

PERPENDICULAR MAGNETIC RECORDING MEDIUM

FIELD OF THE INVENTION

[0001]

This invention relates to a perpendicular magnetic recording medium, which includes a granular layer having a magnetic material dispersed in a non-magnetic material containing a metal oxide, and a cap layer formed on the granular layer and containing no metal oxide, as layers forming at least a part of a recording layer. More particularly, this invention proposes a technique capable of contributing to improvement of switching field distribution (SFD) required for high density recording.

BACKGROUND OF THE INVENTION

[0002]

In a hard disk drive, a perpendicular magnetic recording system for recording magnetism in a direction perpendicular to a recording surface has been put to practical use. This method is widely adopted because it enables high-density recording as compared with an in-plane magnetic recording method.

[0003]

The perpendicular magnetic recording medium is generally formed by sequentially laminating a soft magnetic layer, an intermediate layer, a recording layer, and the like on a substrate such as aluminum or glass. Among these layers, the recording layer includes, on its lower part, a granular layer having a non-magnetic material of SiO_2 or other metal oxide dispersed in a magnetic material such as a Co-Pt-based alloy mainly based on Co. Accordingly, in the recording layer, the above metal oxide, which is the non-magnetic material, is deposited on grain boundaries of magnetic particles of the magnetic material such as the Co alloy, which is oriented in a perpendicular direction, to reduce magnetic interaction between the magnetic particles, thereby achieving improvement of noise

characteristics and high recording density. The relevant technique is described in Patent Literature 1 and the like.

[0004]

Each layer of such a magnetic recording medium is typically formed by carrying out sputtering with a magnetron sputtering apparatus using a sputtering target having a predetermined composition corresponding to the layer, for example, as described in Patent Literature 2.

CITATION LIST

Patent Literatures

[0005]

[Patent Literature 1] Japanese Patent No. 4021435 B

[Patent Literature 2] Japanese Patent No. 5960287 B

SUMMARY OF THE INVENTION

Technical Problem

[0006]

In the recording layer of the perpendicular magnetic recording medium as described above, the recording layer generally includes, in addition to the granular layer, a cap layer which is formed on the granular layer, contains no metal oxide and mainly composed of a magnetic material. This can allow low noise to be achieved by particle separability of the granular layer having the magnetic particles magnetically separated by the metal oxide, while providing appropriate interaction between the magnetic particles by the cap layer in which the interaction between the magnetic particles remains by the absence of the metal oxide, thereby ensuring easy writing to the medium, reduction of SFD, thermal stability, and the like.

[0007]

When the cap layer is formed on the granular layer by sputtering or the like in order to form the recording layer of such a perpendicular magnetic recording medium, a thin film of the cap layer selectively grows at a portion of the granular layer where no metal oxide is present, due to a wettability difference between the metal oxide in the granular layer and the metal of the cap layer. This leads to ununiform initial growth of the thin film of the cap layer following the morphology of the granular layer containing the metal oxide. Therefore, there is a problem that even if the cap layer having a predetermined thickness is formed, the switching field distribution (SFD) is not improved. On the other hand, if a thicker cap layer is formed, the SFD is improved, but a distance between a head and a center of the medium is increased to decrease the resolution, and the thicker cap layer increases an exchange bond between the magnetic particles to increase a magnetic cluster size, so that the recording density cannot be increased.

[0008]

An object of the present invention is to solve such problem suffering from the conventional perpendicular magnetic recording medium, and to provide a perpendicular magnetic recording medium, which can have a cap layer uniformly laminated onto a granular layer of a recording layer, thereby improving switching field distribution (SFD).

Solution to Problem

[0009]

As a result of intensive studies, the present inventors have found that an oxide of a certain metal contained in a boundary portion of a granular layer located directly below a cap layer in a recording layer with the cap layer results in lamination of the cap layer onto a non-magnetic portion of the granular layer in addition to a magnetic portion of the granular layer from an initial growth stage of the cap layer, based on good wettability to the cap layer containing a large amount of that oxide of

the metal and Co or the like, and as a result, the uniform cap layer is formed on the granular layer. Further, since the oxide of the metal effectively separates the magnetic particles, required magnetic separability of the magnetic particles in the granular layer can be achieved when the oxide of the metal is used as a metal oxide at the boundary portion of the granular layer.

