

DESCRIPTION

TITLE OF INVENTION

5 PERPENDICULAR MAGNETIC RECORDING MEDIUM

TECHNICAL FIELD

[0001]

The present invention relates to a perpendicular magnetic
10 recording medium, and in detail, to a perpendicular magnetic
recording medium having a perpendicular magnetic recording layer
and a cap layer covering the perpendicular magnetic recording layer.
In this application, the cap layer is a layer covering the
perpendicular magnetic recording layer in a perpendicular magnetic
15 recording medium and adjusting the degree of intergranular exchange
coupling between the magnetic crystal grains of the perpendicular
magnetic recording layer.

BACKGROUND ART

20 [0002]

The perpendicular magnetic recording layer of a current
perpendicular magnetic recording medium is a granular layer, and
a non-magnetic grain boundary oxide is used to magnetically separate
each magnetic grain from adjacent magnetic grains (see, for example,
25 Patent Literature 1).

[0003]

In this current perpendicular magnetic recording medium, attempts are being made to achieve even higher recording densities, but are faced with the problem of trilemma. The problem of trilemma is to improve all three characteristics: signal-to-noise ratio (SNR), thermal stability, and ease of magnetic recording. In order to overcome the problem of trilemma by improving all three properties, it is necessary that the intergranular exchange coupling between the magnetic grains in the perpendicular recording layer, which is a granular layer, is adjusted appropriately to improve the thermal stability of the perpendicular recording layer and to reduce the switching magnetic field (the magnetic field necessary for magnetization reversal of the magnetic grains).

[0004]

Therefore, in a current perpendicular magnetic recording medium, a cap layer is provided on top of the perpendicular magnetic recording layer that is a granular layer. The current cap layer is, for example, a CoPt alloy such as CoPtCrB (see, for example, Patent Literatures 2 and 3).

[0005]

However, in order to overcome the aforementioned problem of trilemma, it is required to develop a cap layer with better characteristics than the current cap layer to improve the thermal stability of the perpendicular magnetic recording medium and to reduce the switching magnetic field.

CITATION LIST

Patent Literature

[0006]

5 Patent Literature 1: Japanese Patent Application Laid-Open
Publication No. 2000-306228

 Patent Literature 2: Japanese Patent Application Laid-Open
Publication No. 2009-59402

 Patent Literature 3: Japanese Patent Application Laid-Open
10 Publication No. 2011-34665

SUMMARY OF INVENTION

Technical Problem

[0007]

15 The present invention has been made in view of such points,
and it is an object of the present invention to provide a perpendicular
magnetic recording medium that achieves improved thermal stability
and reduction in switching magnetic field by equipping it with a
cap layer having characteristics (characteristics contributing to
20 reducing switching magnetic field of the perpendicular magnetic
recording medium as well as to improving thermal stability thereof)
superior to current cap layers.

Solution to Problem

25 [0008]

The present inventors observed the cap layer of the current perpendicular magnetic recording media using a transmission electron microscope (hereinafter referred to as "TEM"), and found that the current cap layer has concavity and convexity in the boundary surface with the perpendicular magnetic recording layer, and voids are formed above the non-magnetic grain boundary oxide of the perpendicular magnetic recording layer, resulting in non-uniformity in thickness direction of the current cap layer. The present inventors considered that, since the current cap layer consists of a metal alloy layer (for example, CoPt alloys such as CoPtCrB), the current cap layer is difficult to wet with the non-magnetic grain boundary oxide in the magnetic recording layer (granular layer), so that non-uniformity in thickness direction of the current cap layer results. Therefore, the present inventors conducted research and development of a cap layer by using a material that becomes a granular structure similar to that of the perpendicular magnetic recording layer, and have arrived at the present invention that solves the aforementioned problem.

[0009]

That is, a first aspect of a perpendicular magnetic recording medium according to the present invention is a perpendicular magnetic recording medium comprising a perpendicular magnetic recording layer and a cap layer covering the perpendicular magnetic recording layer, wherein the perpendicular magnetic recording layer contains a granular structure having CoPt alloy magnetic crystal grains and

a non-magnetic grain boundary oxide; the cap layer contains a granular structure having CoPt alloy magnetic crystal grains and a magnetic grain boundary oxide; the CoPt alloy magnetic crystal grains in the cap layer contain Co in a range of 65 at% or more and 90 at% or less and Pt in a range of 10 at% or more and 35 at% or less; and the volume fraction of the magnetic grain boundary oxide to the entire cap layer is 5 vol% or more and 40 vol% or less.

[0010]

A second aspect of a perpendicular magnetic recording medium according to the present invention is a perpendicular magnetic recording medium comprising a perpendicular magnetic recording layer and a cap layer covering the perpendicular magnetic recording layer, wherein the perpendicular magnetic recording layer contains a granular structure having CoPt alloy magnetic crystal grains and a non-magnetic grain boundary oxide; the cap layer contains a granular structure having CoPt alloy magnetic crystal grains and a magnetic grain boundary oxide; the CoPt alloy magnetic crystal grains in the cap layer contain Co in a range of 70 at% or more and less than 85 at%, Pt in a range of 10 at% or more and 20 at% or less, and at least one element selected from the group consisting of Cr, Ti, B, Mo, Ta, Nb, W and Ru in a range of 0.5 at% or more and 15 at% or less; and the volume fraction of the magnetic grain boundary oxide to the entire cap layer is 5 vol% or more and 40 vol% or less.

[0011]

A rare earth oxide may be used as the magnetic grain boundary

oxide.

[0012]

The magnetic grain boundary oxide is, for example, at least one oxide of a Gd oxide, a Nd oxide, a Sm oxide, a Ce oxide, an
5 Eu oxide, a La oxide, a Pr oxide, a Ho oxide, an Er oxide, a Yb oxide, and a Tb oxide.

Advantageous Effects of Invention

[0013]

10 According to the present invention, it is possible to provide a perpendicular magnetic recording medium that achieves improved thermal stability and reduction in switching magnetic field by equipping it with a cap layer having characteristics
(characteristics contributing to reducing switching magnetic field
15 of the perpendicular magnetic recording medium as well as to improving thermal stability thereof) superior to current cap layers.

BRIEF DESCRIPTION OF DRAWINGS

[0014]

20 FIG. 1 is a cross-sectional schematic diagram illustrating a perpendicular magnetic recording medium 10 according to an embodiment of the present invention.

FIG. 2 is a vertical cross-sectional diagram schematically illustrating a portion of a vertical cross section of the
25 perpendicular magnetic recording medium 10 according to the present

embodiment.

FIG. 3 is a vertical cross-sectional diagram schematically illustrating a portion of a vertical cross section of the perpendicular magnetic recording medium 10 (after optimizing the cap layer 26) according to the present embodiment.

FIG. 4 is a vertical cross-sectional diagram schematically illustrating a portion of a vertical cross section of a current perpendicular magnetic recording medium 100.

FIG. 5 is a cross-sectional TEM photograph of a region containing a cap layer ($\text{Co}_{80}\text{Pt}_{20}$ -30vol% Gd_2O_3) (deposited at an argon gas pressure of 0.6 Pa) with a thickness of 9 nm in Example 17.

FIG. 6 is a cross-sectional TEM photograph of a region containing a cap layer ($\text{Co}_{80}\text{Pt}_{20}$ -30vol% Gd_2O_3) (deposited at an argon gas pressure of 4.0 Pa) with a thickness of 9 nm in Example 8.

FIG. 7 is a cross-sectional TEM photograph of a region containing a cap layer (CoPtCrB) in a current perpendicular magnetic recording medium (Comparative Example 20).

FIG. 8 is a dark field image of a portion of the cross-sectional region of Example 17 shown in FIG. 5, taken by a scanning transmission electron microscope (STEM).

FIG. 9 is photographs showing the measurement results of energy dispersive X-ray analysis (EDX) performed by a scanning transmission electron microscope (STEM) for a portion of the cross-sectional region of Example 17 shown in FIG. 5, where (a) shows the distribution results of Gd, (b) shows the distribution results of O (oxygen),

(c) shows the distribution results of Co, and (d) shows the distribution results of Pt.

FIG. 10 is a dark field image of a portion of the cross-sectional region of Example 8 shown in FIG. 6, taken by a scanning transmission electron microscope (STEM).

FIG. 11 is photographs showing the measurement results of energy dispersive X-ray analysis (EDX) performed by a scanning transmission electron microscope (STEM) for a portion of the cross-sectional region of Example 8 shown in FIG. 6, where (a) shows the distribution results of Gd, (b) shows the distribution results of O (oxygen), (c) shows the distribution results of Co, and (d) shows the distribution results of Pt.

FIG. 12 is dark-field images of a portion of the cross-sectional region of the current perpendicular magnetic recording media (comparative example 20) shown in FIG. 7, taken by a scanning transmission electron microscope (STEM).

FIG. 13 is photographs showing the measurement results of energy dispersive X-ray analysis (EDX) performed by a scanning transmission electron microscope (STEM) for a portion of the cross-sectional region of the current perpendicular magnetic recording medium (comparative example 20) shown in FIG. 7, where (a) shows the distribution results of Cr, (b) shows the distribution results of O (oxygen), (c) shows the distribution results of Co, and (d) shows the distribution results of Pt.

