

Method for producing a magnetic recording medium and a
magnetic recording medium produced by the method

5 Technical field of the invention

The present invention relates to a method for producing a
perpendicular magnetic recording medium and to a perpendicular
magnetic recording medium produced by the method. Such a
perpendicular magnetic recording medium is mounted on a variety of
10 magnetic recording devices.

Background of the invention

A perpendicular magnetic recording system with recording
magnetization perpendicular to the medium surface has been
15 drawing attention as an alternative to a conventional longitudinal
magnetic recording system, to attain higher recording density. A
perpendicular magnetic recording medium is principally composed of
a magnetic recording layer of a hard magnetic material, an
underlayer for aligning the magnetic recording layer to an aimed
20 direction, a protective layer for protecting the surface of the magnetic
recording layer, and a soft magnetic underlayer having a function to
converge a magnetic flux that is generated by a magnetic head for
recording in the magnetic layer.



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The soft magnetic underlayer is sometimes absent since recording is possible without the soft magnetic underlayer, although the soft magnetic underlayer can improve media performance. A medium without the soft magnetic underlayer is called a single-layered perpendicular magnetic recording medium, and a medium having the backing layer is called a double-layered perpendicular magnetic recording medium. A perpendicular magnetic recording medium, as well as a longitudinal magnetic recording medium, must perform high thermal stability compatible with low media noise in order to achieve high recording density.

In conventional longitudinal magnetic recording media, various compositions and structures of a magnetic recording layer and materials for a nonmagnetic underlayer have ever been proposed. Practically applied magnetic recording layers use an alloy of Co and Cr (hereinafter referred to as CoCr) and obtain magnetically isolated magnetic grains by segregation of the chromium at grain boundary. Another type of a magnetic recording layer, called a granular magnetic recording layer, has been proposed that uses nonmagnetic and nonmetallic substance, for example, oxide or nitride.

In a magnetic recording layer of the CoCr, the substrate must be heated up to a temperature higher than 200°C at depositing the layer for enough segregation of the chromium. On the other hand, the

granular magnetic recording layer has a feature that the nonmagnetic and nonmetallic substance segregates even if the substrate heating is omitted. The magnetic recording layer of CoCr and the granular magnetic recording layer can be applied to a perpendicular magnetic recording medium as well, establishing perpendicular anisotropy by controlling crystal alignment in the recording layer by the aid of an underlayer, for example.

Problem to be solved by the invention

10 In a perpendicular magnetic recording medium, a magnetic recording layer using CoCr is known to show difficulty in chromium segregation to the same extent as in a longitudinal medium. On the hand, a perpendicular magnetic recording layer employing a granular magnetic layer is known to more easily establish a segregation
15 structure than in the CoCr recording layer. As a result, magnetic interaction between the grains is suppressed, leading to low media noise. However, a granular magnetic recording layer in a thin film thickness of about 10 nm or less has revealed insufficient segregation structure, resulting in poor isolation between grains and causing
20 noises.

Because recording in a perpendicular magnetic recording medium is ideally done with a sharp perpendicular magnetic field by a head, the thickness of the magnetic recording layer is desired as

thin as possible. If an initial growth layer with such insufficient segregation is formed, a thin magnetic recording layer is difficult to be achieved. Consequently, lower noise and higher recording density have been obstructed in a conventional granular magnetic recording
5 layers.

The present invention has been made in view of the problems, and an object of the invention is to provide a method to produce a perpendicular magnetic recording medium and to provide a
10 perpendicular magnetic recording medium produced by such a method, wherein the perpendicular magnetic recording medium exhibits low noise and high recording density by achieving excellent segregation structure in the magnetic layer.

