

MAGNETIC MULTILAYERED FILMS WITH REDUCED MAGNETOSTRICTION**Field of the Invention**

This invention relates to the magnetic materials used in recording heads for disk and tape drives and more specifically to the reduction of magnetostriction in these materials.

Background of the Invention

Recording heads are widely used in disk drives and tape drives for storage and retrieval of digital information. Recording heads usually have separate write and read elements. Soft magnetic material having a low coercivity and a high saturated magnetic moment is used for the poles of the write element and the shields for the read element. In a tape drive the tape is in frequent contact with the recording head. Therefore, wear resistance is an important additional consideration in a tape drive.

The shield layers and write head poles are in close proximity to the read sensor. Because of this proximity, it is important that the layers be magnetically stable. It is important for the performance of the drive that the soft magnetic material be relatively free of stress and magnetostriction because these effects can lead to magnetic instability. If the magnetic domains in the shields and poles move when subjected to extraneous fields such as fields from the write head or fields from the rotating magnetic disk (or more precisely, when the walls between different magnetic domains move, resulting in the growing or shrinking of domains), Barkhausen noise is generated and is sensed in the read element. This noise can seriously degrade the quality of the readback signal. Furthermore, when after movement the domains do not come back to their original position, the shield or pole exerts a field which is oriented differently on the sensor layer in the read element. This changes the magnetic bias on the read element leading to signal asymmetry and increased error rates. Finally, the magnetic permeability of the shields or pole layers can be reduced with this non-repeatable or hysteretic behavior of the domains and this also has a detrimental effect on the read element performance.

A common set of materials used in shields and poles are alloys of nickel and iron. For example Ni(80%)Fe(20%) has good magnetostriction but somewhat limited saturated moment (M_s @ 10kG). Increasing the Fe content increases the moment but leads to high magnetostriction. For example

Ni(45%)Fe(55%) has better moment (M_s @ 16kG) but a rather high magnetostriction of about 25×10^{-6} . Attempts have been made in the past to laminate materials using alternate layers of materials having positive and negative magnetostriction. These films tend to have high local stress at the interfaces between layers. Another approach to develop a material with improved magnetic stability has lead to the development of alternate layers of magnetic and non-magnetic layers. The addition of a significant amount of non-magnetic material results in a significantly reduced moment for the overall laminate.

A material is needed to construct recording heads which exhibits very low magnetostriction while not sacrificing the good magnetic properties of low coercivity and high magnetic moment.

DISCLOSURE OF THE INVENTION

In one embodiment of the present invention a material is provided to use in forming recording heads which has reduced magnetostriction and good magnetic properties. In another embodiment of the present invention disk drives and tape drives are provided having recording heads formed from a material having reduced magnetostriction and good magnetic properties. The reduced magnetostriction in a material according to one embodiment of the present invention provides a significant improvement in the performance of the recording heads.

In a preferred embodiment the material according to the present invention is a repeating sequence of three layers. One layer is made from an alloy of NiFe. Another layer comprises $FeX(N)$ where the (N) indicates a nitrogenated film and the additional element, X, is preferentially Ta but can be selected from a group of other elements. The third layer, disposed between the $FeX(N)$ and NiFe layers is tantalum. The sequence of three layers is repeated to obtain the required thickness for the final material.

The material has an intrinsically smaller value of magnetostriction and the magnetostriction is usually decreased with annealing resulting in simplified processing. The material also has improved magnetic moment compared with permalloy. Other aspects and advantages of the present invention will become apparent from the following detailed description, which when taken along with the drawings, illustrate by way of invention the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Fig. 1a shows a top view of a prior art disk drive;

5 Fig. 1b shows a cross section side view of a disk drive as taken from line 1b-1b in Fig. 1a;

Fig. 2 shows a detailed perspective view of a prior art recording head attached to a slider such as that shown in Figure 1a;

10 Fig. 3 shows a prior art tape drive used primarily for storage and retrieval of digital information;

Fig. 4 shows a prior art tape drive used primarily for storage and retrieval of audio and video information;

Fig. 5 shows a diagram of a write element such as one used in the disk drive of Figure 1a and the tape drives of Figures 3 and 4;

15 Fig. 6 shows a view of one embodiment of the present invention in a recording head used in a tape drive such as that of Figures 3 and 4;