FIG. 14 is a planar TEM photograph of the horizontal cross

section of the region containing a cap layer ($\text{Co}_{80}\text{Pt}_{20}$ -30vol% Gd_2O_3) of Example 143.

FIG. 15 is a planar TEM photograph of the horizontal cross section of the region containing a cap layer ($\text{Co}_{80}\text{Pt}_{20}$ -30vol% Nd_2O_3) of Example 144.

FIG. 16 is a planar TEM photograph of the horizontal cross section of the region containing a cap layer ($\text{Co}_{80}\text{Pt}_{20}$ -30vol% Sm_2O_3) of Example 145.

DESCRIPTION OF EMBODIMENTS

[0015]

Embodiments of the present invention will be described below with reference to the drawings.

[0016]

FIG. 1 is a cross-sectional schematic diagram illustrating a perpendicular magnetic recording medium 10 according to an embodiment of the present invention. FIG. 2 is a vertical cross-sectional diagram schematically illustrating a portion of a vertical cross section of the perpendicular magnetic recording medium 10 according to the present embodiment, and FIG. 3 is a vertical cross-sectional diagram schematically illustrating a portion of a vertical cross section of the perpendicular magnetic recording medium 10 (after optimizing the cap layer 26) according to the present embodiment.

[0017]

(1) Structure of the perpendicular magnetic recording medium 10

The perpendicular magnetic recording medium 10 according to the present embodiment has a structure in which an adhesion layer 14, a seed layer 16, a first Ru underlayer 18, a second Ru underlayer 20, a buffer layer 22, a perpendicular magnetic recording layer 24, a cap layer 26, and a surface protection layer 28 are formed in sequence on a substrate 12.

[0018]

As the substrate 12, various known substrates used for perpendicular magnetic recording media can be used, and for example, a glass substrate can be used.

[0019]

The adhesion layer 14 is a layer for enhancing adhesion between the seed layer 16, which is a metallic film, and the substrate 12. For example, a Ta layer or the like can be used as the adhesion layer 14.

[0020]

The seed layer 16 is a layer for controlling the crystal orientation and crystal growth of the first Ru underlayer 18, and for example, a $\text{Ni}_{90}\text{W}_{10}$ layer or the like can be used as the seed layer 16.

[0021]

The first Ru underlayer 18 is a layer for suitably controlling the crystal orientation, grain size, and grain boundary segregation of the perpendicular magnetic recording layer 24. The first Ru

underlayer 18 is a hexagonal close-packed (hcp) structure. The thickness of the first Ru underlayer 18 is, for example, about 10 nm.

[0022]

5 The second Ru underlayer 20 is a layer to provide an uneven shape on the surface (i.e., the surface of the second Ru underlayer 20) of the two-layer Ru underlayer (the first Ru underlayer 18 and the second Ru underlayer 20) so that the buffer layer 22 has a desirable layer structure. The thickness of the second Ru underlayer 20 is, 10 for example, about 10 nm. When a $\text{Ru}_{50}\text{Co}_{25}\text{Cr}_{25}$ -30vol% TiO_2 layer is provided as a buffer layer 22 on top of the second Ru underlayer 20, $\text{Ru}_{50}\text{Co}_{25}\text{Cr}_{25}$ is formed in the convex part of the second Ru underlayer 20 and TiO_2 is formed in the concave part of the second Ru underlayer 20.

15 [0023]

 The buffer layer 22 is a layer for improving the separation between columnar CoPt alloy magnetic crystal grains in the granular structure of the perpendicular magnetic recording layer 24. For example, a $\text{Ru}_{50}\text{Co}_{25}\text{Cr}_{25}$ -30vol% TiO_2 layer or the like can be used as 20 the buffer layer 22.

[0024]

 The perpendicular magnetic recording layer 24 is a layer for performing magnetic recording, and its layer structure is a granular structure. As the perpendicular magnetic recording layer 24, for 25 example, a $\text{Co}_{80}\text{Pt}_{20}$ -30vol% B_2O_3 layer or the like can be used, and

in this case, the columnar CoPt alloy magnetic crystal grains 24A are separated by the non-magnetic grain boundary oxide 24B (B_2O_3) (see FIGS. 2 and 3). The thickness of the perpendicular magnetic recording layer 24 is about 16 nm, for example.

5 [0025]

The cap layer 26 covers the perpendicular magnetic recording layer 24, and is a layer for improving the thermal stability of the perpendicular magnetic recording layer 24 and reducing the switching magnetic field (the magnetic field necessary for magnetization reversal of the magnetic crystal grains), by appropriately adjusting the intergranular exchange coupling between the CoPt alloy magnetic crystal grains 24A of the perpendicular magnetic recording layer 24. The cap layer 26 has a granular structure having CoPt alloy magnetic crystal grains 26A and a magnetic grain boundary oxide 26B (see FIGS. 2 and 3). For example, $Co_{80}Pt_{20}$ -30vol% magnetic oxide (Gd_2O_3 , Nd_2O_3 , Sm_2O_3 , CeO_2 , etc.) can be used as the cap layer 26, in which case the cap layer 26 is a granular structure in which the columnar CoPt alloy magnetic crystal grains 26A are divided by the magnetic grain boundary oxide 26B (Gd_2O_3 , Nd_2O_3 , Sm_2O_3 , CeO_2 , etc.) The thickness of the cap layer 26 can be determined appropriately depending on the size required for the intergranular exchange coupling between the CoPt alloy magnetic crystal grains 24A of the perpendicular magnetic recording layer 24 and the size of the intergranular exchange coupling 26C between the CoPt alloy magnetic crystal grains 26A of the cap layer 26. The thickness of

the cap layer 26 is, for example, 1 nm or more and 9 nm or less.

[0026]

The surface protection layer 28 is a layer for protecting the surface of the perpendicular magnetic recording medium 10. For example, a protective film consisting mainly of carbon can be used as the surface protection layer 28, and the thickness of the surface protection layer 28 is 7 nm, for example.

[0027]

(2) Further explanation of the composition of the cap layer 26

The cap layer 26 has a granular structure having the CoPt alloy magnetic crystal grains 26A and the magnetic grain boundary oxide 26B, as described above, and the CoPt alloy magnetic crystal grains 26A of the cap layer 26 contain Co in a range of 65 at% or more and 90 at% or less and Pt in a range of 10 at% or more and 35 at% or less. From the viewpoint of increasing more the coercive force H_c of the perpendicular magnetic recording medium 10, the CoPt alloy magnetic crystal grains 26A of the cap layer 26 preferably contain Co in a range of 70 at% or more and 75 at% or less and Pt in a range of 25 at% or more and 30 at% or less.

[0028]

The CoPt alloy magnetic crystal grains 26A of the cap layer 26 may contain Co in a range of 70 at% or more and less than 85 at%, Pt in a range of 10 at% or more and 20 at% or less, and at least one element of Cr, Ti, B, Mo, Ta, Nb, W, and Ru in a range of 0.5 at% or more and 15 at% or less.

[0029]

From the viewpoint of increasing more the coercive force H_c of the perpendicular magnetic recording medium 10 and increasing the intergranular exchange coupling 26C of the CoPt alloy magnetic crystal grains 26A of the cap layer 26 to reduce the saturation magnetic field H_s of the perpendicular magnetic recording medium 10, the volume fraction of the magnetic grain boundary oxide 26B to the entire cap layer 26 is preferably 5 vol% or more and 40 vol% or less, more preferably 10 vol% or more and 35 vol% or less, and particularly preferably 15 vol% or more and 30 vol% or less. Depending on the characteristics required for the perpendicular magnetic recording medium 10, the volume fraction of the magnetic grain boundary oxide 26B to the entire cap layer 26 may be determined accordingly.

[0030]

The magnetic grain boundary oxide 26B of the cap layer 26 is preferably a rare earth oxide from the viewpoint of increasing the magnetism, and is preferably an oxide of at least one element of Gd, Nd, Sm, Ce, Eu, La, Pr, Ho, Er, Yb, and Tb, specifically.

[0031]

The magnetic grain boundary oxide 26B of the cap layer 26 does not have to be a rare earth oxide. Specifically, the following magnetic oxides, for example, Fe_2O_3 , Fe_3O_4 , CoFe_2O_4 , $\text{MnTi}_{0.44}\text{Fe}_{1.56}\text{O}_4$, $\text{Mn}_{0.4}\text{Co}_{0.3}\text{Fe}_2\text{O}_4$, $\text{Co}_{1.1}\text{Fe}_{2.2}\text{O}_4$, $\text{Co}_{0.7}\text{Zn}_{0.3}\text{Fe}_2\text{O}_4$, $\text{Ni}_{0.35}\text{Fe}_{1.3}\text{O}_4$, NiFe_2O_4 , $\text{Li}_{0.3}\text{Fe}_{2.5}\text{O}_4$, $\text{Fe}_{2.69}\text{Ti}_{0.31}\text{O}_4$, $\text{Mn}_{0.98}\text{Fe}_{2.02}\text{O}_4$, $\text{Mn}_{0.8}\text{Zn}_{0.2}\text{Fe}_2\text{O}_4$, $\text{Y}_2\text{Fe}_5\text{O}_{12}$,