[0010]

Based on the findings, a perpendicular magnetic recording medium according to this invention comprises: a granular layer containing a metal oxide as a non-magnetic material, the granular layer having the magnetic material dispersed in the non-magnetic material; and a cap layer formed on the granular layer, the cap layer containing no metal oxide, as layers forming at least a part of a recording layer, wherein at least one oxide phase of the granular layer immediately below the cap layer at a boundary portion with the cap layer comprises at least one selected from the group consisting of Zn, W, Mn, Fe and Mo.

[0011]

In the perpendicular magnetic recording medium according to the present invention, it is preferable that the oxide phase of the granular layer at the boundary portion comprises at least Zn, among the above metals.

In the perpendicular magnetic recording medium according to the present invention, the oxide phase of the granular layer at the boundary portion may further comprise at least one of B and Si, and the oxide phase of the granular layer at the boundary portion may further comprise Ti.

[0012]

The perpendicular magnetic recording medium according to the present invention preferably has a Zn-free layer in a remaining portion of the granular layer, the remaining portion excluding the boundary portion.

In this case, it is more preferable that the remaining portion of the granular layer comprises an oxide of at least one element selected from the group consisting

of Si, B and Ti as the oxide phase, and the oxide phase in the remaining portion has a total oxide content of from 20 vol.% to 50 vol.%.

[0013]

Further, in the perpendicular magnetic recording medium according to the present invention, it is preferable that the oxide phase of the granular layer at the boundary portion comprises Zn, and the oxide phase has a Zn content of 3 at% or more.

[0014]

Further, the perpendicular magnetic recording medium according to the present invention more preferably has a ratio of a thickness of the boundary portion to a thickness of the entire granular layer of from 3% to 50% in a total lamination direction of the recording layer.

[0015]

Here, magnetic particles of the entire granular layer including the boundary portion may be based Co, and further contain at least one metal selected from the group consisting of Pt, Ru and Cr, as the magnetic material. The magnetic material can have a so-called ECL (Exchange Coupling Layer) which is divided in a perpendicular direction by a non-magnetic layer based on Co or Ru.

Further, the cap layer may be based on Co and further contain at least one metal selected from the group consisting of Cr, Pt and B.

[0016]

Further, in the perpendicular magnetic recording medium according to the present invention, the cap layer preferably has a thickness of from 1 nm to 3 nm in the lamination direction of the recording layer.

Advantageous Effects of Invention

[0017]

According to the perpendicular magnetic recording medium of the present invention, the oxide phase of the granular layer immediately below the cap layer at the boundary portion with the cap layer can contain the metal as described above, whereby the cap layer also grows on the non-magnetic portion of the oxide phase containing the metal of the granular layer from the initial growth stage of the cap layer, so that the cap layer can be uniformly laminated on the granular layer, thereby improving the switching field distribution (SFD).

BRIEF DESCRIPTION OF THE DRAWINGS

[0018]

FIG. 1 is a cross-sectional view schematically showing a recording layer of a perpendicular magnetic recording medium according to an embodiment of the present invention in a lamination direction of the recording layer;

FIG. 2 is a cross-sectional view schematically showing a recording layer of a conventional perpendicular magnetic recording medium in a lamination direction of the recording layer.

FIG. 3 is a graph showing a change in R_a with an increase in a thickness t_c of a cap layer during sputtering of Test Example 1 of Examples;

FIG. 4 is a graph showing a change in $-H_n$ with an increase in a thickness t_c of a cap layer during sputtering of Test Example 1 of Examples;

FIG. 5 is a graph showing a relationship between a Zn content in Test Example 3 of Examples and a thickness of a cap layer in which R_a of the cap layer is less than $5\text{\AA}$; and

FIG. 6 is a graph showing a relationship between a Zn content in Test Example 3 of Examples and a film thickness of a cap layer in which $-H_n$ is positive.

