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Perpendicular Magnetic Recording Medium And A Method For Manufacturing The Same

Technical field of the invention

5 The present invention relates to a magnetic recording medium mounted on a magnetic recording device such as an external memory device of a computer, and to a method for manufacturing such a medium.

10 Background of the invention

As a technique to attain high density magnetic recording, a perpendicular magnetic recording system is drawing attention as an alternative to a conventional longitudinal magnetic recording system.

15 A crystalline film of CoCr alloy system is now mainly studied as a material for a magnetic recording layer of a perpendicular magnetic recording medium. In order to use in perpendicular magnetic recording, the crystal orientation is controlled such that c-axis of the CoCr alloy system having hcp structure aligns perpendicular to the
20 film surface, that is, c-plane is parallel to the film surface. In order to achieve higher density in the CoCr alloy system, attempts are being made for finer grain size, reduction of dispersion of grain size distribution, and decrease in magnetic interaction between grains.



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A conventionally used metallic magnetic film of CoCr system is deposited on a substrate at a high temperature. Grain boundary phase is formed by segregation of chromium from magnetic grains of cobalt system. The grain boundary phase reduces magnetic
5 interaction between magnetic grains. When this method is employed, the substrate for deposition is necessary to be heated to a temperature at least 200°C.

As a method for controlling structure of a longitudinal magnetic
10 recording medium directing towards high density recording, Japanese Unexamined Patent Application Publication No. H8-255342 and United States Patent No. 5,679,473, for example, disclose a magnetic recording layer having structure commonly called a granular magnetic recording layer in which each of magnetic grains are
15 surrounded by nonmagnetic and nonmetallic substance such as oxide or nitride. Because the nonmagnetic and nonmetallic grain boundary phase physically separates the magnetic grain in such a granular magnetic film, magnetic interaction between the magnetic grains decreases, which in turn, suppresses formation of zigzag-shaped
20 magnetic domain wall that would be formed in a transition region of a recording bit. Thus, low noise can be achieved. It is known in such a granular magnetic recording layer that the interaction between magnetic grains can be reduced even if substrate heating is not executed. This is because the nonmagnetic and nonmetallic

substance used for the grain boundary phase segregates easier than conventionally used chromium and generates segregation without heating.

5 The granular magnetic recording layer has been proposed to use for a recording layer of a perpendicular magnetic recording medium combining above-described technique. IEEE Trans. Mag., Vol. 36, p2393 (2000), for example, discloses a perpendicular recording medium that comprises an underlayer of ruthenium metal and a
10 magnetic recording layer of CoPtCrO alloy having granular structure. C-axis alignment enhances with increase of thickness of the ruthenium layer that is an underlayer for the granular magnetic recording layer. The thickness of the ruthenium underlayer needs to be about 40 nm or more to obtain satisfactory magnetic
15 characteristics and electromagnetic conversion performance in the granular perpendicular magnetic recording medium. However, since ruthenium is a rare metal element and expensive, the thickness of the ruthenium underlayer is required to be thin from the viewpoint of production cost reduction.

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A so-called double layer perpendicular magnetic recording medium has been proposed that comprises a soft magnetic backing layer under a magnetic recording layer to enhance sharpness of magnetic field generated at a head region. In order to enhance

recording density of a magnetic recording medium having this structure, the thickness of the nonmagnetic layer disposed between the magnetic recording layer and the soft magnetic backing layer is considered indispensably to be at most 20 nm. Consequently, the
5 above-described structure of thick ruthenium underlayer poses technological restriction in the production of a double layer perpendicular magnetic recording medium.

Problem to be solved by the invention

10 To attain higher recording density, more reduction of noises is indispensable. One of the factors that deteriorate performance of a perpendicular recording medium is increase in dispersion of orientation distribution in the magnetic recording layer. The axis of easy magnetization of the magnetic recording layer in a
15 perpendicular recording medium needs to be aligned perpendicular to the surface of the medium. If the dispersion of orientation distribution of the axis of easy magnetization is large, output signal decreases due to decrease of perpendicular component of the magnetic flux. In addition, transition loses sharpness and noises increase.
20 Therefore, the dispersion of orientation distribution in the magnetic recording layer needs to be reduced as small as possible in order to achieve high output and low noise in a perpendicular magnetic recording medium.

