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Perpendicular magnetic recording medium



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Technical field of the invention

The present invention relates to a perpendicular magnetic
5 recording medium, and in particular, to a perpendicular magnetic
recording medium exhibiting excellent effect to suppress spike noises.

Background of the invention

A perpendicular magnetic recording system is drawing attention
10 in place of a conventional longitudinal magnetic recording system as
a technique to achieve high density magnetic recording. In particular,
a double layer perpendicular magnetic recording medium is known to
be favorable for a perpendicular magnetic recording medium
attainable high density recording. The double layer perpendicular
15 magnetic recording medium is provided with a soft magnetic film
called a soft magnetic backing layer beneath a magnetic recording
layer that carries information records. The soft magnetic backing
layer facilitates passing through of magnetic flux generated by a
magnetic head. In the double layer perpendicular magnetic recording
20 medium, the intensity and gradient of the magnetic field generated
by the magnetic head is enhanced and resolution of recording is
improved. In addition, leakage flux from such a medium is also
increased. Consequently, high density recording is possible in the
double layer perpendicular magnetic recording medium.

A perpendicular magnetic recording medium with such structure has a problem of media noise including spike noises, which are known attributable to magnetic domain walls formed in the soft magnetic backing layer. Therefore, the reduction of noises in a perpendicular magnetic recording medium requires restriction of domain wall formation in the soft magnetic backing layer.

The control of the domain wall formation in the soft magnetic backing layer is disclosed by Japanese Unexamined Patent Application Publication Nos. H6-180834 and H10-214719. The references propose a method to form a ferromagnetic layer(s) of cobalt alloy, for example, on or beneath a soft magnetic backing layer and magnetize the ferromagnetic layer(s) in a desired direction, and a method to form an antiferromagnetic thin film(s) on or beneath a soft magnetic layer(s) and magnetize the soft magnetic layer(s) in one fixed direction by taking advantage of exchange coupling between the antiferromagnetic film(s) and the soft magnetic layer(s). In these methods, the method to control domain walls by exchange coupling between an antiferromagnetic film and soft magnetic backing layer quite effectively inhibits formation of domain walls in the soft magnetic backing layer if exchange coupling is sufficiently performed.

Problem to be solved by the invention

However, in order to obtain sufficient exchange coupling, heat

treatment before and after deposition and complicated layer structure are needed in most cases in this method, which is particularly disadvantageous to mass production. The above-mentioned Japanese Unexamined Patent Application Publication No. H10-214719, for
5 example, remarks that heat treatment after deposition is necessary for sufficient exchange coupling.

The inventors of the present invention have studied and found that fixed magnetic domain walls may be formed even after
10 depositing an antiferromagnetic film and a soft magnetic backing layer, and conducting heat treatment. For example, when a substrate is heated to deposit a magnetic recording layer, if the temperature exceeds the blocking temperature at which an antiferromagnetic film loses the antiferromagnetic characteristic, and if an external
15 magnetic field is not applied in an appropriate direction, the direction of magnetization in the antiferromagnetic film may change, resulting in domain wall formation.

In view of the above, an object of the present invention is to
20 provide a perpendicular magnetic recording medium that achieves remarkable effect to suppress spike noises.

Means to solve the problem

To achieve the object, the invention recited in claim 1 is a

perpendicular magnetic recording medium comprising a soft magnetic backing layer, a nonmagnetic underlayer, a magnetic recording layer, and a protective film sequentially laminated on a nonmagnetic substrate, wherein the soft magnetic backing layer comprises

5 alternately laminated nonmagnetic metal layers at most 5 nm thick and soft magnetic layers at least 10 nm thick, a top layer and a bottom layer of the backing layer being soft magnetic layers, and two of the soft magnetic layers sandwiching one of the nonmagnetic metal layers have magnetization directions parallel to planes of the soft

10 magnetic layers and different from each other by 180 degrees, and the two of the soft magnetic layers are antiferromagnetically coupled.

The invention recited in claim 2 is a perpendicular magnetic recording medium according to claim 1, wherein a direction of easy

15 magnetization of the soft magnetic layers is in a plane parallel to the substrate surface and in the direction perpendicular to a running direction of a magnetic head at a time of reading and writing.

The invention recited in claim 3 is a perpendicular magnetic

20 recording medium according to claim 1 or claim 2, wherein the nonmagnetic metal layer is composed of a material mainly consisting of a metal selected from the group consisting of Cu, Ru, Rh, Pd, Re, Os, Ir, Pt, and Au or an alloy of one or more of the metals from the group.