DETAILED DESCRIPTION OF THE INVENTION

[0019]

Hereinafter, embodiments of this invention will be described in detail.

A perpendicular magnetic recording medium according to an embodiment of the present invention includes a recording layer, and as illustrated in FIG. 1, a recording layer 1 includes: a granular layer 2 which contains a metal oxide as a non-magnetic material and which has a magnetic material dispersed in the non-magnetic material; and a cap layer 3 formed on the granular layer 2 and containing no metal oxide, as layers forming a part of the recording layer 1. Therefore, in the recording layer 1 of this embodiment, the granular layer 2 includes oxide phases 4a made of the non-magnetic material and metal phases 4b made of the magnetic material, while the cap layer 3 contains no metal oxide and consists of only a certain metal.

[0020]

The perpendicular magnetic recording medium may be formed, for example by laminating a substrate, a soft magnetic layer, an intermediate layer, and the recording layer 1 in this order, and those other than the recording layer 1 are the same as the prior arts. Therefore, the descriptions of those layers will be omitted here. Further, the recording layer 1 according to this embodiment is composed of the granular layer 2 and the cap layer 3, but may further include an onset layer, an ECL layer or the like, which is non-magnetic or has magnetism with a small magnetic moment.

[0021]

(Cap Layer)

The cap layer 3 contains no metal oxide and is made of only a magnetic metal. Specific examples of such a metal can include those based on Co and further containing at least one metal selected from the group consisting of Cr, Pt and B.

Typically, the metal making up the cap layer 3 is mainly composed of Co and Pt, and may optionally contain one or more metals selected from the group consisting of Cr and B. The cap layer 3 is generally an alloy based on CoCrPtB.

[0022]

In this embodiment, as will be described later, when the cap layer 3 is formed, the cap layer 3 can be uniformly laminated on the granular layer 2 from the initial stage of the film formation, so that switching field distribution (SFD) can be efficiently improved without making a thickness t_c of the cap layer 3 unnecessarily thicker. The thickness t_c of the cap layer 3 can preferably be from 3% to 30% in a percentage to a total thickness t_g of the entire granular layer 2. More particularly, the thickness t_c of the cap layer 3 may preferably be from 0.5 nm to 3 nm.

[0023]

(Granular Layer)

The entire granular layer 2 is composed of the oxide phases 4a made of a non-magnetic metal oxide and the magnetic metal phases 4b. It is important to form the granular layer 2 with at least two layers including a boundary portion 2a located immediately below the cap layer 3 and a remaining portion 2b located below the boundary portion 2a other than the boundary portion 2a, as viewed in the lamination direction of the recording layer 1, as shown in FIG. 1. The boundary portion 2a and the remaining portion 2b has different metal oxides forming the oxide phases 4a.

[0024]

More particularly, the oxide phases 4a at the boundary portion 2a contain at least one selected from the group consisting of Zn, W, Mn, Fe and Mo, and preferably contains Zn. Here, the oxide contained in the boundary portion 2a is mainly ZnO.

This can allow both the metal forming the cap layer 3 containing no metal oxide, and ZnO at the boundary portion 2a of the granular layer 2 to exhibit good wettability when forming the cap layer 3 on the granular layer 2 by sputtering, so that the metal forming the cap layer 3 can be uniformly laminated over the entire boundary portion 2a of the granular layer 2 including the oxide phases 4a from the initial growth stage of the cap layer 3. This can effectively exert the function of the cap layer 3, so that the switching field distribution (SFD) can be improved. Further, since ZnO can effectively separate the magnetic particles of the metal phases 4b in the granular layer 2, required magnetic separability can be ensured even at the boundary portion 2a of the granular layer 2 in the substantially same manner as that of the remaining portion 2b.