$\text{Y}_3\text{Al}_{0.83}\text{Fe}_{4.17}\text{O}_{12}$, $\text{Y}_3\text{Ga}_{0.4}\text{Fe}_{4.6}\text{O}_{12}$, $\text{Bi}_{0.2}\text{Ca}_{2.8}\text{V}_{1.4}\text{Fe}_{3.6}\text{O}_{12}$,
 $\text{Y}_{1.4}\text{Ca}_{1.26}\text{V}_{0.63}\text{Fe}_{4.37}\text{O}_{12}$, $\text{Y}_2\text{Gd}_1\text{Fe}_5\text{O}_{12}$, $\text{Y}_{1.2}\text{Gd}_{1.8}\text{Fe}_5\text{O}_{12}$,
 $\text{Y}_{2.64}\text{Gd}_{0.36}\text{Al}_{0.56}\text{Fe}_{4.44}\text{O}_{12}$, $\text{Y}_{2.36}\text{Gd}_{0.64}\text{Al}_{0.43}\text{Fe}_{4.57}\text{O}_{12}$, $\text{BaFe}_{12}\text{O}_{19}$, $\text{BaFe}_{18}\text{O}_{27}$,
 $\text{BaZnFe}_{17}\text{O}_{27}$, $\text{BaZn}_{1.5}\text{Fe}_{17.5}\text{O}_{27}$, $\text{BaMnFe}_{16}\text{O}_{27}$, $\text{BaNi}_2\text{Fe}_{16}\text{O}_{27}$, $\text{BaNi}_{0.5}\text{ZnFe}_{16.5}\text{O}_{27}$,
5 $\text{Ba}_4\text{Zn}_2\text{Fe}_{36}\text{O}_{69}$, GdFeO_3 , $\text{SrFe}_{12}\text{O}_{19}$, $\text{Sn}_{0.985}\text{Mn}_{0.015}\text{O}_2$, $\text{In}_{1.75}\text{Sn}_{0.2}\text{Mn}_{0.05}$, etc.

can also be used as the magnetic grain boundary oxide 26B of the cap layer 26.

[0032]

(3) Function effect of the cap layer 26

10 As mentioned above, FIG. 2 is a vertical cross-sectional diagram schematically illustrating a portion of a vertical cross section of the perpendicular magnetic recording medium 10 according to the present embodiment, and FIG. 3 is a vertical cross-sectional diagram schematically illustrating a portion of a vertical cross
15 section of the perpendicular magnetic recording medium 10 (after optimizing the cap layer 26) according to the present embodiment. FIG. 4 is a vertical cross-sectional diagram schematically illustrating a portion of a vertical cross section of a current perpendicular magnetic recording medium 100. In FIGS. 2 and 3, the
20 intergranular exchange coupling 26C between the CoPt alloy magnetic crystal grains 26A of the cap layer 26 is schematically represented by spring-like lines, and similarly, in FIG. 4, the intergranular exchange coupling 102B between the CoPt alloy magnetic crystal grains 102A of a cap layer 102 is schematically represented by spring-like
25 lines.

[0033]

Referring to FIGS. 2 to 4, the function effect of the cap layer 26 will be described in detail. For the sake of explanation, it is assumed here that a $\text{Co}_{80}\text{Pt}_{20}$ -30vol%B₂O₃ layer is used as the perpendicular magnetic recording layer 24 and a $\text{Co}_{80}\text{Pt}_{20}$ -30vol%Gd₂O₃ layer is used as the cap layer 26. A $\text{Ru}_{50}\text{Co}_{25}\text{Cr}_{25}$ -30vol%TiO₂ layer is assumed to be used as the buffer layer 22. In addition, a CoPtCrB alloy is assumed to be used as the cap layer 102 of the current perpendicular magnetic recording medium 100.

[0034]

The cap layer 26 is a layer for appropriately adjusting the intergranular exchange coupling between the CoPt alloy magnetic crystal grains 24A in the perpendicular magnetic recording layer 24 to improve the thermal stability of the perpendicular magnetic recording layer 24 and to reduce the switching magnetic field (a magnetic field necessary for magnetization reversal of the magnetic crystal grains). The perpendicular magnetic recording layer 24 itself is a granular structure, and the CoPt alloy magnetic crystal grains 24A are separated by the non-magnetic grain boundary oxide 24B (B₂O₃). Therefore, the intergranular exchange coupling between the CoPt alloy magnetic crystal grains 24A is small in the perpendicular magnetic recording layer 24 itself, and thus, the thermal stability is insufficient and reduction of the switching magnetic field is also insufficient.

[0035]

The cap layer 26 serves to compensate for the intergranular exchange coupling between the CoPt alloy magnetic crystal grains 24A, which is lacking in the perpendicular magnetic recording layer 24 itself, and for this reason, it is necessary to increase the intergranular exchange coupling 26C between the CoPt alloy magnetic crystal grains 26A to some extent in the cap layer 26.

[0036]

Therefore, in the cap layer 26 of the perpendicular magnetic recording medium 10 according to the present embodiment, a magnetic oxide (a rare earth oxide is preferred because of its large magnetism) is used as an oxide to form the magnetic grain boundary oxide 26B, so that the intergranular exchange coupling 26C between the CoPt alloy magnetic crystal grains 26A in the cap layer 26 is enlarged to some extent. As the result, the intergranular exchange coupling between the CoPt alloy magnetic crystal grains 24A in the perpendicular magnetic recording layer 24 can also be appropriately supplemented.

[0037]

The intergranular exchange coupling 26C between the CoPt alloy magnetic grains 26A in the cap layer 26 is controlled by the thickness of the cap layer 26. As the thickness of the cap layer 26 increases, the intergranular exchange coupling 26C between the CoPt alloy magnetic crystal grains 26A in the cap layer 26 increases. The thickness of the cap layer 26 can be determined according to the size of the required intergranular exchange coupling 26C. From the

viewpoint of not reducing the coercive force H_c , the thickness of the cap layer 26 is preferably 1 nm or more and 7 nm or less.

[0038]

FIG. 4 is a vertical cross-sectional diagram schematically illustrating a portion of a vertical cross section of the current perpendicular magnetic recording medium 100, wherein, as shown in FIG. 4, a void 104 is generated over the non-magnetic grain boundary oxide 24B (B_2O_3) of the perpendicular magnetic recording layer 24. The cap layer 102 of the current perpendicular magnetic recording medium 100 is a CoPtCrB alloy and does not contain oxides, so that it is difficult to wet the non-magnetic grain boundary oxide 24B (B_2O_3) of the perpendicular magnetic recording layer 24, and therefore, it is thought that the void 104 is generated over the non-magnetic grain boundary oxide 24B (B_2O_3) of the perpendicular magnetic recording layer 24. Even if no voids 104 are observed in the current perpendicular magnetic recording media, as can be read from the cross-sectional TEM photographs shown later as FIG. 7 (Comparative Example 20), the dark field image shown later as FIG. 12 (Comparative Example 20), and the measurement results of energy dispersive X-ray analysis (EDX) shown later as FIG. 13 (Comparative Example 20), in the current perpendicular magnetic recording media, the boundary surface between the perpendicular magnetic recording layer (CoPt- B_2O_3 layer) and the cap layer (CoPtCrB layer) is wavy and the unevenness of the surface is large.

[0039]

Therefore, the cap layer 102 of the current perpendicular magnetic recording medium 100 has a large unevenness in its thickness direction (i.e., a large unevenness in cross section when the cap layer 102 is cut at different positions in the thickness direction by a plane orthogonal to the thickness direction), so that the magnitude of the intergranular exchange coupling 102B between the CoPt alloy magnetic grains 102A in the cap layer 102 does not change precisely proportional to the thickness of the cap layer even if the thickness of the cap layer 102 is varied. Consequently, it is difficult to accurately control the magnitude of the intergranular exchange coupling 102B between the CoPt alloy magnetic grains 102A in the cap layer 102, even if the thickness of the cap layer 102 is controlled.

[0040]

In contrast, as shown in FIG. 2, the cap layer 26 of the perpendicular magnetic recording medium 10 according to the present embodiment is a $\text{Co}_{80}\text{Pt}_{20}$ -30 vol% Gd_2O_3 layer and has a magnetic oxide Gd_2O_3 , and the magnetic grain boundary oxide 26B (Gd_2O_3), which is easily wetted with B_2O_3 , is formed on top of the non-magnetic grain boundary oxide 24B (B_2O_3) of the perpendicular magnetic recording layer 24, and thus no voids are generated. Therefore, since the cap layer 26 of the perpendicular magnetic recording medium 10 according to the present embodiment has a high degree of uniformity in its thickness direction (the cross sections of the cap layer 26 when cut at different positions in the thickness direction in

a plane orthogonal to the thickness direction are all nearly identical), when the thickness of the cap layer 26 is changed, in proportion to the thickness, the magnitude of the intergranular exchange coupling 26C between the CoPt alloy magnetic crystal grains 26A of the cap layer 26 changes. Therefore, by controlling the thickness of the cap layer 26, the magnitude of the intergranular exchange coupling 26C between the CoPt alloy magnetic crystal grains 26A in the cap layer 26 can be accurately controlled.

[0041]

As described above, the cap layer 26 of the perpendicular magnetic recording medium 10 according to the present embodiment has a granular structure having the CoPt alloy magnetic crystal grains 26A and the magnetic grain boundary oxide 26B. The magnetic grain boundary oxide 26B (Gd_2O_3) are magnetic, and the intergranular exchange coupling 26C between the CoPt alloy magnetic crystal grains 26A in the cap layer 26 is increased.

