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Perpendicular magnetic recording medium and a method for manufacturing same

5 Technical field of the invention

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
10 external memory of a computer or other magnetic recording apparatus, and to a method for manufacturing such a recording medium.

Background of the invention

15 As a technique to achieve high density magnetic recording, there 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
20 CoCr alloy having hexagonal closest packed (hcp) crystal structure has principally been 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
25 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.

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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
10 nitride, is formed at the grain boundary of a crystal grain composing a magnetic recording 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
15 grains in the granular magnetic layer are three dimensionally isolated with each other by the nonmagnetic and non-metallic grain boundary. Since magnetic interaction between the magnetic grains decreases, "zigzag domain wall" in the transition region of a recording bit is suppressed to develop, which is considered to
20 result in noise reduction.

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
25 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
5 crystal grains composing the magnetic layer enhances as the ruthenium underlayer becomes thicker, bringing about improvement in magnetic characteristics and electromagnetic conversion performances of the magnetic recording layer.

10 A study has also been made to make a magnetic recording layer of a perpendicular magnetic recording medium by using an amorphous alloy of a rare earth element and 3d transition metal, such as a TbFeCo alloy.

15 Problem to be solved by the invention

A perpendicular magnetic recording layer employing the above-mentioned granular magnetic layer exhibits relatively good magnetic properties and electromagnetic conversion characteristics. For further enhancement of magnetic recording
20 density, it is considered necessary to further minimize the grain size in the ferromagnetic layer and to further reduce magnetic interaction between magnetic grains by promoting precipitation of oxides or nitrides to the grain boundary.

25 When grain size in the magnetic layer is minimized and

magnetic interaction between crystal grains is decreased by increasing the quantity of oxide or nitride precipitated at the grain boundary, thermal stability of information recorded on the magnetic recording layer rapidly deteriorates. In the worst case, the problem of so-called "thermal fluctuation" arises, in which once recorded information disappears due to thermal disturbance.

On the other hand, an amorphous film of a rare earth-transition metal alloy has a high perpendicular magnetic anisotropy constant K_u and is free of grain boundary because it is amorphous. Therefore, such an amorphous film has high thermal stability for a magnetic recording layer. However, the free of grain boundary also means lack of a core to hold the once recorded signal within the written place, and the recorded signal is susceptible to the phenomenon of shift or disappearance. These phenomena occur particularly in the magnetic recording at a high frequency. Therefore, such a material is unfavorable for perpendicular magnetic recording that is directed toward high density magnetic recording.

The present invention has been made in view of the foregoing, and an object of the present invention is to provide a perpendicular magnetic recording medium that allows high density recording, exhibits excellent electromagnetic conversion

characteristics and thermally stable performance.

Means to solve the problem

5 The present invention has been accomplished to solve the above problem, and a perpendicular magnetic recording medium according to the invention comprises a nonmagnetic substrate, and at least a nonmagnetic underlayer, a first magnetic layer, a second magnetic layer, a protective layer, and a liquid lubricant
10 layer sequentially laminated on the substrate. The first magnetic layer comprises crystal grains of a ferromagnetic Co-Cr alloy system and nonmagnetic grain boundaries substantially consisting of oxide or nitride. The thickness a of the first magnetic layer is in the range of 10 nm to 30 nm. The second
15 magnetic layer comprises an amorphous alloy composed of rare earth element(s) and transition metal element(s). The thickness b of the second magnetic layer is in the range of 2 nm to 15 nm. A ratio a/b of the thickness a of the first magnetic layer to the thickness b of the second magnetic layer is at least two.

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Advantageously, the nonmagnetic underlayer is composed of a metal or an alloy of hexagonal closest-packed crystal structure. The metal is selected from the group consisting of Ti, Re, Ru, and Os. The alloy contains at least one element selected from the
25 group consisting of Ti, Re, Ru, and Os.

Advantageously, the second magnetic layer contains at least one metal element selected from Ni, Fe, and Co, and also contains at least one element selected from Pr, Nd, Gd, Tb, Dy, and Ho in a
5 concentration from 10 at% to 35 at%.

Advantageously, the nonmagnetic substrate is formed of plastic resin.

10 A method according to the invention for manufacturing a perpendicular magnetic recording medium comprises steps of depositing and laminating 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
15 the layers and the film are 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 and laminating the layers and the film included in the
20 perpendicular magnetic recording medium according to the invention as described above, and the depositing steps are conducted without preheating the nonmagnetic substrate.

