

Method for producing multilayer film perpendicular magnetic recording medium

Field of the Invention

The present invention relates to a method for producing a perpendicular magnetic recording medium used for a magnetic recording apparatus. In particular, the present invention relates to a perpendicular magnetic recording medium that has a high recording density, a superior read-write characteristic, that is written to easily, and that has a high thermal stability.

Prior Art

Recently, a magnetic recording apparatus having a larger capacity and a smaller size has been desired as a memory device used for a personal computer or a workstation. In order to realize this, a magnetic recording medium has been required to have a further higher recording density. One of the magnetic recording methods in present use is the in-plane magnetic recording method (or a longitudinal magnetic recording method) by which an easy magnetization axis is parallel to a magnetic recording medium face. In order to improve a recording density in the in-plane magnetic recording method, it is required to reduce the product of the residual magnetization (B_r) of a magnetic film of a magnetic recording medium and a magnetic layer thickness (t). Coercivity (H_c) is also required to be increased. Thus, an attempt has been made to reduce the film thickness of a magnetic film to control the grain diameter of magnetic crystals. However, the in-plane magnetic recording method has a demerit in that a demagnetizing field is increased in accordance with the shortening of a bit length to cause the reduction of the residual flux density, thus reducing the reproduction output. The in-plane magnetic recording method also has a problem due to thermal stability, brought about by the smaller magnetic crystal grains or thinner film. Therefore, it is presumed that it is technically difficult to use this method to provide a magnetic recording medium having a further higher density.

On the other hand, a perpendicular magnetic recording method has been examined as a means for solving the above-described problems and for improving the areal recording density. In the perpendicular magnetic recording method, a magnetic recording medium is provided such that the easy magnetization axis of a magnetic film is provided to be perpendicular to a substrate face and neighboring magnetizations in a magnetization transition region are not opposed to each other. Thus, even when a bit

length is reduced, the magnetization is stable and the reduction in magnetic flux as in the in-plane magnetic recording is small. Therefore, this medium is appropriate as a high density magnetic recording medium.

As described above, the perpendicular magnetic recording medium is more advantageous as a high density magnetic recording medium than the in-plane magnetic recording medium. However, in the case of a perpendicular magnetic recording medium, segregation of non-magnetic elements at a magnetic crystal grain boundary is not satisfactorily performed, causing a problem in which magnetic interaction among magnetic crystal grains is increased, giving rise to increased noise. Therefore, an attempt has been conventionally made to improve, in order to achieve a high density magnetic recording or the reduction of the medium noise, the layer structure of the perpendicular magnetic recording medium.

As a known structure of a perpendicular magnetic recording medium, a bilaminar perpendicular magnetic recording medium has been disclosed in which a non-magnetic substrate consisting of aluminum, glass or the like for example has thereon a soft magnetic backing layer on which an underlayer for providing the perpendicular magnetic layer is provided. The underlayer has thereon a perpendicular magnetic layer and a protection layer. As a perpendicular magnetic layer, many perpendicular magnetic layers have been examined, including a perpendicular magnetic layer consisting of a Co-base alloy (e.g., CoCr, CoCrTa, CoCrPt); a multilayer lamination perpendicular magnetic layer in which a Co layer and a Pt layer or a Co layer and a Pd layer are alternately laminated (hereinafter simply referred to as Co/Pt, Co/Pd or the like); an amorphous perpendicular magnetic layer (e.g., TbCo, TbFeCo); and, recently, a perpendicular magnetic layer including an oxide (e.g., CoPtCrO, CoPtCr-SiO₂) (see Japanese Patent Laid-Open Publication No. 2003-178413 for example). When a perpendicular magnetic layer includes oxide, a non-magnetic substance (oxide) is segregated at the magnetic crystal grain boundary to provide a superior perpendicular magnetic recording medium that has a small magnetic crystal grain diameter and that has a small magnetic exchange interaction among magnetic crystal grains.

Co/Pt or Co/Pd in particular has been actively researched as a future high recording density medium because it has a high perpendicular magnetic anisotropy constant (K_u) and thus has a high thermal stability, a high coercivity, a squareness ratio 1.0 is easily obtainable (see Japanese Patent Application No. 2003-206091 for example). On the other hand, a magnetic recording head for writing information to a magnetic recording medium has limitation on the magnetic field that may be generated due to the writing process and thus has difficulty in the writing when the magnetic recording medium has a high anisotropic magnetic field (H_k). For a conventional

magnetic recording medium, the increase in Ku causes the increase in Hk, thus making it difficult to provide both thermal stability and ease of writing by the recording head.