15 Means to solve the problem

To attain the object, nucleation sites are introduced on the surface on which a granular magnetic recording layer is to be formed, for the purpose of promoting growth of a nonmagnetic and nonmetallic grain boundary phase. Specifically, a method for
20 producing a perpendicular magnetic recording medium according to the invention comprises steps of sequentially laminating an underlayer, laminating a magnetic recording layer, laminating a protective layer, and laminating a liquid lubricant layer on a nonmagnetic substrate, wherein the magnetic recording layer

comprises ferromagnetic crystalline grains and nonmagnetic grain boundary region consisting mainly of oxide or nitride surrounding the crystalline grains, and the method comprises a step of exposing the substrate after the step of laminating the underlayer, to O₂ or N₂ atmosphere or to a mixed gas atmosphere of a rare gas with an addition of O₂ or N₂, before the step of laminating the magnetic recording layer.

Advantageously, in the method for producing a perpendicular magnetic recording medium of the invention, the underlayer is composed of Ru or an alloy of Ru, preferably RuW, RuCu, RuC, RuB, or RuCoCr.

Advantageously, the method for producing a perpendicular magnetic recording medium further comprises a step of laminating a seed layer just before the step of laminating the underlayer, the seed layer being composed of a Ni-base alloy, preferably NiFe, NiFeNb, NiFeB, NiFeSi, or NiFeCr.

A perpendicular magnetic recording medium of the invention is produced by the method described above.

In the present invention having such constitutions, both the magnetic portion and the nonmagnetic and nonmetallic grain

boundary region are simultaneously formed from the initial stage of the recording layer formation, and the ferromagnetic crystalline grains are magnetically separated. Specifically, an oxide or a nitride is used for the nonmagnetic and nonmetallic substance, and the
5 substrate surface before deposition of the granular magnetic recording layer is exposed to an atmosphere containing O₂ or N₂. The O₂ or N₂ attached on the substrate surface with the underlayer by the exposure acts as nucleation sites to grow the nonmagnetic and nonmetallic region causing separation of ferromagnetic crystalline
10 grains from the initial growth layer of the magnetic recording layer.

Brief description of drawings

Figure 1 is a schematic cross sectional view illustrating an
15 example of embodiment of a perpendicular magnetic recording medium according to the present invention.

Figure 2 is a chart showing dependence of magnetic cluster size on the magnetic recording layer thickness obtained from MFM evaluation for Examples 1 and 2 and Comparative Examples 1 and 2.

20 Figure 3 is a chart showing dependence of standard deviation of magnetic cluster size on the magnetic recording layer thickness obtained from MFM evaluation for Examples 1 and 2 and Comparative Examples 1 and 2.

Figure 4 is a chart showing dependence of the normalized media

noise in the case of the magnetic recording layer thickness of 15 nm on linear recording density obtained from the evaluation of magnetic parametric performance for Examples 1 and 2 and Comparative Examples 1 and 2.

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Aspects of embodiments of the present invention

Some aspects of preferred embodiments of the present invention will be described with reference to the accompanied drawings in the following. Fig. 1 is a schematic cross sectional view illustrating an
10 example of embodiment of a perpendicular magnetic recording medium according to the present invention. The perpendicular magnetic recording medium has a structure comprising at least an underlayer 2, a magnetic layer 3, and a protective layer 4 sequentially formed on a nonmagnetic substrate 1. A liquid lubricant
15 layer 5 is further formed on the layers.

The nonmagnetic substrate 1 can be composed of a NiP-plated aluminum alloy, strengthened glass, or crystallized glass, each of which is used in a usual magnetic recording medium. A plastic
20 substrate made of a resin such as polycarbonate, polyolefin, or the like may be used when a temperature of substrate heating is held under about 100°C.

The underlayer 2 is preferably composed of a metal with a

hexagonal closest packed structure or an alloy of such a metal, or a metal with a face centered cubic structure or an alloy of such a metal. The metal with the hexagonal closest packed structure includes Ti, Zr, Ru, Zn, Tc, and Re. The metal with the face centered cubic structure
5 includes Cu, Rh, Pd, Ag, Ir, Pt, Au, Ni, and Co. Of the materials exemplified above, Ru or Ru alloy exhibits excellent effect because of weak reactivity with exposed O₂ or N₂. Although a thin film is desirable, a thickness at least 3 nm is preferable, in which crystal growth becomes to an acceptable mass.

