

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 same, in particular, to a perpendicular magnetic recording medium that exhibits high recording density and excellent read-write characteristics, and a method for manufacturing such a magnetic
10 recording medium.

Background of the invention

Personal computers and work stations in recent years are provided with a magnetic recording device having large capacity and
15 a small size. On this background, higher recording density is needed by the magnetic disks.

Magnetic recording systems practically used at present employ an in-plane or longitudinal magnetic recording system, in which the
20 axis of easy magnetization is parallel to the plane of the magnetic recording medium. Enhancement of recording density in this longitudinal magnetic recording system needs reduction of a product of remanent magnetization B_r and thickness t of the magnetic film of the recording medium, as well as increase in coercive force H_c .

Accordingly, efforts are being made to reduce the film thickness and control the grain size of the magnetic film.

However, the longitudinal magnetic recording system involves a
5 problem of decrease in readback signal output due to decrease of residual magnetic flux density caused by enhancement of demagnetizing field which results from shortened length of a bit. In addition, a problem of thermal fluctuation becomes significant with minimization of grain size and reduction of thickness of the magnetic
10 film. In these circumstances, there is a perception that achieving higher density is technically difficult in the magnetic disks based on the longitudinal magnetic recording system.

On the other hand, in order to solve these problems and to
15 improve areal recording density, studies are being made on a perpendicular magnetic recording system. A magnetic recording medium based on the perpendicular magnetic recording system is designed so that the axis of easy magnetization of the magnetic film orients perpendicularly to the substrate surface. Accordingly,
20 adjacent magnetization in a transition region of magnetization does not oppose each other, and even short bit length preserves stable magnetization and magnetic flux does not decrease, thus the perpendicular magnetic recording system is appropriate to a magnetic recording method for a high density magnetic recording

medium.

The perpendicular magnetic recording medium, despite these advantages, involves a disadvantage of high media noise due to
5 relatively large magnetic interaction between magnetic particles in the magnetic layer, which is caused by insufficient segregation of nonmagnetic substance to the grain boundary region. Therefore, it is required to develop a material control technique for promoting the grain boundary segregation of nonmagnetic substance, in order to
10 reduce media noise and enhance SN ratio. High recording density has to be achieved accompanying the reduction of noises and improvement of the SN ratio.

A structure of a known perpendicular magnetic recording
15 medium comprises a soft magnetic backing layer formed on a nonmagnetic substrate of aluminum or glass, an underlayer for perpendicular orientation of a magnetic layer formed on the soft magnetic backing layer, a perpendicular magnetic recording layer on the underlayer, and a protective layer formed thereon. Such a
20 medium is called "a double layer perpendicular magnetic recording medium". (See, for example, Japanese Unexamined Patent Application Publication No. 2002-203306.) Studies have been made on perpendicular magnetic recording layer including perpendicular magnetization films of cobalt- base alloys such as Co-Cr, Co-Cr-Ta,

and Co-Cr-Pt, multilayered lamination perpendicular magnetization films such as Pt/Co and Pd/Co, and amorphous perpendicular magnetization films such as Tb-Co and Tb-Fe-Co. Among them, the multilayered lamination perpendicular magnetization films including
5 Pt/Co and Pd/Co exhibit large perpendicular magnetic anisotropy, high thermal stability, large coercive force, and ease to achieve a squareness ratio approximately 1.0. Therefore, this type of perpendicular magnetization film is being studied extensively in an attempt to approach to a high recording density medium in the next
10 generation. (See, for example, Japanese Unexamined Patent Application Publication Nos. 2002-025032 and 2001-155329.)

Problems to be solved by the invention

The reduction of media noise in a perpendicular magnetic
15 recording medium having known multilayer structure is, however, not satisfactory yet, and more reduction of media noise and further improvement in read-write characteristics are required.

The present invention has been made in view of this problem,
20 and an object of the present invention is to reduce media noise and to provide a perpendicular magnetic recording medium performing high recording density and excellent read-write characteristics, and also to provide a method for manufacturing such a medium.

Means to solve the problem

In order to achieve the above objectives, the present invention takes the featured means as follows. A perpendicular magnetic recording medium according to the present invention comprises a
5 magnetic layer having a multilayered lamination structure composed by alternately laminating a mainly-cobalt layer of a cobalt layer and a noble metal layer of a platinum or palladium layer repetitively, at least one type of layers of the cobalt layers and the platinum or
10 palladium layers containing at least one element selected from the group consisting of Ru, Ta, Nb, Mo, Mn, Cr, Si, and Ni, or at least one oxide.

The at least one element or one oxide is contained preferably in an amount in a range from 1 to 15 at%.

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Advantageously, the mainly-cobalt layer contains silicon oxide in an amount from 5 to 11 mol%, and the noble metal layer is composed of platinum and contains silicon oxide in an amount from 1 to 8 mol%.

20 Preferably, the mainly-cobalt layer has a thickness in a range from 0.2 to 0.8 nm and the noble metal layer has a thickness in the range from 0.05 to 1.2 nm.

A magnetic recording medium according to the invention

advantageously further comprises an underlayer between the magnetic layer and the substrate, the magnetic layer being formed directly on the underlayer.

5 Advantageously, the underlayer is substantially composed of a platinum film, a palladium film, ruthenium film, or a platinum and palladium lamination film.

10 A thickness of the underlayer is preferably in a range from 1 to 20 nm.

15 Advantageously, a perpendicular magnetic recording medium according to the invention further comprises an orientation control layer between the substrate and the underlayer for controlling crystalline orientation of the underlayer.

20 The orientation control layer is preferably composed of a lamination of a first seed layer and a second seed layer, and a composition of the second seed layer is selected so as to orient the underlayer in a c-crystal axis.

 The first seed layer is preferably composed of a tantalum layer, and the second seed layer is preferably composed of a layer selected from a NiFeCr layer, a NiFeNbB layer, and a NiFeSi layer.

A thickness of the first seed layer is preferably in a range from 1 to 10 nm, and a thickness of the second seed layer is preferably in a range from 5 to 20 nm.

- 5 Advantageously, a perpendicular magnetic recording medium according to the invention further comprises a soft magnetic backing layer between the substrate and the first seed layer.

- 10 The soft magnetic backing layer is preferably composed of a CoZrNb alloy or a CoZrTa alloy having a thickness in a range from 50 to 400 nm.

- 15 A method for manufacturing a perpendicular magnetic recording medium according to the present invention comprises a step of depositing, on a nonmagnetic substrate, a magnetic layer having a multilayered lamination structure by alternately laminating a mainly-cobalt layer of a cobalt layer and a noble metal layer of a platinum or palladium layer repetitively, by means of a sputtering method using a target containing at least one element selected from
20 the group consisting of Ru, Ta, Nb, Mo, Mn, Cr, Si, and Ni, or at least one oxide, in an amount in a range from 1 to 15 at%.

Preferably the method for manufacturing a perpendicular magnetic recording medium comprises the step of depositing the

magnetic layer is conducted using a sputtering gas containing oxygen in a range from 0.05 to 0.5 % in a relative mass flow rate.

Preferably the method for manufacturing a perpendicular
5 magnetic recording medium further comprises a step of depositing an underlayer composed of a film selected from a platinum film, a palladium film, ruthenium film, or a platinum and palladium lamination film, on the substrate before the step of depositing the magnetic layer, by means of a sputtering method.

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The step of depositing the underlayer and the step of depositing the magnetic layer are conducted preferably using a sputtering gas selected from krypton, xenon, a mixed gas of krypton and argon, and a mixed gas of xenon and argon.

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Advantageously, a method for manufacturing a perpendicular magnetic recording medium according to the invention further comprising a step of adsorption of oxygen on the underlayer surface after the step of depositing the underlayer and before the step of
20 depositing the magnetic layer, the step of adsorption including a process of exposing a surface of the underlayer to argon gas containing 1 to 10 % of oxygen in relative mass flow rate under a pressure of 0.1 to 10 Pa for 1 to 20 seconds.

Brief description of drawings

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

Fig. 2 shows relations between platinum layer thickness and
5 coercive force in a multilayered lamination film consisting of pure cobalt layers and pure platinum layers formed using a sputtering gas of argon, krypton, or xenon.

Fig. 3 illustrates the dependence of the gradient in a magnetization curve around the point of H_c on the platinum layer
10 thickness of a multilayered lamination film consisting of pure cobalt layers and pure platinum layers formed using a sputtering gas of argon, krypton, or xenon.