[0042]

Since the cap layer 26 of the perpendicular magnetic recording medium 10 according to the present embodiment has a high degree of uniformity in its thickness direction (the cross sections of the cap layer 26 when cut at different positions in the thickness direction in a plane orthogonal to the thickness direction are all nearly identical), it is possible to accurately control the magnitude of the intergranular exchange coupling 26C between the CoPt alloy magnetic crystal grains 26A in the cap layer 26 by controlling the

thickness of the cap layer 26.

[0043]

Therefore, in the perpendicular magnetic recording medium 10 according to the present embodiment, by controlling the thickness of the cap layer 26, the magnitude of the intergranular exchange coupling 26C between the CoPt alloy magnetic crystal grains 26A in the cap layer 26 can be accurately controlled, and thus the magnitude of the intergranular exchange coupling between the CoPt alloy magnetic crystal grains 24A in the perpendicular magnetic recording layer 24 can be accurately controlled.

[0044]

FIG. 3 is a vertical cross-sectional diagram schematically illustrating a portion of a vertical cross section of the perpendicular magnetic recording medium 10 (after optimizing the cap layer 26) according to the present embodiment, as described above.

[0045]

In the optimized state of the cap layer 26 in the perpendicular magnetic recording medium 10 according to the present embodiment, the thickness of the magnetic grain boundary oxide 26B (Gd_2O_3) in the cross section in the direction orthogonal to the thickness direction is minimized, and the surface unevenness of the cap layer 26 is also minimized.

[0046]

By minimizing the thickness of the magnetic grain boundary

oxide 26B (Gd_2O_3) in the cap layer 26 (the distance between the CoPt alloy magnetic grains 26A in the cap layer 26), the strength of the intergranular exchange coupling 26C between the CoPt alloy magnetic grains 26A in the cap layer 26 can be strengthened. Therefore, even if the cap layer 26 is made thinner, the strength of the intergranular exchange coupling 26C between the CoPt alloy magnetic crystal grains 26A in the cap layer 26 can be controlled to a certain degree. By minimizing the surface unevenness of the cap layer 26, the magnitude of the intergranular exchange coupling 26C between the CoPt alloy magnetic crystal grains 26A in the cap layer 26 can be more accurately controlled by controlling the thickness of the cap layer 26, and thus the magnitude of intergranular exchange coupling between magnetic grains 24A in the CoPt alloy of the intergranular magnetic recording layer 24 can be controlled more accurately.

[0047]

(4) Sputtering target for forming the cap layer 26

(4-1) Composition of sputtering targets

The sputtering target used for forming the cap layer 26 has the same composition as the cap layer 26 and contains metals and a magnetic oxide, and specifically, for example, contains Co in a range of 65 at% or more and 90 at% or less and Pt in a range of 10% or more and 35 at% or less to the total of the metals, and contains the magnetic oxide in a range of 5 vol% or more and 40 vol% or less to the total of the sputtering target. Also, specifically, for example,

the sputtering target contains Co in a range of 70 at% or more and less than 85 at% and Pt in a range of 10% or more and 20 at% or less, and one or more elements of Cr, Ti, B, Mo, Ta, Nb, W, and Ru in a range of 0.5 at% or more and 15 at% or less to the total of the metals, and contains a magnetic oxide in a range of 5 vol% or more and 40 vol% or less to the entire sputtering target.

[0048]

(4-2) Production method for sputtering targets

Next, production method for sputtering targets for forming the cap layer 26 will be described, taking a sputtering target whose composition is $\text{Co}_{80}\text{Pt}_{20}$ -30vol% Gd_2O_3 as an example. However, the production method for the sputtering target for forming the cap layer 26 is not limited to the following specific examples.

[0049]

First, the metal Co and the metal Pt are weighed so that the atomic ratio of the metal Co is 80 at% and the atomic ratio of the metal Pt is 20 at% to the total of the metal Co and the metal Pt, and a molten CoPt alloy is prepared. Then, gas atomization is performed to prepare CoPt alloy atomized powder. The prepared CoPt alloy atomized powder is classified so that the particle diameter becomes not larger than a predetermined particle diameter (for example, 106 μm or smaller).

[0050]

Gd_2O_3 powder is added to the prepared CoPt alloy atomized powder so as to be 30vol%, and mixed and dispersed with a ball mill to

prepare a powder mixture for pressure sintering. By mixing and dispersing the CoPt alloy atomized powder and the Gd₂O₃ powder with a ball mill, a powder mixture for pressure sintering in which the CoPt alloy atomized powder and the Gd₂O₃ powder are finely dispersed
5 can be prepared.

[0051]

As described above, from the viewpoint of increasing more the coercive force H_c of the perpendicular magnetic recording medium
10 and the viewpoint of increasing the intergranular exchange
10 coupling 26C of the CoPt alloy magnetic crystal grains 26A of the cap layer 26 to reduce the saturation magnetic field H_s of the perpendicular magnetic recording medium 10, the volume fraction of the magnetic grain boundary oxide 26B to the entire cap layer 26 is preferably 5 vol% or more and 40 vol% or less. Therefore,
15 it is preferable to make the volume fraction of the Gd₂O₃ powder to the total of the mixed powder for pressure sintering to be 5 vol% or more and 40 vol% or less.

[0052]

The prepared powder mixture for pressure sintering is
20 pressure-sintered and molded using, for example, a vacuum hot press method to produce a sputtering target. Since the prepared powder mixture for pressure sintering is mixed and dispersed with a ball mill, and the CoPt alloy atomized powder and the Gd₂O₃ powder are finely dispersed, defects such as generation of nodules and particles
25 are unlikely to occur during sputtering by using the sputtering

targets obtained by this production method.

[0053]

The method for pressure sintering the powder mixture for pressure sintering is not particularly limited. The method may be a method other than the vacuum hot press method, and may be, for example, the HIP method or the like.

[0054]

In the example of the production method described above, the CoPt alloy atomized powder is prepared using the atomization method, and a Gd_2O_3 powder is added to the prepared CoPt alloy atomized powder and mixed and dispersed with the ball mill to prepare the powder mixture for pressure sintering. Instead of using the CoPt alloy atomized powder, a Co single powder and a Pt single powder may be used. In this case, a Co single powder, a Pt single powder, and a Gd_2O_3 powder are mixed and dispersed with a ball mill to prepare a powder mixture for pressure sintering.

EXAMPLES

[0055]

The following describes examples and comparative examples, as well as the experimental data obtained in connection with the present invention.

[0056]

(Examples 1 to 142, Comparative Examples 1 to 20)

The perpendicular magnetic recording media of Examples 1 to

142 and Comparative Examples 2 to 20 were produced with the same layer structure as in Fig. 1 (a layer structure in which an adhesion layer 14, a seed layer 16, a first Ru underlayer 18, a second Ru underlayer 20, a buffer layer 22, a perpendicular magnetic recording layer 24, a cap layer 26, and a surface protection layer 28 are formed in sequence on a substrate 12). Specifically, the following steps were taken.

[0057]

As the substrate 12, a glass substrate was used.

10 [0058]

As the adhesion layer 14, a Ta layer was deposited with a thickness of 5 nm under the conditions of an argon gas pressure of 0.6 Pa and supplying power of 500 W.

[0059]

15 As the seed layer 16, a $\text{Ni}_{90}\text{W}_{10}$ layer was deposited with a thickness of 6 nm under the conditions of an argon gas pressure of 0.6 Pa and supplying power of 500 W.

[0060]

20 As the first Ru underlayer 18, a Ru layer was deposited with a thickness of 10 nm under the conditions of an argon gas pressure of 0.6 Pa and supplying power of 500 W.

[0061]

25 As the second Ru underlayer 20, a Ru layer was deposited with a thickness of 10 nm under the conditions of an argon gas pressure of 8.0 Pa and supplying power of 500 W.

[0062]

As the buffer layer 22, a $\text{Ru}_{50}\text{Co}_{25}\text{Cr}_{25}$ -30vol% TiO_2 layer was deposited with a thickness of 2 nm under the conditions of an argon gas pressure of 0.6 Pa and supplying power of 300 W.

5 [0063]

As the perpendicular magnetic recording layer 24, a $\text{Co}_{80}\text{Pt}_{20}$ -30vol% B_2O_3 layer was deposited with a thickness of 16 nm under the conditions of an argon gas pressure of 4.0 Pa and supplying power of 500 W.

10 [0064]

As the cap layer 26, a sputtering target produced as described in "(4) Sputtering target for forming the cap layer 26" above was used under the conditions of an argon gas pressure of 0.6 Pa or 4.0 Pa and supplying power of 500 W to deposit a CoPt alloy- magnetic grain boundary oxide with the compositions and thicknesses shown in Tables 1-4.

[0065]

As the surface protection layer 28, carbon was deposited with a thickness of 7 nm under the conditions of an argon gas pressure of 0.6 Pa and supplying power of 300 W.

[0066]

As a comparative example 1, a perpendicular magnetic recording medium in which the cap layer 26 was deleted in the above structure was produced.

25 [0067]

The conditions that were changed in Examples 1-142 and Comparative Examples 2-20 are the composition of the cap layer, the thickness of the cap layer, and the argon gas pressure at the time of cap layer deposition. Comparative Example 20 is a comparative example in which, as the cap layer thereof, the cap layer (CoPtCrB) of the current perpendicular magnetic recording media was used.

