

DESCRIPTION

PERPENDICULAR MAGNETIC RECORDING DISK AND METHOD OF MANUFACTURING THE SAME

Technical Field

[0001]

This invention relates to a perpendicular magnetic recording medium adapted to be mounted in a perpendicular magnetic recording type HDD (hard disk drive) or the like.

Background Art

[0002]

Various information recording techniques have been developed following the increase in volume of information processing in recent years. Particularly, the areal recording density of HDDs (hard disk drives) using the magnetic recording technique has been increasing at an annual rate of about 100%. Recently, the information recording capacity exceeding 100GB has been required per 2.5-inch magnetic disk adapted for use in a HDD or the like. In order to satisfy such a requirement, it is necessary to realize an information recording density exceeding 200Gbits/inch². In order to achieve the high recording density in a magnetic disk for use in a HDD or the like, it is necessary to reduce the size of magnetic crystal grains forming a magnetic recording layer serving to record information signals, and further, to reduce the thickness of the layer. However, in the case of conventionally commercialized magnetic disks of the in-plane magnetic recording type (also called the longitudinal magnetic recording type or the horizontal magnetic recording type), as a result of the reduction in size of magnetic crystal grains, there has arisen a so-called thermal

fluctuation phenomenon where the thermal stability of recorded signals is degraded due to superparamagnetism so that the recorded signals are lost, which has thus become an impeding factor for the increase in recording density of the magnetic disks.

[0003]

In order to solve this impeding factor, magnetic disks of the perpendicular magnetic recording type have been proposed in recent years. In the case of the perpendicular magnetic recording type, as different from the case of the in-plane magnetic recording type, the easy magnetization axis of a magnetic recording layer is adjusted so as to be oriented in a direction perpendicular to the surface of a substrate. As compared with the in-plane magnetic recording type, the perpendicular magnetic recording type can suppress the thermal fluctuation phenomenon and thus is suitable for increasing the recording density. For example, Japanese Unexamined Patent Application Publication (JP-A) No. 2002-92865 (Patent Document 1) discloses a technique about a perpendicular magnetic recording medium having an underlayer, a Co-based perpendicular magnetic recording layer, and a protective layer that are formed on a substrate in the order named. Further, United States Patent No. 6468670 Specification (Patent Document 2) discloses a perpendicular magnetic recording medium having a configuration in which an exchange-coupled artificial lattice film continuous layer (exchange-coupled layer) is adhered to a granular recording layer.

Patent Document 1: Japanese Unexamined Patent Application
Publication (JP-A) No. 2002-92865

Patent Document 2: United States Patent No. 6468670 Specification

Disclosure of the Invention

Problem to be Solved by the Invention

[0004]

Also in the case of the perpendicular magnetic recording medium, like in the case of the in-plane magnetic recording medium, the recording density of the magnetic disk is improved mainly by reducing noise in a magnetization transition region of a magnetic recording layer. For the noise reduction, it is necessary to improve the crystal orientation of the magnetic recording layer and to reduce the crystal grain size and the magnitude of magnetic interaction. That is, in order to increase the recording density of the medium, it is desirable to equalize and reduce the crystal grain size in the magnetic recording layer and, further, to provide a segregated state where individual magnetic crystal grains are magnetically separated.

[0005]

In the meantime, the Co-based perpendicular magnetic recording layer disclosed in Patent Document 1, particularly a CoPt-based perpendicular magnetic recording layer, has a high coercive force (H_c) and can cause a reversed domain nucleation magnetic field (H_n) to be a small value less than zero and, therefore, the resistance against thermal fluctuation can be improved and a high S/N ratio can be achieved, which is thus preferable. Further, by causing an element such as Cr to be contained in such a perpendicular magnetic recording layer, Cr can be segregated at grain boundary portions of the magnetic crystal grains to block the exchange interaction between the magnetic crystal grains, thereby contributing to increasing the recording density.

[0006]

Further, by adding an oxide such as SiO_2 to the CoPt-based perpendicular magnetic recording layer, it is possible to form an excellent segregated structure without impeding the epitaxial growth of CoPt. That is, by segregating the oxide such as SiO_2 at the grain boundaries to reduce the crystal grain size and further to reduce the magnetic interaction between the magnetic

grains, the low noise is achieved.