Problem to be Solved by the Invention

The present invention has been made in view of the problems described above, and one object of the present invention to provide a method for producing a magnetic recording medium that provides both of a high Ku and low Hk. It is a further object of the present invention to provide a method for producing a magnetic recording medium by which the noise of a magnetic recording medium is reduced and the thermal stability of a recorded magnetization is improved, while also enabling easy writing by a recording head.

Means for Solving the Problem

In order to achieve the objective as described above, the present invention provides a method for producing a perpendicular magnetic recording medium, characterized in comprising: an underlayer formation step for forming on a non-magnetic substrate a non-magnetic underlayer having a hexagonal close-packed crystal structure; and a magnetic layer formation step for providing a alternately laminated multilayer of a Co layer as a first magnetic layer and a Pt layer or a Pd layer as a second magnetic layer directly above the underlayer, wherein the underlayer is formed with a deposition rate equal to or lower than 0.7nm/second.

The underlayer formation step is preferably a sputter method.

At least one of the first and second magnetic layers is preferably added with Si oxide. More preferably, SiO₂ is used. Si oxide is preferably added in an amount equal to or higher than 1mol% and equal to or lower than 10mol%.

The underlayer preferably consists of Ru.

Utilizing the structure as described above, the improvement of the thermal stability of a recorded magnetization and easy writing by a recording head can be both provided. The reason will be described hereinafter.

In order to improve the thermal stability of the magnetization recorded in a perpendicular magnetic recording medium, a perpendicular magnetic anisotropy constant (Ku) is desirably higher. Specifically, when assuming that the volume of a magnetic grain is V, the magnetization recorded in the

magnetic recording medium has a magnetic anisotropic energy represented by K_uV . Taking the Boltzmann constant as k and the absolute temperature as T , the surrounding environment has a heat energy represented by kT and the thermal stability of the recorded magnetization is represented by K_uV/kT . Thus, to improve the thermal stability requires an increase in K_u .

However, to increase K_u generally causes an increase in H_c and/or H_k , thus making it difficult for the recording head to perform writing to the magnetic recording medium.

On the other hand, K_u is given by $K_u = K_{u1} + K_{u2}$. In this formula, K_{u1} and K_{u2} represent uniaxial anisotropy constants. A magnetic field required for providing the inversion of magnetization when a magnetic recording medium is recorded (switching magnetic field) is H_k . When saturation magnetization is assumed as M_s , $H_k = 2K_{u1}/M_s$ is given. Thus, the smaller K_{u1} is, the smaller H_k is, thus providing easier writing to the magnetic recording medium.

As described above, in order to provide a superior read-write characteristic, K_{u1} must be reduced. In order to improve the thermal stability of a recorded magnetization, K_u must be increased, and this can be done by increasing the K_{u2}/K_{u1} ratio, since $K_u = K_{u1} + K_{u2}$.

As described above, in order to provide a superior read-write characteristic and to improve the thermal stability of a recorded magnetization, the present invention uses a multilayer lamination film (e.g., Co/Pt) as a magnetic layer to obtain a high K_u and controls the crystal structure and deposition rate of an underlayer provided immediately beneath the magnetic layer, thereby realizing a magnetic recording medium having a high K_{u2}/K_{u1} ratio.

It is preferable to further provide between the underlayer formation step and the magnetic layer formation step a step for subjecting the surface of the underlayer to Ar gas being mixed with oxygen of a mass/flow rate ratio of 1% to 10% and having a gas pressure of 0.1 to 10Pa for 1 to 10 seconds. By providing this step, the surface of the underlayer of a hexagonal close-packed crystal structure (hcp) can absorb oxygen and the slope of a magnetization curve in the vicinity of H_c can be made to be gentle so that the magnetic interaction among grains of the perpendicular magnetic layer can be reduced, thus achieving the objective of the present invention more effectively.

It is also preferable that, in order to provide the crystals of the underlayer having C axis orientation perpendicular to the substrate face, the non-magnetic substrate and the underlayer further have therebetween an

orientation control layer.

The orientation control layer is provided by layering the first orientation control layer and the second orientation control layer. The first orientation control layer is preferably a Ta layer and the second orientation control layer is preferably any one of a NiFeNbB layer, a NiFeCr layer, and a NiFeSi layer.