[0068]

The magnetic properties of the produced perpendicular magnetic recording media of Examples 1-142 and Comparative Examples 1-20 were measured using a sample vibrating magnetometer (Squid-VSM) (manufacturing company: QUANTUM DESIGN, product number: MPMS3) using a superconducting quantum interference device, a high-sensitivity magnetic anisotropy torque meter (torque magnetometer) (manufacturing company: TAMAKAWA CO., Ltd., product number: TM-TR2050-HGC), and Magneto Optical Kerr Effect (MOKE) measurement apparatus. In addition, the microstructure of the cap layers of the produced perpendicular magnetic recording media of Examples 1-142 and Comparative Examples 1-20 were observed using planar TEM-EDX and cross-sectional TEM-EDX.

[0069]

Tables 1 to 4 below show the coercive force H_c and saturation magnetic field H_s measured for the perpendicular magnetic recording media of Examples 1 to 142 and Comparative Examples 1 to 20. The coercive force H_c and saturation magnetic field H_s were determined from the hysteresis loops measured using a sample vibrating

magnetometer (Squid-VSM).

[0070]

In Tables 1-4, the thickness indicates the thickness of the cap layer, and the Ar gas pressure indicates the Ar gas pressure at the time of cap layer deposition.

[0071]

[Table 1]

10

15

20

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	Composition of cap layer	Thickness (nm)	Ar gas pressure (Pa)	Hc (kOe)	Hs (kOe)
Comparative Example 01	None	0	4.0	9.3	21.5
Comparative Example 02	Co ₈₀ Pt ₂₀ -30vol%B ₂ O ₃	2	4.0	7.5	21.0
Comparative Example 03	Co ₈₀ Pt ₂₀ -30vol%B ₂ O ₃	4	4.0	7.9	21.5
Comparative Example 04	Co ₈₀ Pt ₂₀ -30vol%B ₂ O ₃	6	4.0	7.7	21.5
Comparative Example 05	Co ₈₀ Pt ₂₀ -30vol%B ₂ O ₃	8	4.0	7.0	21.0
Comparative Example 06	Co ₈₀ Pt ₂₀ -30vol%B ₂ O ₃	1	0.6	7.5	20.0
Comparative Example 07	Co ₈₀ Pt ₂₀ -30vol%B ₂ O ₃	2	0.6	8.5	20.5
Comparative Example 08	Co ₈₀ Pt ₂₀ -30vol%B ₂ O ₃	3	0.6	8.5	20.0
Comparative Example 09	Co ₈₀ Pt ₂₀ -30vol%B ₂ O ₃	4	0.6	8.5	20.5
Comparative Example 10	Co ₈₀ Pt ₂₀ -30vol%B ₂ O ₃	5	0.6	8.0	20.0
Comparative Example 11	Co ₈₀ Pt ₂₀ -30vol%B ₂ O ₃	6	0.6	8.2	20.3
Comparative Example 12	Co ₈₀ Pt ₂₀ -30vol%B ₂ O ₃	7	0.6	8.0	20.5
Comparative Example 13	Co ₈₀ Pt ₂₀ -30vol%B ₂ O ₃	8	0.6	7.7	20.5
Comparative Example 14	Co ₈₀ Pt ₂₀ -30vol%B ₂ O ₃	9	0.6	7.7	20.0
Comparative Example 15	Co ₈₀ Pt ₂₀ -4vol%Gd ₂ O ₃	5	0.6	4.5	10.0
Comparative Example 16	Co ₈₀ Pt ₂₀ -41vol%Gd ₂ O ₃	5	0.6	8.5	20.0
Comparative Example 17	Co ₉₅ Pt ₅ -30vol%Gd ₂ O ₃	5	0.6	4.0	12.5
Comparative Example 18	Co ₆₀ Pt ₄₀ -30vol%Gd ₂ O ₃	5	0.6	4.5	13.0
Comparative Example 19	Co ₆₅ Pt ₂₀ Cr ₁₅ -30vol%Gd ₂ O ₃	5	0.6	4.5	13.5
Comparative Example 20	CoPtCrB	9	0.6	4.9	12.5
Example 1	Co ₈₀ Pt ₂₀ -30vol%Gd ₂ O ₃	2	4.0	8.0	19.0
Example 2	Co ₈₀ Pt ₂₀ -30vol%Gd ₂ O ₃	3	4.0	8.5	19.0
Example 3	Co ₈₀ Pt ₂₀ -30vol%Gd ₂ O ₃	4	4.0	8.4	19.0
Example 4	Co ₈₀ Pt ₂₀ -30vol%Gd ₂ O ₃	5	4.0	8.9	19.0
Example 5	Co ₈₀ Pt ₂₀ -30vol%Gd ₂ O ₃	6	4.0	8.5	19.0
Example 6	Co ₈₀ Pt ₂₀ -30vol%Gd ₂ O ₃	7	4.0	8.5	19.0
Example 7	Co ₈₀ Pt ₂₀ -30vol%Gd ₂ O ₃	8	4.0	7.7	17.7
Example 8	Co ₈₀ Pt ₂₀ -30vol%Gd ₂ O ₃	9	4.0	7.0	16.0
Example 9	Co ₈₀ Pt ₂₀ -30vol%Gd ₂ O ₃	1	0.6	7.6	19.0
Example 10	Co ₈₀ Pt ₂₀ -30vol%Gd ₂ O ₃	2	0.6	7.5	18.5
Example 11	Co ₈₀ Pt ₂₀ -30vol%Gd ₂ O ₃	3	0.6	7.5	17.5
Example 12	Co ₈₀ Pt ₂₀ -30vol%Gd ₂ O ₃	4	0.6	7.6	18.0
Example 13	Co ₈₀ Pt ₂₀ -30vol%Gd ₂ O ₃	5	0.6	7.0	17.0
Example 14	Co ₈₀ Pt ₂₀ -30vol%Gd ₂ O ₃	6	0.6	8.6	19.0
Example 15	Co ₈₀ Pt ₂₀ -30vol%Gd ₂ O ₃	7	0.6	7.5	16.5
Example 16	Co ₈₀ Pt ₂₀ -30vol%Gd ₂ O ₃	8	0.6	6.4	14.0
Example 17	Co ₈₀ Pt ₂₀ -30vol%Gd ₂ O ₃	9	0.6	5.5	12.5
Example 18	Co ₈₀ Pt ₂₀ -30vol%Nd ₂ O ₃	2	4.0	7.1	17.5
Example 19	Co ₈₀ Pt ₂₀ -30vol%Nd ₂ O ₃	3	4.0	8.0	19.0
Example 20	Co ₈₀ Pt ₂₀ -30vol%Nd ₂ O ₃	4	4.0	7.7	17.0
Example 21	Co ₈₀ Pt ₂₀ -30vol%Nd ₂ O ₃	5	4.0	7.2	17.5
Example 22	Co ₈₀ Pt ₂₀ -30vol%Nd ₂ O ₃	6	4.0	7.3	18.0
Example 23	Co ₈₀ Pt ₂₀ -30vol%Nd ₂ O ₃	7	4.0	7.2	16.5
Example 24	Co ₈₀ Pt ₂₀ -30vol%Nd ₂ O ₃	8	4.0	7.5	16.8
Example 25	Co ₈₀ Pt ₂₀ -30vol%Nd ₂ O ₃	9	4.0	6.0	14.0
Example 26	Co ₈₀ Pt ₂₀ -30vol%Nd ₂ O ₃	1	0.6	7.4	16.8
Example 27	Co ₈₀ Pt ₂₀ -30vol%Nd ₂ O ₃	2	0.6	7.3	17.2
Example 28	Co ₈₀ Pt ₂₀ -30vol%Nd ₂ O ₃	3	0.6	7.5	17.0
Example 29	Co ₈₀ Pt ₂₀ -30vol%Nd ₂ O ₃	4	0.6	7.3	19.0
Example 30	Co ₈₀ Pt ₂₀ -30vol%Nd ₂ O ₃	5	0.6	8.2	19.0
Example 31	Co ₈₀ Pt ₂₀ -30vol%Nd ₂ O ₃	6	0.6	8.1	18.5
Example 32	Co ₈₀ Pt ₂₀ -30vol%Nd ₂ O ₃	7	0.6	7.0	16.0
Example 33	Co ₈₀ Pt ₂₀ -30vol%Nd ₂ O ₃	8	0.6	7.1	16.0
Example 34	Co ₈₀ Pt ₂₀ -30vol%Nd ₂ O ₃	9	0.6	7.2	15.3

[0072]

[Table 2]