[0007]

In this manner, by increasing the content of SiO_2 , the low-noise characteristics can be improved. On the other hand, an excessive increase in the amount of SiO_2 causes degradation of perpendicular magnetic anisotropy, so that there arises a problem of thermal fluctuation. As one means for avoiding this thermal fluctuation problem, it is considered to increase the coercive force. In order to improve the coercive force, a configuration has conventionally been employed, for example to increase an anisotropy constant (K_u) of a magnetic layer by optimizing the composition of the magnetic layer or to improve the crystal orientation of a magnetic layer by optimizing materials of an orientation control layer and an underlayer or optimizing the film structures of them.

[0008]

It is an object of this invention to provide a perpendicular magnetic recording disk that can achieve a high coercive force (H_c) and low-noise characteristics (high S/N ratio) by realizing both segregation of SiO_2 and high perpendicular magnetic anisotropy, without adding a large change to its manufacturing process.

Means for Solving the Problem

[0009]

In order to solve the aforementioned problem, according to a typical aspect of this invention, there is provided a perpendicular magnetic recording disk for use in perpendicular magnetic recording, comprising at least an underlayer, a first magnetic recording layer, and a second magnetic recording layer on a substrate in this order, wherein the first magnetic recording layer and the second magnetic recording layer are each a ferromagnetic layer of a

granular structure having a nonmagnetic substance forming a grain boundary portion between crystal grains containing at least cobalt (Co), and, given that a content of the nonmagnetic substance in the first magnetic recording layer is A mol% and a content of the nonmagnetic substance in the second magnetic recording layer is B mol%, $A > B$.

[0010]

The content of the nonmagnetic substance in the first magnetic recording layer is preferably 8mol% to 20mol% and more preferably 10mol% to 14mol%. This is because if it is 8mol% or less, a sufficient compositional separation (segregation) structure cannot be formed and thus a high S/N ratio cannot be obtained. Further, this is because if it is 20mol% or more, it is difficult for Co to form an hcp structure, so that sufficient perpendicular magnetic anisotropy cannot be obtained and thus high H_n cannot be obtained. The content of the nonmagnetic substance in the second magnetic recording layer is preferably 8mol% to 20mol% and more preferably 8mol% to 12mol%. The magnetic recording layers are preferably formed by a sputtering method. A DC magnetron sputtering method is particularly preferable because uniform film formation is enabled.

[0011]

The thickness of the first magnetic recording layer is preferably 10nm or less and more preferably 0.5nm to 2nm. This is because if it is less than 0.5nm, compositional separation of the second magnetic recording layer cannot be facilitated and, if it is greater than 2nm, the R/W characteristics (read/write characteristics) are degraded. The thickness of the second magnetic recording layer is preferably 3nm or more and more preferably 7nm to 15nm. This is because if it is less than 7nm, a sufficient coercive force cannot be obtained and, if it is greater than 15nm, high H_n cannot be obtained. In order to obtain high H_n , the total thickness of the first magnetic recording layer and

the second magnetic recording layer is preferably 15nm or less.

[0012]

The nonmagnetic substance may be any substance as long as it is a substance that can form grain boundary portions around magnetic grains so as to suppress or block the exchange interaction between the magnetic grains and that is a nonmagnetic substance not solid-soluble to cobalt (Co). For example, chromium (Cr), oxygen (O), and oxides such as silicon oxide (SiO_x), chromium oxide (CrO₂), titanium oxide (TiO₂), zirconium oxide (ZrO₂), and tantalum oxide (Ta₂O₅) can be cited as examples.

[0013]

An orientation control layer having an amorphous or fcc structure is preferably provided between the substrate and the underlayer. The orientation control layer is a layer having a function of controlling the orientation of crystal grains of the underlayer. The orientation control layer can be formed of a material such as, for example, Ta, Nb, a Ni-based alloy such as NiP, a Co-based alloy such as CoCr, a nonmagnetic layer containing Ta or Ti, Pd, or Pt.