Fig. 4 illustrates the dependence of coercive force H_c on pressure of sputtering gas for a multilayered lamination film consisting of pure
15 cobalt layers and pure platinum layers formed using a sputtering gas of argon, krypton, or xenon.

Fig. 5 illustrates the effect of addition of oxygen into the sputtering gas for depositing the magnetic layer.

Fig. 6 illustrates read-write characteristics (specifically, SN
20 characteristics) of a perpendicular magnetic recording medium having a magnetic layer of a multilayered lamination film consisting of 95 at% Co - 5 at% Ni layers and platinum layers (CoNi / Pt medium), and of a perpendicular magnetic recording medium having a magnetic layer of a multilayered lamination film consisting of [90

mol% (95 at% Co - 5 at% Ni) - 10 mol% SiO₂] layers and platinum layers (CoNi- SiO₂ / Pt medium).

Fig. 7 illustrates read-write characteristics (specifically, SN characteristics) of a perpendicular magnetic recording medium having a magnetic layer of a multilayered lamination film consisting of 95 at% Co - 5 at% Ru layers and platinum layers (CoRu/Pt medium), and of a perpendicular magnetic recording medium having a magnetic layer of a multilayered lamination film consisting of [99.8 mol% (95 at% Co - 5 at% Ni) - 0.2 mol% O₂] layers and platinum layers (CoRuO₂/Pt medium).

Fig. 8 illustrates an effect of the crystal orientation control layer included in a perpendicular magnetic recording medium according to the present invention.

Fig. 9 illustrates the effect of oxygen adsorption on the surface of the underlayer.

Fig. 10 illustrates readback signal output, which is a read-write characteristic, measured on a conventional product and an invented product.

Fig. 11 illustrates the media noise, which is a read-write characteristic, measured on a conventional product and an invented product.

Fig. 12 illustrates the SNR, which is a read-write characteristic, measured on a conventional product and an invented product.

Fig. 13 shows areal TEM images illustrating the diameter of

magnetic particles and the width of nonmagnetic grain boundary in the Co-SiO₂ layer constituting the magnetic layer.

Fig. 14 illustrates variation of magnetic characteristics in relation to variation of thickness of a platinum layer.

5 Fig. 15 illustrates variation of magnetic characteristics in relation to variation of thickness of the NiFeNbB layer.

Fig. 16 illustrates variation of magnetic characteristics in relation to variation of thickness of a palladium layer.

Fig. 17 illustrates the effect of the ruthenium underlayer on
10 magnetic characteristics of a magnetic layer of Co-SiO₂ / Pd multilayered lamination structure.

Fig. 18 illustrates the read-write characteristics measured on the perpendicular magnetic recording medium having a magnetic layer of Co-SiO₂ / Pt multilayered lamination structure of Example 4 of the
15 invention and the perpendicular magnetic recording medium having a magnetic layer of Co-SiO₂ / Pd multilayered lamination structure of Example 5 of the invention.

Fig. 19 illustrates H_c of three types of a perpendicular magnetic recording media in relation to thickness of a noble metal layer of each
20 medium. First of the three types of media comprises a magnetic layer of a multilayered lamination film of 91 mol% Co - 9 mol% SiO₂ / 95 mol% Pt - 5 mol % SiO₂. Second of the three types of media comprises a magnetic layer of a multilayered lamination film of 94 mol% Co - 6 mol% SiO₂ / 95 mol% Pt - 5 mol% SiO₂. Third of the three types of

media comprises a magnetic layer of a multilayered lamination film of 91 mol% Co - 9 mol% SiO₂ / Pt.

Fig. 20 illustrates relation between the values of gradient α in the magnetization curve around the H_c point and the thickness of noble metal layer obtained on the three types of perpendicular
5 magnetic recording media described above in the caption of Fig. 19

Fig. 21 illustrates dependence of magnetic anisotropy constant K_u on thickness of noble metal layer for a medium comprising a magnetic layer of a multilayered lamination film of 91 mol% Co - 9
10 mol% SiO₂ / 95 mol% Pt - 5 mol% SiO₂ and a medium comprising a magnetic layer of a multilayered lamination film of 91 mol% Co - 9 mol% SiO₂ / Pt.

Fig. 22 illustrates result of H_c measurement on the medium comprising a magnetic layer of a multilayered lamination film of Co-
15 SiO₂ /Pt containing 18 to 38 vol% of SiO₂ in the cobalt layer.

Fig. 23 illustrates the effect on the H_c value of SiO₂ addition into the platinum layer.

Aspects of embodiments of the present invention

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

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

invention. The medium comprises a nonmagnetic substrate 1 made of aluminum or glass, a soft magnetic backing layer 2, an orientation control layer (3 and 4), an underlayer 5, a perpendicularly oriented magnetic layer 6, and a protective layer 7, laminated in this sequence.

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A basic feature of a perpendicular magnetic recording medium according to the present invention exists in a magnetic layer 6 having a basic structure of a multilayered lamination film composed by laminating cobalt layers and platinum layers, at least one type of
10 layers of the cobalt layers and the platinum layers containing an oxide of a metal, for example, silicon. Besides, the magnetic layer 6 having such structure is formed on an underlayer 5 provided for reducing magnetic interaction between magnetic particles constituting the magnetic layer 6. The underlayer 5 is preferably
15 composed of a platinum film, a ruthenium film, a palladium film, or a platinum and palladium lamination film. A composition of the oxide added to the magnetic layer 6 is preferably a stoichiometric composition. When the additive oxide is a silicon oxide, for example, the oxide preferably has a composition SiO_2 , while the silicon oxide
20 generally has a composition SiO_x , where $0 < x \leq 2$. The soft magnetic backing layer 2 and the orientation control layer (3 and 4) shown in Fig. 1 are preferably added between the underlayer 5 and the substrate 1 for improving performance of the perpendicular magnetic recording medium, although a perpendicular magnetic

recording medium of the invention may lack those layers.

More specifically describing, the underlayer 5 is composed of platinum, ruthenium, or the like, having a thickness in the range
5 from 1 to 20 nm. Magnetic performance of the magnetic layer 6 can be enhanced when the magnetic layer 6 is formed after giving oxygen adsorption treatment onto the surface of the underlayer 5. The oxygen adsorption on the underlayer surface suppresses magnetic interaction between magnetic particles in the magnetic layer 6 that is
10 formed on this underlayer 5, and loosens the gradient in the magnetization curve of the magnetic layer 6 around the Hc point, producing an effect to facilitating read-write of information.

The magnetic layer 6 has a basic structure of Co/Pt multilayered
15 lamination film composed of mainly cobalt layers 6a of cobalt layers and noble metal layers 6b of platinum layers, both of which contains silicon oxide (SiOx), resulting in a multilayered lamination film having a composition of Co-SiO₂/Pt-SiO₂. The silicon oxide is preferably contained in the range from 1 to 15 mol%, more preferably
20 5 to 11 mol% in the cobalt layer, and 1 to 8 mol% in the platinum layer.

Although the silicon oxide is contained in both the cobalt layer and the platinum layer in the above-described example, the silicon

oxide may be contained in only one type of layers of the cobalt layers and the platinum layers, as mentioned earlier. The magnetic layer 6 can be composed of a multilayered lamination film of Co/Pd in place of the multilayered lamination film of Co/Pt. In the case of the
5 multilayered lamination structure of Co/Pd too, the silicon oxide may be contained either in both the cobalt layers and the palladium layers or in only one type of layers of the cobalt layers and the palladium layers. Instead of the silicon oxide (or in addition to the silicon oxide), at least one additive may be selected from a group consisting of Ru,
10 Ta, Nb, Mo, Mn, Cr, and Ni, and an oxide.

The reason for provision of the underlayer 5 having oxygen adsorbed on the surface thereof in a perpendicular magnetic recording medium of the invention is to control the gradient of the
15 magnetization curve near the point of coercive force H_c of the magnetic layer 6 formed on this underlayer 5. The reason for employing a Co/Pt multilayered lamination film for the magnetic layer 6 is because such a magnetic layer provides a large value of H_c as compared with a magnetic layer of Co-Cr alloy, readily achieves a
20 squareness ratio of 1, and brings about large crystalline magnetic anisotropy taking advantage of interface magnetic anisotropy. The reason for adding silicon oxide to either one or both of the cobalt layer and the platinum layer that compose the multilayered lamination film is for the purpose of enhancing H_c and improving read-write

characteristics. The added nonmagnetic silicon oxides segregate in the region between magnetic particles constituting the cobalt layer and the platinum layer, and minimize and isolate each magnetic particle. Thus, H_c can be increased and higher recording density can
5 be achieved in comparison with a magnetic layer like Co/Pt that does not contain silicon oxide.