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A seed layer 12 may be provided beneath the underlayer 2 to improve alignment of the underlayer 2. Although the seed layer may be nonmagnetic, a material with soft magnetic property is preferable for acting as a part of a soft magnetic underlayer in a structure of a
15 double-layered perpendicular magnetic recording medium. Examples for material of the seed layer 12 exhibiting soft magnetic property include nickel-base alloys such as NiFe, NiFeNb, NiFeB, NiFeSi, and NiFeCr.

20 In the case a seed layer 12 is provided beneath the underlayer 2, a soft magnetic underlayer 11 may be further provided under the seed layer for converging the magnetic field generated by a magnetic head to construct a double-layered perpendicular magnetic recording medium. Materials that can be used for the soft magnetic underlayer

11 include crystalline materials of a NiFe alloy and a Sendust alloy (FeSiAl), fine crystalline materials of FeTaC and CoTaZr, and an amorphous cobalt alloy of CoZrNb.

5 While the optimum thickness of the soft magnetic underlayer depends on a structure and characteristic of a magnetic head used for recording, a thickness from 10 nm to 500 nm is desirable considering a balance with productivity.

10 The magnetic recording layer 3 takes a structure consisting of ferromagnetic crystalline grains and a nonmagnetic grain boundary region surrounding the grains. The magnetic recording layer employs a granular magnetic recording layer, in which the magnetic grain boundary region is composed of nonmagnetic nonmetallic substance.

15 The ferromagnetic crystalline grains are preferably composed of a CoPt alloy, an FePt alloy, or one of these alloys that contains additive element(s) selected from Cr, Ni, Nb, Ta, and B.

20 The nonmagnetic metallic substance of the nonmagnetic grain boundary region is preferably an oxide or a nitride, for example, an oxide or a nitride of an element selected from Cr, Co, Si, Al, Ti, Ta, Hf, Zr, Y, and Ce. The ferromagnetic crystalline grains needs to exhibit magnetic anisotropy perpendicular to the film surface in order to be used in a perpendicular magnetic recording medium.

The substrate surface before forming the magnetic recording layer 3, namely the surface of the underlayer 2, is exposed to an atmosphere of O₂ or N₂, or to a mixed gas atmosphere of rare gas and added O₂ or N₂. The O₂ or N₂ is attached as nucleation sites for
5 growing the nonmagnetic nonmetallic region. After that, the magnetic recording layer 3 is formed. As a result, both the ferromagnetic crystalline grains and the grain boundary region of the nonmagnetic nonmetallic substance are formed from the initial stage of the magnetic layer formation. Thus, a magnetic recording layer
10 having excellent segregation structure can be formed.

The protective layer 4 can be composed of a thin film of mainly carbon. The liquid lubricant layer 5 can be formed of perfluoropolyether lubricant.

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The following describes specific examples of embodiments of perpendicular magnetic recording media according to the present invention.

Example 1

20 A chemically strengthened glass substrate with smooth surface (N-5 glass substrate, manufactured by HOYA Corporation) was used for a nonmagnetic substrate. After cleaning, the substrate was introduced into a sputtering apparatus. A soft magnetic CoZrNb layer 300 nm thick was formed using a target of Co-5Zr9Nb under

argon gas pressure of 5 mTorr. Subsequently, a seed layer of NiFeNb 20 nm thick was deposited using a soft magnetic Ni-base alloy target of Ni-12Fe9Nb under argon gas pressure of 5 mTorr.

5 Then, a Ru underlayer 20 nm thick was formed using a Ru target under argon gas pressure of 30 mTorr. After that, the resulted substrate was exposed to an argon gas atmosphere containing 2 % of O₂ for 10 sec. The pressure of the mixed gas of argon and oxygen was 5 mTorr, and the flow rate was 60 sccm.