[0014]

An amorphous soft magnetic layer is preferably provided between the substrate and the underlayer. In this invention, the soft magnetic layer is not particularly limited as long as it is formed of a magnetic body that exhibits the soft magnetic properties and, for example, use can be made of an Fe-based soft magnetic material such as FeTaC-based alloy, FeTaN-based alloy, FeNi-based alloy, FeCoB-based alloy, or FeCo-based alloy, a Co-based soft magnetic material such as CoTaZr-based alloy or CoNbZr-based alloy, an FeCo-based alloy soft magnetic material, or the like.

[0015]

Further, the soft magnetic layer preferably has as its magnetic property a coercive force (H_c) of 0.01 to 80 oersteds (Oe) and more preferably 0.01 to 50

oersteds. Further, it preferably has as its magnetic property a saturation magnetic flux density (Bs) of 500emu/cc to 1920emu/cc. The thickness of the soft magnetic layer is preferably 10nm to 1000nm and more preferably 20nm to 150nm. When it is less than 10nm, there is a case where it becomes difficult to form a suitable magnetic circuit between magnetic head - perpendicular magnetic recording layer - soft magnetic layer, while, when it exceeds 1000nm, there is a case where the surface roughness increases. Further, when it exceeds 1000nm, there is a case where the sputtering film formation becomes difficult.

[0016]

The substrate is preferably an amorphous glass. When magnetic field annealing is necessary for controlling magnetic domains of the soft magnetic layer, the substrate is preferably a glass because it is excellent in heat resistance. As the glass for the substrate, an amorphous glass or a crystallized glass can be used and, for example, there can be cited an aluminosilicate glass, an aluminoborosilicate glass, a soda lime glass, or the like. Among them, the aluminosilicate glass is preferable. When the soft magnetic layer is amorphous, the substrate is preferably the amorphous glass. When a chemically strengthened glass is used, the rigidity is high, which is thus preferable.

[0017]

The surface roughness of the main surface of the substrate is preferably 6nm or less in Rmax and 0.6nm or less in Ra. By providing such a smooth surface, a gap between perpendicular magnetic recording layer - soft magnetic layer can be set constant so that it is possible to form a suitable magnetic circuit between magnetic head - perpendicular magnetic recording layer - soft magnetic layer.

[0018]

According to a typical aspect of this invention, there is provided a method of manufacturing a perpendicular magnetic recording disk for use in perpendicular magnetic recording, the disk comprising at least an underlayer, a first magnetic recording layer, and a second magnetic recording layer on a substrate in this order, comprising forming, as the first magnetic recording layer, a ferromagnetic layer of a granular structure in which a nonmagnetic substance is segregated between magnetic grains containing at least cobalt (Co), and forming, as the second magnetic recording layer, a ferromagnetic layer of a granular structure in which a nonmagnetic substance is segregated between magnetic grains containing at least cobalt (Co), wherein, given that a content of the nonmagnetic substance in the first magnetic recording layer is A mol% and a content of the nonmagnetic substance in the second magnetic recording layer is B mol%, $A > B$. A sputtering method, particularly a DC magnetron sputtering method, can be suitably used for forming the magnetic recording layers.

Effect of the Invention

[0019]

According to this invention, it is possible to achieve both segregation of a nonmagnetic substance and high perpendicular magnetic anisotropy to thereby obtain a high coercive force (H_c) and low-noise characteristics (high S/N ratio), without adding a large change to the manufacturing process.

Brief Description of the Drawings

[0020]

Fig. 1 is a diagram for explaining the configuration of a perpendicular magnetic recording medium according to a first embodiment.

Fig. 2 is an exemplary diagram for explaining the vicinity of magnetic recording layers.

Fig. 3 is a diagram showing the relationship between coercive force and

noise when the thicknesses of the first and second magnetic recording layers are changed.

Fig. 4 is a diagram for explaining the configuration of a perpendicular magnetic recording medium according to a second embodiment.

Fig. 5 is a diagram showing the relationship between coercive force and noise when the thicknesses of first and second magnetic recording layers according to the second embodiment are changed.