Advantageously, the second magnetic layer is deposited by
25 sputtering under argon gas pressure of 10 mTorr to 200 mTorr.

Brief description of the drawings

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

Fig. 2 is a graph for illustrating a relationship between D_{50} value
and argon gas pressure in a perpendicular magnetic recording
medium according to the present invention.

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Aspects of embodiments of the invention

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

15 Fig. 1 is a schematic cross sectional view of a perpendicular
magnetic recording medium according to an embodiment of the
present invention. On a nonmagnetic substrate 1, nonmagnetic
underlayer 2, first magnetic layer 3, second magnetic layer 4, and
a protective layer 5 are deposited in this order. On the protective
20 layer 5, a liquid lubricant layer 6 is formed. A soft magnetic
backing layer may be provided between the nonmagnetic
substrate 1 and the nonmagnetic underlayer 2, to construct a so-
called double-layered perpendicular magnetic recording medium,
if necessary. A seed layer may be provided between the substrate
25 1 and the underlayer 2, to control alignment of the crystal grain

composing the underlayer 2.

The nonmagnetic substrate 1 may be formed of NiP-plated aluminum alloy, strengthened glass, or crystallized glass, which
5 are 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.

10 The protective film 5 consists of a thin film composed mainly of carbon, for example. The liquid lubricant layer 6 is composed of perfluoropolyether lubricant, for example.

The first magnetic layer 3 is a so-called granular magnetic
15 layer. The layer comprises crystal grains of a ferromagnetic alloy of CoCr system and nonmagnetic grain boundaries composed of nonmagnetic metal oxide or metal nitride formed between the crystal grains.

20 The magnetic layer 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 using a ferromagnetic metallic target under an
25 argon gas atmosphere containing oxygen or nitrogen.

One of the favorable materials for depositing ferromagnetic crystalline layer is an alloy of CoCr system. In order to obtain excellent magnetic characteristics and recording performance, it is
5 preferable to add at least one element selected from Pt, Ni, and Ta to the CoCr alloy.

In order to form a stable granular structure, it is preferable to form nonmagnetic grain boundaries using an oxide of at least one
10 element selected from the group consisting of Cr, Co, Si, Al, Ti, Ta, Hf, and Zr.

The thickness of the first magnetic layer 3 is preferably at least 10 nm in order to stabilize magnetization bits of the second
15 magnetic layer 4. On the other hand, the thickness of the first magnetic layer is preferably at most 30 nm in order to achieve high recording resolution by decreasing a total thickness of the magnetic recording layer consisting of the first magnetic layer 3 and the second magnetic layer 4.

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The second magnetic layer 4 is composed of an amorphous film of a rare earth element - transition metal alloy. To achieve high Ku value, in particular, the second magnetic layer 4 preferably contains at least one 3d transition metal element
25 selected from Ni, Fe, and Co, and also contains at least one rare

earth element selected from Pr, Nd, Gd, Tb, Dy, and Ho in a concentration from 10 at% to 35 at%.

Thickness of the second magnetic layer 4 is preferably at least
5 2 nm in order to hold high Ku value, and at most 15 nm in order to achieve high recording density.

The process for laminating the second magnetic layer 4 is preferably conducted by a sputtering method. Argon gas pressure
10 in the lamination process is preferably controlled in the range of 10 mTorr to 200 mTorr, more preferably in the range from 20 mTorr to 150 mTorr in order to improve recording performance in a high density recording condition.

15 Besides these conditions, the ratio a/b of the thickness a of the first magnetic layer to the thickness b of the second magnetic layer is preferably at least two in order to stabilize magnetization bits of the second magnetic layer 4. If the first magnetic layer 3 is relatively too thin and the second magnetic layer 4 is relatively
20 too thick, the magnetic energy of the second magnetic layer 4 is dominant, and therefore, the contribution of the first magnetic layer 3 to the magnetization behavior of the whole magnetic layer consisting of the first and the second magnetic layers relatively diminishes, reducing the effect that would be brought about by
25 the double-layer structure of the magnetic layer.

Next, the nonmagnetic underlayer 2 will be described. The nonmagnetic underlayer 2 may be formed using a material that appropriately control crystal orientation, grain size, and grain boundary segregation of impurities in the first magnetic layer 3. To appropriately control alignment of the crystal orientation in the first magnetic layer, in particular, the underlayer is preferably composed of a metal with a hcp crystal structure selected from Ti, Re, Ru, and Os or an alloy containing at least one metal selected from Ti, Re, Ru, and Os.

