilayer MO films. These multilayers are candidates for second generation recording media [4,5]. Furthermore, their recording properties are less well understood than for the RE-TM films. To obtain a large perpendicular anisotropy for Co/Pt MO films, the optimum Co layer thickness is about 4 Å. Increasing the Pt layer thickness reduces the Curie temperature (T_c), the effective magnetization (M_s) and effective domain wall energy (both per multilayer volume). The lower T_c and M_s are advantageous for writing with low laser power and at low fields. However, the lower Kerr rotation for thicker Pt layers leads to a lower carrier level, and the lower wall energy might promote a tendency to form subdomains within the written marks. Co/Pt multilayers with a total thickness of about 200 Å were deposited either by electron-beam evaporation or by dc magnetron sputtering using Kr gas, on 2" glass disks with a pregrooved 2p lacquer and an 80 nm thick AlN optical enhancement layer. Recently, we reported that by using Kr instead of Ar, dense films were obtained with relatively high coercivities [6]. This is attributed to the sharper Co-Pt interfaces due to reduced

bombardment by reflected sputter gas neutrals in case of sputtering with Kr gas. Four disks were studied; three with evaporated 13x(4.3 Å Co + 9.5 Å Pt), 13x(3.4 Å Co + 10.6 Å Pt), and 9x(4.1 Å Co + 19.0 Å Pt) multilayers respectively (denoted by 4.3/9.5, 3.4/10.6 and 4.1/19.0), and one with a sputtered 10x(4.1 Å Co + 14.7 Å Pt) multilayer (4.1/14.7). Domains were written on these disks in a test recorder at 750 kHz and 1.4 m/s linear disk velocity and read out in a bandwidth of 10 kHz. The 2" disks had a relatively high disk noise level of 8-12 dB which was most likely related to a less smooth structure of the glass/2p/AlN underlayers. Therefore, the CNR's were slightly lower than those reported in previous studies on larger diameter disks.

IMAGES AND DISCUSSION

The 8 μm vertical scan range of the force microscope covers 5 tracks and therefore, we used 4 and sometimes 5 different writing or erasure conditions in each experiment. In the figures, these conditions are indicated on the left side and the carrier (C), noise (N) and CNR of the read-out signal on the right side. The read laser power was 0.8 mW for all the measurements to make comparison for the different disks possible.

Figs. 1a,b show the images of marks written with laser modulation (LM) at various fields for the disks with an evaporated 3.4/10.6 and 4.1/19.0 multilayer film respectively. For Co/Pt multilayers, the T_c decreases with increasing Pt content. Consequently, the laser power required for writing domains with about 1.1 μm diameter, decreased from 6.7 mW for the 3.4/10.6 disk to 4.5 mW for the 4.1/19.0 disk. On both disks, marks were written for all the external fields applied. Even at zero field, the marks are clearly present. However, writing without an external magnetic field gave rise to more subdomains within the written marks. These subdomains diminished when the marks were written in higher external fields, and both the carrier and CNR increased until the marks were uniformly magnetized. For both disks relatively large fields of about 30 kA/m were required to obtain marks with a uniform magnetization. In general, the tendency to form subdomains is largest for films with a high magnetization and a low wall energy because in that case, the reduction of the magnetostatic energy by splitting up into smaller domains is larger than the corresponding increase in wall energy. For Co/Pt multilayers both the effective magnetization and effective wall energy decrease for multilayers with

Fig. 1 Images of marks written with laser modulation at various fields on disks with an evaporated a) 13x(3.4 Å Co + 10.6 Å Pt) and b) 9x(4.1 Å Co + 19.0 Å Pt) multilayer.

thicker Pt, resulting in a similar behaviour for the two disks with respect to the writing field dependence. The 3.4/10.6 disk shows a better regularity of the mark edges than for the 4.1/19.0 disk. This was not reflected in the write noise of less than 1 dB for both disks, which is most likely due to the masking by the relatively high disk noise. Another noteworthy difference is the magnetic structure observed within the grooves; the grooves of the 3.4/10.6 disk were full of small domains while the grooves of the other disk are uniformly magnetized. This is due to an inadequate laser power (3.7 mW) used to erase the 3.4/10.6 disk. For this multilayer composition the Curie temperature is about 360° C and a relatively high laser power is required for erasure. About the same laser power used to erase the 4.1/19.0 disk gave a good erasure of the tracks. For both disks, erasure fields of 50-70 kA/m were used.