It is preferable that the non-magnetic substrate and the orientation control layer further have therebetween a soft magnetic backing layer.

Brief Description of the Drawings

Fig. 1 is a schematic view for explaining an example of the structure of the perpendicular magnetic recording medium according to the present invention.

Fig. 2 shows the M-H curve of the perpendicular magnetic recording medium of Embodiment 1.

Fig. 3 illustrates the relation between the deposition rate of the underlayer and K_{u2}/K_{u1} ratio.

Best Mode for Carrying out the Invention

Hereinafter, an embodiment of the present invention will be described with reference to the drawings.

Fig. 1 is a schematic view for explaining an exemplary structure of a perpendicular magnetic recording medium using the production method of the present invention. In Fig. 1, the non-magnetic substrate 1 has thereon a lamination structure of a soft magnetic backing layer 2, orientation control layer 3, underlayer 4, magnetic layer 5, and protection layer 6 that are provided in this order. The protection layer 6 has thereon a lubricant layer 7. The orientation control layer 3 is provided by the first orientation control layer 31 and the second orientation control layer 32. The magnetic layer 5 has a structure in which the first magnetic layer 51 and the second magnetic layer 52 are alternately layered to provide a multilayer lamination.

The part from the soft magnetic backing layer 2 to the protection layer 6 is provided by a film formation method such as a sputter method (e.g., DC magnetron sputtering, RF magnetron sputtering), vapor deposition, CVD, or

plating. The respective layers may be provided by different film formation methods depending on the function required for the respective layers, but are preferably subjected, from the viewpoint of productivity, to a continuous film formation using the same film formation method.

The underlayer 4 is a layer provided just under the magnetic layer 5 and is provided in order to favorably control the crystal orientation, crystal grain diameter, and grain boundary segregation of the magnetic layer.

With regards to materials for the underlayer 4, a metal or an alloy having a hexagonal close-packed crystal structure (hcp) can be used to provide the axis c of the magnetic layer 5 to be perpendicular to the substrate face. Preferable materials having this hcp structure include Ti, Re, Ru, Os, Zr, Zn, and Tc or an alloy thereof. A particularly preferred material is Ru because it has a small reactivity to oxygen included in the non-magnetic grain boundary element of the first magnetic layer 51 (which will be described later) and thus it prevents from disturbing the crystal orientation of Co which is a main element of the ferromagnetic crystal grains of the first magnetic layer 51.

Film formation methods for the underlayer 4 include: a sputter method (e.g., DC magnetron sputtering, RF magnetron sputtering), vapor deposition or CVD. The sputter method is preferably used in order to preferably control the crystalline characteristic and the deposition rate of the underlayer.

By providing the deposition rate of the underlayer 4 to be equal to or lower than 0.7nm/second, a preferable underlayer can be formed to increase Ku_2 of the magnetic layer 5. When Ku_2 is increased, Ku of the magnetic layer can be maintained to be high while reducing H_k to provide both thermal stability of the magnetic recording medium and an easy writing by a recording head. Although a lower deposition rate of the underlayer can provide the effect by the increase of Ku_2 more effectively, the deposition rate is preferably equal to or higher than 0.3 nm/second from the viewpoint of productivity.

The film thickness of the underlayer 4 is not particularly limited. However, from the viewpoints of improvement in the read-write resolution and productivity, a minimal film thickness required for controlling the crystal structure of the first magnetic layer 51 is preferable, this film thickness preferably being equal to or higher than 3 nm and equal to or lower than 20 nm. This range will enable sufficient crystal growth in the underlayer 4.

When the surface of the underlayer 4 is subjected to an oxygen adsorption processing to subsequently form the magnetic layer 5, the magnetic characteristic of the magnetic layer 5 can be further increased. Specifically,

when the surface of the underlayer 4 is subjected to an oxygen adsorption, an advantage is provided in which the magnetic interaction among magnetic grains of the magnetic layer 5 provided on this underlayer 4 is suppressed and the slope α of the magnetization curve in the vicinity of H_c (also referred to as " α " in the present specification) is gentle, which provides easy read-write operation. The oxygen adsorption to the underlayer 4 is performed by subjecting, after the formation of the underlayer 4, the surface to Ar gas being mixed with oxygen of a mass/flow rate ratio of 1% to 10% and gas pressure of 0.1 to 10 Pa for 1 to 10 seconds. The above-mentioned α is an indicator representing the magnitude of the magnetic interaction among magnetic grains constituting the magnetic layer 5. When α is small, it shows that the medium noise is reduced, because the magnetic interaction among magnetic grains is reduced.

