

PERPENDICULAR MAGNETIC RECORDING MEDIUM AND A METHOD OF MANUFACTURING THE SAME

CROSS-REFERENCE TO RELATED APPLICATION

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This application is based on, and claims priority to, Japanese Application No. 2004-180355, filed on June 18, 2004, the contents of which are incorporated herein by reference.

10 BACKGROUND OF THE INVENTION

1. Field of the Invention

15 The present invention relates to a perpendicular magnetic recording medium mounted on various magnetic recording devices, and to a method of manufacturing such a medium.

2. Description of the Related Art

20 A perpendicular magnetic recording system is drawing attention as a technology to achieve high density recording in place of a conventional longitudinal magnetic system.

25 A perpendicular magnetic recording medium is mainly composed of a magnetic layer of a hard magnetic material, an underlayer for aligning the magnetic layer in an aimed direction, a protective layer

for protecting the surface of the magnetic layer, and a backing layer of a soft magnetic material for concentrating the magnetic flux generated by a magnetic head for recording on the magnetic layer. A structure without the soft magnetic backing layer can be taken since
5 the recording is possible by the structure, while the performance of the medium is higher in a structure having the backing layer. A medium without a soft magnetic backing layer is called a single layer perpendicular magnetic recording medium (also called simply a single layer perpendicular medium), and a medium with a soft magnetic
10 backing layer is called a double layer perpendicular magnetic recording medium (also called simply a double layer perpendicular medium).

A perpendicular magnetic recording medium, like a longitudinal
15 magnetic recording medium, must have compatibility between high thermal stability and low noises to achieve high recording density. Research and development on a magnetic layer of a perpendicular magnetic recording medium are extensively being made now using CoCr alloy crystalline materials that are used in a magnetic layer of a
20 longitudinal magnetic recording medium. It is also important in a perpendicular magnetic recording medium to increase the crystalline magnetic anisotropy constant K_u for improving thermal stability and to suppress magnetic interaction between grains as well as minimization of the grain size in the magnetic layer for noise
25 reduction. Therefore, the researches have been made on the composition of the magnetic layer and on the underlayer disposed

beneath the magnetic layer.

Among them, a magnetic layer generally called a granular type magnetic layer is drawing attention as a magnetic layer suited to high density recording and is a subject of intensive researches. In the granular type magnetic layer, each of the ferromagnetic crystal grains is surrounded by nonmagnetic nonmetallic substance of oxide or nitride. Because the nonmagnetic nonmetallic grain boundary physically separates the ferromagnetic crystal grains and reduces magnetic interaction between the ferromagnetic crystal grains, formation of the zigzag magnetic domain wall occurring in the transition region of recording bits is suppressed. Therefore, low noise characteristics are considered to be achieved.

To obtain a perpendicular magnetic recording medium exhibiting favorable read/write performance using a granular type magnetic layer, some proposals have been made including: control of the grain size in a nonmagnetic underlayer (see for example, Japanese Unexamined Patent Application Publication No. 2003-162811), control of the lattice constants of ferromagnetic crystal grains and crystals in a nonmagnetic underlayer (see for example, Japanese Unexamined Patent Application Publication No. 2003-203330), and control of the thickness of a nonmagnetic underlayer (see for example, Japanese Unexamined Patent Application Publication No. 2003-77122). All these proposals pay attention to the ferromagnetic crystal grains composing the granular type magnetic layer and aim at

favorable epitaxial growth of the ferromagnetic crystal grains on a nonmagnetic underlayer.

On the other hand, to achieve excellent read/write performance
5 with the granular type magnetic layer, the ferromagnetic crystal grains and the nonmagnetic grain boundary must be appropriately separated. In addition, fine particles and enlarged particles must be suppressed to reduce noises. Conventional techniques are methods that depend upon spontaneous isolation utilizing the property that
10 the material composing the grain boundary hardly makes solid solution with the ferromagnetic crystal grains, and basically expects spontaneous separation between them. Thus, we can hardly say that sufficiently studies are made on the method that actively promotes the separation between the ferromagnetic crystal grains and the
15 material composing the ferromagnetic grain boundary.