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 Then, a magnetic recording layer of CoCrPt-SiO₂ was deposited using a target of 91(Co-10Cr17Pt)-9SiO₂ under argon gas pressure of 30 mTorr. Thickness of the magnetic recording layer was varied in the range from 10 to 30 nm. After depositing a carbon protective film
15 8 nm thick using a carbon target, the resulted substrate was taken out from the vacuum chamber.

 Finally, a liquid lubricant layer 2 nm thick was formed of perfluoropolyether by means of a dip-coating method. Thus, a double-
20 layered perpendicular magnetic recording medium was produced. Deposition of the magnetic recording layer was conducted by means of an RF magnetron sputtering method; deposition of all other layers was conducted by means of a DC magnetron sputtering method.

Example 2

A double-layered perpendicular magnetic recording medium was produced in the same manner as in Example 1 except that the steps for forming from an underlayer to a magnetic recording layer were
5 conducted by the steps of forming a RuW underlayer 15 nm thick, exposing to an atmosphere of argon containing 3 % of N₂ for 10 sec, and forming a magnetic recording layer of CoCrPt-SiN using a 92(Co-10Cr15Pt)-8SiN target.

10 Comparative Example 1

A double-layered perpendicular magnetic recording medium was produced in the same manner as in Example 1 except that the step of exposure to the Ar + O₂ atmosphere before the step of forming the CoCrPt-SiO₂ magnetic recording layer was omitted in this

15 Comparative Example 1.

Comparative Example 2

A double-layered perpendicular magnetic recording medium was produced in the same manner as in Example 2 except that the step of
20 exposure to the Ar + N₂ atmosphere before the step of forming the CoCrPt-SiN magnetic recording layer was omitted in this Comparative Example 2.

Results of magnetic properties evaluation for the Examples and

Comparative Examples are described below. The magnetic performance was measured by magnetic Kerr effect. Table 1 shows coercivity Hc for the magnetic recording layers having thickness of 15 nm. Specifically, the Table 1 gives the coercivity Hc for the magnetic recording layers having thickness of 15 nm obtained from magnetic properties evaluation on Examples 1 and 2 and Comparative Examples 1 and 2.

Table 1

	Hc [Oe]
Example 1	4,320
Example 2	3,460
Comp Example 1	4,000
Comp Example 2	3,200

Thickness of magnetic recording layer: 15 nm

Squareness ratio S for every Examples and Comparative Examples was 1.0. Comparing Example 1 with Comparative Example 1, the Example 1, which experienced the exposure to the Ar + O₂ atmosphere, demonstrated improvement in Hc as compared with the Comparative Example 1, which did not experience the exposure. Similarly, comparing Example 2 with Comparative Example 2, the Example 2, which experienced the exposure to the Ar + N₂ atmosphere, showed improvement in Hc. Thus, the exposure to the atmosphere containing O₂ or N₂ promoted segregation structure and contributed to improvement in Hc.

Fig. 2 and Fig. 3 show dependences of a diameter d [nm] and a standard deviation of the diameter σ [nm], respectively, of a magnetic cluster size on the thickness of the magnetic recording layer for Examples and Comparative Examples. The values of magnetic cluster size were obtained by MFM measurement for each of the AC-demagnetized media. It is generally apparent that both Examples 1 and 2, which were subjected to the exposure, significantly decreased in both d and σ as compared with Comparative Examples 1 and 2, which did not experience the exposure.

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Focusing on the case of 10 nm thickness of the magnetic recording layer in particular, Comparative Examples 1 and 2, both the diameter d and the standard deviation σ are very large, which indicates that separation of the ferromagnetic crystalline grains was insufficient in the initial growth layer, resulting in the large values of the sizes and the deviation of sizes of the magnetic cluster size.

Examples 1 and 2, which were subjected to the exposure, in contrast, both the diameter d and the standard deviation σ are small even at the thickness of 10 nm of the magnetic recording layer, which indicates that O_2 or N_2 acted as nucleation sites for the growth of the nonmagnetic nonmetallic region and promoted separation of the ferromagnetic crystalline grains from the initial stage of the growth of the magnetic recording layer.