The invention recited in claim 4 is a perpendicular magnetic recording medium according to any one of claims 1 through 3, wherein a thickness of the nonmagnetic metal layer is in a range from 0.3 nm to 1.2 nm or in a range from 1.7 nm to 3.0 nm.

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The invention recited in claim 5 is a perpendicular magnetic recording medium according to any one of claims 1 through 4, wherein the soft magnetic backing layer essentially consists of three layers of first soft magnetic layer, a nonmagnetic metal layer, and a
10 second soft magnetic layer laminated in this order.

The invention recited in claim 6 is a perpendicular magnetic recording medium according to claim 5, wherein the first soft magnetic layer and the second soft magnetic layer have substantially
15 equal saturation magnetic flux density B_s and substantially equal thickness.

The invention recited in claim 7 is a perpendicular magnetic recording medium according to any one of claims 1 through 4,
20 wherein the soft magnetic backing layer essentially consists of five layers of first soft magnetic layer, a first nonmagnetic metal layer, a second soft magnetic layer, a second nonmagnetic metal layer, and a third soft magnetic layer laminated in this order.

The invention recited in claim 8 is a perpendicular magnetic recording medium according to claim 7, wherein the first soft magnetic layer, the second soft magnetic layer, and the third soft magnetic layer have substantially equal saturation magnetic flux density B_s and a sum of a thickness of the first soft magnetic layer and a thickness of the third soft magnetic layer is substantially equal to a thickness of the second soft magnetic layer.

The invention recited in claim 9 is a perpendicular magnetic recording medium according to any one of claims 1 through 8, wherein a thickness of each of the soft magnetic layers is in the range from 30 nm to 150 nm.

Brief description of drawings

Fig. 1 illustrates an example of construction of a perpendicular magnetic recording medium according to the present invention.

Fig. 2 illustrates a soft magnetic backing layer having a three layer structure.

Fig. 3 illustrates a soft magnetic backing layer having a five layer structure.

Fig. 4 shows a magnetization curve (M-H loop) of a soft magnetic backing layer with a ruthenium film thickness of 2.3 nm, measured in the direction of the disk radius by a vibrating sample magnetometer (VSM).

Fig. 5 shows H_{in} , an absolute value of the maximum applied magnetic field for sustaining null magnetization, as a function of thickness of the ruthenium film.

Fig. 6 shows number of magnetic domain walls as a function of
5 ruthenium film thickness, observed on the whole surface of a disk by means of magnetic Kerr effect.

Aspects of embodiments of the present invention

Some aspects of preferred embodiment of the invention will be
10 described in the following with reference to accompanying drawings.

Fig. 1 illustrates an example of construction of a perpendicular magnetic recording medium according to the present invention. The perpendicular magnetic recording medium has laminated structure
15 comprising a soft magnetic backing layer 12, a nonmagnetic underlayer 13, a magnetic recording layer 14, and a protective layer 15 sequentially formed on a nonmagnetic substrate 11. A liquid lubricant layer 16 is formed on the protective film 15.

20 The nonmagnetic substrate 11 can be formed of Ni-P plated aluminum alloy, strengthened glass, or crystallized glass, which are used in a common magnetic recording medium. In addition, a substrate can be made by injection-molding plastic resin such as polycarbonate or polyolefin.

The soft magnetic backing layer 12 has lamination structure comprising alternately laminated nonmagnetic metal layer at most 5 nm thick and soft magnetic layers at least 10 nm thick. The top layer and the bottom layer of the backing layer are soft magnetic layers.

- 5 Two soft magnetic layers sandwiching a nonmagnetic metal layer necessarily have magnetization directions parallel to the plane of the soft magnetic layers and different from each other by 180 degree, and the two soft magnetic layers are antiferromagnetically coupled.

- 10 Fig. 2 illustrates a lamination structure of the soft magnetic backing layer 12 in three layer structure. Fig. 3 illustrates a lamination structure of the soft magnetic backing layer 12 in five layer structure. The structure in Fig. 2 comprises a nonmagnetic metal layer 22 and a second soft magnetic layer 23 laminated on a
- 15 first soft magnetic layer 21. The structure in Fig. 3 comprises a first nonmagnetic metal layer 32, a second soft magnetic layer 33, a second nonmagnetic metal layer 34, and a third soft magnetic layer 35 sequentially laminated on a first soft magnetic layer 31.