	Composition of cap layer	Thickness (nm)	Ar gas pressure (Pa)	Hc (kOe)	Hs (kOe)
Example 35	Co ₈₀ Pt ₂₀ -30vol%Sm ₂ O ₃	2	4.0	8.4	18.8
Example 36	Co ₈₀ Pt ₂₀ -30vol%Sm ₂ O ₃	3	4.0	8.1	18.5
Example 37	Co ₈₀ Pt ₂₀ -30vol%Sm ₂ O ₃	4	4.0	7.3	17.0
Example 38	Co ₈₀ Pt ₂₀ -30vol%Sm ₂ O ₃	5	4.0	7.5	16.5
Example 39	Co ₈₀ Pt ₂₀ -30vol%Sm ₂ O ₃	6	4.0	7.7	17.3
Example 40	Co ₈₀ Pt ₂₀ -30vol%Sm ₂ O ₃	7	4.0	6.7	16.0
Example 41	Co ₈₀ Pt ₂₀ -30vol%Sm ₂ O ₃	8	4.0	7.1	16.0
Example 42	Co ₈₀ Pt ₂₀ -30vol%Sm ₂ O ₃	9	4.0	6.7	14.5
Example 43	Co ₈₀ Pt ₂₀ -30vol%Sm ₂ O ₃	1	0.6	7.7	17.0
Example 44	Co ₈₀ Pt ₂₀ -30vol%Sm ₂ O ₃	2	0.6	8.1	18.0
Example 45	Co ₈₀ Pt ₂₀ -30vol%Sm ₂ O ₃	3	0.6	8.2	19.0
Example 46	Co ₈₀ Pt ₂₀ -30vol%Sm ₂ O ₃	4	0.6	8.1	18.3
Example 47	Co ₈₀ Pt ₂₀ -30vol%Sm ₂ O ₃	5	0.6	7.2	16.5
Example 48	Co ₈₀ Pt ₂₀ -30vol%Sm ₂ O ₃	6	0.6	7.7	17.0
Example 49	Co ₈₀ Pt ₂₀ -30vol%Sm ₂ O ₃	7	0.6	7.7	17.0
Example 50	Co ₈₀ Pt ₂₀ -30vol%Sm ₂ O ₃	8	0.6	7.4	16.0
Example 51	Co ₈₀ Pt ₂₀ -30vol%Sm ₂ O ₃	9	0.6	6.6	14.3
Example 52	Co ₈₀ Pt ₂₀ -30vol%CeO ₂	2	4.0	8.8	18.8
Example 53	Co ₈₀ Pt ₂₀ -30vol%CeO ₂	3	4.0	8.2	19.0
Example 54	Co ₈₀ Pt ₂₀ -30vol%CeO ₂	4	4.0	8.9	19.0
Example 55	Co ₈₀ Pt ₂₀ -30vol%CeO ₂	5	4.0	9.0	19.0
Example 56	Co ₈₀ Pt ₂₀ -30vol%CeO ₂	6	4.0	8.1	18.5
Example 57	Co ₈₀ Pt ₂₀ -30vol%CeO ₂	7	4.0	7.2	17.0
Example 58	Co ₈₀ Pt ₂₀ -30vol%CeO ₂	8	4.0	7.4	16.5
Example 59	Co ₈₀ Pt ₂₀ -30vol%CeO ₂	9	4.0	6.2	14.8
Example 60	Co ₈₀ Pt ₂₀ -30vol%CeO ₂	1	0.6	7.7	18.0
Example 61	Co ₈₀ Pt ₂₀ -30vol%CeO ₂	3	0.6	8.6	19.0
Example 62	Co ₈₀ Pt ₂₀ -30vol%CeO ₂	4	0.6	8.1	18.0
Example 63	Co ₈₀ Pt ₂₀ -30vol%CeO ₂	5	0.6	8.0	18.0
Example 64	Co ₈₀ Pt ₂₀ -30vol%CeO ₂	6	0.6	7.2	16.5
Example 65	Co ₈₀ Pt ₂₀ -30vol%CeO ₂	7	0.6	7.2	16.5
Example 66	Co ₈₀ Pt ₂₀ -30vol%CeO ₂	8	0.6	6.9	15.0
Example 67	Co ₈₀ Pt ₂₀ -30vol%CeO ₂	9	0.6	5.7	13.0
Example 68	Co ₈₀ Pt ₂₀ -30vol%Eu ₂ O ₃	1	0.6	8.0	19.0
Example 69	Co ₈₀ Pt ₂₀ -30vol%Eu ₂ O ₃	2	0.6	8.1	19.0
Example 70	Co ₈₀ Pt ₂₀ -30vol%Eu ₂ O ₃	3	0.6	8.1	19.0
Example 71	Co ₈₀ Pt ₂₀ -30vol%Eu ₂ O ₃	4	0.6	8.0	18.3
Example 72	Co ₈₀ Pt ₂₀ -30vol%Eu ₂ O ₃	5	0.6	7.5	17.5
Example 73	Co ₈₀ Pt ₂₀ -30vol%Eu ₂ O ₃	6	0.6	7.7	17.0
Example 74	Co ₈₀ Pt ₂₀ -30vol%Eu ₂ O ₃	7	0.6	7.3	17.0
Example 75	Co ₈₀ Pt ₂₀ -30vol%Eu ₂ O ₃	8	0.6	7.1	15.5
Example 76	Co ₈₀ Pt ₂₀ -30vol%Eu ₂ O ₃	9	0.6	6.6	14.0
Example 77	Co ₈₀ Pt ₂₀ -30vol%La ₂ O ₃	1	0.6	7.5	19.0
Example 78	Co ₈₀ Pt ₂₀ -30vol%La ₂ O ₃	2	0.6	7.3	18.5
Example 79	Co ₈₀ Pt ₂₀ -30vol%La ₂ O ₃	3	0.6	7.2	17.5
Example 80	Co ₈₀ Pt ₂₀ -30vol%La ₂ O ₃	4	0.6	7.1	18.0
Example 81	Co ₈₀ Pt ₂₀ -30vol%La ₂ O ₃	5	0.6	7.0	17.0
Example 82	Co ₈₀ Pt ₂₀ -30vol%La ₂ O ₃	6	0.6	7.3	18.5
Example 83	Co ₈₀ Pt ₂₀ -30vol%La ₂ O ₃	7	0.6	7.1	16.0
Example 84	Co ₈₀ Pt ₂₀ -30vol%La ₂ O ₃	8	0.6	6.3	13.5
Example 85	Co ₈₀ Pt ₂₀ -30vol%La ₂ O ₃	9	0.6	5.3	12.0

[0073]

[Table 3]

	Composition of cap layer	Thickness (nm)	Ar gas pressure (Pa)	Hc (kOe)	Hs (kOe)
Example 86	Co ₈₀ Pt ₂₀ -30vol%Pr ₆ O ₁₁	1	0.6	8.2	19.0
Example 87	Co ₈₀ Pt ₂₀ -30vol%Pr ₆ O ₁₁	2	0.6	8.1	19.0
Example 88	Co ₈₀ Pt ₂₀ -30vol%Pr ₆ O ₁₁	3	0.6	8.0	19.0
Example 89	Co ₈₀ Pt ₂₀ -30vol%Pr ₆ O ₁₁	4	0.6	7.9	18.5
Example 90	Co ₈₀ Pt ₂₀ -30vol%Pr ₆ O ₁₁	5	0.6	7.7	17.5
Example 91	Co ₈₀ Pt ₂₀ -30vol%Pr ₆ O ₁₁	6	0.6	7.5	17.0
Example 92	Co ₈₀ Pt ₂₀ -30vol%Pr ₆ O ₁₁	7	0.6	7.3	16.5
Example 93	Co ₈₀ Pt ₂₀ -30vol%Pr ₆ O ₁₁	8	0.6	7.1	15.0
Example 94	Co ₈₀ Pt ₂₀ -30vol%Pr ₆ O ₁₁	9	0.6	6.7	13.5
Example 95	Co ₈₀ Pt ₂₀ -30vol%Ho ₂ O ₃	1	0.6	7.9	19.0
Example 96	Co ₈₀ Pt ₂₀ -30vol%Ho ₂ O ₃	2	0.6	7.8	18.5
Example 97	Co ₈₀ Pt ₂₀ -30vol%Ho ₂ O ₃	3	0.6	7.7	18.5
Example 98	Co ₈₀ Pt ₂₀ -30vol%Ho ₂ O ₃	4	0.6	7.7	18.0
Example 99	Co ₈₀ Pt ₂₀ -30vol%Ho ₂ O ₃	5	0.6	7.6	17.5
Example 100	Co ₈₀ Pt ₂₀ -30vol%Ho ₂ O ₃	6	0.6	7.2	17.0
Example 101	Co ₈₀ Pt ₂₀ -30vol%Ho ₂ O ₃	7	0.6	6.9	16.5
Example 102	Co ₈₀ Pt ₂₀ -30vol%Ho ₂ O ₃	8	0.6	6.5	16.0
Example 103	Co ₈₀ Pt ₂₀ -30vol%Ho ₂ O ₃	9	0.6	6.0	14.5
Example 104	Co ₈₀ Pt ₂₀ -30vol%Er ₂ O ₃	1	0.6	8.3	19.0
Example 105	Co ₈₀ Pt ₂₀ -30vol%Er ₂ O ₃	2	0.6	8.1	18.7
Example 106	Co ₈₀ Pt ₂₀ -30vol%Er ₂ O ₃	3	0.6	7.8	18.5
Example 107	Co ₈₀ Pt ₂₀ -30vol%Er ₂ O ₃	4	0.6	7.7	18.0
Example 108	Co ₈₀ Pt ₂₀ -30vol%Er ₂ O ₃	5	0.6	7.6	18.0
Example 109	Co ₈₀ Pt ₂₀ -30vol%Er ₂ O ₃	6	0.6	7.3	17.5
Example 110	Co ₈₀ Pt ₂₀ -30vol%Er ₂ O ₃	7	0.6	7.0	17.0
Example 111	Co ₈₀ Pt ₂₀ -30vol%Er ₂ O ₃	8	0.6	6.7	16.5
Example 112	Co ₈₀ Pt ₂₀ -30vol%Er ₂ O ₃	9	0.6	6.5	15.0
Example 113	Co ₈₀ Pt ₂₀ -30vol%Yb ₂ O ₃	1	0.6	8.0	19.0
Example 114	Co ₈₀ Pt ₂₀ -30vol%Yb ₂ O ₃	2	0.6	7.8	18.5
Example 115	Co ₈₀ Pt ₂₀ -30vol%Yb ₂ O ₃	3	0.6	7.7	18.0
Example 116	Co ₈₀ Pt ₂₀ -30vol%Yb ₂ O ₃	4	0.6	7.6	18.0
Example 117	Co ₈₀ Pt ₂₀ -30vol%Yb ₂ O ₃	5	0.6	7.6	17.5
Example 118	Co ₈₀ Pt ₂₀ -30vol%Yb ₂ O ₃	6	0.6	7.2	17.0
Example 119	Co ₈₀ Pt ₂₀ -30vol%Yb ₂ O ₃	7	0.6	7.0	16.5
Example 120	Co ₈₀ Pt ₂₀ -30vol%Yb ₂ O ₃	8	0.6	6.5	16.0
Example 121	Co ₈₀ Pt ₂₀ -30vol%Yb ₂ O ₃	9	0.6	6.0	14.0