In addition to reduction of the dispersion of orientation distribution, decrease of initial growth layer is also required of a magnetic recording layer for improvement of performance of a perpendicular recording medium. A magnetic recording layer of a conventional perpendicular magnetic recording medium includes an initial growth layer having in-plane component of magnetization and being several nm thick. The initial growth layer is a source of noises. This is considered to be caused by inferior alignment of the underlayer of titanium alloy used in a conventional perpendicular magnetic recording medium or interdiffusion between the underlayer and the magnetic recording layer. From the view point of recording, a thin magnetic recording layer is favorable. However, if an initial growth layer exists and the film thickness is decreased, relative proportion occupied by the initial growth layer increases and S/N ratio (SNR) decreases. That is, the initial growth layer inhibits reducing film thickness of a magnetic recording layer.

In addition to the above, noise reduction of a magnetic recording medium requires decrease of a grain size of the magnetic recording layer. When the grain size of the magnetic recording layer increases, a bit transition region becomes zigzag shaped and transition noises increase. Accordingly, reduction of the transition noises needs the grain size to be decreased and the bit transition region to be strait line shape.

According to the above, requirements for achieving performance improvement of a perpendicular magnetic recording medium includes: decrease of the dispersion of orientation distribution in the magnetic recording layer, reduction of initial growth layer in the magnetic recording layer, and minimization of the grain size of the magnetic recording layer.

Therefore, the problem to be solved by the present invention is to achieve improvement in media performance including output enhancement and noise reduction by means of (1) improvement of alignment in the magnetic recording layer, (2) reduction of initial growth layer in the magnetic recording layer, and (3) minimization of the grain size in the magnetic recording layer.

Means to solve the problem

The underlayer plays an important role to decrease the dispersion of orientation distribution in the magnetic recording layer and to minimize the thickness of the initial growth layer as close to zero as possible. The reasons are: (a) alignment in the magnetic recording layer is improved by selecting a well-aligned underlayer; and (b) matching of the lattice constants between the underlayer and the magnetic recording layer improves epitaxial growth at the interface between the underlayer and the magnetic recording layer,

which in turn reduces initial growth layer in the magnetic recording layer. It is well known that the grain size of a magnetic recording layer that is epitaxially grown on an underlayer follows the grain size of the underlayer. Therefore, (c) reduction of the grain size in the
5 underlayer is essential for reduction of the grain size of the magnetic recording layer.

The inventors of the present invention have found that further noise reduction can be achieved by using a ruthenium base alloy for a
10 nonmagnetic underlayer and employing for a magnetic recording layer a granular film that allows minimization of the grain size of the magnetic recording layer without difficulty. An excellent perpendicular magnetic recording medium is obtained by this construction of layers.

15 When a granular film is used for a magnetic recording layer, substrate heating is unnecessary for isolating magnetic grains in that layer. As a result, the production process is simplified and the production cost is reduced. Further, inexpensive plastics can be used
20 for a substrate in addition to the conventional aluminum substrate and glass substrate.

Brief description of drawings

Figure 1 is a schematic cross-sectional view of a perpendicular

magnetic recording medium according to the present invention.

Figure 2 is a graph showing dependence of coercive force H_c on the thickness of the magnetic recording layer in Example 1 and Comparative Example 1.

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Aspects of embodiments of the invention

Some preferred embodiments of the present invention will be described below. Figure 1 is a schematic cross sectional view of a perpendicular magnetic recording medium according to the present invention. The perpendicular magnetic recording medium has a structure comprising a nonmagnetic substrate 1, and a nonmagnetic alignment control layer 2, a seed layer 3, a nonmagnetic underlayer 4, a magnetic recording layer 5, and a protective layer 6 that are sequentially formed on the substrate 1. On the top of the laminated substrate, a liquid lubrication layer 7 is formed.