Description of Symbols

[0021]

- 1 disk substrate
- 2 adhesive layer
- 3 soft magnetic layer
- 4 orientation control layer
- 5a, 5b underlayers
- 6 first magnetic recording layer
- 6a magnetic grain
- 6b silicon oxide
- 7 second magnetic recording layer
- 7a magnetic grain
- 7b silicon oxide
- 8 coupling control layer
- 9 exchange energy control layer
- 10 medium protective layer
- 11 lubricating layer
- 10 medium protective layer
- 11 lubricating layer
- 23 soft magnetic layer

23a	first soft magnetic layer
23b	spacer layer
23c	second soft magnetic layer
24	orientation control layer
26	onset layer
27	first magnetic recording layer
28	second magnetic recording layer

Best Mode for Carrying Out the Invention

[0022]

[First Embodiment]

A first embodiment of a perpendicular magnetic recording medium according to this invention will be described with reference to the drawings. Fig. 1 is a diagram for explaining the configuration of the perpendicular magnetic recording medium according to the first embodiment, Fig. 2 is an exemplary diagram for explaining the vicinity of magnetic recording layers, and Fig. 3 is a diagram showing the relationship between coercive force and noise when the thicknesses of the first and second magnetic recording layers are changed. Numerical values given in the following embodiment are only examples for facilitating the understanding of this invention and are not intended to limit this invention unless otherwise stated.

[0023]

The perpendicular magnetic recording medium shown in Fig. 1 comprises a disk substrate 1, an adhesive layer 2, a soft magnetic layer 3, an orientation control layer 4, an underlayer 5a, an underlayer 5b, a first magnetic recording layer 6, a second magnetic recording layer 7, a coupling control layer 8, an exchange energy control layer 9 (continuous layer), a medium protective layer 10, and a lubricating layer 11.

[0024]

At first, an amorphous aluminosilicate glass was molded into a disk shape by direct press, thereby producing a glass disk. This glass disk was ground, polished, and chemically strengthened in sequence, thereby obtaining the smooth nonmagnetic disk substrate 1 in the form of a chemically strengthened glass disk. The disk diameter was 65mm. The surface roughness of the main surface of the disk substrate 1 was measured by an AFM (atomic force microscope) and it was a smooth surface shape with Rmax of 4.8nm and Ra of 0.42nm. Rmax and Ra follow Japanese Industrial Standard (JIS).

[0025]

Using an evacuated film forming apparatus, the layers from the adhesive layer 2 to the exchange energy control layer 9 were formed in sequence on the obtained disk substrate 1 in an Ar atmosphere by a DC magnetron sputtering method and then the medium protective layer 10 was formed by a CVD method. Thereafter, the lubricating layer 11 was formed by a dip coating method. In terms of capability of uniform film formation, it is also preferable to use an in-line type film forming method. Hereinbelow, the structures and manufacturing methods of the respective layers will be described.

[0026]

The adhesive layer 2 was formed using a Ti-alloy target so as to be a Ti-alloy layer of 10nm. By forming the adhesive layer 2, the adhesion between the disk substrate 1 and the soft magnetic layer 3 can be improved and, therefore, it is possible to prevent stripping of the soft magnetic layer 3. As a material of the adhesive layer 2, use can be made of, for example, a Ti-containing material. In terms of practical use, the thickness of the adhesive layer is preferably set to 1nm to 50nm.

[0027]

The soft magnetic layer 3 was formed using a CoTaZr target so as to be an amorphous CoTaZr layer of 50nm.

[0028]

The orientation control layer 4 has a function of protecting the soft magnetic layer 3 and a function of facilitating miniaturization of crystal grains of the underlayer 5a. As the orientation control layer 4, an amorphous layer of Ta was formed to a thickness of 3nm using a Ta target.

[0029]

The underlayers 5a and 5b form a two-layer structure made of Ru. By forming Ru on the upper layer side at an Ar gas pressure higher than that used when forming Ru on the lower layer side, the crystal orientation can be improved.

[0030]

Using a hard magnetic target made of CoCrPt and silicon oxide (SiO_2) as an example of a nonmagnetic substance, the first magnetic recording layer 6 with an hcp crystal structure of 2nm was formed. The first magnetic recording layer can be suitably set in a range of 0.5nm to 2nm. The composition of the target for forming the first magnetic recording layer 6 is 88(mol%) CoCrPt and 12(mol%) SiO_2 .