- 20 In order for the two soft magnetic layers sandwiching the nonmagnetic metal layer to have magnetization directions parallel to the plane of the soft magnetic layer and different from each other by 180 degrees, and for the two magnetic layers to be antiferromagnetically coupled, the nonmagnetic metal layer is

preferably composed of a material mainly consisting of a metal selected from Cu, Ru, Rh, Pd, Re, Os, Ir, Pt, and Au or an alloy of each of these metals, and further, a thickness of the nonmagnetic metal layer is preferably in the range from 0.3 nm to 1.2 nm or in the
5 range from 1.7 nm to 3.0 nm.

When a direction of easy magnetization of the soft magnetic layers is in a plane parallel to the substrate surface and in the direction perpendicular to the running direction of the magnetic head
10 during reading or writing, that is the direction of a track, the strength and the gradient of the magnetic field generated by the magnetic head can be effectively enhanced.

It is desirable to control the direction of easy magnetization by
15 applying magnetic field in the event of formation of the soft magnetic layer or by heat treatment accompanied by magnetic field application after the formation of the soft magnetic layer.

There is no upper limit in a number of repetitions of the
20 alternating lamination of the soft magnetic layer and the nonmagnetic metal layer. Although stability in magnetization improves by increasing repetition number, the three layer structure of Fig. 2 or the five layer structure of Fig. 3 is preferable considering productivity in mass production.

There is no special limitation on a thickness and saturation magnetic flux density of the soft magnetic layer in the three layer structure or in the five layer structure. However, in order to reduce magnetostatic energy at the end regions of the nonmagnetic substrate, that is, inner and outer edge regions in the case of disk substrate, to a sufficiently low level and prevent a magnetic domain wall from forming, the soft magnetic layers 21 and 23 in the soft magnetic backing layer of three layer structure shown in Fig. 2 preferably have substantially equal saturation magnetic flux density B_s and substantially equal thickness. In the soft magnetic backing layer of five layer structure shown in Fig. 3, the three soft magnetic layers 31, 33 and 35 preferably have substantially equal saturation magnetic flux density B_s , and a sum of the thickness of the top and bottom soft magnetic layers 31 and 35 is substantially equal to the thickness of the middle soft magnetic layer 33.

Concerning thickness of each soft magnetic layer, at least 10 nm can present necessary soft magnetic performance, and 30 nm or more is desirable to sufficiently enhance intensity and sharpness of the head magnetic field. On the other hand, at most 150 nm is desirable because strength of antiferromagnetic coupling lowers with increase of the thickness.

A material for use in the soft magnetic layer may be selected

from commonly used NiFe alloy, FeSiAl alloy, amorphous cobalt alloy, and fine particle precipitation type FeTaC alloy.

A soft magnetic backing layer as constructed above, comprises
5 nonmagnetic metal layers at most 5 nm thick and soft magnetic
layers at least 10 nm thick being alternately laminated, in which the
top layer and the bottom layer are soft magnetic layers. The direction
of magnetization in the two soft magnetic layers sandwiching a
nonmagnetic metal layer are parallel to the plane of the soft magnetic
10 layer and different from each other by 180 degrees, and the two soft
magnetic layers are antiferromagnetically coupled. Consequently, a
magnetic domain wall is not formed on application of external
magnetic field, providing a soft magnetic backing layer that does not
generate spike noises. The magnetization in the soft magnetic layers
15 sandwiching the nonmagnetic metal layer are antiparallel and
antiferromagnetically coupled, and each direction of magnetization
does not change on application of external magnetic field of several
tens of oersted (Oe). If more intense magnetic filed is applied, when
the field is removed, the magnetization in the two soft magnetic
20 layers restores original state before the application of the magnetic
field, which is the state where the magnetizations of the two layers
are coupled in antiparallel. Therefore, a magnetic domain wall is
hardly produced in that circumstance.

Although free magnetic poles develop and magnetostatic energy tends to become large in end regions of a nonmagnetic substrate in a conventional system, that is, inner and outer edge regions in the case of disk substrate, the layer structure of the invention allows

5 circulation of magnetic flux through upper and lower soft magnetic layers to suppress the magnetostatic energy, thus generation of a magnetic domain wall is inhibited even in these end regions. When direction of easy magnetization of the soft magnetic layer is in a plane parallel to the substrate surface and in the direction
10 perpendicular to the running direction of the magnetic head during reading and writing, that is, if the direction of easy magnetization coincides with the radial direction in the case of a nonmagnetic substrate of a disk, the intensity and gradient of the magnetic field generated by the magnetic head can be effectively enhanced.

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The soft magnetic layers and the nonmagnetic metal layers can be formed by common methods for forming a thin film, such as a sputtering method, or a vacuum deposition method. A seed layer may be appropriately provided beneath the bottom soft magnetic layer for
20 the purpose of improving adhesion with the substrate.