The nonmagnetic substrate 1 may be made of NiP-plated aluminum alloy, strengthened glass, or crystallized glass, which are all used in a usual magnetic recording medium. Because a manufacturing method of the invention does not need substrate heating, a substrate can be employed that is made by injection-molding plastic resin such as polycarbonate or polyolefin. This plastic resin substrate is inexpensive and has the advantage that a texturing

process can be easily conducted.

The nonmagnetic alignment control layer 2 is now described.
The nonmagnetic alignment control layer must be composed of a
5 metal or an alloy that has a body centered cubic (bcc) lattice structure
or an amorphous structure. By providing the alignment control layer,
the tendency to align in (111) plane of the fcc structure in the seed
layer formed on this layer can be more enhanced. Thus,
characteristics of the magnetic recording layer are improved through
10 promoting the alignment of the nonmagnetic underlayer. This effect
is most significant when the material having bcc structure is a
nonmagnetic metal selected from Nb, Mo, Ta, and W, or a
nonmagnetic alloy containing at least one element selected from Nb,
Mo, Ta, and W. A material having amorphous structure such as NiP
15 or CoZr can also be preferably used. Thickness of the nonmagnetic
alignment control layer is preferably at least 3 nm, more preferably 5
nm or more for controlling crystal alignment of the seed layer.

Material used for seed layer 3 can be a metal selected from Cu,
20 Au, Pd, Pt, and Ir, an alloy containing at least one element selected
from Cu, Au, Pd, Pt, and Ir, or an alloy containing at least Ni and Fe.
Specific examples of the alloy containing at least Ni and Fe include
Ni₁₅Fe₂₅Cr, Ni₁₈Fe₂₅Cr, and Ni₁₅Fe₃₀Cr.

When one of these materials having fcc crystal structure is laminated on a substrate, the (111) plane that is the closest-packed plane of the fcc crystal structure tends to align parallel to the film surface. Since a nonmagnetic underlayer 4 in the present invention
5 has an hcp crystal structure, when the underlayer is laminated on the seed layer aligning in (111) plane of fcc structure, hcp (002) plane that best matches to the seed layer tends to grow aligning parallel to the film surface. By laminating a granular magnetic layer on such a nonmagnetic underlayer, the metallic crystal grains in the magnetic
10 recording layer also grow with their hcp (002) plane aligning parallel to the film surface, and the c-axis orients perpendicular to the film surface, to provide an excellent perpendicular magnetic recording medium. The employment of these materials effectively provides favorable lattice matching between the seed layer and the
15 nonmagnetic underlayer, and between the nonmagnetic underlayer and the granular magnetic recording layer.

Thickness of the seed layer is at least 3 nm, more preferably 5 nm or more in order to control orientation of the nonmagnetic
20 underlayer. In a double-layered perpendicular magnetic recording medium provided with a soft magnetic backing layer under the seed layer, the thickness of the seed layer needs to be as thin as possible insofar as alignment control is possible, because the distance between the recording layer and the soft magnetic backing layer is preferably

as small as possible. Thus, the thickness of the seed layer is preferably in the range from 3 to 20 nm.

The nonmagnetic underlayer 4 needs to be a metal or an alloy
5 having hexagonal closest-packed (hcp) crystal structure. The underlayer is formed of a ruthenium-base alloy added with one or more materials selected from the group consisting of C, Cu, W, Mo, Cr, Ir, Pt, Re, Rh, Ta, and V. The relative content of the additive with respect to ruthenium is not restricted in the case of the additives of C,
10 Cu, and Re. However, an additive of W, Mo, Cr, Ir, Pt, Rh, Ta, or V must be mixed within an extent in which any phase other than hcp-ruthenium phase is not formed at the time of thin film deposition. Specifically, the addition is restricted within the values of 32 at% for W, 36 at% for Mo, 40 at% for Cr, 44 at% for Ir, 20 at% for Pt, 60 at%
15 for Rh, 20 at% for Ta, and 16 at% for V. A ruthenium base alloy containing one or more of these materials exhibits excellent alignment and has fine grain size when formed on a seed layer 3. The ruthenium base alloy provides superior epitaxial growth with the magnetic recording layer, and suppresses the initial growth layer in
20 the magnetic recording layer.