[0031]

Likewise, using a hard magnetic target made of CoCrPt and silicon oxide (SiO_2) as an example of a nonmagnetic substance, the second magnetic recording layer 7 with an hcp crystal structure of 9nm was formed. The second magnetic recording layer 7 can be suitably set in a range of 7nm to 15nm. The composition of the target for forming the second magnetic recording layer 7 is 90(mol%) CoCrPt and 10(mol%) SiO_2 .

[0032]

That is, given that the content of Si in the first magnetic recording layer 6 is A mol% and the content of Si in the second magnetic recording layer 7 is B mol%, $A > B$ (the first magnetic recording layer 6 contains more Si).

[0033]

The coupling control layer 8 was formed by a Pd (palladium) layer. The coupling control layer 8 can be formed by a Pt layer instead of the Pd layer. The thickness of the coupling control layer 8 is preferably 2nm or less and more preferably 0.5 to 1.5nm.

[0034]

The exchange energy control layer 9 is in the form of alternately layered films of CoB and Pd and was formed in a low Ar gas. The thickness of the exchange energy control layer 9 is preferably 1 to 8nm and more preferably 3 to 6nm.

[0035]

The medium protective layer 10 was formed by film formation of carbon by the CVD method while maintaining a vacuum. The medium protective layer 10 is a protective layer for protecting the perpendicular magnetic recording layer from an impact of a magnetic head. Since, in general, carbon formed into a film by the CVD method is improved in film hardness as compared with that by the sputtering method, it is possible to protect the perpendicular magnetic recording layer more effectively against the impact from the magnetic head.

[0036]

The lubricating layer 11 was formed of PFPE (perfluoropolyether) by the dip coating method. The thickness of the lubricating layer 11 is about 1nm.

[0037]

Through the manufacturing process described above, the perpendicular magnetic recording medium was obtained. The first magnetic recording layer 6 and the second magnetic recording layer 7 in the obtained perpendicular

magnetic recording disk were analyzed in detail by the use of a transmission electron microscope (TEM) and they each had a granular structure. Specifically, it was confirmed that grain boundary portions made of silicon oxide were formed between crystal grains of the hcp crystal structure containing Co.

[0038]

Herein, as shown in Fig. 2, magnetic grains 6a (Co-based alloy) of the first magnetic recording layer 6 and magnetic grains 7a (Co-based alloy) of the second magnetic recording layer 7 are crystallographically connected to Ru of the underlayer 5b. This is because the magnetic grains 6a and 7a and silicon oxides 6b and 7b of the first and second magnetic recording layers 6 and 7 continuously grow, respectively.

[0039]

For comparison, perpendicular magnetic recording media were manufactured by changing the thickness of the first magnetic recording layer 6 from 0 to 11nm while the sum of the thicknesses of the first magnetic recording layer 6 and the second magnetic recording layer 7 was set to 11nm, and the magnetostatic properties of the obtained perpendicular magnetic recording disks were measured and evaluated using the Kerr effect. Fig. 3 shows changes in coercive force (H_c) and noise (S/N ratio [dB]) when the ratio between the thicknesses of the first magnetic recording layer 6 and the second magnetic recording layer 7 is changed. When the first magnetic recording layer 6 is 0nm, the second magnetic recording layer 7 is 11nm and thus it is shown that substantially only the second magnetic recording layer 7 is formed. Likewise, when the first magnetic recording layer 6 is 11nm, the second magnetic recording layer 7 is 0nm and thus it is shown that substantially only the first magnetic recording layer 6 is formed.

[0040]

As shown in Fig. 3, it is seen that when the ratio between the

thicknesses of the first magnetic recording layer 6 and the second magnetic recording layer 7 is changed, the coercive force H_c and the S/N ratio change. The coercive force is high when the thickness of the first magnetic recording layer 6 is about 0nm to 3nm, and the maximum coercive force is exhibited particularly when the thickness is 2nm. In this event, there are observed an improvement of about 1800[Oe] as compared with the case of only the first magnetic recording layer 6 (plot at the right end in the figure) and an improvement of about 150[Oe] as compared with the case of only the second magnetic recording layer 7 (plot at the left end in the figure).