Though thickness of each of the layers constituting the magnetic layer can be varied corresponding to the intended magnetic property,
10 each of the cobalt layers can be 0.2 to 0.8 nm thick, preferably 0.2 to 0.5 nm thick; each of the platinum layers can be 0.05 to 1.2 nm thick, preferably 0.05 to 0.25 nm thick. The magnetic layer 6 is deposited by a sputtering method using a sputtering gas of argon, krypton, xenon, or a mixed gas of these gases. The sputtering gas may contain
15 0.05 to 0.5 % of oxygen in relative mass flow rate.

The orientation control layer (3 and 4) is provided for the purpose of crystal orientation (c-axis orientation) of the underlayer 5. The orientation control layer (3 and 4) consists of preferably laminated
20 two layers: a first seed layer 3 of tantalum and a second seed layer 4 of NiFeCr. Material of the second seed layer can be composed of NiFeNbB or NiFeSi, as well. By enhancing c-axis orientation of the underlayer 5, crystal orientation of the magnetic layer 6 that is formed on the underlayer 5 can also be enhanced, thereby improving

magnetic performance of the magnetic layer 6. The tantalum layer and the NiFeCr layer composing an orientation control layer of two layer structure have preferably thicknesses in the range of 1 to 10 nm and in the range of 5 to 20 nm, respectively. Composition of the
5 NiFeCr layer is determined not to degrade crystallinity and orientation of the underlayer of a ruthenium film, and appropriately selected in the range of 50 to 70 at% Ni, 10 to 20 at% Fe, and 20 to 30 at% Cr.

10 The soft magnetic backing layer 2 is provided for enhancing writing ability using a recording head, and is composed of, for example, a soft magnetic film of CoZrNb or CoZrTa having a thickness from 50 to 400 nm.

15 The present invention will be described more in detail referring to examples of preferred embodiments of a perpendicular magnetic recording medium according to the invention.

Example 1

20 An example of embodiment according to the present invention described here comprises a substrate 1 of glass, a soft magnetic backing layer 2 of CoZrNb film, an underlayer 5 of a platinum film, a protective layer 7 of a carbon film, and a magnetic layer 6 of multilayered lamination of mainly cobalt layers 6a of cobalt layers

composed of CoNi-SiO₂ and noble metal layers 6b of platinum layers composed of platinum.

The manufacturing method of a perpendicular magnetic
5 recording medium of this example is as follows.

The substrate 1 is a glass substrate having a diameter of 95mm (about 3.5 inches) and a thickness of 1 mm. The diameter and the thickness, however, are not essential and the substrate 1 may be an
10 aluminum substrate that is plated with Ni-P and subjected to an appropriate texturing.

After adequately cleaning the substrate 1, a soft magnetic backing layer 2 of a CoZrNb film is formed on the substrate by a
15 sputtering method. The target used for sputtering in this example has a composition of 87 at% Co - 5 at% Zr - 8 at% Nb. The sputtering was conducted to a film thickness of 200 nm at the room temperature using sputtering gas of argon at a pressure of about 1 Pa. The CoZrNb film exhibits adequate soft magnetic performance
20 notwithstanding of the amorphous state of the film that is deposited at room temperature.

Subsequently, an underlayer 5 of platinum was deposited by sputtering on the CoZrNb film. The target used was pure platinum.

The sputtering was conducted to a thickness of about 10 nm at room temperature using a mixed gas of Kr + 4%Ar + 0.2%O₂ in relative mass flow rate at a pressure of about 5 Pa.

5 On the platinum underlayer 5 formed is a magnetic layer 6 of a multilayered lamination film of CoNi-SiO₂/ Pt by sputtering. The composition of the target used was an alloy of 95 at% Co-5 at% Ni with an addition of 10 mol% SiO₂ for the cobalt layer and pure platinum for the platinum layer. These targets were simultaneously
10 discharged and sputtered while rotating, to deposit a CoNi-SiO₂ layer and a platinum layer alternately. The sputtering was conducted to a film thickness of 0.45 nm for each of the CoNi-SiO₂ layers and 0.4 nm for each of the platinum layers at room temperature using a mixed gas of Kr + 4%Ar + 0.2%O₂ in relative mass flow rate at a pressure of
15 about 5 Pa. The composition of the laminated CoNi-SiO₂ layers was 90 mol% (95 at% Co-5 at% Ni) - 10 mol% SiO₂ reflecting the composition of the target used for the sputtering.

20 Finally, a protective layer 7 of a carbon film was formed on the top surface of the magnetic layer 6 by a sputtering method. The sputtering was conducted to a film thickness of about 7 nm using a carbon target and a sputtering gas of argon at about 1 Pa at room temperature.

Figures 2 through 4 illustrate the effects of the sputtering gas used in depositing the magnetic layer 6 on the performances of the magnetic layer 6. Fig. 2 shows relations between platinum layer thickness and coercive force in a multilayered lamination film consisting of pure cobalt layers (containing neither Ni nor SiO₂) and pure platinum layers formed using a sputtering gas of Ar, Kr, or Xe. In the figure, the ordinate represents coercive force and the abscissa represents the platinum film thickness.

Sputtering by using argon gas resulted in the maximum coercive force of about 4,000 Oe at a platinum film thickness of 0.2 nm, while the use of Kr gas resulted in the maximum coercive force of about 4,800 Oe at a platinum film thickness of 0.75 nm, and the use of Xe gas resulted in the maximum coercive force of about 6,000 Oe at a platinum film thickness of 1.0 nm. The platinum film thickness that gives the maximum coercive force varies with the type of the sputtering gas. The use of a sputtering gas of krypton or xenon provides a perpendicular magnetic recording medium exhibiting a larger coercive force than the use of argon gas.

Fig. 3 illustrates the dependence of the gradient α in a magnetization curve around the point of H_c on the platinum layer thickness of a multilayered lamination film consisting of pure cobalt layers and pure platinum layers formed using a sputtering gas of

argon, krypton, or xenon. In the figure, the ordinate represents the gradient α and the abscissa represents the platinum layer thickness. The gradient α of the magnetization curve is an index of the intensity of magnetic interaction between magnetic particles constituting the magnetic layer 6. Smaller values of the gradient α are considered more favorable.

As apparent from Fig 3, the deposited films using sputtering gas of krypton or xenon showed the α values approximately unity, while the use of a sputtering gas of argon resulted in the α values larger than three. This result demonstrates reduced magnetic interaction between magnetic particles in the magnetic layers formed using sputtering gases of krypton and xenon, and means that sputtering using krypton or xenon reduces media noises.

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Fig. 4 illustrates the dependence of coercive force H_c on pressure of sputtering gas for a multilayered lamination film consisting of pure cobalt layers and pure platinum layers formed using a sputtering gas of argon, krypton, or xenon. In the figure, the ordinate represents coercive force, and the abscissa represents gas pressure. The thicknesses of the cobalt layers and the platinum layers are adjusted approximately at the value that gives the maximum coercive force for each kind of gas. Specific values of the layers were: in the case of argon, 0.44 nm for cobalt layers and 0.26 nm for platinum layers, in

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the case of xenon, 0.43 nm for cobalt layers and 0.87 nm for platinum layers, and in the case of krypton, 0.44 nm for cobalt layers and 0.72 nm for platinum layers.

5 In the case of argon gas, the higher pressure resulted in larger coercive force within the pressure range up to 10 Pa. In the krypton gas, the maximum coercive force was obtained at the pressure of 6.5 Pa, and in the xenon gas, the pressure value of 5 Pa gave the maximum coercive force. The maximum values of the coercive force
10 for the cases of krypton and xenon were larger than the maximum value for the case of argon.

Table 1 gives the evaluation results of crystalline magnetic anisotropy for perpendicular magnetic recording media having a
15 magnetic layer 6 manufactured by using sputtering gases of argon, krypton, and xenon. The larger value of the crystalline magnetic anisotropy constant K_u implies the higher and better thermal stability of the medium.