The non-magnetic substrate 1 can be made of an Al alloy provided with a NiP plating, glass, reinforced glass, or crystallized glass or the like which are used for a normal magnetic recording medium. When the temperature for heating a substrate is kept below 100°C, a plastic substrate consisting of a resin (e.g., polycarbonate, polyolefin) can be used.

The soft magnetic backing layer 2 is a layer that is preferably formed in order to control the magnetic flux from a magnetic head used for a magnetic recording, to improve the read-write characteristics, but this layer can be omitted. The soft magnetic backing layer can be provided by a crystalline NiFe alloy, SENDUST (FeSiAl) alloy, CoFe alloy or the like, FeTaC, CoTaZr, CoFeNi, CoNiP or the like having a microcrystalline characteristic, for example. However, an amorphous Co alloy (e.g., CoNbZr, CoTaZr) can be used to provide an improved electromagnetic conversion characteristic. The optimal film thickness of the soft magnetic backing layer 2 depends on the structure and characteristics of the magnetic recording head. However, when the soft magnetic backing layer 2 is subjected to a continuous film formation with other layers, the film thickness of the soft magnetic backing layer 2 is preferably equal to or higher than 10 nm and equal to or lower than 500 nm, in consideration of productivity. The film thickness of the soft magnetic backing layer 2 also can be increased to a few μm when a plating method or the like is used prior to the film formation of other layers to previously form the soft magnetic backing layer 2 on a non-magnetic substrate.

The orientation control layer 3 is a layer that is preferably formed in order to control the crystal orientation, crystal grain diameter or the like of the underlayer 4 and is more preferably formed by a plurality of layers. This orientation control layer may also be omitted.

The orientation control layer 3 can be provided by a non-magnetic material

or a soft magnetic material. When the soft magnetic backing layer 2 is formed under the orientation control layer, such a soft magnetic material is more preferably used that can function as a part of the soft magnetic backing layer.

Materials for the orientation control layer 3 showing a soft magnetic characteristic include a Ni-base alloy (e.g., NiFe, NiFeNb, NiFeB, NiFeCr) and a Co-base alloy (e.g., Co or CoB, CoSi, CoNi, CoFe). The above materials may also be layered to provide a plurality of layers in order to separately provide a function for securing the consistency in crystal lattice and a function for controlling the crystal grain diameter.

When Ru is used for the underlayer 4, in order to preferably control Ru in the hcp crystal structure, the second orientation control layer 32 preferably uses an alloy including Ni as a main element. An NiFe-base material (e.g., NiFeNbB alloy, NiFeCr alloy or NiFeSi alloy) is particularly preferable because the crystal orientation of Ru can be provided in the axis c to be perpendicular to the substrate face and the crystal orientation of the perpendicular magnetic layer above the underlayer can be provided in the axis c to be perpendicular to the substrate face. The composition of NiFeCr alloy is provided such that Fe is 10 to 20at%, Cr is 20 to 30at%, and the remainder is Ni in a range which enables the best read-write characteristic. The composition of NiFeNbB alloy comprises Fe at 10 to 20at%, Nb at 2 to 10at%, B at 2 to 6 at%, and the remainder Ni, which is in a range by which the best read-write characteristic is provided in the composition showing the soft magnetic characteristic. The composition of NiFeSi alloy comprises Fe at 10 to 20at%, Si at 2 to 10at%, and the remainder Ni, which is a range showing a soft magnetic characteristic by which the best read-write characteristic is provided. NiFeCr having the above composition is non-magnetic but NiFeNbB and NiFeSi are soft magnetic and an effect for improving the recording status by increasing the thickness of the soft magnetic film can be simultaneously provided, which is further preferable.

When the second orientation control layer 32 has a film thickness equal to or lower than 5 nm, the crystal orientation of the underlayer 4 cannot be controlled and a film thickness exceeding 30 nm causes an excessively high H_c , which prevents a currently-available head from providing saturation recording, causing an inconvenience in the recording.