Although thickness of the nonmagnetic underlayer 2 is not limited to a specific range, the minimum thickness required by controlling the crystal structure of the first magnetic layer 3 is desirable in order to enhance recording resolution in the case of a double-layered perpendicular magnetic recording medium and to increase productivity of the perpendicular magnetic recording medium.

A perpendicular magnetic recording medium having above-described structure exhibits excellent magnetic performance even if the process of heating the substrate is omitted. The substrate heating process has been requisite for manufacturing a conventional magnetic recording medium. The manufacturing process has been simplified and the manufacturing cost has been

reduced by the present invention. Because substrate heating is unnecessary, a nonmagnetic substrate of plastic resin such as polycarbonate or polyolefin can be employed.

5 Some specific examples of preferred embodiments of the present invention will be described below. The examples are merely intended to illustrate the spirit of the present invention, and shall not limit the scope of the invention.

10 Example 1

 The nonmagnetic substrate used was a polycarbonate substrate of 3.5" disk shape made by injection molding. The substrate was cleaned and mounted on a substrate holder in a sputtering device. Omitting a step of preheating the substrate
15 before deposition processes, a nonmagnetic underlayer composed of ruthenium (Ru) of 50 nm thickness was deposited by sputtering under argon gas pressure of 5 mTorr.

 Subsequently, a first magnetic layer having a thickness in the
20 range from 5 to 40 nm was deposited by 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. Then, a second magnetic layer having a thickness in the range from 1 to 20 nm was deposited by RF sputtering method using a target of $\text{Tb}_{20}\text{Co}_{80}$
25 under argon gas pressure of 50 mTorr.

After depositing a carbon protective layer having thickness of 10 nm by RF sputtering method, the resulted substrate was taken out from the sputtering device. A liquid lubricant was coated to a thickness of 1.5 nm on the carbon protective layer. Thus, a perpendicular magnetic recording medium having structure shown in Fig. 1 was produced.

Table 1 summarizes characteristics of the thus laminated set of perpendicular magnetic recording media. The table includes the thickness a of the first magnetic layer, the thickness b of the second magnetic layer, the ratio a/b of the thickness a of the first magnetic layer and the thickness b of the second magnetic layer, the indicator D_{50} of the maximum magnetic recording density, which is defined by a recording density at which the output is a half of the output of an isolated pulse waveform, and an output signal ratio as an index of thermal stability, which is defined by a ratio of a regenerative output at 1000 seconds after writing to a regenerative output immediately after writing.

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The D_{50} and the output signal ratio were measured by using a spinning stand tester and a GMR head with a writing track width 1 μ m, a gap length 0.25 μ m, a regenerative track width 0.7 μ m, and a shield gap length of 0.12 μ m. The head flying height was about 20 nm.

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As is apparent from Table 1, both high density magnetic recording and excellent thermal stability have been achieved in the perpendicular magnetic recording media in which the thickness of the first magnetic layer is from 10 to 30 nm, the thickness of the second magnetic layer is from 2 to 15 nm, and the ratio a/b of the first magnetic layer thickness a to the second magnetic layer thickness b is two or larger.

Table 1

thickness of first magnetic layer a (nm)	thickness of second magnetic layer b (nm)	a/b	D50 (kFCI)	regeneration output ratio (%)
5	2	2.5	83	65
5	5	1	52	90
10	1	10	160	62
10	2	5	213	95
10	5	2	244	98
10	10	1	66	99
20	1	20	173	73
20	2	10	222	97
20	5	4	266	99
20	10	2	270	100
20	15	1.3	54	99
20	20	1	32	100
30	2	15	198	97
30	5	6	219	99
30	10	3	248	100
30	15	2	210	98
40	2	20	181	96
40	10	4	170	98
40	20	2	147	97

Example 2

A set of perpendicular magnetic recording media having structure as shown in Fig. 1 was produced using various materials for the second magnetic layer. The thickness of the first magnetic layer was 20 nm, and the thickness of the second magnetic layer was 5 nm. The conditions for the lamination process were the same as those in Example 1 except the material for the second magnetic layer.

