MAGNETIC FORCE MICROSCOPY ON THIN FILM MAGNETIC RECORDING MEDIA

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ABSTRACT. In order to understand the magnetic behaviour of thin film magnetic recording media high resolution magnetic observation techniques are very essential to see magnetic details smaller than 100 nm size. Magnetic Force Microscopy (MFM) is used for analysing thin magnetic films and multilayers as well as for investigation of written bits in high density recording media. Continuous attention is given to increase the performance of the used magnetic tips.

This presentation briefly shows the basic measurement principle used in our set-up. An overview will be given about the results obtained from magneto-optically recorded bits as well as bits on Co-Cr-Ta/Ni-Fe perpendicular hard disk media. In the latter small tracks of 200 kFRPI (kilo flux reversals per inch) will be shown. Furthermore we present domain structure observations on Co/Pd multilayer materials used for MO application. Domains of 70 nm size have been observed here.

1. Introduction

The continuously growing need of magnetic storage density in the past gave rise not only to new techniques and to new magnetic thin film materials but consequently also to increased micromagnetic characterisation requirements. Magnetic Force Microscopy [1, 2] has been demonstrated in the last few years to be one of the most promising methods to investigate domain structure and written bits in high density magnetic recording materials in the sub micron scale. A micro machined ferromagnetic tip mounted on a leaf spring (cantilever) is scanned above the surface of the sample of interest. By detecting the force (or force gradient) on the magnetic probe it is possible to image the magnetic stray field emanating from the sample.

2. Experimental

2.1 THE SET- UP

Interferometer The cantilever deflection is sensed by a Michleson type interferometer [3]. The light source is a laser diode with a collimating optics. The reference mirror of the interferometer can be moved by a piezo. The out coming light is focused on the back side of the cantilever in a $5\text{ }\mu\text{m}$ size spot.

Measurement principle The measurement principle used for the MFM images in this paper is called dynamic scan mode [3].

A change in force gradient acting on the tip in the stray field of the sample will change the effective spring constant of the cantilever and thus its resonance frequency. An amplifier always vibrates the cantilever on it's resonance frequency, so that changes in cantilever resonance frequency can be FM demodulated. Due to the feedback via the Z-piezo the resulting image is a surface of constant force gradient. An electric voltage is applied between tip and sample. This results in an additional force gradient and ensures that the overall gradient always keeps attractive so that a feedback loop can work.

dynamic MFM (force gradient)

Fig. 1: Set-up for dynamic MFM

2.2 MAGNETIC TIPS

The lateral resolution in Magnetic Force Microscopy [4] mostly depends on the dimensions, tip materials and consequently the magnetic behaviour of the used magnetic tip. In the dynamic mode tungsten wire cantilevers are used (fig. 2 and 3). The L-shaped cantilever is bend from $10\text{ }\mu\text{m}$ tungsten wire, the length of the long arm is 0.95 mm the

Fig. 2: Electron microscope photograph of a tungsten wire MFM cantilever.

Fig. 3: Magnification of the tip in fig. 2

short arm is about 100 μm long. On the end of the short arm the tip is etched electrochemically in KOH [3]. According to [5] a tungsten wire tip can be etched sharper when it points upwards in the etching bath so that the gas bubbles help to sharpen the tip. Due to the application of this reverse electrochemical etching tip radii of about 20 nm can be reached (fig. 3). After etching the tips are coated by a 40 nm thick layer of Co-Ni alloy. The tungsten wire cantilevers have a k_c of about 1 N/m, a resonance frequency of 5kHz and a Q-factor of about 100. In our set-up they are vibrated by capacitive excitation.

3. Results

In the following chapter we will give an overview over our MFM observations on thin film magnetic recording materials.

3.1 WRITTEN BIT OBSERVATIONS ON A CO-CR-TA LAYER

For conventional magnetic recording the fact of media noise due to domains inside the bits and irregular track boundaries has to be studied. Fig. 4 and 5 show a track of 200 kFRPI (127 nm bit length) on a Co-Cr-Ta hard disk with a Ni-Fe underlayer [6] written by a single pole head. The track width is about 900 nm. The recording layer has a magnetic anisotropy perpendicular to the film normal. The rough structure next to the bit track is caused by the remanent domains next to the track. Fig. 5 shows that this structure can influence the shape of the side border of the bit track especially for these narrow tracks. For higher bit densities this effect will increase the readback noise and form the limit for the maximum recording density on this material.

Fig. 4: Bit track 200 kFRPI (127 nm bit size) written in a Co-Cr-Ta perpendicular recording layer.

Fig. 5: Zoom into fig. 4

3.2 MAGNETO- OPTIC MULTILAYERS

We also applied Magnetic Force Microscopy on the natural domain structure of Co/X Multilayers. The superposition of the layer interface anisotropies of the layer stack [7] leads to a high perpendicular anisotropy in these samples. Process parameters during sputtering of the layers as background pressure and bias voltage can strongly influence the interface morphology which results in a strong correlation to magnetic parameters and also reflects in the domain structure.

Magneto-optic multilayers are very suitable samples for MFM observations. From TEM observations [8] it is known that these samples have a very flat surface so that the magnetic signal is not influenced by the topographical features. Domain sizes of down to 70 nm have been observed on Co/Pd multilayers (fig. 6). In order to compare different samples the samples have been AC demagnetised to get close to the equilibrium domain structure.

Fig. 6: Domains of 70 nm width on a Co/Pd multilayer

Co-Ni/Pt multilayers Due to differing process parameters we are able to modify the interlayer interface morphology of Co-Ni/Pd multilayers. This reflects in large differences

Fig. 7: Domain image of the higher coercivity Co-Ni/Pt multilayer sample

Fig. 8: Domain image of the lower coercivity Co-Ni/ Pt multilayer sample

in the magnetic behaviour. Figures 7 and 8 compare two samples having the same layer thicknesses but different magnetic properties due to their different interface morphology. The AC demagnetised domain structure of the two layers is completely different. The higher coercivity sample in fig. 7 has stripe domains of about 200 nm width, the lower coercivity sample in fig. 8 (note the different scale) shows much smaller dot like structures.

Bits on a MO disk. In the development of magneto- optic recording materials the question of the shape of the written domains is very interesting. Subdomains inside the bits as well as irregular domain wall shapes will result in noise during read-back of the signal. For this reason the shape of the written bits can be studied by MFM [9] which gives sufficient resolution to see these details. Fig. 9 shows that fine details can be seen on bits of about 800 nm diameter on a Co/Pd multilayer MO disk. This image is made in a constant a force gradient of about 0.002 N/m. Because of the demagnetisation inside the bit the stray field is strongest in the neighbourhood of the boundary of the bits. The bit domain wall shows slight undulations and there are no subdomains visible inside the bits.

Fig. 9: Bits on a Co/Pt multilayer MO disk

4. Summary

We have used Magnetic Force Microscopy for the investigation of various magnetic materials for magnetic storage applications. MFM proved to be a very efficient tool for the investigation of the structure of the materials in the submicron scale. Details of 50 nm size can be observed by this method. Since it is possible to observe the intrinsic domain structure as well as bit patterns written in the samples the micromagnetic behaviour of the samples can be related to the recording characteristics. From high density bit observation it becomes obvious that the minimum achievable bit size with respect to the S/N ratio is closely related to the intrinsic domain structure of the media.

Further research has to be done to improve the magnetic tips for high resolution.

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6. References

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