Furthermore, when an alloy having Ni as a main element is used for the second orientation control layer 32, the first orientation control layer 31 is preferably further provided. In this case, a layer consisting of Ta is particularly preferable as the first orientation control layer 31 so that the first orientation control layer 31 can cooperate with the second orientation control layer 32 having Ni as a main element, which preferably controls the

crystal structure of the underlayer 4 as an hcp structure. When the Ta layer 31 has a film thickness lower than 1 nm, the NiFe layer has a deteriorated crystal orientation thus the crystal orientation of the underlayer 4 cannot be controlled. When the thickness is greater than 5 nm, the distance between the magnetic layer 5 and the soft magnetic backing layer 2 is increased, which also deteriorates the read-write characteristic.

Due to the above reasons, the Ta layer as the first orientation control layer 31 preferably has a film thickness of 1 to 5nm, while the NiFeCr layer, NiFeNbB layer or NiFeSi layer as the second orientation control layer 32 preferably has a film thickness of 5 to 30 nm.

This orientation control layer 31 is not always required to have a multilayer structure consisting of a plurality of layers, and may be an orientation control layer having a single layer if desired.

The magnetic layer 5 is basically provided as a multilayer lamination film which is obtained by providing the Co layer as the first magnetic layer 51 and the Pt layer or Pd layer as the second magnetic layer 52 to provide a multiplelayer lamination. Both or either one of the first magnetic layer 51 and the second magnetic layer 52 is preferably added with Si oxide.

The reason why the multilayer lamination film of Co/Pt or Co/Pd is used for the magnetic layer 5 is that Hc is increased as compared to a magnetic layer such as a Co-Cr alloy, the squareness ratio easily becomes 1, and the interface magnetic anisotropic characteristic can be used to provide a high Ku. The purpose of adding Si oxide to both or any one of Co layer and Pt layer or Co layer and Pd layer for constituting these multilayer lamination films is to further improve Hc of the medium and to improve the read-write characteristic. Specifically, the addition of Si oxide allows the grain boundary of the ferromagnetic crystal grains constituting the respective layers of Co layer, Pt layer, and Pd layer to have the segregation of non-magnetic Si oxide, thus causing the respective ferromagnetic crystal grains to be minute and isolated, and reducing the interaction among the crystal grains. By doing this, Hc can be increased as compared to a magnetic layer such as Co/Pt that is not added with Si oxide to provide a higher recording density. In the following section, when the addition of Si oxide to Co layer, Pt layer, and Pd layer is specifically described, the addition will be described as Co-SiO₂ layer, Co-SiO_x layer, Pt-SiO_x layer, and Pd-SiO_x layer, for example.

The composition of Si oxide added to the magnetic layer 5 has SiO_x (0<x=2) but preferably is SiO₂. The addition amount of Si oxide preferably is within the range of 2 to 10mol% in the case of a Co-SiO_x layer, 1 to 8mol% in the case of a Pt-SiO_x layer, and 2 to 8mol% in the case of a Pd-SiO_x layer. This is

because the addition amount of Si oxide lower than this causes an insufficient segregation of Si oxide to the crystal grain boundary, while a Si oxide amount higher than this causes Hc to be excessively reduced on the contrary.

The respective layers for constituting the magnetic layer 5 can have various thicknesses, according to the magnetic characteristics desired. However, for example, the Co layer or the Co-SiO_x layer has a film thickness of 0.2 to 0.8 nm, the Pt layer or Pt-SiO_x layer has a film thickness of 0.05 to 1.2 nm, and the Pd layer or Pd-SiO_x layer has a film thickness of 0.5 to 1.5 nm. Preferably, the Co layer or the Co-SiO_x layer has a film thickness of 0.2 to 0.5 nm, the Pt layer or Pt-SiO_x layer has a film thickness of 0.05 to 0.4 nm, and the Pd layer or Pd-SiO_x layer has a film thickness of 0.5 to 1 nm.

The magnetic layer 5 is preferably formed by the sputtering method using as a sputter gas a gas including Ar as an element. The sputter gas may be pure Ar gas, a mixed gas of Kr and Ar, a mixed gas of Xe and Ar, for example. Such sputter gas may be added with oxygen gas in the range of mass/flow rate ratio from 0.05 to 0.5%.

The protection layer 6 may be provided by a conventionally used protection film and may use, for example, a protection film mainly including carbon. The lubricant layer 7 also may be provided by a conventionally used material and may use, for example, a perfluoropolyether liquid lubricant. With regards to the conditions such as the film thickness of the protection layer 6 and the film thickness of the lubricant layer 7, conditions used for a normal magnetic recording medium can be directly used.