In a double layer perpendicular medium, the nearer the distance between the magnetic layer and the soft magnetic backing layer, the better the read/write performance. Consequently, the nonmagnetic
20 underlayer is desired as thin as possible. Nevertheless, conventional media tend to perform better with thicker nonmagnetic underlayer. Thus, there is a problem to achieve reduction of the film thickness of the nonmagnetic underlayer.

SUMMARY OF THE INVENTION

In view of the above problems, an object of the present invention is to provide a perpendicular magnetic recording medium exhibiting excellent read/write performance and a method of manufacturing such a media by promoting separation between the ferromagnetic crystal grains and the nonmagnetic grain boundary that compose the granular type magnetic layer. The invention provides a perpendicular magnetic recording medium exhibiting excellent read/write performance and a manufacturing method by reducing a film thickness of the nonmagnetic underlayer, as well.

The inventors of the present invention have made intensive studies and found that the performances of a perpendicular magnetic recording medium employing a granular type magnetic layer improve by enhancing surface energy of a nonmagnetic underlayer. The invention has been accomplished based on the finding.

A perpendicular magnetic recording medium of the invention comprises a nonmagnetic substrate, a nonmagnetic underlayer, and a magnetic layer disposed directly on the nonmagnetic underlayer. The magnetic layer comprises ferromagnetic crystal grains having a hexagonal close-packed structure and nonmagnetic grains boundaries surrounding each of the ferromagnetic crystal grain and substantially composed of oxide or nitride. The nonmagnetic underlayer exhibits surface energy of at least 70 mN/m (milli-Newton per meter).

Advantageously, the nonmagnetic underlayer is composed of a metal selected from rhenium, ruthenium, and osmium, or an alloy containing at least an element selected from rhenium, ruthenium, and osmium. The thickness of the nonmagnetic underlayer is
5 preferably at most 30 nm.

A method of the invention for manufacturing a perpendicular magnetic recording medium comprises a first step of depositing the nonmagnetic underlayer to exhibit surface energy of at least 70
10 mN/m, and a second step of depositing the magnetic layer directly on the nonmagnetic underlayer by means of an RF sputtering method using a sputtering target of a ferromagnetic material containing oxide or nitride.

15 Advantageously, the method for manufacture of a perpendicular magnetic recording medium omits a substrate heating step.

Advantageously, the method of manufacture with the omission
20 of the substrate heating step further allows the use of a nonmagnetic base plate of a resin material such as polycarbonate or polyolefin, reducing manufacturing costs owing to the simplified manufacturing process.

25 A perpendicular magnetic recording medium having a construction as described above promotes separation between

ferromagnetic crystal grains and nonmagnetic grain boundary that
compose a granular type magnetic layer, and suppress fine
ferromagnetic crystal grains and enlarged ferromagnetic crystal
grains. Thus, excellent read/write performance is achieved with high
5 coercivity (H_c) and low noises. At the same time, reduction of the
film thickness of the nonmagnetic underlayer can be achieved.

BRIEF DESCRIPTION OF THE DRAWINGS

10 Fig. 1 is a schematic cross-sectional view of a structure of a
perpendicular magnetic recording medium of an embodiment
according to the invention;

Fig. 2 illustrates a relation between the surface energy of a
15 nonmagnetic underlayer and coercivity (H_c) of a perpendicular
magnetic recording medium; and

Fig. 3 illustrates a relation between the surface energy of a
nonmagnetic underlayer and signal-to-noise ratio (SNR) of a
20 perpendicular magnetic recording medium.

DETAILED DESCRIPTION OF THE INVENTION

Some preferred embodiments of the invention will be described in
25 the following with reference to the accompanying drawings.

Fig. 1 is a schematic cross-sectional view of an example of structure of a perpendicular magnetic recording medium according to the invention. The medium is constructed by sequentially laminating a soft magnetic backing layer 2, an alignment control layer 3, a nonmagnetic underlayer 4, a granular type magnetic layer 5, and a protective layer 6 on a nonmagnetic substrate 1. A lubricant layer 7 is formed on the protective layer 6.