Erasure has been studied in more detail using a disk with an evaporated 4.3/9.5 multi-

Fig. 2 Images of erased tracks on a disk with an evaporated $13 \times (4.3 \text{ \AA} \text{ Co} + 9.5 \text{ \AA} \text{ Pt})$ multilayer, a) using various laser powers and fields, b) using laser powers that degrade the disk and thereafter erasure of the complete disk in a large field at room temperature, c) the same area as (b) showing the surface topography.

layer. Due to the higher Co content, the T_c for this disk is even higher than for the disk shown in Fig. 1a. Within the area shown in Fig. 2a, tracks were erased at various fields and laser powers. The application of a 36 kA/m field and laser powers of 3.8 and 4.5 mW gave tracks with the fewest domains. However, none of the tracks is completely erased. The tracks erased at 0 and 9 kA/m, which contain many small domains, had the lowest noise level. This is due to the small average size of these domains compared to the size of the laser spot, resulting in about 1 dB lower contribution to the noise level than the fewer but larger domains for the tracks erased at higher fields. However, writing domains in the tracks erased at low fields will result in a smaller modulation depth and thus lower carrier than for the tracks erased at higher fields. In another area, several tracks were erased at even higher

laser powers which gave rise to an observable deterioration of the signals in the recorder. Thereafter, the complete disk was erased, in a large field at room temperature outside the recorder. Figs. 2b and c show this area scanned with mainly magnetic and with mainly surface topography contrast respectively. It is clear that the structures on the tracks are mainly magnetic. The SMFM observation, that after room temperature erasure, areas with small domains were still present on the tracks that were thermomagnetically erased with too high laser power, indicates that the nucleation field within these areas became negative. Apparently, the degradation of the read-out signal when using too high laser powers is due to loss of the 100 % remanence in certain parts of the tracks. The other parts of the disk which were not

Fig. 3 Images of a disk with a Kr sputtered $10 \times (4.1 \text{ \AA} \text{ Co} + 14.7 \text{ \AA} \text{ Pt})$ multilayer a) marks written with 5.6 mW laser pulses at various fields and b) an erased track (er.) and crescents written with magnetic field modulation at various strengths in combination with a 3.7 mW pulsed laser and a small bias field.

erased with high laser powers, showed a uniform magnetization on the land and in the groove.

Figs. 3a,b show images of LM and Magnetic Field Modulation (MFM) written domains as well as an erased track on a disk with a Kr sputtered 4.1/14.7 multilayer. Before writing, the area was erased using 4.5 mW laser power and a field of about 50 kA/m. The LM written marks showed some subdomains when writing without an external field but these marks were nearly free of subdomains for applied fields as low as 9 kA/m. This was also reflected in the carrier level which increased by only 1 dB from 0 to 9 kA/m and became almost constant for fields from 9 to 36 kA/m. This is quite different from the disks with evaporated Co/Pt multilayers shown in Figs. 1a,b. A similar difference was observed for MFM writing in the evaporated and sputtered disks [7]. The crescents shown in Fig. 3b were written with 750 kHz MFM in combination with 110 ns pulsing of the laser at 4.5 MHz and the application of a small external bias field. The ascending edge of the laser pulse was coincident with the switching of the field to obtain a steeper temperature gradient before the field achieves its maximum absolute value. SMFM images (not shown here) revealed that the pulsing of the laser improved the regularity of the edges of the crescents, while the bias field reduced the asymmetry of the number of subdomains within the crescents corresponding to the two polarities of the writing field [7]. Although the effects of pulsing the laser as well as the application of a bias field could be clearly seen in the SMFM images, it had little influence on the CNR, probably because the disk noise is dominant. The 77 kA/m coercivity of the sputtered disk was lower than the coercivities of the evaporated disks shown in Figs. 1a and b with H_c of respectively 155 and 85 kA/m. This shows that a high coercivity is not essential for obtaining regularly shaped marks. We attribute the difference of the sputtered and evaporated disks to differences in microstructure of the Co/Pt multilayer film. From TEM cross-sections we know that the sputtered films are smoother than the evaporated ones [5]. In ref. 7 we discussed the dependence of domain formation on film microstructure with regard to the low wall stiffness and to the fact that for Co/Pt multilayers the coercivity becomes zero at about 50° below T_c .

CONCLUSIONS

SMFM is a very powerful and relatively

simple technique to obtain images of domains in Co/Pt multilayers. The key advantage over other techniques is that regular MO disks can be used. We noted that the small domains left after incomplete erasure and the irregularities of the written marks, as observed with SMFM, had only a small influence on the read-out signal. This information is however important for further optimization of the Co/Pt disks, because these effects will become important for disks with lower disk noise and for recording at higher frequencies and shorter wavelengths. Because of the high T_c of Co/Pt multilayers with Pt layers thinner than about 11 Å, one needs high erasure laser powers which can degrade the layer. On the other hand, for multilayers with Pt layers of about 19 Å or thicker the marks are less regular and the Kerr rotations are lower, leading to lower CNR's. Multilayers with a Pt layer thickness of 15 Å, especially the Kr sputtered ones, showed a very good erasure, writing and read-out performance for LM as well as MFM.

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