

A Perpendicular magnetic recording medium and a method for manufacturing same

Technical field of the invention

5 The present invention relates to a perpendicular magnetic recording medium and a method for manufacturing the recording medium. In particular, the present invention relates to a perpendicular magnetic recording medium that is mounted on an external memory of a computer or other magnetic recording
10 apparatus, and to a method for manufacturing such a recording medium.

Background of the invention

As a technique to achieve high density magnetic recording, there
15 is interest in a perpendicular magnetic recording as an alternative to a conventional longitudinal magnetic recording. As a magnetic recording layer to carry magnetic recording in a perpendicular magnetic recording medium, a crystalline film of CoCr alloy having hexagonal closest packed (hcp) crystal structure has principally been
20 studied. To make perpendicular magnetic recording possible, crystal alignment is controlled so that c-axis of each crystal grain is perpendicular to the film surface, that is, c-plane is parallel to the film surface. For addressing higher recording density in a perpendicular magnetic recording medium, attempts have been made



to minimize grain size and to reduce dispersion of grain size of the CoCr alloy composing the magnetic recording layer, and to reduce magnetic interaction between crystal grains.

5 A technique has been proposed to achieve high density recording in a longitudinal magnetic recording medium by reducing magnetic interaction between crystal grains, in which a layer of nonmagnetic and non-metallic substance such as oxide or nitride, is formed at the grain boundary of a crystal grain composing a magnetic recording
10 layer. This magnetic layer is called “a granular magnetic layer”, and disclosed in Japanese Unexamined Patent Application Publication Hei 8-255342 and United States Patent No. 5,679,473, for example. The magnetic grains in the granular magnetic layer are three dimensionally isolated with each other by the nonmagnetic and non-
15 metallic grain boundary. Since magnetic interaction between magnetic grains decreases, “zigzag domain wall” in the transition region of a recording bit is suppressed to develop, which is considered to result in noise reduction.

20 On this background, the use of the granular magnetic layer has been proposed in the magnetic recording layer of a perpendicular magnetic recording medium. For example, IEEE Trans. Mag., vol. 36, p. 2393 (2000) discloses a perpendicular magnetic recording medium that comprises an underlayer of ruthenium (Ru) and a magnetic layer

of a CoPtCrO alloy having granular structure. The document shows that c-axis alignment of crystal grains composing the magnetic layer enhances as the ruthenium underlayer becomes thicker, bringing about improvement in magnetic characteristics and electromagnetic
5 conversion performances of the magnetic recording layer.

Problem to be solved by the invention

However, the thickness of the ruthenium (Ru) underlayer of at least 40 nm is necessary to obtain a granular perpendicular magnetic
10 recording medium that exhibits excellent characteristics.

A so-called double-layered perpendicular magnetic recording medium has been proposed, in which a soft magnetic backing layer is provided under the magnetic recording layer to enhance sharpness of
15 the magnetic field produced at the head position. In order to achieve high density recording in a magnetic recording medium with this structure, it is considered to be essential that the thickness of the nonmagnetic layer provided between the magnetic recording layer and the soft magnetic layer is 20 nm or thinner. This places a
20 restriction on the magnetic recording medium.

Even in a structure without the soft magnetic backing layer, the thickness of the ruthenium underlayer is desired to be thin from the viewpoint of reduction of a manufacturing cost since the ruthenium is

a rare metallic element and expensive.

The present invention has been made in view of the above problem and an object of the invention is to provide a perpendicular
5 magnetic recording medium exhibiting excellent magnetic characteristics and superior electromagnetic conversion performance, at a low cost.

Means to solve the problem

10 To solve the above problem, a perpendicular magnetic recording medium of the present invention comprises a nonmagnetic substrate, and at least a nonmagnetic underlayer, a magnetic layer, and a protective film sequentially laminated on the substrate; wherein the magnetic layer is composed of ferromagnetic crystal grains and
15 nonmagnetic grain boundaries mainly composed of oxide; the nonmagnetic underlayer is made of a metal or an alloy having hexagonal closest-packed crystal structure; and a seed layer made of a metal or an alloy having face-centered cubic crystal structure is provided between the nonmagnetic underlayer and the nonmagnetic
20 substrate.