Embodiment 1

In this embodiment, an example of an effect of the deposition rate of the underlayer to the ratio of K_{u2}/K_{u1} will be described.

A perpendicular magnetic recording medium of this embodiment has a structure shown in Fig. 1 and is provided by laminating the glass substrate 1, the CoZrNb soft magnetic backing layer 2, the Ta first orientation control layer 31, the NiFeNbB second orientation control layer 32, the Ru underlayer 4, the magnetic layer 5 consisting of Co-SiO and Pt, the carbon protection layer 6, and the perfluoropolyether lubricant layer 7 in this order.

The glass substrate has a diameter of 2.5 inches and thickness of 0.635 mm. The substrate was cleaned well to be subsequently attached to a film formation apparatus and the following film formation of the respective layers was performed. In this film formation method, the film layers from

the soft magnetic backing layer to the protection layer were prepared by the DC magnetron sputter method.

First, CoZrNb was formed as the soft magnetic backing layer 2. The used target was $\text{Co}_{87}\text{Zr}_5\text{Nb}_8$ (the subindexes hereinafter show atomic %). Ar gas was used to perform sputtering with the gas pressure of 1 Pa to form the film having the film thickness of 200 nm. The film formation temperature was room temperature. CoZrNb has a sufficient soft magnetic characteristic even in the amorphous status when the film formation was performed at room temperature. The Ta layer 31 is continuously formed on the CoZrNb soft magnetic film. The used target is pure Ta. Sputtering was performed in Ar gas to form a film having a film thickness of 3 nm. The film formation was performed at room temperature and the gas pressure was 1 Pa. The NiFeNbB layer 32 is continuously formed on the Ta layer. The target used had a composition of $\text{Ni}_{79}\text{Fe}_{12}\text{Nb}_3\text{B}_6$. Sputtering was performed in Ar gas to form a film having a film thickness of 25 nm. The film formation was performed at room temperature and the gas pressure was 1 Pa. The Ta layer 31 and NiFeNbB layer 32 are both used for providing the hcp crystal structure to the Ru underlayer to be formed next.

Next, the Ru layer 4 as a underlayer 4 is formed. The used target is pure Ru. Sputtering was performed in Ar gas to form a film having a film thickness of 7 nm. The film formation was conducted at room temperature and the gas pressure is 4 Pa. The film formation was performed while changing the deposition rate from 0.3 nm/second to 1 nm/second. For comparison, the deposition rate is varied over a wide range. The formed Ru layer showed a hcp crystal structure. Next, the Ru underlayer was subjected to a mixed gas consisting of Ar and oxygen, at a mass/flow rate ratio of 2% and gas pressure of 1 Pa for 10 seconds. As a result, the Ru surface absorbs an appropriate amount of oxygen. This oxygen adsorption allows the slope of the magnetization curve in the vicinity of H_c to be gentle. This shows that the magnetic exchange interaction among grains is reduced, thus the recording characteristic can be improved. Absorption of oxygen by the Ru surface has an effect as described above.

On the Ru underlayer 4, the magnetic layer 5 is formed by the Co-SiO₂/Pt multilayer lamination film. Two types of targets are used in which one target has a composition of 94mol% Co - 6mol% SiO₂ and the other is pure Pt. Both of the targets are simultaneously subjected to an electric discharge while being rotated by sputtering to laminate the Co-SiO₂ layer and the Pt layer alternately. Sputtering was performed in Ar gas to form the Co layer having the film thickness of 0.5 nm and the Pt layer having the film thickness of 0.28 nm. The film formation was performed for 14 cycles (28 layers) to provide a magnetic layer of about 11 nm thickness. The film formation is performed at room temperature, and at a gas pressure of 5 Pa.

Next, the C-N film is formed as the protection layer 6. The target used is C. Ar gas mixed with nitrogen gas having a mass/flow rate ratio of 4% was used to perform sputtering to form a film of 7 nm thickness. The film formation is performed at room temperature, and the Ar gas pressure is 1 Pa.

Finally, the lubrication layer 7 consisting of perfluoropolyether is coated by a dip method, which completes a perpendicular magnetic recording medium.

Embodiment 2

In this embodiment, the amount of SiO₂ added to the Co-SiO₂ layer is altered. Embodiment 2 comprises a perpendicular magnetic recording medium as in Embodiment 1 except that, when the magnetic layer 5 is formed, one target has a composition of 91mol% Co - 9mol% SiO₂ and the other target is pure Pt.