Table 2 summarizes the materials for laminating the second magnetic layer and the coercive force H_c of thus laminated perpendicular magnetic recording media. The coercive force H_c was measured using a vibrating sample magnetometer applying a magnetic field perpendicular to the film surface.

As the results in Table 2 show, it is preferable to laminate the second magnetic layer using a material that contains at least one 3d transition metal selected from Ni, Fe, and Co, and also at least one rare earth element selected from Pr, Nd, Gd, Tb, Dy, and Ho in a concentration from 10 at% to 35 at%.

Table 2

material of second magnetic layer	H _c (Oe)
Co-20%Ce	<100
Co-20%Pr	5100
Co-20%Nd	4280
Co-20%Pm	<100
Co-20%Sm	<100
Co-20%Eu	<100
Co-20%Gd	3090
Co-5%Tb	620
Co-20%Tb	8230
Co-30%Tb	6550
Co-40%Tb	810
Co-10%Fe-15%Tb	7240
Co-20%Dy	6970
Co-20%Ho	3510
Co-20%Er	<100
Co-20%Tm	<100

5 Example 3

A set of perpendicular magnetic recording media having structure as shown in Fig. 1 was produced laminating the second magnetic layer under various argon gas pressures. The thickness of the first magnetic layer was 20 nm and the thickness of the second magnetic layer was 10 nm. The conditions for the production process were the same as those in Example 1 except the argon gas pressure in the step of laminating the second magnetic layer.

Fig.2 is a graph showing a relation between D_{50} of the thus produced perpendicular magnetic recording media and the argon gas pressure in the lamination process. As the result of Fig. 2 shows, it is preferable to control argon gas pressure in the range from 10 mTorr to 200 mTorr, more preferably from 20 mTorr to 150 mTorr, for enhancement of recording performance in high density recording.

10 Example 4

A set of perpendicular magnetic recording media having structure as shown in Fig. 1 was produced laminating the nonmagnetic underlayer having thickness of 50 nm using various materials. The first magnetic layer having thickness of 20 nm and the second magnetic layer having thickness of 10 nm were deposited on the nonmagnetic underlayer. The conditions for the production process were the same as those in Example 1 except the materials of the nonmagnetic underlayer.

20 Table 3 shows a result of evaluating crystallinity of the first magnetic layer of thus produced perpendicular magnetic recording media by means of X-ray diffraction method. The value $\Delta \theta_{50}$ is a half-width of a rocking curve of hcp (002) diffraction line obtained with the first magnetic layer. Values for nonmagnetic underlayers of Ta and Cr having bcc structure are also shown for

comparison.

Table 3 shows that $\Delta \theta_{50}$ values in the cases employing a nonmagnetic underlayer made of the various materials having hcp structure are suppressed small as compared with $\Delta \theta_{50}$ values in the cases employing a nonmagnetic underlayer made of Ta and Cr having bcc structure. The X-ray diffraction peak has become sharp as a result of enhancement of c-axis alignment of the crystal grains composing the first magnetic layer

Table 3

material of nonmagnetic underlayer	crystal structure of underlayer	$\Delta \theta_{50}$ (degree)
Ru	hcp	5.6
Re	hcp	5.2
Os	hcp	6.1
Ti	hcp	7.9
Ru-20%W	hcp	5.0
Ti-10%Cr	hcp	7.2
Ta	bcc	25.0
Cr	bcc	19.3

Advantageous Effect of the invention

As described so far, in the perpendicular magnetic recording medium according to the present invention, the magnetic layer consists of two layers. The first magnetic layer that is a lower layer comprises crystal grains of a ferromagnetic alloy of CoCr

system and nonmagnetic grain boundaries of mainly oxide or nitride. The second magnetic layer that is an upper layer comprises an amorphous film of a rare earth - transition metal alloy. Thickness of the first magnetic layer is in the range from 10 nm to 30 nm, and thickness of the second magnetic layer is in the range of 2 nm to 15 nm. In addition, the ratio a/b of the first magnetic layer thickness a to the second magnetic layer thickness b is at least two. A perpendicular magnetic recording medium having such structure has been demonstrated to exhibit a favorable electromagnetic conversion characteristic under a high recording density condition and excellent thermal stability.

Alignment of the first magnetic layer can be favorably controlled by making the nonmagnetic underlayer using a metal selected from Ti, Re, Ru, and Os having hcp crystal structure, or an alloy containing at least an element selected from Ti, Re, Ru, and Os.