The nonmagnetic underlayer is necessarily composed of a metal or an alloy having hexagonal closest-packed (hcp) crystal structure in order to control crystal alignment of the granular magnetic layer.

Preferably, the metal is selected from Ti, Re, Ru, and Os; and the alloy contains at least one element selected from Ti, Re, Ru, and Os.

5 The seed layer is necessarily composed of a metal or an alloy having face-centered cubic (fcc) crystal structure in order to control crystal alignment of the underlayer. Preferably, the metal is selected from Cu, Au, Pd, Pt, and Ir. The alloy is preferably an alloy containing at least an element selected from Cu, Au, Pd, Pt, and Ir, or an alloy containing at least Ni and Fe.

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Advantageously, the nonmagnetic underlayer is composed of a metal selected from Ti, Re, Ru, and Os, or an alloy containing at least one element selected from Ti, Re, Ru, and Os.

15 Advantageously, the seed layer is composed of a metal selected from Cu, 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.

20 Advantageously, a nonmagnetic alignment control layer is further provided between the seed layer and the nonmagnetic substrate. The nonmagnetic alignment control layer is composed of a metal or an alloy that has body-centered cubic crystal structure or amorphous structure.

The nonmagnetic alignment control layer is preferably composed of a nonmagnetic metal having bcc crystal structure 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
5 amorphous structure such as NiP or CoZr may also be used.

Advantageously, the metal or the alloy composing the nonmagnetic alignment control layer is a nonmagnetic metal selected from Nb, Mo, Ta, and W, or a nonmagnetic alloy containing at least
10 one element selected from Nb, Mo, Ta, and W.

Advantageously, the nonmagnetic substrate is composed of a plastic resin.

15 A method according to the invention for manufacturing a perpendicular magnetic recording medium comprises steps of depositing the layers and the film included in the perpendicular magnetic recording medium according to the invention as described above, and each of the steps of depositing the layer and the film are
20 conducted under a temperature of the substrate lower than 80°C.

Another method according to the invention for manufacturing a perpendicular magnetic recording medium comprises steps of depositing the layers and the film included in the perpendicular magnetic recording medium according to the invention as described

above, and the steps of depositing the layer and the film are conducted omitting preheating the nonmagnetic substrate.

Brief description of the drawings

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Fig. 1 is a drawing for illustrating a structure of an embodiment of a perpendicular magnetic recording medium according to the present invention.

10 Fig. 2 is a drawing for illustrating a structure of another embodiment of a perpendicular magnetic recording medium according to the present invention.

Fig. 3 is a graph for illustrating a relationship between $\Delta \theta_{50}$ value
15 and the thickness of the nonmagnetic underlayer, in which $\Delta \theta_{50}$ is a half-width of a rocking curve of hcp (002) plane of the CoCrPt magnetic layer obtained by an X-ray diffraction method.

Aspects of embodiments of the invention

20 Now, some preferred embodiments of the present invention will be described with reference to the accompanying drawings.

Fig. 1 is a drawing to illustrate a structure of an embodiment of a perpendicular magnetic recording medium of the present invention. A seed layer 3, a nonmagnetic underlayer 4, a magnetic layer 5, and a

protective film 6 are laminated in this order on a nonmagnetic substrate 1. The protective film 6 is coated with a liquid lubricant layer 7.

5 Fig. 2 is a drawing to illustrate a structure of another embodiment of a perpendicular magnetic recording medium of the present invention. A nonmagnetic alignment control layer 2, a seed layer 3, a nonmagnetic underlayer 4, a magnetic layer 5, and a protective film 6 are laminated in this order on a nonmagnetic
10 substrate 1. The protective film 6 is coated with a liquid lubricant layer 7.