[0025]

In the conventional perpendicular magnetic recording medium, as shown in FIG. 2, oxide phases 14a in the granular layer 12 consist of an oxide of a metal other than the above metals in the entire lamination direction. Therefore, when the cap layer 13 is formed, a metal of the cap layer 13 will be selectively laminated onto metal phases 14b in the granular layer 12 in which the metal oxide is not present, at the initial growth stage. In other words, as schematically shown in FIG. 2, in a lower portion of the cap layer 13 close to the granular layer 12, there is a portion where the metal of the cap layer 13 cannot be laminated due to good crystallinity, so-called epitaxial growth. Accordingly, even if the cap layer 13 having a predetermined thickness is formed, the improvement of the switching field distribution (SFD) cannot be achieved. It is also considered that this can be prevented by forming a sufficiently thicker cap layer 13. However, in this case, there are other problems that a distance between a head and a center of the medium is increased to decrease resolution, and the thicker cap layer 13 increases

exchange coupling between the magnetic particles to increase a magnetic cluster size, so that recording density cannot be increased.

In the embodiment according to the present invention as shown in FIG. 1, the oxide phases at the boundary portion 2a contain Zn, W, Mn, Fe and/or Mo, which are easily wetted to the cap layer 3, and hence such conventional problems can effectively be solved.

[0026]

When the boundary portion 2a at the granular layer 2 contains Zn, the Zn content is preferably 3 at% or more. If the Zn content in the boundary portion 2a is less than 3 at%, any improvement of wettability cannot be expected, the cap layer may be difficult to grow epitaxially on the oxide phases, and if the Zn content in the boundary portion 2a is more than 25 at%, magnetic anisotropy and crystallinity may be deteriorated due to a large amount of Zn incorporated into the metal phases.

[0027]

The oxide phases at the boundary portion 2a of the granular layer 2 may even more preferably be made of at least one selected from the group consisting of Zn, W, Mn, Fe, and Mo for improving the wettability, B and Si for improving an amorphous nature, and Ti for improving the separability. That is, although the oxide phases at the boundary portion 2a of the granular layer 2 may only contain at least one selected from the group consisting of Zn, W, Mn, Fe and Mo, they may further contain at least one of B and Si, and/or Ti.

[0028]

As viewed in the lamination direction of the recording layer, a ratio of a thickness t_b of the boundary portion 2a of the granular layer 2 to a total thickness t_g of the entire granular layer 2 (t_b / t_g) is preferably from 3% to 50% in a percentage. If the ratio (t_b / t_g) of the thickness t_b of the boundary portion 2a to the total thickness t_g is less than 3%, the effect of uniform formation of the cap layer 3 by

ZnO of the boundary portion 2a may not be sufficiently obtained. The ratio (t_b / t_g) of the thickness t_b of the boundary portion 2a to the total thickness t_g of the entire granular layer 2 is more preferably from 3% to 30%.

[0029]

On the other hand, the oxide phases of the remaining portion 2b in the granular layer 2, which would not significantly affect the uniform formation of the cap layer 3, may contain Zn as with the boundary portion 2a, but it is preferable that they do not contain Zn. It is also preferable that the remaining portion 2b in the granular layer 2 is a layer that does not contain not only ZnO but also Zn. This is because if the remaining portion 2b in the granular layer 2 contains Zn, magnetic anisotropy K_u may be decreased.

[0030]

The remaining portion 2b in the granular layer 2 can contain, as the oxide phases, an oxide of at least one element selected from the group consisting of Si, B and Ti, rather than the predetermined metal oxide such as ZnO as described above. The total content of the oxides in the remaining portion 2b, including oxides other than that oxide, is preferably from 20 vol.% to 50 vol.%. If the total content of the oxides in the remaining portion 2b is less than 20 vol.%, the separation of the metal phases may be insufficient and the magnetic cluster size may be increased, and if it is more than 50 vol.%, the proportion of the metal phases is decreased, and sufficient K_u and magnetic anisotropy cannot be obtained, which may result in insufficient thermal stability and reproduction signal strength. The volume percentage of the oxide in the layer is determined by TEM observation.