Thickness of the nonmagnetic underlayer is desired to be at least 2 nm, preferably 5 nm or more to control alignment of the granular magnetic recording layer. However, the thickness of the nonmagnetic

underlayer is required to be as thin as possible in view of reduction of production cost and for the purpose of attaining a minimum distance between the recording layer and the soft magnetic backing layer in a double layer perpendicular magnetic recording medium insofar as
5 alignment control of the magnetic recording layer is possible. Thus, the thickness of the nonmagnetic underlayer is preferably in the range from 2 to 40 nm.

A magnetic recording layer 5 in a perpendicular magnetic
10 recording medium according to the present invention is a so-called granular magnetic recording layer. The layer comprises ferromagnetic grains and nonmagnetic grain boundary phase surrounding the grains. The grain boundary phase is composed of oxide or nitride of metal. As disclosed in United States Patent No.
15 5,679,473, the granular structure can be deposited by a sputtering method using a ferromagnetic target containing the oxide that composes the grain boundary, or by a reactive sputtering method using a ferromagnetic metallic target in oxygen-containing argon gas. According to these methods, each of the ferromagnetic crystal grains
20 can be isolated by the grain boundary without substrate heating.

An alloy of CoPt system is one of the preferable materials for composing the ferromagnetic crystal grains. In order to reduce media noise, in particular, it is desirable to add at least one element selected

from Cr, Ni, and Ta to the CoPt alloy. In order to form a stable granular structure, it is particularly desirable to form the nonmagnetic grain boundary using an oxide of at least one element selected from Cr, Co, Si, Al, Ti, Ta, Hf, and Zr. The thickness of the magnetic recording layer is necessary to have a value for attaining enough head regeneration output and recording resolution.

A thin film composed mainly of carbon, for example, is used for the protective film 6. Also, various thin film materials can be used that are commonly employed as a protective film of a magnetic recording medium. Perfluoropolyether lubricant, for example, can be used for the liquid lubrication layer 7. Also, various lubricant materials can be used that are commonly employed as a material for a liquid lubrication layer of a magnetic recording medium.

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In the case of manufacturing a double layer perpendicular magnetic recording medium in order to enhance sharpness of magnetic field generated at the head region, either of the two methods can be employed: 1) to use a seed layer of NiFe soft magnetic alloy with fcc structure as a soft magnetic backing layer; and 2) to use a thin film of NiFe soft magnetic alloy with fcc structure as a seed layer, the thin film being provided on the top of a nonmagnetic backing layer made of other material. By laminating a nonmagnetic underlayer and a magnetic recording layer on such a seed layer,

alignment control of the nonmagnetic underlayer and the magnetic recording layer can be performed. In this construction, the distance between the magnetic recording layer and the soft magnetic backing layer is substantially reduced to the thickness of the nonmagnetic underlayer. Thus, a superior perpendicular magnetic recording medium can be produced.

The soft magnetic backing layer can be formed of crystalline FeTaC alloy, Sendust alloy (FeSiAl), or an amorphous cobalt alloy such as CoZrNb or CoTaZr. Although the optimum value of the thickness of the soft magnetic backing layer varies depending on the structure and the characteristics of a magnetic head used for recording, preferable thickness is in the range from 10 nm to 500 nm considering productivity.

Each layer laminated on a nonmagnetic substrate can be formed by means of various deposition techniques that are usually employed in the field of a magnetic recording medium. The techniques that can be employed for forming the layers except for the liquid lubrication layer includes DC magnetron sputtering, RF magnetron sputtering, and vacuum evaporation, for example. A liquid lubrication layer can be formed by means of a dipping method or a spin coating method, for example.

In the process of manufacturing a magnetic recording medium

having layer construction described above and shown in Fig. 1, omitting the step of substrate heating, which is required by a conventional magnetic recording medium, still allows obtaining a perpendicular magnetic recording medium with satisfactory c-axis alignment. Reduction of production cost can be achieved by virtue of the simplification of the production process. Because substrate heating is unnecessary, a substrate made of plastics such as polycarbonate or polyolefin may be employed.

10 Examples

The following describes some examples of preferred embodiments of the present invention.