Evaluation of the perpendicular magnetic recording media of Embodiments 1 and 2

Fig. 2 shows the M-H curve of the perpendicular magnetic recording medium prepared in Embodiment 1. The magnetic characteristic is that $H_c = 6.9$ kOe, $M_s = 410$ emu/cc, $S = 1.0$, $H_n = -3.4$ kOe, and $\alpha = 1.4$. S represents the squareness ratio and H_n represents a magnetic field in which the inversion of a magnetic domain is generated.

In this way, the perpendicular magnetic recording medium by the Co/Pt multilayer lamination can provide both of high H_c , H_n , and S , and low α .

Fig. 3 shows the result of evaluating the effect by the Ru deposition rate to the Ku_2/Ku_1 ratio when the perpendicular magnetic recording media prepared by Embodiments 1 and 2 are used.

The procedure as shown below was used to measure Ku , Ku_1 , and Ku_2 . Under the conditions in which the magnetization of the magnetic layer is almost saturated, a torque magnetometer was used to measure the magnetic torque curves under the applied magnetic field H in a range from 10 kOe to 25 kOe, and the magnetic torque curves to the respective magnetic fields H were subjected to Fourier analysis. Then, by using the relation in which the crystal magnetic anisotropic energy E of the magnetic film is approximated by $E = Ku_1 \sin^2 \theta + Ku_2 \sin^4 \theta$ (θ is an angle given by the spontaneous magnetization and the easy magnetization axis of the magnetic film), Ku and Ku_2 to the respective magnetic fields H were calculated. The

calculated K_u and K_{u2} for the respective magnetic fields H in this manner were plotted by the inverse number of the magnetic field ($1/H$) and were approximated in a straight line. Specifically, K_u was defined as such a value that is obtained by adding a value obtained by the extrapolation in the straight line to $1/H=0$ (i.e., intercept “y”) to $2\pi Ms^2$ (M_s represents saturation magnetization). K_{u2} was defined as such a value that is obtained by directly using a value by the extrapolation in the above straight line. Since $K_u = K_{u1} + K_{u2}$, K_{u1} was defined as a value obtained by $K_u - K_{u2}$.

The deposition rate was defined in the manner as described below. A time at which the electric discharge voltage for sputtering is applied in order to start the film formation of the underlayer was assumed as a start time, while a time at which the electric discharge voltage for sputtering was reduced in order to finish the film formation of the underlayer was assumed as a finish time. The time from the start time to the finish time is assumed as a film formation time (seconds). The thickness of the deposited underlayer was divided by the film formation time and a resultant value was assumed as a deposition rate.

As can be seen from Fig. 3, the lower the Ru deposition rate is, the higher the K_{u2}/K_{u1} ratio is, regardless of the amount of SiO_2 added to Co. A deposition rate equal to or lower than 0.7 nm/second causes a rapid increase in the K_{u2}/K_{u1} ratio. A deposition rate equal to or lower than 0.5nm/second in particular causes the K_{u2}/K_{u1} ratio to exceed 10% regardless of the amount of SiO_2 added to Co. If the deposition rate is too slow, the time required for the film formation of the underlayer is increased excessively to cause a problem from the viewpoint of productivity. Thus, in the case of the film thickness of the underlayer of the present invention, the underlayer is preferably deposited with a deposition rate equal to or higher than 0.3 nm/second.

Table 1 shows K_u , K_{u1} , K_{u2} , K_{u2}/K_{u1} , H_k , H_k (calculation) of the perpendicular magnetic recording medium of Embodiment 1. The term “ H_k (calculation)” is obtained by calculating the value of H_k when K_{u2} is assumed as 0. It indicates the effect of K_{u2} .

Table 1

Ru deposition rate	K_u (*10 ⁶ erg/cc)	K_{u1} (*10 ⁶ erg/cc)	K_{u2} (*10 ⁶ erg/cc)	K_{u2}/K_{u1} (%)	H_k (kOe)	H_k (calculation) (kOe)
1 nm/second	5.0	4.5	0.5	11.1	21.9	24.4
0.5 nm/second	5.5	4.8	0.7	14.5	21.1	23.9

When the deposition rate of the underlayer is 0.5 nm/second, K_u is significantly increased as compared to a deposition rate of 1.0 nm /second. However, K_{u2} is increased and thus H_k is reduced on the contrary. H_k (calculation), calculated on the assumption that K_{u2} is 0, is 23.9 kOe, which makes the saturation recording by a head difficult, but actually, H_k can be substantially reduced because K_{u2} is greater than 0.