20 Table 1

sputtering gas	K_u (erg/cc)
Ar	2.26×10^6
Kr	3.60×10^6
Xe	3.57×10^6

As apparent in the Table 1, the medium having a magnetic layer 6 deposited by using sputtering gases of krypton and xenon showed higher crystalline magnetic anisotropy than the medium formed by using a sputtering gas of argon.

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Table 2 gives magnetic cluster sizes in the magnetic layer 6 obtained by a magnetic force microscope (MFM) for each of the media. The smaller magnetic cluster sizes are the more favorable for high density recording.

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Table 2

sputtering gas	magnetic cluster size (nm)
Ar	47
Kr	37
Xe	36

As apparent in Table 2, the sputtering gases of krypton and xenon resulted in smaller magnetic cluster sizes and have been shown favorable for higher density recording as compared with the argon sputtering gas. Thus, magnetic performance of a perpendicular magnetic recording medium can be improved by using sputtering gas of krypton or xenon in the deposition process of a magnetic layer 6.

20 Based on the above results, krypton was selected for a sputtering

gas and a variety of elements as mentioned previously was contained in the cobalt layers in order to improve read-write characteristics.

Fig. 5 illustrates the effect of addition of oxygen into the sputtering gas for depositing the magnetic layer. The Fig. 5 shows the coercive force, in relation to the oxygen content in the sputtering gas, of perpendicular magnetic recording media with the cobalt layers constituting the magnetic layer containing an element selected from Ni, Ta, Nb, Mo, Mn, Cr, and Si and the sputtering gas of krypton containing oxygen up to 0.2 % in relative mass flow rate. In the figure, the ordinate represents coercive force and the abscissa represents oxygen content.

Although the oxygen content dependence of the coercive force varies with the type of the added element, it has been confirmed that the addition of oxygen improves coercive force. A reason for this improvement can be considered as follows. The additive element can be oxidized by oxygen in the atmosphere of the process and produces oxides that precipitate in the region between the cobalt particles. The oxide can decrease magnetic interaction between cobalt particles. This fact can also contribute to improvement in read-write characteristic, as described later.

Fig. 6 illustrates read-write characteristics (specifically, SN

characteristics) of a perpendicular magnetic recording medium (medium A) having a magnetic layer of a multilayered lamination film consisting of cobalt layers containing 5 at% nickel (95 at% Co - 5 at% Ni layers) and platinum layers, and of a perpendicular magnetic recording medium (medium B) having a magnetic layer of a multilayered lamination film consisting of 95 at% Co - 5 at% Ni layers containing 10 mol% of SiO₂ (90 mol% (95 at% Co - 5 at% Ni) - 10 mol% SiO₂ layers) and platinum layers. In the figure, the ordinate represents signal-to-noise ratio (SNR) and the abscissa represents linear recording density. Also shown in the figure is a read-write characteristic (specifically, an SN characteristic) of a perpendicular magnetic recording medium (medium C) having a magnetic layer of a multilayered lamination film consisting of pure cobalt layers and platinum layers for comparison. All the magnetic layers of these media were deposited using sputtering gas of krypton containing 0.2 % of oxygen in relative mass flow rate. Evaluation of the read-write characteristic was performed using a ring head for longitudinal magnetic recording media.

Although the medium C was possible to read-write up to the limited recording density of around 400 kFCI, the medium A showed significantly improved SNR as compared with the medium C in the region over 200 kFCI, and has demonstrated certified possibility to read-write in the region as high as 550 kFCI. The medium B has

demonstrated further improvement in SNR than the medium A. It has been confirmed that addition of a metal or an oxide such as nickel or SiO₂ into the cobalt layers can improve read-write characteristic and are effective to enhance recording density.

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Example 2

In this example of embodiment according to the present invention, a perpendicular magnetic recording medium was produced comprising a magnetic layer 6 of multilayered lamination structure of
10 CoRu/Pt and a soft magnetic backing layer 2 of a CoZrNb film.

The manufacturing method of a perpendicular magnetic recording medium of this example is as follows.

15 The substrate 1 is a glass substrate having a diameter of 95mm (about 3.5 inches) and a thickness of 1 mm. The diameter and the thickness, however, are not essential and the substrate 1 may be an aluminum substrate that is plated with Ni-P and subjected to an appropriate texturing.

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After adequately cleaning the substrate 1, a soft magnetic backing layer 2 of a CoZrNb film is formed on the substrate by a sputtering method. The target used for sputtering in this example has a composition 87 at% Co - 5 at% Zr - 8 at% Nb. The sputtering

was conducted to a film thickness of 200 nm at the room temperature using sputtering gas of argon at a pressure of about 1 Pa. The CoZrNb film exhibits adequate soft magnetic performance notwithstanding of the amorphous state of the film that is deposited
5 at room temperature.

Subsequently, an underlayer 5 of platinum was deposited by sputtering on the CoZrNb film. The target used was pure platinum. The sputtering was conducted to a thickness of about 10 nm at room
10 temperature using a mixed gas of Kr + 4%Ar + 0.2%O₂ in relative mass flow rate at a pressure of about 5 Pa.

On the platinum underlayer 5 formed is a magnetic layer 6 of a multilayered lamination film of CoRu / Pt by sputtering. The
15 composition of the target used was 95 at% Co - 5 at% Ru for the cobalt layer and pure platinum for the platinum layer. These targets were simultaneously discharged and sputtered while rotating, to deposit a CoRu layer and a platinum layer alternately. The sputtering was conducted to a film thickness of 0.45 nm for each of
20 the CoRu layers and 0.8 nm for each of the platinum layers at room temperature using a sputtering gas of Kr + 4%Ar + 0.2%O₂ in relative mass flow rate at a pressure of 5 Pa.

Finally, a protective layer 7 of a carbon film was formed on the

top surface of the magnetic layer 6 by a sputtering method. The sputtering was conducted to a film thickness of about 7 nm using a carbon target and a sputtering gas of argon at about 1 Pa at room temperature.

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Fig. 7 illustrates read-write characteristics (specifically, SN characteristics) of a perpendicular magnetic recording medium (medium D) having a magnetic layer of a multilayered lamination film consisting of cobalt layers containing 5 % ruthenium (95 at% Co - 5 at% Ru layers) and platinum layers, and of a perpendicular magnetic recording medium (medium E) having a magnetic layer of a multilayered lamination film consisting of 95 at% Co - 5 at% Ru layers containing 0.2 mol% of O₂ (99.8 mol% (95 at% Co - 5 at% Ru) - 0.2 mol% O₂ layers) and platinum layers. In the figure, the ordinate represents SNR and the abscissa represents linear recording density. Also shown in the figure is a read-write characteristic (specifically, an SN characteristic) of a perpendicular magnetic recording medium (medium F) having a magnetic layer of a multilayered lamination film consisting of pure cobalt layers and platinum layers for comparison. All the magnetic layers of these media were deposited using sputtering gas of krypton containing up to 0.2 % of oxygen. Evaluation of the read-write characteristic was performed using a ring head for longitudinal magnetic recording media.

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Although the medium F was possible to read-write up to the limited recording density of around 500 kFCI, the medium D showed significantly improved SNR as compared with the medium F, and has demonstrated certified possibility to read-write in the region up to 500 kFCI. The medium E has demonstrated further improvement in SNR than the medium D.

It has been confirmed that addition of ruthenium into the cobalt layers, or further addition of oxygen can improve read-write characteristic and are effective to enhance recording density.

Example 3

A perpendicular magnetic recording medium of Example 3 according to the present invention comprises, as shown in Fig. 1, a nonmagnetic substrate 1 made of aluminum or the like, and the layers including a soft magnetic backing layer 2, a first seed layer 3, a second seed layer 4, an underlayer 5, a magnetic layer 6 of a multilayered lamination film, and a carbon protective layer 7 sequentially laminated on the substrate in this order.

20

A magnetic layer 6 of this example uses Co-SiO₂ / Pt that is a multilayered lamination film composed by alternately laminating a Co-SiO₂ layer 6a and a platinum layer 6b repetitively. By adding SiO₂ in the cobalt layer, the nonmagnetic SiO₂ segregates between

the cobalt particles, leading to minimization and isolation of cobalt particles. Content of SiO₂ in the Co-SiO₂ layer is preferably adjusted in the range from 2 to 15 mol%, more preferably in the range from 5 to 11 mol%.

5

By using a ruthenium underlayer 5 with adsorbed oxygen on the surface thereof, the gradient of a magnetization curve at around H_c becomes less steep and the magnetic interaction between the particles in the perpendicular magnetic layer can be decreased, which facilitates read-write.