 The nonmagnetic substrate 1 may be formed of NiP-plated aluminum alloy, strengthened glass, or crystallized glass, which are
15 used in a substrate of a usual magnetic recording medium. In a case substrate heating is unnecessary, a plastic substrate made by injection molding of a plastic resin, such as polycarbonate or polyolefin, may be used.

20 The magnetic layer 5 is a so-called granular magnetic layer. The layer comprises ferromagnetic crystal grains, between which nonmagnetic grain boundaries are formed of nonmagnetic metal oxide or metal nitride.

The magnetic layer 5 with such structure may be deposited by a sputtering method using a ferromagnetic metallic target containing the oxide or nitride that constructs the grain boundary. Alternatively, the magnetic layer may be deposited by a reactive sputtering method
5 using a ferromagnetic metallic target under an argon gas atmosphere containing oxygen or nitrogen.

While material for laminating the ferromagnetic crystals is not limited to a specific material, an alloy of CoPt system is a preferable
10 one. In order to reduce recording media noise, in particular, it is preferable 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 preferable to form nonmagnetic grain boundaries using an oxide of at least one element selected from Cr, Co, Si, Al, Ti, Ta, Hf, and Zr.
15 Thickness of the magnetic layer 5 is necessary to allow generating enough head regeneration output and achieving desired recording resolution.

The protective film 6 consists of a thin film composed mainly of
20 carbon, for example. The liquid lubricant layer 7 is composed of perfluoropolyether lubricant, for example.

The nonmagnetic underlayer 4 is necessarily composed of a metal or an alloy having hexagonal closest-packed (hcp) crystal structure.

In order to control crystal alignment of the granular magnetic layer 5, the nonmagnetic underlayer 4 is preferably composed of a metal selected from Ti, Re, Ru, and Os, or an alloy containing at least one element selected from Ti, Re, Ru, and Os.

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The seed layer 3 is necessarily composed of a metal or an alloy having a face-centered cubic (fcc) crystal structure. The seed layer 3 is preferably composed of a metal selected from Cu, 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.

When a seed layer 3 having an fcc crystal structure is laminated on a nonmagnetic substrate 1, the (111) plane that is the closest-packed plane of the fcc crystal structure tends to align parallel to the film surface. Crystal grains of the nonmagnetic underlayer 4 growing on the crystal grains of the seed layer 3 aligned in the (111) plane have a tendency to grow so as to minimize the strain energy due to lattice mismatch between the crystal grain of the underlayer 4 and the crystal grain of the seed layer 3. As a result, the hcp (002) plane of the nonmagnetic underlayer 4 tends to align parallel to the film surface.

When a granular magnetic layer 5 is laminated on the nonmagnetic underlayer in this crystal alignment condition, the

metal crystal grains of the magnetic layer 5 having hcp crystal structure also tends to grow with their (002) plane aligning parallel to the film surface. This leads to excellent magnetic characteristic of the perpendicular magnetic recording medium.

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The lattice matching between the seed layer 3 and the nonmagnetic underlayer 4 and the lattice matching between the nonmagnetic underlayer 4 and the granular magnetic layer 5 are favorable if the materials of the seed layer 3 and the nonmagnetic underlayer 4 are appropriately chosen from the materials listed below. The preferable materials for the seed layer 3 include: a metal selected from Cu, Au, Pd, Pt, and Ir; an alloy containing at least one element selected from Cu, Au, Pd, Pt, and Ir; and an alloy containing at least Ni and Fe. The preferable materials for the nonmagnetic underlayer 4 include: a metal selected from Ti, Re, Ru, and Os; and an alloy containing at least an element selected from Ti, Re, Ru, and Os. A perpendicular magnetic recording medium using these materials exhibits superior magnetic characteristic.