[0074]

[Table 4]

	Composition of cap layer	Thickness (nm)	Ar gas pressure (Pa)	Hc (kOe)	Hs (kOe)
Example 122	Co ₈₀ Pt ₂₀ -5vol%Gd ₂ O ₃	5	0.6	5.0	11.0
Example 123	Co ₈₀ Pt ₂₀ -10vol%Gd ₂ O ₃	5	0.6	5.3	12.5
Example 124	Co ₈₀ Pt ₂₀ -15vol%Gd ₂ O ₃	5	0.6	5.8	13.5
Example 125	Co ₈₀ Pt ₂₀ -20vol%Gd ₂ O ₃	5	0.6	6.2	14.5
Example 126	Co ₈₀ Pt ₂₀ -25vol%Gd ₂ O ₃	5	0.6	6.5	16.0
Example 127	Co ₈₀ Pt ₂₀ -35vol%Gd ₂ O ₃	5	0.6	7.5	18.0
Example 128	Co ₈₀ Pt ₂₀ -40vol%Gd ₂ O ₃	5	0.6	7.9	19.0
Example 129	Co ₉₀ Pt ₁₀ -30vol%Gd ₂ O ₃	5	0.6	5.0	13.5
Example 130	Co ₈₅ Pt ₁₅ -30vol%Gd ₂ O ₃	5	0.6	6.0	15.0
Example 131	Co ₇₅ Pt ₂₅ -30vol%Gd ₂ O ₃	5	0.6	7.5	18.0
Example 132	Co ₇₀ Pt ₃₀ -30vol%Gd ₂ O ₃	5	0.6	7.7	18.5
Example 133	Co ₆₅ Pt ₃₅ -30vol%Gd ₂ O ₃	5	0.6	6.0	15.5
Example 134	Co ₇₅ Pt ₂₀ Cr ₅ -30vol%Gd ₂ O ₃	5	0.6	6.0	16.0
Example 135	Co ₇₀ Pt ₂₀ Cr ₁₀ -30vol%Gd ₂ O ₃	5	0.6	5.0	15.0
Example 136	Co ₇₅ Pt ₂₀ Ru ₅ -30vol%Gd ₂ O ₃	5	0.6	6.1	16.5
Example 137	Co ₇₅ Pt ₂₀ B ₅ -30vol%Gd ₂ O ₃	5	0.6	6.5	16.8
Example 138	Co ₇₅ Pt ₂₀ Ta ₅ -30vol%Gd ₂ O ₃	5	0.6	6.4	16.5
Example 139	Co ₇₅ Pt ₂₀ Nb ₅ -30vol%Gd ₂ O ₃	5	0.6	6.2	16.0
Example 140	Co ₇₅ Pt ₂₀ W ₅ -30vol%Gd ₂ O ₃	5	0.6	6.0	16.0
Example 141	Co ₇₅ Pt ₂₀ Ti ₅ -30vol%Gd ₂ O ₃	5	0.6	6.3	16.0
Example 142	Co ₇₅ Pt ₂₀ Mo ₅ -30vol%Gd ₂ O ₃	5	0.6	6.1	16.0

[0075]

5 As can be seen from Tables 1-4, Examples 1-142, which are included within the scope of the present invention, all have a coercive force Hc of 5 kOe or more and a saturation magnetic field Hs of less than 20 kOe. In contrast, for Comparative Examples 1 to 20, which are not within the scope of the present invention, the coercive

10 force Hc is less than 5 kOe or the saturation magnetic field Hs is 20 kOe or more.

[0076]

If the coercive force Hc is less than 5 kOe, for any of them, the thermal stability is insufficient, and if the saturation magnetic

15 field Hs is 20 kOe or more, the switching magnetic field is too

large, and the ease of magnetic recording is insufficient.

[0077]

(Examples 143-159, Comparative Example 21)

In Examples 143-159 and Comparative Example 21, samples were produced by changing the composition of the cap layer, and the thermal stability of the cap layer was evaluated by measuring the activated grain diameter GD_{act} of the cap layer. In the samples of Examples 143-159 and Comparative Example 21, the perpendicular magnetic recording layer 24 was not provided, and the cap layer 26 with a thickness of 16 nm was provided on top of the buffer layer 22. Other than that, the samples were produced in the same manner as in Examples 1 to 142. The deposition conditions for providing the cap layer 26 with a thickness of 16 nm on top of the buffer layer 22 were an argon gas pressure of 4.0 Pa and supplying power of 500 W.

[0078]

For each sample of Examples 143-159 and Comparative Example 21, the activated grain diameter GD_{act} was measured using a magneto optical Kerr effect (MOKE) measurement apparatus.

[0079]

The following Table 5 shows the measured activated grain diameter GD_{act} . B_2O_3 used in Comparative Example 21 is the oxide used in Comparative Examples 2-14, Gd_2O_3 used in Examples 143, 153-159 is the oxide used in Examples 1-17, 122-142, and Comparative Examples 15-19, Nd_2O_3 used in Example 144 is the oxide used in Examples 18-34, Sm_2O_3 used in Example 145 is the oxide used in Examples 35-51, CeO_2

used in Example 146 is the oxide used in Examples 52-67, Eu_2O_3 used in Example 147 is the oxide used in Examples 68-76, La_2O_3 used in Example 148 is the oxide used in Examples 77-85, Pr_6O_{11} used in Example 149 is the oxide used in Examples 86-94, Ho_2O_3 used in Example 150 is the oxide used in Examples 95-103, Er_2O_3 used in Example 151 is the oxide used in Examples 104-112, and Yb_2O_3 used in Example 152 is the oxide used in Examples 113-121.

[0080]

Examples 143, 153-159 are examples in which the volume fraction of Gd_2O_3 was changed in the range of 5-40 vol%.

[0081]

[Table 5]

	Composition of cap layer	GD_{act} (nm)
Comparative Example 21	$\text{Co}_{80}\text{Pt}_{20}$ -30vol% B_2O_3	6.5
Example 143	$\text{Co}_{80}\text{Pt}_{20}$ -30vol% Gd_2O_3	10.1
Example 144	$\text{Co}_{80}\text{Pt}_{20}$ -30vol% Nd_2O_3	8.8
Example 145	$\text{Co}_{80}\text{Pt}_{20}$ -30vol% Sm_2O_3	8.7
Example 146	$\text{Co}_{80}\text{Pt}_{20}$ -30vol% CeO_2	9.5
Example 147	$\text{Co}_{80}\text{Pt}_{20}$ -30vol% Eu_2O_3	8.9
Example 148	$\text{Co}_{80}\text{Pt}_{20}$ -30vol% La_2O_3	10.5
Example 149	$\text{Co}_{80}\text{Pt}_{20}$ -30vol% Pr_6O_{11}	9.1
Example 150	$\text{Co}_{80}\text{Pt}_{20}$ -30vol% Ho_2O_3	8.5
Example 151	$\text{Co}_{80}\text{Pt}_{20}$ -30vol% Er_2O_3	9.0
Example 152	$\text{Co}_{80}\text{Pt}_{20}$ -30vol% Yb_2O_3	8.6
Example 153	$\text{Co}_{80}\text{Pt}_{20}$ -5vol% Gd_2O_3	21.6
Example 154	$\text{Co}_{80}\text{Pt}_{20}$ -10vol% Gd_2O_3	19.3
Example 155	$\text{Co}_{80}\text{Pt}_{20}$ -15vol% Gd_2O_3	17.5
Example 156	$\text{Co}_{80}\text{Pt}_{20}$ -20vol% Gd_2O_3	14.7
Example 157	$\text{Co}_{80}\text{Pt}_{20}$ -25vol% Gd_2O_3	12.1
Example 158	$\text{Co}_{80}\text{Pt}_{20}$ -35vol% Gd_2O_3	8.6
Example 159	$\text{Co}_{80}\text{Pt}_{20}$ -40vol% Gd_2O_3	7.3

[0082]

Among the oxides listed in Table 5, the non-magnetic oxide

is only B_2O_3 in Comparative Example 21, while the oxides in Examples 143-159 (Gd_2O_3 , Nd_2O_3 , Sm_2O_3 , CeO_2 , Eu_2O_3 , La_2O_3 , Pr_6O_{11} , Ho_2O_3 , Er_2O_3 , and Yb_2O_3) are magnetic oxides.