For the purpose of c-axis orientation of the crystals in the ruthenium underlayer 5 and enhancing coercive force, the first seed layer 3 employs a tantalum layer and the second seed layer 4 employs a NiFeCr layer for controlling crystal orientation. A composition of the NiFeCr layer is appropriately selected to improve crystallinity and to keep controllability of crystal orientation of the ruthenium underlayer disposed just on the NiFeCr layer, and is preferably adjusted in the range of 50 to 70 at% Ni - 10 to 20 at% Fe - 20 to 30 at% Cr.

Thickness of each layer is preferably determined to a value in the range of: 1 to 10 nm for the first seed layer 3, 5 to 15 nm for the second seed layer 4, 10 to 20 nm for the underlayer 5, 0.2 to 0.8 nm

for each of the Co-SiO₂ layers, and 0.1 to 1 nm for each of the platinum layers.

A soft magnetic backing layer 2 of a soft magnetic CoZrTa film
5 with a thickness of 50 to 400 nm is further provided between the nonmagnetic substrate 1 and the first seed layer 3 to enhance writing ability using a recording head.

The manufacturing method of a perpendicular magnetic
10 recording medium having a structure described above is as follows.

The substrate is an aluminum substrate having a diameter of 95mm (about 3.5 inches) and a thickness of 1 mm. The diameter and the thickness, however, are not essential and the substrate may be a
15 glass substrate.

After adequately cleaning the substrate, a soft magnetic backing layer of a soft magnetic CoZrTa film is formed on the substrate by a sputtering method. The target used here for sputtering has a
20 composition of 92 at% Co - 5 at% Zr - 3 at% Ta. The sputtering was conducted to a film thickness of 200 nm at the room temperature using sputtering gas of argon at a pressure of about 1 Pa. The CoZrTa film exhibits adequate soft magnetic performance despite the film is in an amorphous state and is deposited at room temperature.

Subsequently, a first seed layer 3 of tantalum was deposited by sputtering on this CoZrTa film. The target used was pure tantalum. The sputtering was conducted to a thickness of 5 nm at room temperature using argon gas at a pressure of about 1 Pa.

5

Subsequently, a second seed layer 4 of NiFeCr was deposited by sputtering on the tantalum layer. The target used was 60 at% Ni - 15 at% Fe - 25 at% Cr. The sputtering was conducted to a thickness of 10 nm using argon gas at a pressure of about 1 Pa at room

10 temperature.

On this NiFeCr film, an underlayer 5 of a ruthenium film was deposited by sputtering. The target used was pure ruthenium. The sputtering was conducted to a thickness of about 20 nm using argon gas at a pressure of about 4 Pa at room temperature. The surface of the thus deposited ruthenium underlayer was exposed to a gas atmosphere of Ar + 1 to 10% O₂ in relative mass flow rate under a pressure of 0.1 to 10 Pa for 1 to 20 seconds so as to adsorb proper amount of oxygen on the ruthenium surface.

20

On this ruthenium underlayer 5 formed is a perpendicularly oriented magnetic layer 6 of a multilayered lamination film of Co-SiO₂ / Pt by sputtering. The compositions of the targets used were cobalt containing 9 mol% of SiO₂ (91 mol% Co - 9 mol% SiO₂) and pure

platinum. These targets were simultaneously discharged and sputtered while rotating, to deposit a Co-SiO₂ layer and a platinum layer alternately. The composition of the deposited Co-SiO₂ layers was 91 mol% Co - 9 mol% SiO₂ reflecting the composition of the target
5 used for depositing these layers. The sputtering was conducted using argon gas at a pressure of 5 Pa at room temperature. Thickness of each of the Co-SiO₂ layers was 0.3 nm, and thickness of each of the platinum layers was 0.1 nm.

10 Finally, a protective layer 7 of a nitrogen-doped carbon (C: N) film was formed on the top surface of the magnetic layer 6 by a sputtering method. The sputtering was conducted to a film thickness of 7 nm under argon gas pressure of about 1 Pa and at room temperature.

15

Fig. 8 illustrates an effect of the crystal orientation control layer included in a perpendicular magnetic recording medium according to the present invention. Fig. 8 shows an X-ray diffraction pattern obtained on a sample prepared by sequentially depositing first and
20 second seed layers of tantalum and NiFeCr respectively, a ruthenium underlayer 5, and a Co-SiO₂ / Pt magnetic layer 6 of a multilayered lamination structure. As apparent from the figure, solely observed diffraction from the ruthenium underlayer 5 was the diffraction from (002) plane, which indicated that the orientation control layers (3 and

4) effectively worked for c-axis orientation of the ruthenium underlayer 5.

Fig. 9 illustrates the effect of oxygen adsorption on the surface of the ruthenium underlayer 5. Fig. 9 shows a magnetization curve obtained on a perpendicular magnetic recording medium manufactured by the above-described method according to the invention. Unit of the abscissa is 'Oe' and unit of the ordinate is 'emu'. The figure indicates that the gradient of the magnetization curve at around the coercive force H_c is less steep and the magnetic interaction between magnetic particles constituting the magnetic layer is decreased. The adsorption of oxygen on the surface of the ruthenium underlayer 5 has been demonstrated to facilitate read-write on a magnetic recording layer.

15

Table 3 shows the coercive force of a medium comprising a Co-SiO₂ / Pt magnetic layer of the invention in comparison with the coercive force of a medium comprising a Co-B / Pt magnetic layer based on conventional technology. The Co-B / Pt magnetic layer was a multilayered lamination film of Co-B layers that are boron-containing cobalt layers, and platinum layers. The underlayer for the Co-B/Pt magnetic layer was a platinum layer.

Table 3

sample	coercive force Hc (Oe)	square- ness S	saturation magnetization Ms (emu/cc)	nucleation field Hn (Oe)	gradient α
Pt/(CoB/Pt)	5,120	1.0	348	4,500	8.5
Ru/(CoSiO ₂ /Pt)	6,290	1.0	542	2,500	1.8

The coercive force of the Co-SiO₂ / Pt magnetic layer according to
 5 the invention has been demonstrated higher than that of the Co-B /
 Pt magnetic layer by more than 1,000 Oe. The gradient α of a
 magnetization curve is remarkably decreased from 8.5 to 1.8. As
 shown above, a perpendicular magnetic recording medium has been
 obtained that exhibits simultaneously high coercive force and gentle
 10 gradient in a magnetization curve by provision of a multilayered
 lamination of alternately layered Co-SiO₂ layer and platinum layer on
 a ruthenium underlayer 5.

Table 4 shows evaluation results of crystalline magnetic
 15 anisotropy for these two types of perpendicular magnetic recording
 media. Larger value of a crystalline magnetic anisotropy constant
 (Ku) means higher thermal stability of a medium.

Table 4

sample	Ku (erg/cc)
Pt/(CoB/Pt)	5.0 x 10 ⁶
Ru/(CoSiO ₂ /Pt)	5.3 x 10 ⁶

As apparent from Table 4, the Ku value of the Co-SiO₂ / Pt magnetic layer according to the invention is a little larger than the Ku value of the Co-B/Pt, indicating improvement in thermal stability by the invention. Thus, superior magnetic characteristics of a
5 perpendicular magnetic recording medium of the invention have been shown in comparison with a conventional perpendicular magnetic recording medium.

Fig. 10 illustrates readback signal output, which is a read-write
10 characteristic, measured on a conventional product and an invented product. The abscissa of the graph represents linear recording density and the ordinate represents TAA (Track Average Amplitude). The measurement was conducted using a ring head for an longitudinal magnetic recording medium. The conventional product
15 comprising a lamination consisting of Co-B layers and platinum layers on a platinum underlayer was possible up to only the limited recording density of around 400 kFCI, while the invented product comprising a lamination consisting of Co-SiO₂ layers and platinum layers on a ruthenium underlayer was possible to detect playback
20 signals up to 540 kFCI or higher recording density. Thus, it has been shown that playback is possible in the high linear recording density.

Fig. 11 illustrates the media noise, which is a read-write characteristic, measured on the conventional product and the

invented product. The abscissa of the graph represents linear recording density and the ordinate represents the noise. This measurement was also conducted using a ring head for an longitudinal magnetic recording medium. The conventional product
5 comprising a lamination of Co-B layers and platinum layers on a platinum underlayer showed decreased medium noise in the recording density region beyond 200 KFCI, indicating insufficient read-write. Moreover, the magnitude of the noise itself was large. In contrast, the invented product comprising a lamination of Co-SiO₂
10 layers and platinum layers on a ruthenium underlayer showed lower noises than the conventional product in the whole linear recording density range. In addition, increase of the noise was observed up to the linear recording density of 540 kFCI, confirming sufficient read-write performance.