Example 1

15 An injection molded polycarbonate substrate with 3.5 inch disk shape was used for a nonmagnetic substrate. After cleaning, the substrate was introduced into a sputtering apparatus. A nonmagnetic alignment control layer 5 nm thick was formed of tantalum under argon gas pressure of 0.67 Pa (5 mTorr).
20 Subsequently, a seed layer 5 nm thick was formed of platinum under argon gas pressure of 0.67 Pa (5 mTorr), and a nonmagnetic underlayer 5 nm thick was deposited of Ru20W alloy that is a solid solution of 20 at% tungsten in ruthenium under argon gas pressure of 2.0 Pa (15 mTorr). Then, a granular magnetic recording layer 15 nm

thick was formed by means of RF sputtering using a target of Co₁₀Cr₁₄Pt containing 7 mol% of SiO₂ under argon gas pressure of 0.67 Pa (5 mTorr). After laminating a carbon protective layer 10 nm thick, the resulted substrate was taken out from the vacuum chamber.

- 5 Applying liquid lubricant to the thickness of 1.5 nm, a magnetic recording medium having structure as shown in Figure 1 was produced. Substrate heating prior to the deposition was not executed.

A plurality of samples was additionally produced having
10 thickness of the magnetic recording layer in the range from 10 nm to 30 nm.

Example 2

A perpendicular magnetic recording medium was produced in the
15 same manner as in Example 1 except that a nonmagnetic underlayer was laminated using Ru₃₀C alloy that is a solid solution of 30 at% carbon in ruthenium.

Example 3

20 A perpendicular magnetic recording medium was produced in the same manner as in Example 1 except that a nonmagnetic underlayer was laminated using Ru₂₂Mo alloy that is a solid solution of 22 at% molybdenum in ruthenium.

Example 4

A perpendicular magnetic recording medium was produced in the same manner as in Example 1 except that a nonmagnetic underlayer was laminated using Ru₅Cr₁₀C alloy that is a solid solution of 5 at% chromium and 10 at% of carbon in ruthenium.

Example 5

A perpendicular magnetic recording medium was produced in the same manner as in Example 1 except that a nonmagnetic alignment control layer 5 nm thick was laminated using Ni₂₅P alloy that is a solid solution of 25 at% phosphorus in nickel.

Comparative Example 1

A perpendicular magnetic recording medium was produced in the same manner as in Example 1 except that a nonmagnetic underlayer 5 nm thick was laminated using pure ruthenium. A plurality of samples was additionally produced having thickness of the magnetic recording layer in the range from 10 nm to 30 nm.

Comparative Example 2

A perpendicular magnetic recording medium was produced in the same manner as in Comparative Example 1 except that a magnetic recording layer 15 nm thick was formed using Co₂₀Cr₁₀Pt₄B that has a conventional structure different from a granular structure.

Comparative Example 3

A perpendicular magnetic recording medium was produced in the same manner as in Comparative Example 2 except that a
5 nonmagnetic underlayer 5 nm thick was laminated using Ru₂₀W alloy that is a solid solution of 20 at% tungsten in ruthenium.

Evaluation

A variety of measurements was taken on the perpendicular
10 magnetic recording media of Examples and Comparative Examples including: coercive force H_c , dispersion of orientation distribution of axis of easy magnetization

$\Delta \theta_{50}$, grain size of the magnetic recording layer, and normalized noise and SNR by electromagnetic conversion measurement. The
15 results are given in Table 1 and Table 2. The coercive force H_c was measured by VSM (vibrating sample magnetometer). The $\Delta \theta_{50}$ is a half width of a rocking curve obtained by X-ray diffraction apparatus. The electromagnetic conversion characteristics were measured by a spinning stand tester at the linear recording density of 400 kFCI.
20 Normalized noise that is defined by root mean square of noises (μV unit) / output signal (in mV unit), $\mu V_{rms} / mV_{pp}$ and SNR (signal to noise ratio) are shown in the Tables. The grain size was measured by means of transmission electron microscopy (TEM). The measured results are given in Tables 1 and 2.