20 Thickness of the seed layer 3 is at least 3 nm, more preferably 5 nm or more in order to control crystal orientation of the nonmagnetic underlayer 4. In a double-layered perpendicular magnetic recording medium with a soft magnetic backing layer provided under the seed layer 3, in particular, thickness of the seed layer is desired as thin as

possible insofar as crystal alignment of the nonmagnetic underlayer 4 is possible to be controlled, because the magnetic layer and the soft magnetic backing layer are preferably designed to closely positioned with each other.

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Thickness of the nonmagnetic underlayer 4 is at least 2 nm, preferably 5 nm or more to control crystal orientation of the granular magnetic layer 5. The thickness of the underlayer 4 is desired to be as thin as possible in view of reduction of manufacturing cost and for
10 proximity of the magnetic layer and the soft magnetic backing layer in a double-layered perpendicular magnetic recording medium insofar as control of crystal orientation of the granular magnetic layer 5 is possible.

15 In manufacturing a double-layered perpendicular magnetic recording medium, the soft magnetic backing layer may be composed of a NiFe soft magnetic alloy having fcc structure; or a NiFe soft magnetic alloy layer having fcc structure with minimum thickness may be provided just over the soft magnetic backing layer. Control of
20 crystal orientation of the nonmagnetic underlayer 4 is possible regarding this NiFe soft magnetic alloy layer as a seed layer 3. A distance between the magnetic layer and the soft magnetic backing layer in this case is substantially equal to the thickness of the nonmagnetic underlayer 4. Thus, by making the thickness of the

underlayer thin, superior characteristics can be achieved in the perpendicular magnetic recording medium.

The nonmagnetic alignment control layer 2 is necessarily
5 composed of a metal or an alloy having body-centered cubic (bcc) crystal structure or amorphous structure. By providing a nonmagnetic alignment control layer 2 having this structure, the tendency to align in (111) plane is more promoted in the crystal grain of the seed layer 3 having fcc crystal structure. Thus, crystal
10 alignment of the nonmagnetic underlayer 4 is enhanced, resulting in improvement of the magnetic characteristics of the magnetic layer.

This effect of the alignment control layer is most significant when the material having bcc structure is a nonmagnetic metal selected
15 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 or CoZr may also be employed.

Thickness of the nonmagnetic alignment control layer 2 is
20 preferably at least 3 nm, more preferably 5 nm or more for controlling crystal alignment of the seed layer 3.

In the method for manufacturing a perpendicular magnetic recording medium of the invention, the deposition processes are

conducted under temperatures lower than 80°C, and the substrate preheating step is omitted, which is the step commonly executed in the conventional process for manufacturing a magnetic recording medium. A perpendicular magnetic recording medium according to
5 the invention having structure shown in Fig. 1 or Fig. 2 exhibits excellent characteristics even if the substrate preheating step is omitted. Consequently, the production process is simplified by omitting the substrate preheating step, to achieve reduction in manufacturing cost. Omitting the substrate preheating step also
10 allows employing a nonmagnetic substrate made by molding plastic resin such as polycarbonate or polyolefin.

The following describes specific examples of embodiments of the present invention. The examples are merely for illustrating a spirit
15 of the invention, and the scope of the invention shall not be restricted to the examples.

Example 1

The nonmagnetic substrate used was a polycarbonate substrate
20 of 3.5" disk shape made by injection molding. The substrate was cleaned and introduced into a sputtering apparatus. A platinum seed layer having thickness of 5 nm was deposited under argon gas pressure of 5 mTorr. Subsequently, a nonmagnetic underlayer of ruthenium having a thickness in the range from 0 to 40 nm was

deposited under argon gas pressure of 5 mTorr. Then, a granular magnetic layer having thickness of 30 nm was deposited by an RF sputtering method using a target of $\text{Co}_{76}\text{Cr}_{12}\text{Pt}_{12}$ with the addition of 10 mol% SiO_2 under argon gas pressure of 5 mTorr. After depositing
5 a carbon protective film having thickness of 10 nm on the granular magnetic layer, the resulted substrate was taken out from the sputtering apparatus and coated with liquid lubricant to a thickness of 1.5 nm. Thus, a perpendicular magnetic recording medium having a structure shown in Fig. 1 was produced. In this manufacturing
10 process, a step of preheating the substrate before the deposition steps was not executed.