15

Fig. 12 illustrates the SNR, which is a read-write characteristic, measured on the conventional product and the invented product. The abscissa of the graph represents linear recording density and the ordinate represents SNR. This measurement was also conducted
20 using a ring head for an longitudinal magnetic recording medium. The invented product comprising a lamination of Co-SiO₂ layers and platinum layers showed remarkably higher SNR in the whole range of linear recording density than the conventional product comprising a lamination of Co-B layers and platinum layers, and the invented

product also demonstrated sufficient read-write ability up to the linear recording density of 540 kFCI.

It has been confirmed that the constitution of a perpendicular
5 magnetic recording medium according to the present invention is effective to improve read-write characteristics and can contribute to enhance recording density.

Example 4

10 A perpendicular magnetic recording medium in Example 4 comprises an aluminum substrate 1 and the layers laminated on this substrate in sequence including a soft magnetic backing layer 2 of CoZrNb, an orientation control layer (3 and 4) of double layer structure, an underlayer 5 of ruthenium, and a magnetic layer 6 that
15 is a multiple of laminations of Co-SiO₂ layers and platinum layers. The orientation control layer of the Example 4 employs a first layer of tantalum and second layer of NiFeNbB layer 4. The aluminum substrate 1 in the Example 4 has a diameter of 95mm (about 3.5 inches) and a thickness of 1 mm though the diameter and the
20 thickness are not essential. The aluminum substrate can be replaced by a glass substrate.

The manufacturing process of the perpendicular magnetic recording medium will be described below.

After adequately cleaning the substrate, a soft magnetic backing layer 2 was formed on the substrate with a soft magnetic CoZrNb film by a sputtering method. The sputtering target used here has a composition of 87 at% Co - 5 at% Zr - 8 at% Nb. The sputtering was
5 conducted to a film thickness of 200 nm at the room temperature using sputtering gas of argon at a pressure of about 1 Pa. The CoZrNb film exhibits adequate soft magnetic performance despite the film is in an amorphous state and is deposited at room temperature.

10 Subsequently, a first seed layer 3 of a tantalum layer was deposited by sputtering on the CoZrNb soft magnetic film. The target used was pure tantalum. The sputtering was conducted to a thickness of 5 nm at room temperature using argon gas at a pressure of about 1 Pa.

15 Subsequently, a second seed layer 4 of a NiFeNbB layer was deposited by sputtering on the tantalum film. The target used was 79 at% Ni - 12 at% Fe - 3 at% Nb - 6 at% B. The sputtering was conducted to a thickness of 30 nm using argon gas under a pressure
20 of about 1 Pa at room temperature.

On this NiFeNbB layer, an underlayer 5 of a ruthenium film was deposited by sputtering. The target used was pure ruthenium. The sputtering was conducted to a thickness of about 20 nm using argon

gas at a pressure of about 4 Pa at room temperature. The surface of the thus deposited ruthenium underlayer was exposed to a gas atmosphere of Ar + 2% O₂ in a relative mass flow rate under a pressure of 1 Pa for about 10 seconds so as to adsorb proper amount
5 of oxygen on the ruthenium surface.

On the ruthenium underlayer 5 formed is a magnetic layer 6 that is a perpendicularly oriented multilayered lamination film of Co-SiO₂ / Pt by sputtering. The composition of the target used for the Co-SiO₂
10 layer was 91 mol% Co - 9 mol% SiO₂ or 94 mol% Co - 6 mol% SiO₂; and the composition of the target used for the platinum layer was pure platinum. These two targets were simultaneously discharged and sputtered while rotating, to alternately deposit a Co-SiO₂ layer and a platinum layer repetitively. The sputtering was conducted
15 using argon gas at a pressure of 5 Pa at room temperature. Thickness of each of the Co-SiO₂ layers was 0.3 nm, and thickness of each of the platinum layers was 0.1 nm. The composition of the Co-SiO₂ layers was 91 mol% Co - 9 mol % SiO₂ or 94 mol% Co - 6 mol% SiO₂ reflecting the composition of the target.

20

Finally, a protective layer 7 of a nitrogen-doped carbon (C: N) film was formed on the top surface of the magnetic layer 6 by a sputtering method using a target of carbon and a sputtering gas of Ar + 4 % N₂ in relative mass flow rate under a pressure of about 1 Pa at

room temperature.

Fig. 13(a) and Fig. 13(b) are planar TEM images illustrating the diameter of magnetic particles and the width of nonmagnetic grain boundary in the Co-SiO₂ layer constituting the magnetic layer 6. Fig. 13(a) is on a sample containing SiO₂ additive of 6 mol%, and Fig. 13(b) is on a sample containing SiO₂ additive of 9 mol%. Analysis on the TEM images indicated that the sample of SiO₂ additive of 6 mol% (Fig. 3(a)) had a mean diameter of magnetic particles of 7.1 nm and a mean width of grain boundary of 1.5 nm, while the sample of SiO₂ additive of 9 mol% (Fig. 3(b)) had a mean diameter of magnetic particles of 5.6 nm and a mean width of grain boundary of 1.6 nm. More SiO₂ content tends to give smaller diameter of magnetic particles and wider grain boundary. Generally, a small grain size of the magnetic particles implies reduced magnetic interaction between magnetic particles and intensified isolation of individual magnetic particles, which are favorable to direct to high recording density.

Fig. 14 illustrates variation of magnetic characteristics in relation to variation of thickness of a platinum layer that is a noble metal layer 6b. Fig. 14(a) shows dependence of coercive force H_c on the platinum film thickness, and Fig. 14(b) shows dependence of gradient α of the magnetization curve on the platinum film thickness. The H_c value was 6,000 Oe at a platinum film thickness of 0.12 nm,

while the H_c was zero when the thickness was zero, which means a platinum film was not provided. The H_c value decreased to 1,200 Oe at a platinum film thickness of 0.25 nm, and further decreased with increase of the film thickness. The α value was 1.5 at the platinum
5 film thickness of 0.12 nm, with a tendency to increase with increase of the platinum film thickness. Accordingly, the thinner the platinum film is, the better in view of the α value. The optimum thickness of the platinum layer was 0.12 nm in this specific example.

10 Fig. 15 illustrates variation of magnetic characteristics in relation to variation of thickness of the NiFeNbB layer 4. Fig. 15(a) shows noises at 400 kFCI, which is a read-write characteristic. Fig. 15(b) shows SNR at 400 kFCI. The magnetic characteristics are also shown for comparison in the case a NiFeCr layer 10 nm thick was
15 provided in place of the NiFeNbB layer.

As shown in Fig. 15(a), the noises attenuate when the thickness of the NiFeNbB layer is increased from 10 nm to 30 nm. The noise level for the NiFeNbB layer having thickness of 30 nm is lower than
20 that for the NiFeCr layer having thickness of 10 nm. Fig. 15(b) shows that the SNR values for the case provided with the NiFeNbB layer are higher than the SNR for the NiFeCr layer 10 nm thick, independently of the film thickness of the NiFeNbB layer.

As described above, it has been shown that the grain size of the magnetic particles and the width of the nonmagnetic grain boundary can be controlled by controlling SiO₂ content in the cobalt layer; that a high H_c value can be achieved by optimizing the platinum layer thickness; and that noises and SNR can be improved by replacing the layer disposed just beneath the ruthenium layer of the NiFeCr layer in Example 3 by that layer of NiFeNbB layer 10 to 30 nm thick in this Example 4. Thus, a perpendicular magnetic recording medium can be provided that achieves higher recording density.

10

Example 5

A perpendicular magnetic recording medium of Example 5 has nearly the same construction as that of Example 4, except that the magnetic layer 6 that is provided on the underlayer 5 was a multilayered lamination structure of Co-SiO₂ / Pd. The compositions of the targets used were 91 mol% Co - 9 mol% SiO₂ and pure palladium. These targets were simultaneously discharged and sputtered while rotating, to alternately deposit a Co-SiO₂ layer and a palladium layer repetitively. The sputtering was conducted using argon gas at a pressure of 5 Pa at room temperature. Thickness of each of the Co-SiO₂ layers was 0.3 nm, and thickness of each of the palladium layers was 0.72 nm.