A nonmagnetic underlayer 13 is provided for the major purpose of controlling crystal alignment and grain size of the magnetic recording layer 14. Material and structure of the underlayer are

selected corresponding to material of the magnetic recording layer 14. When the magnetic layer 14 is composed of a CoCrPt alloy, for example, the material of the underlayer can be selected from Ti alloy, CoCr alloy, Pt, and Ru.

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Although a thickness of the nonmagnetic underlayer is not limited to any special value, the thickness is preferably at least 5 nm for structure control of the magnetic recording layer 14 and at most 30 nm for confining the distance between the magnetic head and the soft magnetic backing layer 12 within a necessary level. The nonmagnetic underlayer 13 may consist of a multiple of layers that are different in material or structure for further precise structure control of the magnetic recording layer.

15 The magnetic recording layer 14 can be appropriately composed of semi-hard magnetic material having the axis of easy magnetization perpendicular to the film surface. Examples of the material include CoCrPt alloy, a Co/Pt multilayered film, a TbCo amorphous film, and a composite film consisting of two of these three kinds of films.

20 Although thickness of the magnetic recording layer 14 is not limited to any special value, at least 5 nm is desired for sufficient output of head reading out and at most 50 nm is desired for confining the distance between the magnetic head and the soft magnetic backing layer 12 within a necessary level.

The protective layer 15 can be a thin film composed of mainly carbon. The liquid lubricant layer 16 can be composed of perfluoropolyether lubricant.

5 Each of the nonmagnetic underlayer 13, the magnetic recording layer 14, and the protective layer 15 can be formed by a desired method for thin film formation such as a sputtering method, a CVD method, a vacuum deposition method, or a plating method.

10 Some examples of preferred embodiment of the invention will be described below.

Example 1

A nonmagnetic substrate of a strengthened glass disk with 3.5" diameter was used. After cleaning, the substrate was introduced into the sputtering apparatus. A soft magnetic layer 50 nm thick of $\text{Co}_{87}\text{Zr}_5\text{Nb}_8$, a nonmagnetic metal layer of Ru having one of the thicknesses varied in the range from 0 to 4 nm, and a soft magnetic layer 50 nm thick of $\text{Co}_{87}\text{Zr}_5\text{Nb}_8$, were sequentially formed by a DC magnetron sputtering method under an argon gas pressure of 5 mTorr and taken out from the apparatus to obtain a soft magnetic backing layer of three layer structure shown in Fig. 2. In the processes of depositing the soft magnetic layers, leakage magnetic flux from the target was applied in the direction of the disk radius.

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Fig. 4 shows a magnetization curve (M-H loop) of the thus formed soft magnetic backing layer with the ruthenium film having thickness of 2.3 nm in the direction of the disk radius measured by a vibrating sample magnetometer (VSM). Fig. 4 also shows schematically the
5 direction of magnetization in the upper and lower layers.

In the regions of applied magnetic field larger than 60 Oe in positive and negative directions, the directions of magnetization in the both upper and lower soft magnetic layers are aligned in the
10 direction of the applied magnetic field. In the region of reduced applied magnetic field of between +20 Oe and -20 Oe, the measured values of magnetization were substantially zero because the magnetization in the upper and lower soft magnetic layers couples antiferromagnetically through the ruthenium layer and aligns in
15 antiparallel, resulting in cancellation of the magnetization in the two layers. The region of applied magnetic field in which measured magnetization is substantially zero is a measure of strength of the coupling between the upper and lower soft magnetic layers. The
20 measure of the coupling strength H_{in} is defined by an absolute value of the maximum applied magnetic field within which measured magnetization is substantially zero.

Fig. 5 shows the H_{in} value, an absolute value of the maximum applied magnetic field for sustaining null magnetization, as a

function of thickness of the ruthenium film. When the ruthenium film thickness is zero, which means that the upper and lower soft magnetic layers are directly laminated without an intervening layer, H_{in} is zero, which means the magnetization in the upper and lower soft magnetic layers aligns in parallel regardless of the magnitude of the applied magnetic field. In the regions of the ruthenium layer thickness of from 0.3 nm to 1.2 nm and from 1.7 nm to 3.0 nm, finite values of H_{in} were obtained indicating that the magnetization in the upper and lower soft magnetic layers aligns in antiparallel and stabilizes in the applied magnetic field up to H_{in} .