Fig. 3 is a graph illustrating crystal alignment of the magnetic layer obtained by X-ray diffraction method. The abscissa represents
15 thickness of the nonmagnetic underlayer, and the ordinate represents $\Delta \theta_{50}$ which is a half-width of a rocking curve taken for (002) plane of the CoCrPt magnetic layer having hcp structure. Accordingly, a smaller $\Delta \theta_{50}$ value in Fig. 3 means stronger (002) plane alignment in the plane of the CoCrPt magnetic layer.

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The $\Delta \theta_{50}$ value is about 20° in the case the magnetic layer is laminated without a nonmagnetic underlayer on the seed layer, that is, at the nonmagnetic underlayer thickness of zero nm in Fig. 3. However, the $\Delta \theta_{50}$ value abruptly drops as the thickness of the

nonmagnetic underlayer laminated on the seed layer increases; the $\Delta \theta_{50}$ value decreases to about 6° at 3 nm thick and about 5° at 5 nm thick. The $\Delta \theta_{50}$ value does not significantly change even if the thickness of the nonmagnetic underlayer is increased over 5 nm.

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This result implies the thickness of the nonmagnetic underlayer is favorably at least 3 nm, more preferably 5 nm or more, in order to control crystal alignment of the magnetic layer.

10 Example 2

A set of perpendicular magnetic recording media having structure as shown in Fig. 1 was produced laminating a nonmagnetic underlayer using various materials. Conditions in the laminating processes were the same as those in Example 1 except that the
15 thickness of the nonmagnetic underlayer was 5 nm.

Table 1 summarizes the material of the nonmagnetic underlayer, the crystal structure of the underlayer, coercive force H_c , squareness ratio S , and $\Delta \theta_{50}$ value of the thus produced set of perpendicular
20 magnetic recording media. The $\Delta \theta_{50}$ value is a half-width of a rocking curve of the diffraction line of hcp (002) plane of the CoCrPt magnetic layer. The coercive force H_c and the squareness ratio S were measured by using a vibrating sample magnetometer VSM applying magnetic field perpendicular to the film surface. Table 1

also shows evaluation results for a perpendicular magnetic recording medium having a nonmagnetic underlayer of Ta or Cr with bcc structure, for comparison.

Table 1

material of underlayer	crystal structure of underlayer	Hc (Oe)	squareness ratio S	$\Delta \theta_{50}$ (degree)
Ru	hcp	3020	0.99	5.1
Re	hcp	3430	0.95	4.8
Os	hcp	2980	0.92	5.9
Ti	hcp	2440	0.89	7.2
Ru-20%W	hcp	3310	0.98	4.3
Ti-10%Cr	hcp	2560	0.91	7.0
Ta	bcc	820	0.22	22.9
Cr	bcc	590	0.35	19.3

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Excellent magnetic characteristics have been demonstrated in both the coercive force Hc and the squareness ratio S when the materials having hcp structure were used for the nonmagnetic underlayer as compared with the case Ta or Cr having bcc structure was used for the nonmagnetic underlayer. The $\Delta \theta_{50}$ values are suppressed to low values, which indicates strong (002) plane alignment in the plane of the magnetic layer.

15 Example 3

A set of magnetic recording media having structure as shown in Fig. 1 was produced laminating a seed layer using various materials.

Conditions in the laminating processes were the same as those in Example 1 except that the nonmagnetic underlayer was formed of ruthenium with a 5 nm thickness.

- 5 . Table 2 summarizes the material of the seed layer, the crystal structure of the seed layer, coercive force H_c , squareness ratio S , and $\Delta \theta_{50}$ value of the thus produced set of perpendicular magnetic recording media. The $\Delta \theta_{50}$ value is a half-width of a rocking curve of the diffraction line of hcp (002) plane of the CoCrPt magnetic layer.
- 10 Table 2 also shows evaluation results for a perpendicular magnetic recording medium having a seed layer of Ta or Cr with bcc structure, for comparison.