Fig. 4 shows dependence of normalized media noises on linear recording density, obtained from measurement of magnetic parametric performance in the case of 15 nm thickness of the magnetic recording layer in the Examples and the Comparative Examples. The magnetic parametric performance was obtained by the measurement using a spin-stand tester equipped with a GMR head. As is apparent from Fig. 4, the noises have significantly decreased in Examples 1 and 2, which were subjected to the exposure, as compared with Comparative Examples 1 and 2, which did not experience the exposure. Considering in combination with the above-described evaluation results on the magnetic cluster size, the noise reduction has been attained by virtue of sufficient separation of the magnetic crystalline grains from the initial stage of the growth of the magnetic recording layer, which in turn resulted from the exposure.

Table 2 shows SNR values at 400 kFCI and 600 kFCI in the case of the magnetic recording layer thickness of 15 nm, obtained from evaluation on the magnetic parametric performance for Examples 1 and 2 and Comparative Examples 1 and 2.

Table 2

	SNR[dB] at 400 [kFCI]	SNR[dB] at 600 [kFCI]
Example 1	16.6	4.32
Example 2	12.4	1.86
Comp Example 1	10.9	0.69
Comp Example 2	9.5	0.33

Thickness of magnetic recording layer: 15 nm

The SNRs were obtained from the similar evaluation of the magnetic parametric performance to in the case of the above-described normalized media noise. Reflecting the high H_c and low noise described above, the SNR in the Examples 1 and 2, which were subjected to the exposure, demonstrated substantial improvement as compared with Comparative Examples 1 and 2, which did not experience the exposure.

Advantageous Effect of the invention

As described so far, the present invention brings about the effect to well separate the ferromagnetic crystalline grains from the initial growth layer of the magnetic layer. The effect results from the constitution of the invention in which a granular magnetic recording layer is used comprising nonmagnetic grain boundary region of nonmagnetic and nonmetallic oxide or nitride, and the substrate surface with an underlayer before forming the magnetic layer is exposed to an atmosphere containing O_2 or N_2 to introduce nucleation

sites for the growth of the nonmagnetic and nonmetallic region.

Accordingly, magnetic interaction between the ferromagnetic crystalline grains decreases to reduce media noise, and at the same time, to attain thin magnetic layer. Therefore, high recording density
5 is accomplished in a perpendicular magnetic recording medium.

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Claims

1. A method for producing a perpendicular magnetic recording medium comprising steps of sequentially laminating an underlayer, laminating a magnetic recording layer, laminating a protective layer,
5 and laminating a liquid lubricant layer on a nonmagnetic substrate, wherein the magnetic recording layer comprises ferromagnetic crystalline grains and nonmagnetic grain boundary region consisting mainly of oxide or nitride surrounding the crystalline grains, and the method comprises a step of exposing the substrate after the step of
10 laminating the underlayer, to O₂ or N₂ atmosphere or to a mixed gas atmosphere of a rare gas with an addition of O₂ or N₂, before the step of laminating the magnetic recording layer.
2. A method for producing a perpendicular magnetic recording
15 medium according to claim 1, wherein the underlayer is composed of Ru or a Ru alloy.
3. A method for producing a perpendicular magnetic recording medium according to claim 2, wherein the Ru alloy is RuW, RuCu,
20 RuC, RuB, or RuCoCr.
4. A method for producing a perpendicular magnetic recording medium according to claim 1 further comprising a step of laminating a seed layer just before the step of laminating the underlayer, the

seed layer being composed of a Ni-base alloy.

5. A method for producing a perpendicular magnetic recording medium according to claim 4, wherein the Ni-base alloy is NiFe,
5 NiFeNb, NiFeB, NiFeSi, or NiFeCr.

6. A perpendicular magnetic recording medium that is produced by a method according to claim 1.

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