[0031]

The metal phases 4b as the magnetic materials of the granular layer 2 are based on Co and further contain at least one metal selected from the group consisting of Pt, Ru and Cr.

EXAMPLES

[0032]

Next, the perpendicular magnetic recording medium according to this invention was experimentally produced and its performance was confirmed as described below. However, the descriptions herein are merely for the purpose of illustration and are not intended to be limited thereto.

[0033]

(Test Example 1)

As Example 1-1, Cr-Ti (6 nm), Ni-W (5 nm), and Ru (20 nm) were deposited on a glass substrate in this order by a magnetron sputtering apparatus (C-3010 sputtering system from Canon Anelva Corporation), and on the resulting film, Co-Pt-SiO₂ (10 nm) was formed as a lower granular layer (the remaining portion of the granular layer), and on the lower granular layer, an upper granular layer (the boundary portion of the granular layer with the cap layer) was formed by sputtering using a sputtering target made of Co-Pt-ZnO at 300 W in an Ar atmosphere at 5.0 Pa to form each magnetic film having a thickness of 3 nm, on which Co-Cr-Pt-B (from 0 to 8 nm) was further formed as a cap layer to form each layer. In Example 1-1, the oxide of the upper granular layer is made of ZnO.

[0034]

Further, as each of Examples 1-2 to 1-5, the same film as that of Example 1 was formed with the exception that the oxide of the upper granular layer was composed of WO₃, MnO, Fe₂O₃, and MoO₃.

Furthermore, as Comparative Example 1, each layer was formed in the same method as that of Example 1 with the exception that the oxide phases of the upper granular layer were composed of SiO₂.

[0035]

For these Examples 1-1 to 1-5 and Comparative Example 1, roughness (Ra) and magnetic switching start field (-Hn) relative to the thickness of the cap layer were measured. Comparisons of them are graphically shown in FIGS. 3 and 4. In FIGS. 3 and 4, SiO₂ means Comparative Example 1, ZnO means Example 1-1, WO₃ means Example 1-2, MnO means Example 1-3, Fe₂O₃ means Example 1-4, and MoO₃ means Example 1-5.

[0036]

In each of Examples 1-1 to 1-5 and Comparative Example 1, the lower granular layer had 67Co-23Pt-10SiO₂ (mol%), and the cap layer had 60Co-10Cr-15Pt-5B (mol%).

Further, in Example 1-1, the upper granular layer had 62Co-21Pt-17ZnO (mol%) (ZnO = 30 vol.%), and in Comparative Example 1, the upper granular layer had 67Co-22Pt-10SiO₂ (mol%) (SiO₂ = 30 vol.%). The upper granular layer had 70Co-23Pt-7WO₃ (mol%) (WO₃ = 30 vol.%) for Example 1-2; 61Co-20Pt-19MnO (mol%) (MnO = 30 vol.%) for Example 1-3; 68Co-23Pt-10Fe₂O₃ (mol%) (Fe₂O₃ = 30 vol.%) for Example 1-4; and 62Co-21Pt-18MoO₃ (mol%) (MoO₃ = 30 vol.%) for Example 1-5.

The roughness (Ra) was measured by an atomic force microscope (AFM) from SII, and the magnetic switching start field (-Hn) was measured by a sample vibration magnetometer (VSM) from TAMAGAWA CO., LTD.

[0037]

As can be seen from FIG. 3, in Examples 1-1 to 1-5, the Ra is sufficiently decreased even if the thickness (tc) of the cap layer is thinner than that of Comparative Example 1 where SiO₂ is used, and these Examples had good wettability between the cap layer mainly composed of Co as the upper layer, and the Zn oxide. Further, as can be seen from FIG. 4, in Examples 1-1 to 1-5, the ratio: d (-Hn) / dtc is positive in a range where the cap layer is thinner than that of

Comparative Example 1 where SiO₂ is used, and the SFD effect of the cap layer is obtained.