[0041]

Further, the R/W characteristics (read/write characteristics) of these media were examined and there was observed an improvement in S/N ratio following the changes in coercive force. The S/N ratio is high when the thickness of the first magnetic recording layer 6 is about 0nm to 4nm, and the maximum value is exhibited particularly when the thickness is 2nm. Note that when the thickness of the first magnetic recording layer 6 is 7nm or more, more improvement in S/N ratio is observed as the thickness increases. In this event, however, the medium exhibits a low coercive force and thus does not exhibit sufficient anti-thermal fluctuation properties, and therefore, is not suitable as a medium.

[0042]

In view of the above, the thickness of the first magnetic recording layer 6 is preferably in a range of thicker than 0nm and thinner than 3nm and is desired to be particularly 2nm. In this event, a high coercive force and low noise (high S/N ratio) can be obtained and thus it is possible to obtain suitable properties as a perpendicular magnetic recording medium.

[0043]

In due consideration, in the perpendicular magnetic recording medium

according to the first embodiment, since the first magnetic recording layer 6 contains more nonmagnetic substance, the crystal grains of the hcp crystal structure containing Co are smaller in the first magnetic recording layer 6. Therefore, as compared with the second magnetic recording layer 7, the first magnetic recording layer 6 should exhibit lower noise and a lower coercive force. However, it is considered that, by providing the two-layer structure comprising the first magnetic recording layer 6 and the second magnetic recording layer 7, miniaturized magnetic crystal grains are first formed in the first magnetic recording layer 6 and, based on them, magnetic crystal grains grow (granular structure) in the second magnetic recording layer 7. Consequently, it is considered that the magnetic crystal grains are magnetically separated and thus tend to grow also in the second magnetic recording layer 7 being the upper layer so that the coercive force is improved.

[0044]

That is, by configuring such that the magnetic recording layers form the two-layer structure and the first magnetic recording layer on the lower layer side contains more nonmagnetic substance, it is possible to simultaneously achieve a high coercive force (H_c) and low-noise characteristics (high S/N ratio) as compared with the case where the respective layers are formed independently.

[0045]

It is considered that the reason why the good results are obtained when the first magnetic recording layer 6 is thinner than the second magnetic recording layer 7 is that the first magnetic recording layer 6 is advantageous for magnetic compositional separation because of its crystal grains being small, but is disadvantageous for recording because of its coercive force being low. That is, it is considered that the first magnetic recording layer 6 is only required to be thick enough to satisfy the purpose of compositional separation and, if it is too thick, the R/W characteristics (read/write characteristics) are degraded.

[0046]

On the other hand, although not illustrated, if the total thickness of the magnetic recording layers exceeds 15nm, H_n decreases. This is because since crystal grains become coarse, a magnetization rotation mode becomes non-simultaneous rotation. Therefore, it is necessary to also consider the thickness of the second magnetic recording layer depending on the thickness of the first magnetic recording layer and the total thickness of the first magnetic recording layer and the second magnetic recording layer is preferably 15nm or less.

[0047]

The nonmagnetic substance is described as silicon oxide (SiO_2) in the foregoing embodiment, but may be any substance as long as it is a substance that can form grain boundary portions around magnetic grains so as to suppress or block the exchange interaction between the magnetic grains and that is a nonmagnetic substance not solid-soluble to cobalt (Co). For example, chromium (Cr), oxygen (O), and oxides such as silicon oxide (SiO_x), chromium oxide (CrO_2), titanium oxide (TiO_2), zirconium oxide (ZrO_2), and tantalum oxide (Ta_2O_5) can be cited as examples.

[0048]

[Second Embodiment]

A second embodiment of a perpendicular magnetic recording medium according to this invention will be described with reference to the drawings. Fig. 4 is a diagram for explaining the configuration of the perpendicular magnetic recording medium according to the second embodiment and Fig. 5 is a diagram showing the relationship between coercive force and noise when the thicknesses of first and second magnetic recording layers according to the second embodiment are changed. The same symbols are assigned to those portions of which description overlaps that of the foregoing first embodiment,

thereby omitting explanation thereof.

[0049]

The perpendicular magnetic recording medium shown in Fig. 4 comprises a disk substrate 1, a soft magnetic layer 23, an orientation control layer 24, an underlayer 5, an onset layer 26, a first magnetic recording layer 27, a second magnetic recording layer 28, a medium protective layer 10, and a lubricating layer 11.