Fig. 7 shows a view of one embodiment of the present invention in a recording head used in a disk drive such as that of Figure 1a;

20 Fig. 8 shows the basic sequence of laminated layers used in a recording head of the present invention;

Fig. 9a shows a repeating sequence of layers with Ni(86%)Fe(14%) (500Å)/Ta(35Å)/FeTa(N) (300Å) as the basic sequence of Figure 8;

25 Fig. 9b shows a repeating sequence of layers with Ni(86%)Fe(14%) (500Å)/FeTa(N) (300Å) as the basic sequence of Figure 8;

Fig. 9c shows a repeating sequence of layers with Ni(86%)Fe(14%) (400Å)/Ta(35Å)/FeTa(N) (400Å) as the basic sequence of Figure 8;

Fig. 9d shows a repeating sequence of layers with Ni(86%)Fe(14%)(500Å)/FeTa(N)(300Å) as the basic sequence of Figure 8;

Fig. 10 shows a table of results from the multilayered films shown in Figs. 9a, b, c, and d;

Fig. 11 shows a theta-2theta plot for films such as those shown in Figs. 9a, b, c and d with and without the intervening Ta layer.

DETAILED DESCRIPTION OF THE INVENTION

With reference to Figs. 1a and 1b, the present invention can be incorporated into a disk drive generally referred to as 100. The disk drive 100 includes at least one recording disk 102. The disk 102 is mounted on a spindle 104 which is connected to a motor 106. During the operation of the disk drive 100, the motor 106 spins the spindle 106 thereby rotating the disk 102. A slider 108 which has an attached recording head is connected to a suspension 110. The suspension 110 is attached to an arm 112. The arm 112 has a coil 114 mounted on a distal end from the suspension 110. During normal operation the actuator assembly which includes the slider 108, the suspension 110, the arm 112, and the coil 114 rotates about a pivot point 116 defined by the location of an actuator post 118.

A detailed view of the recording head mounted on the slider is shown in Fig. 2. The slider 200 has a surface 202 which is in close proximity to the recording disk. This surface 202 is commonly called the air bearing surface (ABS). The slider 200 also has a trailing surface 204 upon which a recording head 201 is constructed which will be described in detail below. The recording head 201 includes a read element 214 and a write element 500 (Fig. 5) which will be described in more detail with reference to Fig. 5. The view of the trailing surface 204 of the slider 200 shows metallic pads 206 for making connections to the recording head 201, coils 208 for energizing the write element, and an upper pole 210 of the write element 500. The view of the air bearing surface 202 usually shows a portion of the upper pole 210 of the write element 500, a portion of the lower pole 212 of the write element 500, a read sensor 214, and two shields 216 disposed around the read sensor 214. The write element 500 is comprised of the upper pole 210, the lower pole 212, and the coils 208.

Tape drives can be used for storage and retrieval of digital information and for recording and playback of audio or video information.

recording head 302. Typically there are several recording heads in a row and the head assembly has the capability of some limited lateral movement to compensate for shifts in tape position. In addition to a recording head 302 the tape drive 300 has a tape transport for advancing a tape 304 from a first reel 306 to a second reel 308. The reels 306, 308 (sometimes called spools) can be individual devices or they can be contained in a cassette housing. Typically the tape transport includes one or more rollers 310 to help position and move the tape 304 across the recording head 302.

Another style of tape drive 400, shown in Fig. 4, is commonly used for recording audio and video information. The tape drive in Fig. 4 typically has two or more recording heads 402 mounted in a rotating drum 404. The tape 406 is moved past the rotating drum 404. There are typically two reels 408, 410 which can be independent or contained in a cassette housing. Typically the tape transport includes one or more rollers 412 which help position and move the tape 406 across the recording heads 402 on the rotating drum 404.

With reference to Fig. 5, the basic features of the write element 500 of the recording heads for both disk drives and tape drives are described. The write element 500 is comprised of an upper pole element 502, a lower pole element 504, and a number of coils 506 disposed between the upper 502 and lower 504 poles. There is a gap 508 between the two poles 502, 504 near the recording medium commonly called the write gap. The poles 502, 504 are in magnetic contact at the distal end 510 of the poles from the write gap 508. Fig. 5 shows the upper pole 502 and the lower pole 504 as having a series of thin laminations 512 in accordance with the present invention. While the write element 500 is described with reference to the slider 200 in Fig. 2 it will be appreciated by those skilled in the art that a similar write element could be used with the tape head 302 in Fig. 3 or the tape head 402 in Fig. 4.