Table 2

material of seed layer	crystal structure of seed layer	H_c (Oe)	squareness ratio S	$\Delta \theta_{50}$ (degree)
Cu	fcc	2780	0.89	4.3
Au	fcc	2990	0.92	5.9
Pd	fcc	3120	0.98	4.9
Pt	fcc	3020	0.99	5.1
Ir	fcc	3350	0.88	6.8
Cu-10%Au	fcc	2880	0.90	5.3
Ni-15%Fe-30%Cu	fcc	3070	0.93	6.6
Ta	bcc	2310	0.67	11.5
Cr	bcc	1270	0.36	18.9

Excellent magnetic characteristics have been demonstrated in both the coercive force H_c and the squareness ratio S when the material having fcc structure was used for the seed layer as compared with the case Ta or Cr having bcc structure was used for the seed layer. The $\Delta \theta_{50}$ values are suppressed to low values, which indicates strong (002) plane alignment in the plane of the magnetic layer.

Example 4

A set of magnetic recording media having structure as shown in Fig. 2 was produced by sequentially laminating a nonmagnetic alignment control layer having a thickness of 5 nm using various materials, a seed layer having a thickness of 5 nm, and a nonmagnetic underlayer of a 5 nm thickness. Other conditions than the above-described ones were the same as those in Example 1.

Table 3 summarizes the material of the nonmagnetic alignment control layer, the crystal structure of the nonmagnetic alignment control layer, coercive force H_c , squareness ratio S , and the $\Delta \theta_{50}$ value of the thus produced set of perpendicular magnetic recording media. The $\Delta \theta_{50}$ value is a half-width of a rocking curve of the diffraction line of hcp (002) plane of the CoCrPt magnetic layer. Table 2 also shows evaluation results for a perpendicular magnetic recording medium having a nonmagnetic alignment control layer

made of Cu with fcc structure or Ru with hcp structure, for comparison.

Table 3

material of alignment control layer	crystal structure	Hc (Oe)	squareness ratio S	$\Delta \theta_{50}$ (degree)
Nb	bcc	3350	0.97	4.0
Ta	bcc	3410	0.98	4.1
Mo	bcc	3210	0.94	4.9
W	bcc	3600	0.98	3.8
Ni-20%P	amorphous	3380	0.99	4.6
Cu	fcc	2110	0.55	9.8
Ru	hcp	850	0.21	15.2

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Excellent magnetic characteristics have been demonstrated in both the coercive force Hc and the squareness ratio S when the materials having bcc structure or amorphous structure was used for the nonmagnetic alignment control layer as compared with the case the material having fcc structure or hcp structure was used for the nonmagnetic alignment control layer. The $\Delta \theta_{50}$ values are suppressed to low values, which indicates strong (002) plane alignment in the plane of the magnetic layer.

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Advantageous Effect of the invention

As described so far, a perpendicular magnetic recording medium

according to the present invention comprises a nonmagnetic underlayer of a metal or an alloy having hexagonal closest-packed (hcp) crystal structure, and a seed layer of a metal or an alloy having face-centered cubic (fcc) crystal structure under the nonmagnetic
5 underlayer. Such a perpendicular magnetic recording medium exhibits excellent magnetic characteristics even when the thickness of the underlayer is small or the total thickness of the underlayer and the seed layer is small.

10 By providing a nonmagnetic alignment control layer of a metal or an alloy having body-centered cubic (bcc) structure or amorphous structure beneath the seed layer, crystal alignment of the seed layer is enhanced, resulting in enhancement of crystal alignment of the magnetic layer, as well.

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Employing such intermediate layers provides a perpendicular magnetic recording medium exhibiting excellent magnetic characteristics. Besides, the substrate preheating step may be omitted from a manufacturing process, which allows the use of an
20 inexpensive plastic substrate.