[0038]

(Test Example 2)

As a reference example, a sample in which a single granular layer having 13 nm was formed on a film formed up to Ru in the same manner as that of Test Example 1 was prepared using 67Co-22Pt-10SiO₂ (mol%) (SiO₂ = 30 vol.%) as a Zn-free sputtering target, and 62Co-21Pt-17ZnO (mol%) (ZnO = 30vol.%) as a Zn-containing sputtering target, and magnetic anisotropic Ku was measured.

The magnetic anisotropy (Ku) was measured with a magnetic torque meter (TRQ) from TAMAGAWA CO., LTD.

[0039]

The value of Ku was 6.16×10^6 erg/cc for the case where the oxide of the granular layer was made of SiO₂, whereas it was 5.04×10^6 erg/cc for the case where the oxide of the granular layer was made of ZnO. It is thus understood that the use of the Z-containing sputtering target results in decreased Ku. Therefore, since a sputtering target having a composition such that the Ku is increased is often used for the lower granular layer, it would be desirable that the lower granular layer has the layer that does not contain Zn.

[0040]

(Test Example 3)

As Examples 3-1 to 3-22, samples having various Zn contents were produced with sputtering targets of Co-Pt-ZnO, Co-Pt-SiO₂-ZnO, Co-Pt-B₂O₃-ZnO, and Co-Pt-TiO₂-ZnO. The composition of each sputtering target is shown in Table 1 for reference.

[0041]

[Table 1]

		Zn Content (at%)	Composition of Target (mol%)					
			Co	Pt	SiO ₂	B ₂ O ₃	TiO ₂	ZnO
Example 3-1	Co-Pt-ZnO	12.3	62	21	0	0	0	17
Example 3-2	Co-Pt-SiO ₂ -ZnO	0	67	23	10	0	0	0
Example 3-3	Co-Pt-SiO ₂ -ZnO	0.8	67	22	10	0	0	1
Example 3-4	Co-Pt-SiO ₂ -ZnO	1.7	67	22	9	0	0	2
Example 3-5	Co-Pt-SiO ₂ -ZnO	3.3	66	22	8	0	0	4
Example 3-6	Co-Pt-SiO ₂ -ZnO	5.9	65	22	6	0	0	7
Example 3-7	Co-Pt-SiO ₂ -ZnO	8.4	64	21	5	0	0	10
Example 3-8	Co-Pt-SiO ₂ -ZnO	11.9	63	21	2	0	0	14
Example 3-9	Co-Pt-B ₂ O ₃ -ZnO	0	69	23	0	8	0	0
Example 3-10	Co-Pt-B ₂ O ₃ -ZnO	0.8	69	23	0	7	0	1
Example 3-11	Co-Pt-B ₂ O ₃ -ZnO	1.5	68	23	0	7	0	2
Example 3-12	Co-Pt-B ₂ O ₃ -ZnO	3.1	67	23	0	6	0	4
Example 3-13	Co-Pt-B ₂ O ₃ -ZnO	5.5	66	22	0	5	0	7
Example 3-14	Co-Pt-B ₂ O ₃ -ZnO	8.2	65	22	0	3	0	10
Example 3-15	Co-Pt-B ₂ O ₃ -ZnO	11.5	63	21	0	2	0	14
Example 3-16	Co-Pt-TiO ₂ -ZnO	0	64	22	0	0	14	0
Example 3-17	Co-Pt-TiO ₂ -ZnO	0.8	64	22	0	0	13	1
Example 3-18	Co-Pt-TiO ₂ -ZnO	1.6	64	22	0	0	12	2
Example 3-19	Co-Pt-TiO ₂ -ZnO	3.2	64	21	0	0	11	4
Example 3-20	Co-Pt-TiO ₂ -ZnO	5.6	63	21	0	0	9	7
Example 3-21	Co-Pt-TiO ₂ -ZnO	8.2	63	21	0	0	6	10
Example 3-22	Co-Pt-TiO ₂ -ZnO	11.7	62	21	0	0	3	14

[0042]

A magnetic film was formed using each of these samples by the same method as that of Test Example 1, and the roughness (Ra) and the magnetic switching start field (-H_n) relative to the thickness of the cap layer were measured. It should be noted that each of the above samples was used for forming the upper granular layer of the magnetic film. The relationship between the Zn content and the thickness of the cap layer in which Ra of the cap layer is less than 5Å is shown in FIG. 5, and the relationship between the Zn content and the thickness of the cap layer in which -H_n is positive is shown in FIG. 6.