A tape head which incorporates the present invention is illustrated in Fig. 6. The view in Fig. 6 is the recording head 600 as it is presented to the moving tape. In the usual configuration several tape heads are mounted side by side along a row. The view in Fig. 6 is of a single recording head 600 in the row. Typically there would be a head to the left 616, the n-1 head, and a head to the right 618, the n+1 head. Each recording head comprises a write element and a read element. The write element comprises a lower pole 602 called P1 and an upper pole 604 called P2. The write gap 610 is the space between P1 602 and P2 604. The

read element comprises a sensor 612 which is disposed between a lower shield 606 and an upper shield 608. In the present invention either P1 602 or P2 604 or both P1 and P2 of the write element is formed from laminated material comprising NiFe/Ta/FeX(N). Also either the lower shield 606 or the upper shield 608 or both the lower and the upper shield can be formed from laminated material comprising NiFe/Ta/FeX(N). The direction of the tape movement across the recording head is shown 614.

Fig. 7 illustrates a head 700 according to an embodiment of the invention for use in a disk drive 100 (Figs. 1a, 1b). The recording head is constructed on a substrate 702 usually formed from a rigid ceramic material. The read element comprises a sensor 706 which is disposed between a lower shield 704 and an upper shield 708. The write element is comprised of a lower pole 710 called P1 and an upper pole 712 called P2. The write gap 714 is the space between P1 710 and P2 712. The constituents of the write head and read head are usually embedded in a matrix of insulating material 718 such as alumina. In the present invention either P1 710 or P2 712 or both P1 and P2 of the write element is formed from laminated material comprising NiFe/Ta/FeX(N). The direction of the disk movement relative to the recording head is shown 716.

Disclosed here and shown in Fig. 8 is a high moment iron rich layer 802 laminated with a NiFe alloy 804 where every other interface between the aforementioned layers has an intervening thin Ta layer 806. Due to the low thickness, the presence of the intervening Ta layer 806 does not result in a significant reduction of magnetic moment. In addition, the iron rich layer 802 is alloyed with a another element or combination of elements up to 10% by weight to improve the corrosion resistance of iron. The iron is also nitrogenated to improve wear resistance. The result is a laminated structure which has higher moment than Ni(80%)Fe(20%), good magnetostriction, and good corrosion resistance. Functionally, it is not important if the basic sequence is NiFe/Ta/FeX(N) or FeX(N)/Ta/NiFe.

The preferred embodiment for a laminated material which has excellent magnetostriction and has good magnetic properties is a repeating sequence of NiFe/Ta/FeX(N). The first sequence is labeled as 808 in Fig. 8. The second sequence is also shown 810. The sequences are repeated 812 until a final desired thickness is obtained.

The element X alloyed with iron in the FeX(N) layer is Ta in the preferred embodiment. However other elements or combination of elements

will also be suitable. A non-exhaustive list of other suitable elements includes Ru, Al, Cr, Nb, Ti, Zr, Mo, V, W, Hf, Ga, Ge, Si, B, Mg, Ca, Sr, Ba, Mn, and Zn. These elements generally improve the soft magnetic properties of pure iron and also generally improve corrosion resistance of iron. Substantially pure iron can also be used but is more susceptible to corrosion. The amount of X in the FeX(N) can range up to about 10% by weight. Nitrogenation is indicated by the N in parentheses. This means the films are intended to have nitrogen incorporated in the structure, but not to have any specific nitride phases present. The presence of nitride phases usually results in a decrease in the magnetization and the loss of soft magnetic properties, e.g. an undesirable increase in Hc and anisotropy field (Hk). Using the sputtering conditions listed below, the amount of nitrogen in the FeX(N) is typically between 5 to 7 atomic %.