The nonmagnetic substrate 1 can be composed of an aluminum alloy with NiP plating, strengthened glass, or crystallized glass, which is used in a common magnetic recording medium. The substrate can also be manufactured by injection molding a plastic resin such as polycarbonate, polyolefin, or the like.

The soft magnetic backing layer 2 is preferably formed to improve read/write performance by controlling the magnetic flux generated by the magnetic head used for magnetic recording, although the soft magnetic backing layer may be omitted. The soft magnetic backing layer can be composed of crystalline alloys of NiFe alloy, Sendust alloy (FeSiAl), or a CoFe alloy, or micro crystalline substances of FeTaC, CoTaZr, CoFeNi, or CoNiP. Superior read/write performance can be attained using an amorphous cobalt alloy for example, CoZrNb or CoZrTa. The optimum thickness of the soft magnetic backing layer 2 changes depending on the structure and characteristics of the magnetic head for magnetic recording. The soft magnetic backing layer that is formed by successive deposition

with other layers has preferably a thickness in the range of 10 nm to 500 nm in consideration of productivity. In the case where the backing layer is formed by a plating method on the nonmagnetic base plate before depositing other layers, the thickness can be increased to
5 several μm .

The alignment control layer 3 is preferably formed beneath the nonmagnetic underlayer 4 to improve alignment in the nonmagnetic underlayer. The alignment control layer may be omitted. The
10 alignment control layer can be composed of a nonmagnetic material or a soft magnetic material.

In the case of a nonmagnetic material, Ta, Zr, or Nb having a thickness of 3 to 20 nm is preferably used to ensure crystal matching
15 and control of the crystal grain size.

In the case a soft magnetic backing layer 2 is formed under the alignment control layer 3, the alignment control layer can be composed of a soft magnetic material that functions as a part of a soft
20 magnetic backing layer. A material of the alignment control layer 3 that exhibits the soft magnetic property can be selected from a nickel-base alloy such as NiFe, NiFeNb, NiFeB, or NiFeCr, and cobalt and cobalt-base alloy such as CoB, CoSi, CoNi, and CoFe. A plurality of layers can be formed to separate functions of securing the crystal
25 matching and controlling the crystal grain size.

The nonmagnetic underlayer 4 is provided to appropriately separate the ferromagnetic crystal grains and the nonmagnetic grain boundaries that comprise the granular type magnetic layer 5 formed directly on the underlayer and, at the same time, to suppress occurrence of fine ferromagnetic crystal grains and enlarged ferromagnetic grains.

As described previously, control of the nonmagnetic underlayer is important for improving performances of a perpendicular magnetic recording medium employing a granular type magnetic layer. The performances of a perpendicular magnetic recording medium substantially changes depending on the conditions of the uppermost surface (the interface with the magnetic layer) of the nonmagnetic underlayer, in particular. The surface energy needs to be at least 70 mN/m, for appropriately separating the ferromagnetic crystal grains and the nonmagnetic grain boundaries that comprise the granular type magnetic layer 5. For improving the signal-to-noise ratio (SNR), the surface energy is preferably at least 78 mN/m. For suppressing occurrence of fine ferromagnetic crystal grains and enlarged ferromagnetic grains and obtaining uniform ferromagnetic crystal grains, the surface energy preferably has isotropy in the plane of the magnetic recording medium, that is, the surface energy favorably does not have anisotropy. The nonmagnetic underlayer is preferably formed with approximately uniform thickness and with even surface.

A preferable material for composing the nonmagnetic underlayer

can be selected from metals and alloys having a hexagonal close-packed crystal structure. Among the materials, a metal of rhenium, ruthenium, or osmium, or an alloy containing at least one of rhenium, ruthenium, and osmium is particularly favorable for controlling the
5 alignment of the granular type magnetic layer.