[0050]

The soft magnetic layer 23 is formed by interposing a nonmagnetic spacer layer 23b between a first soft magnetic layer 23a and a second soft magnetic layer 23c so as to have AFC (antiferro-magnetic exchange coupling). With this configuration, magnetization directions of the first soft magnetic layer 23a and the second soft magnetic layer 23c can be aligned antiparallel to each other with high accuracy, so that it is possible to reduce noise generated from the soft magnetic layer 23. Specifically, the composition of the first soft magnetic layer 23a and the second soft magnetic layer 23c can be CoTaZr (cobalt-tantalum-zirconium) or CoFeTaZr (cobalt-iron-tantalum-zirconium). The composition of the spacer layer 23b is Ru (ruthenium).

[0051]

The orientation control layer 24 has a function of protecting the soft magnetic layer 23 and a function of facilitating alignment of the orientation of crystal grains of the underlayer 5. The orientation control layer 24 can be a layer of Pt (platinum), NiW (nickel-tungsten), or NiCr (nickel-chromium) having an fcc structure.

[0052]

The underlayer 5 has a two-layer structure made of Ru. By forming a second underlayer 5b on the upper layer side at an Ar gas pressure higher than that used when forming a first underlayer 5a on the lower layer side, the crystal

orientation and the separation of magnetic grains of the magnetic recording layers can be simultaneously improved.

[0053]

The onset layer 26 is a nonmagnetic granular layer. By forming the nonmagnetic granular layer on an hcp crystal structure of the second underlayer 5b and growing a granular layer of the first magnetic recording layer 27 thereon, the onset layer 26 has a function of separating the magnetic granular layer from an initial stage (buildup). The composition of the onset layer 26 is nonmagnetic CoCr-SiO₂.

[0054]

Using a hard magnetic target made of CoCrPt-8(TiO₂) containing Cr and titanium oxide (TiO₂) as examples of a nonmagnetic substance, the first magnetic recording layer 27 with an hcp crystal structure of 9nm was formed. The first magnetic recording layer is preferably set in a range of 5nm to 20nm and more preferably 7nm to 15nm. The composition of the target for forming the first magnetic recording layer 27 is 92(mol%) Co₇₄Cr₁₁Pt₁₅ and 8(mol%) TiO₂. Therefore, the amount of the nonmagnetic substance (oxide) contained in the first magnetic recording layer 27 is $11 \times 0.92 + 8 = 18.12$ (mol%).

[0055]

Using a hard magnetic target made of CoCrPt containing Cr as an example of a nonmagnetic substance, the second magnetic recording layer 28 with an hcp crystal structure of 10nm was formed. The second magnetic recording layer 28 can be suitably set in a range of 3nm to 15nm. The composition of the target for forming the second magnetic recording layer 28 is CoCr₁₄Pt₁₅. Therefore, the amount of the nonmagnetic substance (oxide) contained in the second magnetic recording layer 28 is 14(mol%).

[0056]

That is, given that the content of the nonmagnetic substance in the first

magnetic recording layer 27 is A mol% and the content of the nonmagnetic substance in the second magnetic recording layer 28 is B mol%, $A > B$ (the first magnetic recording layer 28 being the lower layer contains more nonmagnetic substance).

[0057]

Like in the foregoing first embodiment, the medium protective layer 10 and the lubricating layer 11 were formed on the second magnetic recording layer 28.

[0058]

For comparison, perpendicular magnetic recording media were manufactured by changing the thickness of the second magnetic recording layer 28 from 0 to 10nm while the sum of the thicknesses of the first magnetic recording layer 27 and the second magnetic recording layer 28 was set to 10nm, and the magnetostatic properties of the obtained perpendicular magnetic recording disks were measured and evaluated using the Kerr effect. Fig. 5 shows changes in coercive force (H_c) and noise (S/N ratio [dB]) when the ratio between the thicknesses of the first magnetic recording layer 27 and the second magnetic recording layer 28 is changed.

[0059]

As shown in Fig. 5, it is seen that when the ratio between the thicknesses of the first magnetic recording layer 27 and the second magnetic recording layer 28 is changed, the coercive force H_c and the S/N ratio change. The coercive force H_c becomes maximum when the thickness of the second magnetic recording layer 28 is about 5nm. In this event, there are observed an improvement of about 1600[Oe] as compared with the case of only the second magnetic recording layer 28 (plot at the right end in the figure) and an improvement of about 200[Oe] as compared with the case of only the first magnetic recording layer 27 (plot at the left end in the figure).