As can be seen from FIG. 5, particularly in Examples 3-5 to 3-8, Examples 3-12 to 3-15, and Examples 3-19 to 3-22 where the Zn content in the upper granular layer is 3 at% or more, the Ra is sufficiently decreased even if the cap layer is thinner, resulting in further improved wettability between the upper cap layer mainly based on Co and the Zn oxide. Further, as can be seen from FIG. 6, particularly in Examples 3-5 to 3-8, Examples 3-12 to 3-15, and Examples 3-19 to 3-22 where the

Zn content in the upper granular layer is 3 at% or more, the thickness of the cap layer in which the $d(-H_n)/dC$ is positive is considerably thinner, so that the addition of Zn further improves SFD in the thin cap layer.

Description of Reference Numerals

[0043]

1 recording layer

2 granular layer

2a boundary portion

2b remaining portion

3 cap layer

4a metal phase

4b oxide phase

Tg total thickness of the entire granular layer

Tb thickness of boundary portion

Tk thickness of cap layer

CLAIMS

1. A perpendicular magnetic recording medium, comprising: a granular layer containing a metal oxide as a non-magnetic material, the granular layer having the magnetic material dispersed in the non-magnetic material; and a cap layer formed on the granular layer, the cap layer containing no metal oxide, as layers forming at least a part of a recording layer,
wherein at least one oxide phase of the granular layer immediately below the cap layer at a boundary portion with the cap layer comprises at least one selected from the group consisting of Zn, W, Mn, Fe and Mo.
2. The perpendicular magnetic recording medium according to claim 1, wherein the oxide phase of the granular layer at the boundary portion comprises Zn.
3. The perpendicular magnetic recording medium according to claim 1 or 2, wherein the oxide phase of the granular layer at the boundary portion further comprises at least one of B and Si.
4. The perpendicular magnetic recording medium according to any one of claims 1 to 3, wherein the oxide phase of the granular layer at the boundary portion further comprises Ti.
5. The perpendicular magnetic recording medium according to any one of claims 1 to 4, wherein the perpendicular magnetic recording medium has a Zn-free layer in a remaining portion of the granular layer, the remaining portion excluding the boundary portion.

6. The perpendicular magnetic recording medium according to claim 5, wherein the remaining portion of the granular layer comprises an oxide of at least one element selected from the group consisting of Si, B and Ti as the oxide phase, and the oxide phase in the remaining portion has a total oxide content of from 20 vol.% to 50 vol.%.

7. The perpendicular magnetic recording medium according to any one of claims 1 to 6, wherein the oxide phase of the granular layer at the boundary portion comprises Zn, and the oxide phase has a Zn content of 3 at% or more.

8. The perpendicular magnetic recording medium according to any one of claims 1 to 7, wherein the perpendicular magnetic recording medium has a ratio of a thickness of the boundary portion to a total thickness of the entire granular layer of from 3% to 50% in a lamination direction of the recording layer.

9. The perpendicular magnetic recording medium according to any one of claims 1 to 8, wherein the entire granular layer including the boundary portion comprises at least one metal selected from the group consisting of Pt, Ru and Cr, as at least one metal layer.

10. The perpendicular magnetic recording medium according to any one of claims 1 to 9, wherein the cap layer comprises at least one metal selected from the group consisting of Cr, Pt and B.

11. The perpendicular magnetic recording medium according to any one of claims 1 to 10, wherein the cap layer has a thickness of from 1 nm to 3 nm in the lamination direction of the recording layer.