Fig. 6 shows number of magnetic domain walls as a function of ruthenium film thickness, observed by magnetic Kerr effect on the whole surface of a disk. Generation of a domain wall is inhibited in the same range of ruthenium film thickness as the range in which H_{in} value was finite in Fig. 5. Thus, it has been demonstrated that generation of a domain wall is inhibited in a perpendicular magnetic recording medium according to the present invention.

Example 2

A series of soft magnetic backing layers having the layer structure of Fig. 2 were formed in the same manner as in Example 1 except that the nonmagnetic metal layers were 0.6 nm thick and composed of various materials. Table 1 summarizes a relation

between the material of the nonmagnetic metal layer and the H_{in} value.

Table 1

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nonmagnetic metal layer	H_{in} (Oe)
Cu	16
Ru	39
Pd	21
Re	35
Pt	10
Au	5
C	0
Ti	0
Si	0

Table 1 shows that the H_{in} values vary depending on the material. Finite H_{in} values were observed for Cu, Ru, Pd, Re, Pt, and Au, while the H_{in} value was zero for C, Ti, and Si.

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Advantageous Effect of the invention

As described so far, a soft magnetic backing layer in a perpendicular magnetic recording medium according to the present invention has lamination structure comprising nonmagnetic metal
15 layers at most 5 nm thick and soft magnetic layers at least 10 nm thick being alternately laminated, in which the top layer and the bottom layer are soft magnetic layers. Further, the directions of

magnetization in the two soft magnetic layers sandwiching a nonmagnetic metal layer are parallel to the plane of the soft magnetic layer and different from each other by 180 degrees, and the two soft magnetic layers are antiferromagnetically coupled. Consequently, a magnetic domain wall is not formed on application of external magnetic field, providing a soft magnetic backing layer that does not generate spike noises. Therefore, a perpendicular magnetic recording medium has been provided that exhibits excellent effect to suppress generation of spike noises.

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Claims

1. A perpendicular magnetic recording medium comprising a soft magnetic backing layer, a nonmagnetic underlayer, a magnetic recording layer, and a protective film sequentially laminated on a nonmagnetic substrate, wherein the soft magnetic backing layer comprises alternately laminated nonmagnetic metal layers at most 5 nm thick and soft magnetic layers at least 10 nm thick, a top layer and a bottom layer of the backing layer being soft magnetic layers, and two of the soft magnetic layers sandwiching one of the nonmagnetic metal layers have magnetization directions parallel to planes of the soft magnetic layers and different from each other by 180 degrees, and the two of the soft magnetic layers are antiferromagnetically coupled.
2. A perpendicular magnetic recording medium according to claim 1, wherein a direction of easy magnetization of the soft magnetic layers is in a plane parallel to the substrate surface and in the direction perpendicular to a running direction of a magnetic head during reading and writing.
3. A perpendicular magnetic recording medium according to claim 1 or claim 2, wherein the nonmagnetic metal layer is composed of a material mainly consisting of a metal selected from the group consisting of Cu, Ru, Rh, Pd, Re, Os, Ir, Pt, and Au or an alloy including one or more of the metals from the group.
4. A perpendicular magnetic recording medium according to any

one of claims 1 through 3, wherein a thickness of the nonmagnetic metal layer is in a range from 0.3 nm to 1.2 nm or in a range from 1.7 nm to 3.0 nm.

5 5. A perpendicular magnetic recording medium according to any one of claims 1 through 4, wherein the soft magnetic backing layer essentially consists of three layers of first soft magnetic layer, a nonmagnetic metal layer, and a second soft magnetic layer laminated in this order.

10 6. A perpendicular magnetic recording medium according to claim 5, wherein the first soft magnetic layer and the second soft magnetic layer have substantially equal saturation magnetic flux density and substantially equal thickness.

15 7. A perpendicular magnetic recording medium according to any one of claims 1 through 4, wherein the soft magnetic backing layer essentially consists of five layers of first soft magnetic layer, a first nonmagnetic metal layer, a second soft magnetic layer, a second nonmagnetic metal layer, and a third soft magnetic layer laminated in this order.

20 8. A perpendicular magnetic recording medium according to claim 7, wherein the first soft magnetic layer, the second soft magnetic layer, and the third soft magnetic layer have substantially equal saturation magnetic flux density and a sum of a thickness of the first soft magnetic layer and a thickness of the third soft magnetic layer is substantially equal to a thickness of the second soft magnetic layer.

9. A perpendicular magnetic recording medium according to any one of claims 1 through 8, wherein a thickness of each of the soft magnetic layers is in the range from 30 nm to 150 nm.