Claims

1. A perpendicular magnetic recording medium comprising:
a nonmagnetic substrate;
at least a nonmagnetic underlayer, a magnetic layer, and a
5 protective film sequentially laminated on said substrate; wherein
said magnetic layer is composed of ferromagnetic crystal grains
and nonmagnetic grain boundaries mainly composed of oxide;
said nonmagnetic underlayer is composed of a metal or an alloy
having hexagonal closest-packed crystal structure; and
10 a seed layer composed of a metal or an alloy having face-centered
cubic crystal structure provided between said nonmagnetic
underlayer and said nonmagnetic substrate.
2. A perpendicular magnetic recording medium according to claim 1,
15 wherein
said nonmagnetic underlayer is composed of a metal selected
from a group consisting of Ti, Re, Ru, and Os, or an alloy containing
at least one element selected from a group consisting of Ti, Re, Ru,
and Os.
- 20 3. A perpendicular magnetic recording medium according to claim 1,
wherein said seed layer is composed of
a metal selected from a group consisting of Cu, Au, Pd, Pt, and Ir,
an alloy containing at least one element selected from a group

consisting of Cu, Au, Pd, Pt, and Ir, or
an alloy containing at least Ni and Fe.

4. A perpendicular magnetic recording medium according to claim 1
5 further comprising a nonmagnetic alignment-control layer disposed
between said seed layer and said nonmagnetic substrate, said
alignment control layer being composed of a metal or an alloy that
has body-centered cubic crystal structure or amorphous structure.

10 5. A perpendicular magnetic recording medium according to claim 4,
wherein

said metal composing said alignment-control layer is a
nonmagnetic metal selected from a group consisting of Nb, Mo, Ta,
and W; and

15 said alloy composing said alignment-control layer is a
nonmagnetic alloy containing at least one element selected from a
group consisting of Nb, Mo, Ta, and W.

6. A perpendicular magnetic recording medium according to claim 1,
20 wherein said nonmagnetic substrate is composed of a plastic resin.

7. A perpendicular magnetic recording medium according to claim 4,
wherein said nonmagnetic substrate is composed of a plastic resin.

8. A method for manufacturing a perpendicular magnetic recording medium comprising steps of:

depositing a seed layer that is composed of a metal or an alloy having face-centered cubic crystal structure on a nonmagnetic substrate;

depositing a nonmagnetic underlayer that is composed of a metal or an alloy having hexagonal closest-packed crystal structure on said seed layer;

depositing a magnetic layer that is composed of ferromagnetic crystal grains and nonmagnetic grain boundaries mainly composed of oxide on said underlayer; and

depositing a protective film on said magnetic layer.

9. A method according to claim 8 for manufacturing a perpendicular magnetic recording medium, wherein each of said depositing steps is conducted under a temperature of said substrate lower than 80°C.

10. A method according to claim 8 for manufacturing a perpendicular magnetic recording medium, wherein said depositing steps omit a step of preheating said nonmagnetic substrate.

11. A method for manufacturing a perpendicular magnetic recording medium comprising steps of:

depositing a nonmagnetic alignment-control layer that is composed of a metal or an alloy having body-centered cubic crystal structure or amorphous structure on a nonmagnetic substrate;

depositing a seed layer that is composed of a metal or an alloy having face-centered cubic crystal structure on said nonmagnetic alignment control layer;

depositing a nonmagnetic underlayer that is composed of a metal or an alloy having hexagonal closest-packed crystal structure on said seed layer;

depositing a magnetic layer that is composed of ferromagnetic crystal grains and nonmagnetic grain boundaries mainly composed of oxide on said underlayer; and

depositing a protective film on said magnetic layer.

12. A method according to claim 11 for manufacturing a perpendicular magnetic recording medium, wherein each of said depositing steps is conducted under a temperature of said substrate lower than 80°C.

13. A method according to claim 8 for manufacturing a perpendicular magnetic recording medium, wherein said depositing steps omit a step of preheating said nonmagnetic substrate.