This invention was reduced to practice by depositing experimental films using radio frequency diode sputtering. The constructed films are shown in Figs. 9a, b, c, and d. Other techniques are suitable including radio frequency magnetron sputtering, direct current diode and magnetron sputtering, or any combination of RF and DC sputtering, or ion beam deposition. A negative voltage bias was applied to the substrates during deposition. A small external magnetic field (≤ 70 Oe) was applied in the plane of the substrate during the deposition of the films of the present invention to provide uniaxial magnetic anisotropy. The field was supplied by the use of bar magnets embedded in the substrate holder or pallet and positioned close to the substrates. The field may be applied by other means such as a series of parallel wires behind the substrate.

In general the thickness of the Ta layer can range from very thin to about 10nm (100 Å). The thickness of the Ta layer 904 in the experimental films was 3.5nm (35Å). The thickness of the FeX(N) layer 906 and NiFe layer 902 can range from about 10-100nm (100 to 1000Å).

All the films described in Figs. 9a, b, c, and d are approximately 38μm (1.5 microns) thick. The targets used were FeTa(2 atomic% Ta), NiFe(Ni86%Fe14% and Ni93%Fe7%), and substantially pure Ta. The composition of the films made from the NiFe targets matched the composition of the targets. However the Ta content in the FeTa films was enriched somewhat compared to the target. The deposition rate for the FeTa(N) and NiFe layers was about 7nm/min (70 Å/min) and somewhat less for the Ta layer. The process pressure was about 2Pa (2×10^{-2} mbar). The argon flow was 60 standard cubic centimeters per second (sccm) for all layers. Nitrogen was introduced only during the deposition of the FeTa layer. The

flow was 60 standard cubic centimeters per second (sccm) for all layers. Nitrogen was introduced only during the deposition of the FeTa layer. The temperature of the pallet and wafer surface was between 85 and 90°C immediately after completion of the film. The annealing was done at 250°C for 6 hours in an external magnetic field under a rough vacuum. The field matched the orientation of the field used during film deposition. The magnetostriction was measured on silicon strips and the magnetic properties and stress values were measured on silicon wafers. Negative stress is compressive (film wants to expand off the substrate) and positive stress is tensile (film want to pull in on itself and the wafer becomes concave).

Figs. 9a, b, c, and d show the structures of the constructed laminated films for both the present invention and comparison films. Fig. 9a shows film #1 where the basic sequence of layers is 50 nm (500Å) of Ni(86%)Fe(14%) 902, 3.5nm (35Å) of Ta 904, and 30nm (300Å) of FeTa(N) 906. This basic sequence 908 of layers was repeated 19 times to obtain the desired final thickness of about 38nm (1.5 microns). Fig. 1b shows the sequence of layers for film #2 which is the same as film #1 except that the Ta layer 904 is missing. Film #2 was constructed to compare with film #1 and show the benefit of the Ta layer 904. The nitrogen flow during the FeTa layer 904 deposition was 3.0 sccm for films #1 and #2. Films #3 and #4, shown in Figs. 1c and d, are similar to films #1 and #2 except that the thickness of the FeTa layer 906 and NiFe layer 902 were 40nm (400Å) each. And the nitrogen flow during the FeTa layer deposition was 4.0 sccm.

The evaluation data for films #1, #2, #3, and #4 (shown in Figs. 9a, b, c, and d) is tabulated in Fig. 10. The saturated moment, M_s , for the finished films averaged about 13 kG. This is substantially higher than the value of about 10 kG for non-laminated Ni(80%)Fe(20%). Annealing generally decreases the magnetostriction of the as-deposited film for the laminations with interleaved Ta layers. Without the Ta layer 904, the magnetostriction generally increases with annealing. The stress in the final film has the opposite trend. However, stress is sensitive to deposition conditions and may vary somewhat. The low value of magnetostriction in the invented films #1 and #3 ($\leq |2 \times 10^{-6}|$) significantly reduces the burden of managing the film stress.

Corrosion measurements of single layers of FeTa(N) films and Fe(N) films of similar nitrogen content reveals the FeTa(N) films to have the

same or better corrosion resistance as the Fe(N) layers when subjected to a chlorine based corrosive environment.