[0060]

Further, the R/W characteristics (read/write characteristics) of these media were examined and there was observed an improvement in S/N ratio following the changes in coercive force. The S/N ratio increases as the thickness of the second magnetic recording layer 28 increases from 0nm to about 5nm, and then decreases after the thickness exceeds it. The maximum value is exhibited particularly when the thickness is about 5nm.

[0061]

In view of the above, the thickness of the first magnetic recording layer 6 is preferably in a range of thicker than 0nm and thinner than 3nm and is desired to be particularly 2nm. In this event, a high coercive force and low noise (high S/N ratio) can be obtained and thus it is possible to obtain suitable properties as a perpendicular magnetic recording medium.

[0062]

In view of the above, the thickness of the second magnetic recording layer 28 is preferably in a range of 4nm to 6nm and is desired to be particularly 5nm. In this event, a high coercive force and low noise (high S/N ratio) can be obtained and thus it is possible to obtain suitable properties as a perpendicular magnetic recording medium.

[0063]

That is, also in the second embodiment, it has been confirmed that, by configuring such that the magnetic recording layers form the two-layer structure and the first magnetic recording layer on the lower layer side contains more nonmagnetic substance, it is possible to simultaneously achieve a high coercive force (H_c) and low-noise characteristics (high S/N ratio) as compared with the case where the respective layers are formed independently.

[0064]

While the preferred embodiments of this invention have been described

with reference to the accompanying drawings, it is needless to say that this invention is not limited thereto. It is apparent that a person skilled in the art can think of various changes and modifications in the category described in claims and it is understood that those also naturally belong to the technical scope of this invention.

Industrial Applicability

[0065]

This invention can be used as a perpendicular magnetic recording medium adapted to be mounted in a perpendicular magnetic recording type HDD (hard disk drive) or the like and as a manufacturing method thereof.

CLAIMS

1. A perpendicular magnetic recording disk for use in perpendicular magnetic recording, comprising at least an underlayer, a first magnetic recording layer, and a second magnetic recording layer on a substrate in this order, wherein:

the first magnetic recording layer and the second magnetic recording layer are each a ferromagnetic layer of a granular structure having a nonmagnetic substance forming a grain boundary portion between crystal grains containing at least cobalt (Co), and

given that a content of the nonmagnetic substance in the first magnetic recording layer is A mol% and a content of the nonmagnetic substance in the second magnetic recording layer is B mol%, $A > B$.

2. A perpendicular magnetic recording disk according to claim 1, wherein the content of the nonmagnetic substance in the first magnetic recording layer or the second magnetic recording layer is 8mol% to 20mol%.

3. A perpendicular magnetic recording disk according to claim 1, wherein a total thickness of the first magnetic recording layer and the second magnetic recording layer is 15nm or less.

4. A perpendicular magnetic recording disk according to claim 1, wherein an orientation control layer having an amorphous or fcc structure is provided between the substrate and the underlayer.

5. A perpendicular magnetic recording disk according to claim 1, wherein an amorphous soft magnetic layer is provided between the substrate and the underlayer.

6. A perpendicular magnetic recording disk according to claim 1, wherein the substrate is an amorphous glass.

7. A perpendicular magnetic recording disk according to claim 1,

wherein the nonmagnetic substance contains chromium, oxygen, or an oxide.

8. A method of manufacturing a perpendicular magnetic recording disk for use in perpendicular magnetic recording, the disk comprising at least an underlayer, a first magnetic recording layer, and a second magnetic recording layer on a substrate in this order, comprising:

forming, as the first magnetic recording layer, a ferromagnetic layer of a granular structure in which a nonmagnetic substance is segregated between magnetic grains containing at least cobalt (Co), and

forming, as the second magnetic recording layer, a ferromagnetic layer of a granular structure in which a nonmagnetic substance is segregated between magnetic grains containing at least cobalt (Co),

wherein, given that a content of the nonmagnetic substance in the first magnetic recording layer is A mol% and a content of the nonmagnetic substance in the second magnetic recording layer is B mol%, $A > B$.