The thickness of the nonmagnetic underlayer can be reduced by controlling the surface energy of the nonmagnetic underlayer. A thickness of the nonmagnetic underlayer can be selected at 30 nm or
10 less in a double layer perpendicular magnetic recording medium, which needs small distance between the magnetic layer and the soft magnetic backing layer. Thin film thickness of a nonmagnetic underlayer also produces a favorable effect from the viewpoint of manufacturing costs. For achieving desirable growth of the film of
15 nonmagnetic underlayer, the thickness of at least 5 nm is preferable.

The surface energy of the nonmagnetic underlayer is controlled by the deposition conditions of the nonmagnetic underlayer, or a type and quantity of the additives to the metal or alloy of rhenium,
20 ruthenium, or osmium. The control by deposition conditions in sputtering, for example, can be carried out through variation of the discharge power in sputtering (hereinafter called a deposition power), or the distance between the sputtering target and the nonmagnetic substrate (hereinafter called a T-S distance). Details will be
25 described later. The control through the additives to a metal or an alloy of rhenium, ruthenium, or osmium is carried out by addition of

oxygen, aluminum, tungsten, niobium or the like.

The granular type magnetic layer 5 performs magnetic recording and consists of crystal grains with ferromagnetic property and nonmagnetic grain boundaries surrounding each of the crystal grains. The grain boundary is substantially composed of an oxide or a nitride. Such a structure can be produced by deposition by sputtering using a target of a ferromagnetic alloy containing the oxide or nitride that composes the nonmagnetic grain boundary, or by deposition by reactive sputtering in argon gas containing oxygen or nitrogen using a target of a ferromagnetic alloy. A CoPt alloy is a favorable material for the material composing the ferromagnetic crystal grain, though not limited to the alloy. A CoPt alloy containing at least an element selected from Cr, Ni, and Ta in particular is preferable for reduction of media noise. A favorable material composing the nonmagnetic grain boundary, on the other hand, can be selected from oxides and nitrides of at least one element of Cr, Co, Si, Al, Ti, Ta, Hf, and Zr. Such a material is preferable for forming a stable granular structure. Though the nonmagnetic grain boundary is desired to be composed of an oxide or a nitride only, containment of an element that composes the ferromagnetic crystal grain is permitted as long as the composition is within the range performing nonmagnetic property. The thickness of the magnetic layer is in the range to attain sufficiently large head readback output and high read/write resolution on read/write operation, though not limited to a specific range.

The granular type magnetic layer is not limited to a single layer structure, but can be a multilayer structure. A multilayer structure can be constructed by varying the material of the ferromagnetic crystal grains, or varying the ratio between the ferromagnetic crystal grains and the nonmagnetic grain boundaries through variation of the proportion of the additive of oxide or nitride. The multilayer structure allows appropriate adjustment of the balance between the signal-to-noise ratio and the other characteristics.

The protective layer 6 is a thin film mainly composed of carbon, for example. The lubricant layer 7 can be composed of a liquid lubricant of perfluoropolyether, for example. The conditions such as the thickness of the protective layer and the conditions such as the thickness of the lubricant layer can be same as the conditions employed in common magnetic media.

A magnetic recording medium having the layer structure described above, when manufactured omitting a substrate heating step that is carried out in the manufacturing process of conventional magnetic recording media, still exhibits excellent perpendicular magnetic recording performance. Therefore, manufacturing costs are reduced owing to the simplified manufacturing process. The omission of the substrate heating further allows the use of a nonmagnetic base plate of a resin material such as polycarbonate or polyolefin.

An antiferromagnetic film may be provided between the nonmagnetic substrate 1 and a soft magnetic backing layer 2.

Some specific examples of perpendicular magnetic recording media according to the invention will be described in the following. The examples are merely representative examples for appropriately illustrating a perpendicular magnetic recording medium of the invention, and the invention shall not be limited to the examples.