Fig. 11 shows the theta-2theta x-ray diffraction scan on as-deposited laminate films with and without the 3.5nm (35Å) Ta layer 904 under the FeTa(N) layer 906. The specific films are Ni(93%)Fe(7%) (40nm (400Å))/Ta 3.5nm (35Å)/FeTa(N) (40nm (400Å)) (sequence repeated 19 times) and the counterpart film without the 3.5nm (35Å)Ta layer. Nitrogen flow during FeTa(N) deposition was 2.0 sccm. The (200) crystal structure is preferred in both the FeTa(N) and NiFe layers in the laminate film with the Ta layers at the expense of the NiFe(111), Fe(110), and NiFe(220) crystal structures. The higher peak intensities for the NiFe peaks over the Fe based peaks reveals a higher defect density or smaller grain size in the FeTa(N) layers. The presence of nitrogen in the interstitial sites in the FeTa film are the source of these crystalline defects and also results in small grains.

The Ta layer influences the crystal structure of both the FeTa(N) and the NiFe layers in the laminate films. The following mechanism may explain this influence. The magnetostriction in a single crystal Ni[100] is more negative than [110] or [111] Ni single crystals. The magnetostriction in a single crystal Fe[100] is more positive than in [110] or [111] Fe single crystals. If the influence on the magnetostriction of the entire laminate film is more predominantly dictated by the NiFe layers rather than the FeTa(N) layers, then the enhancement of the NiFe[200] crystal structure with the presence of the Ta layer would decrease the magnetostriction (increase it in a negative direction). However, usually the magnetostriction in a film comprised of magnetic materials with different magnetic moments would be dominated by the component with the highest magnetic moment. The NiFe layer has a magnetic moment that is lower than FeTa, but with the addition of nitrogen to the FeTa layer the magnetic moment is decreased as the magnetostriction is increased and the soft magnetic properties are enhanced. Also, the tantalum layer itself acts as a getter of nitrogen. Thus the magnetostriction in the laminate films with the tantalum layer would be less positive than in the laminate films with no tantalum layer even when the nitrogen content is similar for both.

CLAIMS

1. A laminated material for use in a magnetic recording head, comprising:
a repeating sequence of
a layer of NiFe (804, 902);
5 a layer of iron alloy (802), 906); and,
a layer of substantially pure Ta (806, 904) disposed between
said layer of NiFe and said layer of iron alloy.

2. A laminated material as claimed in claim 1 wherein said layer of iron alloy (802, 906) is nitrogenated.

10 3. A laminated material as claimed in claim 1 wherein said layer of iron alloy (802, 906) comprises at least 90% iron and the remainder comprises tantalum.

4. A laminated material as claimed in claim 1 wherein said layer of iron alloy (802, 906) comprises at least 90% iron and the substantial remainder
15 is chosen from Ru, Al, Cr, Nb, Ti, Zr, Mo, V, W, Hf, Ga, Ge, Si, B, Mg, Ca, Sr, Ba, Mn, and Zn.

5. A laminated material as claimed in claim 1 wherein:
said layer of NiFe (804, 902) comprises Ni in the range of from 80%
by weight to 93% by weight; and
20 said layer of iron alloy (802, 906) comprises a layer of FeTa(N).

6. A laminated material as claimed in claim 1 wherein:
said layer of NiFe (804, 902) has a thickness between 10nm and 100nm;
25 said layer of substantially pure Ta (806, 904) has a thickness up to 10nm; and,
said layer of iron alloy comprises a layer of FeTa (802, 906) having a thickness from 10nm to 100nm.

30 7. A recording head for use in a tape drive or a disk drive, comprising:
a write element including a coil and one or more pole elements disposed around the coil, said pole elements including a laminated material, as claimed in any one of claim 1 to claim 3.

35 8. A recording head for use in a tape drive or a disk drive, comprising:
a read element including a read sensor, a lower shield, and an upper shield, said read sensor being sandwiched between said lower and upper

shields, said lower and upper shields including a laminated material, as claimed in any of claim 1 to claim 3.

9. A tape drive, comprising:

5 a recording head, said recording head having a write element, said write element including at least one pole element, said pole element including a laminated material, said laminated material as claimed in any one of claim 1 to claim 3.

10 10. A disk drive, comprising:

 at least one disk;

 at least one slider with an attached recording head for recording on said disk, said recording head having a write element including a coil and an upper and lower pole element disposed about said coil, said pole
15 element including a laminated material as claimed in any one of claim 1 to claim 3.