20

Fig. 16 illustrates variation of magnetic characteristics in

relation to variation of thickness of a palladium layer that is a noble metal layer 6b. Fig. 16(a) shows dependence of coercive force H_c on the palladium film thickness, and Fig. 16(b) shows dependence of gradient α of the magnetization curve on the palladium film thickness.

- 5 The H_c value increases with increase of the palladium film thickness to reach a saturation value of 5,500 Oe at the thickness of 0.72 nm. On the other hand, the α value is about 2 almost independently on the palladium film thickness, indicating satisfactorily weak magnetic interaction between magnetic particles.

10

- Fig. 17 illustrates the effect of the ruthenium underlayer 5 on magnetic performance of a magnetic layer 6 of Co-SiO₂ / Pd multilayered lamination structure. Fig. 17(a) shows noise, which is a type of read-write characteristic, and Fig. 17(b) shows SNR. The data
- 15 for the cases of platinum underlayer and palladium underlayer are also shown for comparison. As apparent from Fig. 17(a), the underlayer of a platinum film or a palladium film causes much noise and does not allow sufficient read-write in the region of high recording density. In contrast, the use of the ruthenium underlayer
- 20 accomplishes low noise and sufficient read-write in the high recording density region. The SNR data shown in Fig. 17(b) also shows excellent performance obtained by the use of the ruthenium underlayer.

Fig. 18 illustrates the read-write characteristics measured on the perpendicular magnetic recording medium having a magnetic layer of Co-SiO₂ / Pt multilayered lamination structure of Example 4 of the invention and the perpendicular magnetic recording medium having a perpendicular magnetic layer of Co-SiO₂ / Pd multilayered lamination structure of Example 5 of the invention. Fig. 18(a) gives readback signal output (TAA), Fig. 18(b) gives the noises, and Fig. 18(c) gives the SNR. Both the readback signal output and the noises are smaller in the perpendicular magnetic recording medium having a perpendicular magnetic layer of Co-SiO₂ / Pd multilayered lamination structure. However, the SNR is equivalent to the performance in the perpendicular magnetic recording medium having a magnetic layer of Co-SiO₂ / Pt of multilayered lamination structure. Thus, a perpendicular magnetic layer of a Co-SiO₂ / Pd multilayered lamination structure can provide, in combination with the provision of a ruthenium underlayer, a perpendicular magnetic recording medium of excellent performance.

Example 6

A perpendicular magnetic recording medium in this Example 6 comprises an aluminum substrate 1 and the layers laminated on this substrate in sequence including a soft magnetic backing layer 2 of CoZrNb, an orientation control layer of double layer structure consisting of a tantalum layer 3 and a NiFeCr layer 4, an underlayer

5 of ruthenium, and a magnetic layer 6 that is a multiple of laminations of cobalt layers of Co-SiO₂ and platinum layers of Pt-SiO₂. A carbon film was used for a protective layer 7.

5 The manufacturing method of this perpendicular magnetic recording medium is as follows. The aluminum substrate 1 has a diameter of 95mm (about 3.5 inches) and a thickness of 1 mm though the diameter and the thickness are not essential. A glass substrate can be used as well.

10

After adequately cleaning the substrate 1, a soft magnetic backing layer 2 was formed on the substrate depositing a CoZrNb film by a sputtering method. The target used here for sputtering has a composition of 87 at% Co - 5 at% Zr - 8 at% Nb. The sputtering was
15 conducted to a film thickness of 200 nm at the room temperature using sputtering gas of argon at a pressure of about 1 Pa. The CoZrNb film exhibits adequate soft magnetic performance despite the film is in an amorphous state and is deposited at room temperature.

20 Subsequently, a first seed layer 3 of a tantalum layer was deposited by sputtering on the CoZrNb film. The target used was pure tantalum. The sputtering was conducted to a thickness of 3 nm at room temperature using argon gas at a pressure of about 1 Pa. Subsequently, a second seed layer 4 of a NiFeCr layer was deposited

by sputtering on this tantalum layer. The target used was 60 at% Ni - 15 at% Fe - 25 at% Cr. The sputtering was conducted to a thickness of 10 nm using argon gas under a pressure of about 1 Pa at room temperature. The two layers, tantalum layer and the NiFeCr layer, constitute an orientation control layer and orients a ruthenium layer, which is an underlayer formed on the orientation control layer, in the c-axis.

On this NiFeCr layer, an underlayer 5 of a ruthenium film was deposited by sputtering. The target used was pure ruthenium. The sputtering was conducted to a thickness of about 20 nm using argon gas at a pressure of about 4 Pa at room temperature. The surface of the thus deposited ruthenium underlayer was exposed to a gas atmosphere of Ar + 2% O₂ in a relative mass flow rate under a pressure of 1 Pa for about 10 seconds so as to adsorb proper amount of oxygen on the ruthenium surface. By using a ruthenium underlayer 5 with adsorbed oxygen on the surface thereof, the gradient of a magnetization curve at around H_c becomes less steep and the magnetic interaction between the particles constituting the magnetic layer can be decreased.

On this ruthenium underlayer 5 formed is a perpendicularly oriented magnetic layer 6 that is a multilayered lamination film of Co-SiO₂ / Pt - SiO₂ by sputtering. The composition of the target used

for the Co-SiO₂ layer was 91 to 94 mol% Co - 6 to 9 mol% SiO₂ and the composition of the target used for the Pt - SiO₂ layer was 95 mol% Pt - 5 mol% SiO₂. These two targets were simultaneously discharged and sputtered while rotating, to alternately deposit a Co-SiO₂ layer and a Pt - SiO₂ layer repetitively. The sputtering was conducted using argon gas at a pressure of 5 Pa at room temperature. Thickness of each of the Co-SiO₂ layers was 0.3 nm, and thickness of each of the Pt - SiO₂ layers was 0.07 to 0.25 nm.

10 Finally, a protective layer 7 of a nitrogen-doped carbon (C: N) film was formed on the top surface of the magnetic layer 6 by a sputtering method using a target of carbon and a sputtering gas of Ar + 4 % N₂ in relative mass flow rate under a pressure of about 1 Pa at room temperature.

15

Fig. 19 illustrates H_c of three types of a perpendicular magnetic recording media in relation to thickness of a noble metal layer 6b of each medium. First of the three types of media comprises a magnetic layer of a multilayered lamination film of 91 mol% Co - 9 mol% SiO₂ / 95 mol% Pt - 5 mol% SiO₂. Second of the three types of media comprises a magnetic layer of a multilayered lamination film of 94 mol% Co - 6 mol% SiO₂ / 95 mol% Pt - 5 mol% SiO₂. Third of the three types of media comprises a magnetic layer of a multilayered lamination film of 91 mol% Co - 9 mol% SiO₂ / Pt. In the cases where

SiO₂ content in the mainly-cobalt layer of cobalt layer is 9 mol%, Hc of the medium including 5 mol% of SiO₂ in the platinum layer was observed lower by 300 to 500 Oe than that of the medium without SiO₂ additive. However, in the case where SiO₂ content in the
5 mainly-cobalt layer of cobalt layer is 6 mol%, the Hc of the medium including 5 mol% of SiO₂ in the platinum layer showed remarkably high Hc values.

Fig. 20 illustrates the values of gradient α in the magnetization
10 curve around the Hc point obtained on the above-mentioned three types of perpendicular magnetic recording media, in relation to the thickness of noble metal layer 6b. It is apparent from the figure that the optimum thickness of the noble metal layer exists to minimize the α value for each type of medium. Comparing the medium comprising
15 a magnetic layer of a multilayered lamination film of 91 mol% Co - 9 mol% SiO₂ / 95 mol% Pt - 5 mol% SiO₂ with the medium comprising a magnetic layer of a multilayered lamination film of 91 mol% Co - 9 mol% SiO₂ / Pt, the medium including the SiO₂ additive in the platinum layer showed lower α values by 0.15 to 0.4 in the whole
20 range of the thickness of the noble metal layer. Considering that the α value indicates strength of magnetic interaction between magnetic particles, addition of SiO₂ into the platinum layer decreases degree of magnetic interaction between magnetic particles, and consequently reduces noises.