10 Example 1

Perpendicular magnetic recording media were manufactured having a structure shown in Fig. 1 in Example 1. The surface energy was controlled by changing the deposition power in the process of forming the nonmagnetic substrate 4. The deposition power was varied in a wide range for comparison. The nonmagnetic substrate 1 used was a chemically strengthened glass substrate having a smooth surface and a diameter of 2.5 inches (N5 glass substrate manufactured by HOYA Corporation). After cleaning, the substrate was introduced into a sputtering apparatus. A soft magnetic backing layer 2 of CoZrNb having a thickness of 250 nm and subsequently an alignment control layer 3 of tantalum having a thickness of 5 nm were deposited by a DC sputtering method. Then, a nonmagnetic underlayer 4 of ruthenium having a thickness of 20 nm was deposited by a DC sputtering method with a T-S distance of 40 mm. The nonmagnetic underlayer was deposited in the conditions of various

deposition powers. Subsequently, a granular type magnetic layer 5 having a thickness of 15 nm was deposited by an RF sputtering method using a $\text{Co}_{77}\text{Cr}_{10}\text{Pt}_{13}$ target (the subscripts indicate atomic percent) with an addition of 13 mol% SiO_2 . Subsequently, a

5 protective layer 6 of carbon having a thickness of 5 nm was deposited by a DC sputtering method. After that, the substrate having the layers deposited was taken out from the vacuum chamber. Then, a lubricant layer 7 having a thickness of 1.5 nm was formed by applying perfluoropolyether. Here, the heating of the substrate was
10 not conducted prior to the deposition processes.

The surface energy of a nonmagnetic substrate was determined using the Fowkes' formula from a contact angle that was measured by a drop method. The contact angle measurement was conducted
15 using three types of liquid: pure water, α -bromonaphthalene, and methane diiodide, with a drop diameter of about 1 mm. The measurement of the contact angle was conducted on the sample having the deposited layers up to the nonmagnetic underlayer after two hour from the time of taking out to the atmospheric air.

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The magnetic properties and the read/write performance were measured on the thus fabricated perpendicular magnetic recording medium. The coercivity H_c as a magnetic property was determined from a magnetization curve of the obtained perpendicular magnetic
25 recording medium measured with a vibrating sample magnetometer. The SNR and other read/write characteristics were measured using a

spinning stand tester equipped with a GMR head at a linear recording density of 440 kFCI (kilo flux change per inch).

Table 1 shows the deposition power during deposition of the nonmagnetic underlayer, the thickness of the nonmagnetic underlayer, the T-S distance, the surface energy (γ) of the nonmagnetic underlayer, Hc and SNR of the perpendicular magnetic recording medium. The surface energy changes depending on the deposition power; the surface energy increases with decrease of the deposition power. The increase of the surface energy promotes the separation between the ferromagnetic crystal grains and the nonmagnetic grain boundaries that compose the granular type magnetic layer. As a result, the Hc increases and the SNR improve. A deposition power not larger than 660 W results in a surface energy of at least 70 mN/m and a high Hc value of at least 3.5 kOe.

Table 1

sample	deposition power (W)	Thickness of nonmagnetic underlayer (nm)	T-S distance (mm)	γ (mN/m)	Hc (kOe)	SNR (dB)
1	220	20	40	73.32	3.865	14.92
2	440	20	40	71.26	3.676	14.67
3	660	20	40	70.43	3.578	14.67
4	880	20	40	69.44	3.400	14.32

Example 2

In this example 2, the thickness of nonmagnetic underlayer 4

was varied. Perpendicular magnetic recording media were manufactured in the same manner as in Example 1 except that the deposition power was fixed at 220 W or 440 W and the thickness of the nonmagnetic underlayer was varied. Tables 2 and 3 show the results of measurement similar to the Example 1. Table 2 shows the results for the deposition power of 440 W, and the Table 3 shows the results for the deposition power of 220 W. With increase of the thickness of the nonmagnetic underlayer, the surface energy increases, improving the Hc and the SNR.