[0083]

5 As is clear from Table 5, when the volume fraction of the oxide in the cap layer is 30 vol%, the activated grain diameter GD_{act} of the cap layer whose oxide is B_2O_3 , which is a non-magnetic oxide, is 6.5 nm, whereas the activated grain diameter GD_{act} of the cap layer whose oxide is magnetic oxide (Gd_2O_3 , Nd_2O_3 , Sm_2O_3 , CeO_2 , Eu_2O_3 ,
10 La_2O_3 , Pr_6O_{11} , Ho_2O_3 , Er_2O_3 , Yb_2O_3) is 8.5 to 10.5 nm, which is 30% or more larger than the activated grain diameter GD_{act} of the cap layer whose oxide is B_2O_3 , which is a non-magnetic oxide. This suggests that the cap layer whose oxide is magnetic oxide (Gd_2O_3 , Nd_2O_3 , Sm_2O_3 , CeO_2 , Eu_2O_3 , La_2O_3 , Pr_6O_{11} , Ho_2O_3 , Er_2O_3 , Yb_2O_3) has excellent thermal
15 stability.

[0084]

In addition, as is clear from Examples 143, 153-159, when the volume fraction of Gd_2O_3 in the cap layer is changed in the range of 5-40 vol%, the smaller the volume fraction of Gd_2O_3 is, the larger
20 the value of the activated grain diameter GD_{act} is, which is considered to be superior in thermal stability.

[0085]

(Cross-sectional TEM photograph)

FIG. 5 is a cross-sectional TEM photograph of a region
25 containing a cap layer ($Co_{80}Pt_{20}$ -30vol% Gd_2O_3) (deposited at an argon

gas pressure of 0.6 Pa) with a thickness of 9 nm in Example 17, FIG. 6 is a cross-sectional TEM photograph of a region containing a cap layer ($\text{Co}_{80}\text{Pt}_{20}$ -30vol% Gd_2O_3) (deposited at an argon gas pressure of 4.0 Pa) with a thickness of 9 nm in Example 8, and FIG. 7 is a cross-sectional TEM photograph of a region containing a cap layer (CoPtCrB) in a current perpendicular magnetic recording medium (Comparative Example 20).

[0086]

FIG. 8 is a dark field image of a portion of the cross-sectional region of Example 17 shown in FIG. 5, taken by a scanning transmission electron microscope (STEM), and FIG. 9 is photographs showing the measurement results of energy dispersive X-ray analysis (EDX) performed by a scanning transmission electron microscope (STEM) for a portion of the cross-sectional region of Example 17 shown in FIG. 5. FIG. 10 is a dark field image of a portion of the cross-sectional region of Example 8 shown in FIG. 6, taken by a scanning transmission electron microscope (STEM), and FIG. 11 is photographs showing the measurement results of energy dispersive X-ray analysis (EDX) performed by a scanning transmission electron microscope (STEM) for a portion of the cross-sectional region of Example 8 shown in FIG. 6. FIG. 12 is a dark-field image of a portion of the cross-sectional region of the current perpendicular magnetic recording medium (Comparative Example 20) shown in FIG. 7, taken by a scanning transmission electron microscope (STEM), and FIG. 13 is photographs showing the measurement results of energy

dispersive X-ray analysis (EDX) performed by a scanning transmission electron microscope (STEM) for a portion of the cross-sectional region of the current perpendicular magnetic recording medium (Comparative Example 20) shown in FIG. 7.

5 [0087]

As can be read from FIGs. 5, 6, and 8 to 11, in both Example 17, in which the cap layer was deposited to a thickness of 9 nm at an argon gas pressure of 0.6 Pa, and Example 8, in which the cap layer was deposited to a thickness of 9 nm at an argon gas pressure
10 of 4.0 Pa, no voids are created on the non-magnetic grain boundary oxide 24B (B_2O_3) of the perpendicular magnetic recording layer 24. In addition, the boundary between the perpendicular magnetic recording layer (CoPt- B_2O_3 layer) and the cap layer ($Co_{80}Pt_{20}$ -30vol% Gd_2O_3) is flat.

15 [0088]

In contrast, as can be read from FIG. 7, FIG. 12, and FIG. 13, in the current perpendicular magnetic recording media (Comparative Example 20), the boundary surface between the perpendicular magnetic recording layer (CoPt- B_2O_3 layer) and the
20 cap layer (CoPtCrB layer) is wavy and the unevenness of the surface is large.

[0089]

The shape of the CoPt alloy magnetic grains in the perpendicular magnetic recording layer (CoPt- B_2O_3 layer) can be inferred from the
25 distribution state of Co and Pt shown in FIGs. 9, 11, and 13.

[0090]

In addition, as apparent from FIGs. 5 and 6, the surface of the cap layer ($\text{Co}_{80}\text{Pt}_{20}$ -30vol% Gd_2O_3) of Example 17 deposited to a thickness of 9 nm at an argon gas pressure of 0.6 Pa is flatter than that of the cap layer ($\text{Co}_{80}\text{Pt}_{20}$ -30vol% Gd_2O_3) of Example 8 deposited to a thickness of 9 nm at an argon gas pressure of 4.0 Pa, indicating that the cap layer of Example 17 deposited at an argon gas pressure of 0.6 Pa is better.

[0091]

10 (Planar TEM photograph)

Figure 14 is a planar TEM photograph of the horizontal cross section of the region containing the cap layer ($\text{Co}_{80}\text{Pt}_{20}$ -30vol% Gd_2O_3) of Example 143, and Figure 15 is a planar TEM photograph of the horizontal cross section of the region containing the cap layer ($\text{Co}_{80}\text{Pt}_{20}$ -30vol% Nd_2O_3) of Example 144, and Figure 16 is a planar TEM photograph of the horizontal cross section of the region containing the cap layer ($\text{Co}_{80}\text{Pt}_{20}$ -30vol% Sm_2O_3) of Example 145.

[0092]

As shown in Figs. 14-16, it was confirmed that the cap layer of Examples 143-145 has a granular structure.

Industrial Applicability

[0093]

The perpendicular magnetic recording media according to the present invention has a cap layer with better characteristics

(characteristics to improve the thermal stability of the perpendicular magnetic recording media and to reduce the switching magnetic field) than the current cap layer, and the thermal stability is improved and the switching magnetic field is reduced. Therefore, the perpendicular magnetic recording media according to the present invention has an industrial applicability.

Reference Signs List

[0094]

10	10	perpendicular magnetic recording medium
	12	substrate
	14	adhesion layer
	16	seed layer
	18	first Ru underlayer
15	20	second Ru underlayer
	22	buffer layer
	24	perpendicular magnetic recording layer
	24A, 26A	CoPt alloy magnetic grain
	24B	non-magnetic grain boundary oxide
20	26	cap layer
	26B	magnetic grain boundary oxide
	26C	intergranular exchange coupling
	28	surface protection layer

25

CLAIMS

1. A perpendicular magnetic recording medium comprising a perpendicular magnetic recording layer and a cap layer covering the perpendicular magnetic recording layer, wherein

the perpendicular magnetic recording layer contains a granular structure having CoPt alloy magnetic crystal grains and a non-magnetic grain boundary oxide;

the cap layer contains a granular structure having CoPt alloy magnetic crystal grains and a magnetic grain boundary oxide;

the CoPt alloy magnetic crystal grains in the cap layer contain Co in a range of 65 at% or more and 90 at% or less and Pt in a range of 10 at% or more and 35 at% or less; and

the volume fraction of the magnetic grain boundary oxide to the entire cap layer is 5 vol% or more and 40 vol% or less.

2. A perpendicular magnetic recording medium comprising a perpendicular magnetic recording layer and a cap layer covering the perpendicular magnetic recording layer, wherein

the perpendicular magnetic recording layer contains a granular structure having CoPt alloy magnetic crystal grains and a non-magnetic grain boundary oxide;

the cap layer contains a granular structure having CoPt alloy magnetic crystal grains and a magnetic grain boundary oxide;

the CoPt alloy magnetic crystal grains in the cap layer contain Co in a range of 70 at% or more and less than 85 at%, Pt in a range

of 10 at% or more and 20 at% or less, and at least one element selected from the group consisting of Cr, Ti, B, Mo, Ta, Nb, W and Ru in a range of 0.5 at% or more and 15 at% or less; and

the volume fraction of the magnetic grain boundary oxide to the entire cap layer is 5 vol% or more and 40 vol% or less.

3. The perpendicular magnetic recording medium according to claim 1 or 2, wherein the magnetic grain boundary oxide is a rare earth oxide.

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4. The perpendicular magnetic recording medium according to claim 1 or 2, wherein the magnetic grain boundary oxide is at least one oxide of a Gd oxide, a Nd oxide, a Sm oxide, a Ce oxide, an Eu oxide, a La oxide, a Pr oxide, a Ho oxide, an Er oxide, a Yb oxide, and a Tb oxide.

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