Table 1

	Example 1	Comp Example 1	Comp Example 2	Comp Example 3
nonmagnetic alignment control layer	Ta	Ta	Ta	Ta
seed layer	Pt	Pt	Pt	Pt
nonmagnetic underlayer	Ru20W	Ru	Ru	Ru20W
magnetic recording layer	Co10Cr14P t 7SiO ₂	Co10Cr14P t 7SiO ₂	Co20Cr10P t 4B	Co20Cr10P t 4B
coercive force H _c [kA/m (Oe)]	258.6 (3250)	221.0 (2778)	203.6 (2559)	231.3 (2906)
$\Delta \theta_{50}$ [deg]	6.2	7.6	8.2	7.2
grain size in mag record layer [nm]	6.1	10.8	13.4	7.3
normalized noise	70.3	82.3	102.9	87.1
SNR [dB]	17.1	14.5	13.7	15.7

Table 2

	Example 2	Example 3	Example 4	Example 5
nonmagnetic alignment control layer	Ta	Ta	Ta	Ni25P
seed layer	Pt	Pt	Pt	Pt
nonmagnetic underlayer	Ru30C	Ru22Mo	Ru5Cr10C	Ru20W
magnetic recording layer	Co10Cr14Pt 7SiO ₂	Co10Cr14Pt 7SiO ₂	Co10Cr14P t 7SiO ₂	Co10Cr14P t 7SiO ₂
coercive force Hc [kA/m (Oe)]	253.7 (3188)	273.3 (3435)	258.2 (3245)	195.8 (3180)
$\Delta \theta_{50}$ [deg]	5.4	5.9	5.2	6.4
grain size in mag record layer [nm]	6.5	6.2	6.5	6.2
normalized noise	77.8	68.5	75.4	71.5
SNR [dB]	16.2	17.6	16.6	16.9

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Table 1 indicates the difference in coercive force Hc between Comparative Examples 1 and 2. The major reason is the difference in platinum content in the magnetic recording layer, since the other
10 items are the same in the two Comparative Examples.

Comparing Comparative Example 1 and Examples, which all use

a granular film for the magnetic recording layer, it can be seen that remarkable improvement has been achieved in the electromagnetic conversion characteristics by employing a nonmagnetic underlayer according to the invention. As is apparent from the comparison
5 between Comparative Example 2 and Comparative Example 3, improvement in the electromagnetic conversion characteristics can be achieved also in a magnetic recording layer having a conventional and not granular structure when a nonmagnetic underlayer according to the invention is employed.

10

Concerning coercive force H_c , Figure 2 shows the variation of H_c in Comparative Example 1 and Example 1 with the thickness of the magnetic recording layer. In Comparative Example 1, which uses the nonmagnetic underlayer of pure ruthenium, H_c rapidly drops as the
15 magnetic recording layer becomes thinner, because the initial growth layer in the magnetic recording layer is large. In contrast, in Example 1, which uses Ru20W for the nonmagnetic underlayer and a granular magnetic recording layer for the magnetic recording layer, decrease of the H_c is slow even in the region of thin magnetic
20 recording layer. This fact also shows decrease of the initial growth layer in the magnetic recording layer. Other Examples that used different materials for the nonmagnetic underlayer also showed the similar effect that is brought about by the decrease of the initial growth layer in the magnetic recording layer.

Next, looking at the dispersion of orientation distribution $\Delta \theta_{50}$, the values are 7.6° in the medium of Comparative Example 1, 7.2° in the medium of Comparative Example 3, while 5.2° to 6.4° in the media of Examples according to the invention.

Alignment in the magnetic recording layer has been improved.

As comparison of Example 5 with Example 1 indicates, the use of Ni₂₅P for the nonmagnetic alignment control layer shows as well effect as the use of tantalum.

10

As for the grain size of the magnetic recording layer, because fine grain size can be easily attained when a granular magnetic recording layer is employed for the magnetic recording layer, reduction of the grain size of 2.6 nm is achieved in the same layer construction comparing Comparative Example 1 with Comparative Example 2, both of which use underlayer of pure ruthenium. Further, Examples 1 through 4 that employ a ruthenium base alloy for the nonmagnetic underlayer became finer by at least 4.3 nm.