Table 2

sample	deposition power (W)	thickness of nonmagnetic underlayer (nm)	T-S distance (mm)	γ (mN/m)	Hc (kOe)	SNR (dB)
11	440	10	40	64.78	3.215	13.92
12	440	20	40	71.26	3.676	14.67
13	440	30	40	79.47	4.277	15.22
14	440	50	40	79.45	4.303	15.31

Table 3

sample	deposition power (W)	thickness of nonmagnetic underlayer (nm)	T-S distance (mm)	γ (mN/m)	Hc (kOe)	SNR (dB)
21	220	20	40	73.32	3.865	14.92
22	220	25	40	77.44	4.221	14.75
23	220	30	40	81.33	4.401	15.57
24	220	40	40	81.23	4.447	15.56

Example 3

In this Example 3, the T-S distance in the deposition process of the nonmagnetic underlayer 4 was varied. Perpendicular magnetic recording media were manufactured in the same manner as in Example 1 except that the deposition power was fixed at 440 W, the thickness of the nonmagnetic underlayer was 10 nm, and the T-S distance was varied.

Table 4 shows the results of the measurement similar to Example 1. With increase of the T-S distance, the surface energy increases, enhancing the Hc and the SNR. Even with a nonmagnetic underlayer having a small thickness of 10 nm, satisfactory magnetic property and read/write performance have been achieved by increasing the surface energy by controlling the T-S distance.

Table 4

sample	deposition power (W)	thickness of nonmagnetic underlayer (nm)	T-S distance (mm)	γ (mN/m)	Hc (kOe)	SNR (dB)
31	440	10	40	64.78	3.215	13.92
32	440	10	80	78.83	4.333	15.02

Evaluation of the relation between the surface energy and the magnetic property, and the relation between the surface energy and the read/write performance was made using the data on the perpendicular magnetic recording media of Examples 1 through 3.

Fig. 3 shows the relation between the surface energy and the coercivity (H_c). Fig. 2 shows the relation between the surface energy and the SNR. Regardless of the deposition conditions of the nonmagnetic underlayer, a surface energy of the nonmagnetic underlayer of at least 70 mN/m achieves a favorable property of H_c at least 3.5 kOe. A surface energy of the nonmagnetic underlayer larger than 78 mN/m results in a favorable characteristic of SNR larger than 15 dB.

A small thickness of the nonmagnetic underlayer generally tends to cause deterioration of the magnetic property and the read/write performance. Nevertheless, even a thin nonmagnetic underlayer can achieve high H_c and high SNR by increasing the surface energy to a value at least 70 mN/m by decreasing the deposition power in the sputtering process or elongating the T-S distance. The surface energy can also be controlled by controlling the gas pressure during depositing the nonmagnetic underlayer or controlling the additives to the nonmagnetic underlayer as well as controlling the deposition power and the T-S distance.

CLAIMS

What is claimed is:

- 5 1. A perpendicular magnetic recording medium comprising:
a nonmagnetic substrate;
a nonmagnetic underlayer exhibiting surface energy of at least
70 mN/m; and
a magnetic layer that is disposed directly on the nonmagnetic
10 underlayer and comprises ferromagnetic crystal grains having a
hexagonal close-packed structure and nonmagnetic grain boundaries
surrounding each of the ferromagnetic crystal grains and
substantially composed of oxide or nitride.
- 15 2. The perpendicular magnetic recording medium according to
claim 1, wherein the nonmagnetic underlayer is composed of a metal
selected from rhenium, ruthenium, and osmium, or an alloy
containing at least an element selected from rhenium, ruthenium,
and osmium.
- 20 3. The perpendicular magnetic recording medium according to
claim 1 or claim 2, wherein the nonmagnetic underlayer has a
thickness of at most 30 nm.
- 25 4. A method of manufacturing a perpendicular magnetic
recording medium having a nonmagnetic substrate, a nonmagnetic

underlayer, and a magnetic layer, the method comprising:

a first step of depositing the nonmagnetic underlayer by means of a DC sputtering method to exhibit surface energy of at least 70 mN/m; and

5 a second step of depositing the magnetic layer directly on the nonmagnetic underlayer by means of an RF sputtering method using a sputtering target of a ferromagnetic material containing oxide or nitride.

10 5. A method of manufacturing a perpendicular magnetic recording medium as claimed in Claim 4, the method of manufacture omitting a substrate heating step.

6. A method of manufacturing a perpendicular magnetic
15 recording medium as claimed in Claim 5 wherein the omission of the substrate heating step further allows the use of a nonmagnetic base plate of a resin material such as polycarbonate or polyolefin.