A high K_u value is obtained and thermal stability is improved by making the second magnetic layer to contain at least a 3d transition metal selected from Ni, Fe, and Co, and also at least a rare earth element selected from Pr, Nd, Gd, Tb, Dy, and Ho in a concentration of from 10 at% to 35 at%.

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The recording performance in high density recording is improved by controlling the argon gas pressure in the step of depositing the second magnetic layer in the range from 10 mTorr
5 to 200 mTorr, more preferably from 20 mTorr to 150 mTorr.

Since satisfactory performance can be achieved by manufacturing a perpendicular magnetic recording medium having the above-described structure under the above-described conditions, preheating step becomes unnecessary, leading to
10 simplify the manufacturing process and achieve reduction in production cost. At the same time, an inexpensive plastic substrate may be employed.

Claims

1. A perpendicular magnetic recording medium comprising:

a nonmagnetic substrate; and

5 at least a nonmagnetic underlayer, a first magnetic layer, a second magnetic layer, a protective layer, and a liquid lubricant layer sequentially laminated on said substrate; wherein

said first magnetic layer comprises crystal grains of a ferromagnetic Co-Cr alloy system and nonmagnetic grain
10 boundaries mainly composed of oxide or nitride, and a thickness a of said first magnetic layer is from 10 nm to 30 nm; and

said second magnetic layer comprises an amorphous alloy composed of rare earth element(s) and transition metal element(s), and a thickness b of said second magnetic layer is from 2 nm to 15
15 nm; wherein

a ratio a/b of said thickness a to said thickness b is at least two.

2. A perpendicular magnetic recording medium according to
20 claim 1, wherein

said nonmagnetic underlayer is composed of a metal or an alloy having hexagonal closest-packed crystal structure,

said metal being one element selected from a group consisting of Ti, Re, Ru, and Os, and

25 said alloy containing at least one element selected from a

group consisting of Ti, Re, Ru, and Os.

3. A perpendicular magnetic recording medium according to
5 claim 1, wherein

said second magnetic layer contains at least one metal
element selected from a group consisting of Ni, Fe, and Co, and at
least one element selected from a group consisting of Pr, Nd, Gd,
Tb, Dy, and Ho in a concentration in a range from 10 at% to 35
10 at%.

4. A perpendicular magnetic recording medium according to
claim 1, wherein

said nonmagnetic substrate is formed of a plastic resin.
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5. A method for manufacturing a perpendicular magnetic
recording medium comprising steps of:

depositing a nonmagnetic underlayer on a nonmagnetic
substrate;

20 depositing a first magnetic layer that comprises crystal grains
of a ferromagnetic Co-Cr alloy system and nonmagnetic grain
boundaries mainly composed of oxide or nitride, and a thickness a
of said first magnetic layer is from 10 nm to 30 nm;

depositing a second magnetic layer that comprises an
25 amorphous alloy composed of rare earth element(s) and transition

metal element(s), and a thickness b of said second magnetic layer is from 2 nm to 15 nm;

depositing a protective film; and

5 laminating a liquid lubricant layer; wherein

a ratio a/b of said thickness a to said thickness b is at least two, and

each of said depositing steps is conducted under a temperature of said substrate lower than 80°C.

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6. A method for manufacturing a perpendicular magnetic recording medium according to claim 5, wherein said method comprises a step of laminating said second magnetic layer by a sputtering method under an argon gas pressure in the range from
15 10 mTorr to 200 mTorr.

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

20 depositing a nonmagnetic underlayer on a nonmagnetic substrate;

depositing a first magnetic layer that comprises crystal grains of a ferromagnetic Co-Cr alloy system and nonmagnetic grain boundaries mainly composed of oxide or nitride, and a thickness a of said first magnetic layer is from 10 nm to 30 nm;

25 depositing a second magnetic layer that comprises an

amorphous alloy composed of rare earth element(s) and transition metal element(s), and a thickness b of said second magnetic layer is from 2 nm to 15 nm;

- 5 depositing a protective film; and
 laminating a liquid lubricant layer; wherein
 a ratio a/b of said thickness a to said thickness b is at least
two, and
 said depositing steps are conducted without preheating said
10 nonmagnetic substrate.

8. A method for manufacturing a perpendicular magnetic recording medium according to claim 7, wherein said method
15 comprises a step of laminating said second magnetic layer by a sputtering method under an argon gas pressure in the range from 10 mTorr to 200 mTorr.

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