20 As described above, reduction of the initial growth layer and decrease of the grain size have been achieved in the Examples according to the invention by using ruthenium-base alloy. These crystallographic improvements are reflected in the noise reduction and the remarkable improvement of SNR of the Examples.

Advantageous Effect of the invention

- As described so far, it has been demonstrated that the initial growth layer in the magnetic recording layer is decreased and the grain size of the magnetic recording layer is minimized by employing a nonmagnetic underlayer made of an alloy of ruthenium with one or more additives selected from the group consisting of C, Cu, W, Mo, Cr, Ir, Pt, Re, Rh, Ta, and V, and a magnetic recording layer of a granular film, resulting in reduced noises and enhanced SNR.
- Although the every material for magnetic underlayer listed above can produce the effects similar to the above, ruthenium that contains an additive of tungsten or molybdenum has achieved superior effects in the present studies.
- Since excellent characteristics can be easily attained by employing the layer structure according to the present invention, substrate heating becomes unnecessary in the laminating process in a medium of the invention. Consequently, inexpensive plastics can be used for a substrate as well as a conventional aluminum substrate and a glass substrate.

Claims

1. A perpendicular magnetic recording medium comprising:
 - a nonmagnetic substrate;
 - a nonmagnetic alignment control layer provided on said
 - 5 substrate;
 - a seed layer of a metal or an alloy having fcc crystal structure provided on said alignment control layer;
 - a nonmagnetic underlayer of a metal or an alloy having hcp crystal structure laminated on said seed layer;
 - 10 a magnetic recording layer consisting of ferromagnetic grains and nonmagnetic grain boundary phase mainly of oxide surrounding said grains, said recording layer being laminated on said underlayer;
 - a protective film laminated on said recording layer; and
 - a liquid lubrication layer laminated on said protective film.
- 15 2. A perpendicular magnetic recording medium according to claim 1, wherein said nonmagnetic underlayer is composed of a ruthenium base alloy containing one or more additives of a material selected from the group consisting of C, Cu, W, Mo, Cr, Ir, Pt, Re, Rh, Ta, and
- 20 V.
3. A perpendicular magnetic recording medium according to claim 2, wherein said nonmagnetic underlayer is composed of a ruthenium base alloy having hcp structure.

4. A perpendicular magnetic recording medium according to claim 2, wherein said nonmagnetic underlayer is composed of a ruthenium base alloy containing a material selected from a group consisting of at
5 most 32 at% of tungsten, at most 36 at% of molybdenum, at most 40 at% of chromium, at most 44 at% of iridium, at most 20 at% of platinum, at most 60 at% of rhodium, at most 20 at% of tantalum, and at most 16 at% of vanadium.
- 10 5. A perpendicular magnetic recording medium according to any one of claims 1 through 4, wherein said seed layer is composed of a metal selected from Cu, Au, Pd, Pt, and Ir, of an alloy containing at least one element selected from Cu, Au, Pd, Pt, and Ir, or of an alloy containing at least Ni and Fe.
- 15 6. A perpendicular magnetic recording medium according to claim 1, wherein said nonmagnetic alignment control layer is composed of a nonmagnetic metal selected from Nb, Mo, Ta, and W that have bcc crystal structure, or an nonmagnetic alloy having bcc crystal
20 structure and containing at least one element selected from Nb, Mo, Ta, and W.
7. A perpendicular magnetic recording medium according to claim 1, wherein said nonmagnetic alignment control layer is composed of NiP

having amorphous structure or CoZr having amorphous structure.

8. A perpendicular magnetic recording medium according to any one of claims 1 through 7, wherein said nonmagnetic grain boundary
5 phase in said magnetic recording layer is composed of oxide of at least one element selected from a group consisting of Cr, Co, Si, Al, Ti, Ta, Hf, and Zr.
9. A perpendicular magnetic recording medium according to any
10 one of claims 1 through 8, wherein said nonmagnetic substrate is composed of plastic resin.
10. A method for manufacturing a perpendicular magnetic recording medium that is defined by any one of claims 1 through 9, said method
15 comprising steps of laminating said layers and a film without preheating said substrate.