Fig. 21 illustrates dependence of magnetic anisotropy constant K_u on thickness of the noble metal layer $6b$ for a medium comprising a magnetic layer of a multilayered lamination film of 91 mol% Co - 9 mol% SiO_2 / 95 mol% Pt - 5 mol% SiO_2 and a medium comprising a magnetic layer of a multilayered lamination film of 91 mol% Co - 9 mol% SiO_2 / Pt. The two types of media showed approximately equal K_u values, indicating that the addition of SiO_2 into the platinum layer does not degrade the K_u value.

Fig. 22 illustrates dependence of H_c value on SiO_2 content in the cobalt layer measured on the medium comprising a magnetic layer of a multilayered lamination of Co- SiO_2 /Pt containing 18 to 38 vol% of SiO_2 in the cobalt layer. Conversion from mol% to vol% is done as follows.

15

Vol% of SiO_2 in a cobalt layer

$$= (\text{mol\% of SiO}_2 / 100 * \text{vol per mol of SiO}_2) * 100 \\ / [\text{mol\% of SiO}_2 / 100 * \text{vol per mol of SiO}_2 \\ + (1 - \text{mol\% of SiO}_2 / 100) * \text{vol per mol of Co}],$$

20 and

Vol% of SiO_2 in a platinum layer

$$= (\text{mol\% of SiO}_2 / 100 * \text{vol per mol of SiO}_2) * 100 \\ / [\text{mol\% of SiO}_2 / 100 * \text{vol per mol of SiO}_2 \\ + (1 - \text{mol\% of SiO}_2 / 100) * \text{vol per mol of Pt}].$$

The values of vol per mol of SiO₂, Co, and Pt are 23.11, 6.58, and 9.09 (cm³/mol), respectively.

As is apparent from Fig. 22, the Hc value of a medium sharply
5 drops with increase of SiO₂ content in the cobalt layer. This fact
means that high Hc value becomes hardly attainable when the SiO₂ is
intended to much segregate in the grain boundary region between
magnetic particles and isolation of magnetic particles is enhanced
with the intention of noise reduction.

10

Fig. 23 illustrates the effect of SiO₂ addition into platinum layer
on the Hc value. The figure compares the Hc values of the media
comprising a magnetic layer of a multilayered lamination film of Co-
SiO₂ /Pt - SiO₂ with the Hc values of the media comprising a magnetic
15 layer of a multilayered lamination film of Co-SiO₂ /Pt that does not
contain SiO₂ in the platinum layer.

As is explained above with reference to Fig.22, in the medium
comprising a magnetic layer including a cobalt layer containing SiO₂
20 and a platinum layer not containing SiO₂, the Hc value abruptly
decreases with increase of the content of the SiO₂ in the cobalt layer.
However, when the platinum layer also contains SiO₂ as well as the
SiO₂ addition to the cobalt layer, the decreasing rate of the Hc value
is relaxed. When SiO₂ is contained not only in the cobalt layers but

also in the platinum layers, larger amount of SiO_2 can be added in a medium exhibiting the same H_c value as a medium without SiO_2 in the platinum layers. As a result, more amount of SiO_2 is segregated in the grain boundary region between magnetic particles enhancing
5 isolation of each magnetic particle, leading to noise reduction.

Advantageous Effect of the invention

As described so far, a perpendicular magnetic recording medium according to the present invention comprises a magnetic layer that
10 has a basic structure of a multilayered lamination film composed by laminating a cobalt layer and a platinum layer (or a palladium layer) repetitively, at least one type of layers of the cobalt layers and the platinum layers (or the palladium layers) containing an oxide of an element, for example, silicon. Besides, the magnetic layer having
15 such structure is formed on an underlayer of ruthenium, for example, provided for reducing magnetic interaction between magnetic particles constituting the magnetic layer. The surface of the underlayer is treated for oxygen adsorption before depositing the magnetic layer to suppress magnetic interaction between magnetic
20 particles in the magnetic layer. Thus, a perpendicular magnetic recording medium is provided that exhibits high recording density and excellent read-write characteristics.

Claims

1. A perpendicular magnetic recording medium comprising:
a nonmagnetic substrate and
a magnetic layer having a multilayered lamination structure
5 composed by alternately laminating a mainly-cobalt layer of a cobalt layer and a noble metal layer of a platinum or palladium layer repetitively, at least one type of layers of the cobalt layers and the platinum or palladium layers containing at least one element selected from the group consisting of Ru, Ta, Nb, Mo, Mn, Cr, Si, and Ni, or at
10 least one oxide.
2. A perpendicular magnetic recording medium according to claim 1, wherein the at least one element or one oxide is contained in an amount in a range from 1 to 15 at%.
3. A perpendicular magnetic recording medium according to
15 claim 2, wherein the mainly-cobalt layer contains silicon oxide in an amount from 5 to 11 mol%, and the noble metal layer is composed of platinum and contains silicon oxide in an amount from 1 to 8 mol%.
4. A perpendicular magnetic recording medium according to any one of claims 1 through 3, wherein each of the mainly-cobalt
20 layers has a thickness in a range from 0.2 to 0.8 nm and each of the noble metal layers has a thickness in a range from 0.05 to 1.2 nm.
5. A perpendicular magnetic recording medium according to any one of claims 1 through 4 further comprising an underlayer between the magnetic layer and the substrate, the magnetic layer

being formed directly on the underlayer.

6. A perpendicular magnetic recording medium according to claim 5, wherein the underlayer is substantially composed of a platinum film, a palladium film, a ruthenium film, or a platinum and
5 palladium lamination film.

7. A perpendicular magnetic recording medium according to claim 5 or claim 6, wherein a thickness of the underlayer is in a range from 1 to 20 nm.

8. A perpendicular magnetic recording medium according to
10 any one of claims 5 through 7 further comprising an orientation control layer between the substrate and the underlayer for controlling crystalline orientation of the underlayer.

9. A perpendicular magnetic recording medium according to claim 8, wherein the orientation control layer is composed of a
15 lamination of a first seed layer and a second seed layer, and a composition of the second seed layer is selected so as to orient the underlayer in a c-crystal axis.

10. A perpendicular magnetic recording medium according to claim 9, wherein the first seed layer is composed of a tantalum layer
20 and the second seed layer is composed of a layer selected from a NiFeCr layer, a NiFeNbB layer, and a NiFeSi layer.

11. A perpendicular magnetic recording medium according to claim 9 or claim 10, wherein a thickness of the first seed layer is in the range from 1 to 10 nm, and a thickness of the second seed layer is

in the range from 5 to 20 nm.

12. A perpendicular magnetic recording medium according to any one of claims 9 through 11 further comprising a soft magnetic backing layer between the substrate and the first seed layer.

5 13. A perpendicular magnetic recording medium according to claim 12, wherein the soft magnetic backing layer is composed of a CoZrNb alloy or a CoZrTa alloy having a thickness in the range from 50 to 400 nm.

14. A method for manufacturing a perpendicular magnetic
10 recording medium comprising a step of depositing, on a nonmagnetic substrate, a magnetic layer having a multilayered lamination structure by alternately laminating a mainly-cobalt layer of a cobalt layer and a noble metal layer of a platinum or palladium layer repetitively, by means of a sputtering method using a target
15 containing at least one element selected from the group consisting of Ru, Ta, Nb, Mo, Mn, Cr, Si, and Ni, or at least one oxide, in an amount in the range from 1 to 15 at%.

15. A method for manufacturing a perpendicular magnetic recording medium according to claim 14, wherein the step of
20 depositing the magnetic layer is conducted using a sputtering gas containing oxygen in a range from 0.05 to 0.5 % in a relative mass flow rate.

16 A method for manufacturing a perpendicular magnetic recording medium according to claim 14 or claim 15 further

comprising a step of depositing an underlayer composed of a film selected from a platinum film, a palladium film, a ruthenium film, or a platinum and palladium lamination film, on the substrate before the step of depositing the magnetic layer, by means of a sputtering
5 method.

17. A method for manufacturing a perpendicular magnetic recording medium according to claim 16, wherein the step of depositing the underlayer and the step of depositing the magnetic layer are conducted using a sputtering gas selected from krypton,
10 xenon, a mixed gas of krypton and argon, and a mixed gas of xenon and argon.

18. A method for manufacturing a perpendicular magnetic recording medium according to claim 16 further comprising a step of adsorption of oxygen on the underlayer surface after the step of
15 depositing the underlayer and before the step of depositing the magnetic layer, the step of adsorption including a process of exposing a surface of the underlayer to argon gas containing 1 to 10 % of oxygen in relative mass flow rate under a pressure of 0.1 to 10 Pa for 1 to 20 seconds.

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