Table 2 shows the overwrite (OW) characteristic and the signal/noise ratio (SNR) of the same perpendicular magnetic recording medium.

Table 2

Deposition rate	OW1	OW2	SNR (470 kFCI)
1 nm/second	44.3dB	46.4dB	24.7dB
0.5 nm/second	40.8dB	42.9dB	25.8dB

When the deposition rate of the underlayer is 0.5 nm/second, SNR was increased by about 1 dB when compared to the case of a deposition rate of 1.0 nm /second. The OW characteristics are both equal to or higher than 40 dB, thus are of a level causing no problems in practical use. The evaluation of the OW characteristic was performed such that, with regards to the perpendicular magnetic recording medium, the OW characteristic when a high linear recording density is written to a low linear recording density is assumed as OW1 and a signal written with a low linear recording density is overwritten with a high linear recording density so that the ratio between the firstly written signal of the low linear recording density and the residual signal having the low linear recording density after the overwrite is calculated. With regards to the recording densities used, the low linear recording density is 53.5 kFCI (12 T) and the high linear recording density is 642 kFCI (1 T). The OW characteristic in the case where the low linear recording density is written to the high linear recording density (which is referred to as OW2) was obtained as in the case of OW1 in which the ratio between the firstly written signal of the high linear recording density and the residual signal having the high linear recording density after the overwrite is calculated. With regards to the recording densities used, the high linear recording density is 321 kFCI (2 T) and the low linear recording density is 42.8 kFCI (15 T).

Advantageous Effect of the Invention

According to the present invention, a multilayer lamination film (e.g., Co/Pt) is used to provide a high Ku, the underlayer has an hcp crystal structure, and the deposition rate is equal to or lower than 0.7nm/second. Thus, both of a high Ku and a low Hk can be compatible to provide a perpendicular magnetic recording medium having both high thermal stability and which can be easily written to.

Claims

1. A method for producing a perpendicular magnetic recording medium, characterized in comprising:
an underlayer formation step for forming on a non-magnetic substrate a non-magnetic underlayer having a hexagonal close-packed crystal structure; and
a magnetic layer formation step for providing an alternately laminated multilayer of a Co layer as a first magnetic layer and a Pt layer or a Pd layer as a second magnetic layer directly above the underlayer,
wherein the underlayer is formed at a deposition rate equal to or lower than 0.7nm/second.
2. A method for producing a perpendicular magnetic recording medium according to claim 1, characterized in that the underlayer formation step uses a sputter method.
3. A method for producing a perpendicular magnetic recording medium according to any of claim 1 or 2, characterized in that at least one of the first magnetic layer and the second magnetic layer is added with Si oxide.
4. A method for producing a perpendicular magnetic recording medium according to claim 3, characterized in that the method for adding Si oxide is a sputter method using a target added with Si oxide.
5. A method for producing a perpendicular magnetic recording medium according to any of claim 3 or 4, characterized in that the Si oxide is SiO₂.
6. A method for producing a perpendicular magnetic recording medium according to any of claims 3 to 5, characterized in that the Si oxide is added in an amount equal to or higher than 1mol% and equal to or lower than 10mol%.
7. A method for producing a perpendicular magnetic recording medium according to any of claims 1 to 6, characterized in that the underlayer consists of Ru.
8. A method for producing a perpendicular magnetic recording medium according to any of claims 1 to 7, characterized in that the method further comprises a step, between the underlayer formation step and the magnetic layer formation step, for subjecting the surface of the underlayer to Ar gas mixed with oxygen of the mass/flow rate ratio of 1% to 10% under the gas pressure of 0.1 to 10 Pa for 1 to 10 seconds.

9. A method for producing a perpendicular magnetic recording medium according to any of claims 1 to 8, characterized in that the non-magnetic substrate and the underlayer further include therebetween an orientation control layer.

10. A method for producing a perpendicular magnetic recording medium according to claim 9, characterized in that the orientation control layer is provided by laminating the first orientation control layer and the second orientation control layer, the first orientation control layer is a Ta layer, the second orientation control layer is any of a NiFeNbB layer, a NiFeCr layer, and a NiFeSi layer.

11. A method for producing a perpendicular magnetic recording medium according to either claim 9 or 10, characterized in that the non-magnetic substrate and the orientation control layer further include therebetween a soft magnetic backing layer.