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**PERPENDICULAR MAGNETIC RECORDING MEDIUM
AND FABRICATION METHOD THEREOF**



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Technical Field of the Invention

The present invention relates to a perpendicular magnetic recording medium that may be installed in a variety of magnetic recording devices, and to a fabrication method thereof.

Prior Art

As capacities of magnetic disk recording devices have become larger, the demand for high recording densities of magnetic recording media has increased. In conventional magnetic recording methods, longitudinal magnetic recording methods predominate, but, recently, perpendicular magnetic recording methods have been attracting attention as a technique for realizing a high recording density for magnetic recording.

A perpendicular magnetic recording medium has, as constituent elements, a magnetic recording layer of hard magnetic material, and a under layer formed from a soft magnetic material which fulfils the role of concentrating the magnetic flux produced by a magnetic head employed for

recording to the magnetic recording layer. Currently, a CoCr alloy crystalline film is principally used as the material used for the magnetic recording layer of the perpendicular magnetic recording medium. Tests involving the refinement of CoCr crystal grains, a reduction in the particle size distribution, and intergranular interactive control, and the like, have been performed for increasingly higher densities going forward.

On the other hand, a rare earth-transition metal alloy noncrystalline film, which is employed as a material for magneto-optical recording, has a large perpendicular magnetic anisotropy constant K_u , and exhibits highly superior thermal stability, and is therefore extremely promising as a magnetic recording layer material of a perpendicular magnetic recording medium.

Problems to be Solved by the Invention

In the case of the CoCr alloy crystalline magnetic recording material which is mainly employed at present, a columnar structure, which is constituted by growing crystal grains in a film thickness direction, is provided, and this represents one principal cause of medium-produced noise which is generated during recording process. As

subsequent recording is afforded a higher density, the effect exerted by grain boundaries on recording signals is becoming increasingly prevalent. In this regard, tests are also now being conducted which seek to reduce the effect of grain boundaries by means of the refinement of crystal grain size and other means. However, when the crystal grain size becomes too small, the thermal stability of recorded signals deteriorates radically, and, depending on the case, a so-called thermal agitation problem is generated such that recorded signals are lost.

On the other hand, when a rare earth-transition metal alloy noncrystalline film is employed, no such grain boundaries are present due to the noncrystalline nature [of the film], and the above problems are not produced. However, conversely, since no grain boundaries are present, no nucleus or such serving to stop the written signals in locations thereof is present, and signals are sometimes shifted or lost. In particular, this phenomenon is easily generated during high-frequency recording, meaning that this film is hardly preferable as a material for a perpendicular magnetic recording medium that aims at a high recording density.

It is therefore an object of the present invention to

provide a perpendicular magnetic recording medium, which exhibits favorable electromagnetic conversion characteristics even at a high recording density, and which has highly superior thermal stability and superior productivity, and to provide a fabrication method thereof.

Means for Solving the Problems

The problems mentioned hereinabove can be resolved by the perpendicular magnetic recording medium and fabrication method thereof of the present invention illustrated hereinbelow.

A first [invention] of the present invention relates to a perpendicular magnetic recording medium, a first aspect thereof being a perpendicular magnetic recording medium, which is constituted by sequentially stacking, on a nonmagnetic substrate, at least a soft magnetic under layer, an intermediate layer, a bilayer magnetic recording layer, a protective layer, and a liquid lubricant layer, characterized in that the first layer of the bilayer magnetic recording layer is a magnetic layer composed from a CoCr alloy crystalline film, and the second layer thereof is a magnetic layer composed from a rare earth-transition metal alloy

noncrystalline film, the CoCr alloy crystalline film having a film thickness of 10nm or more and no more than 30 nm, and the rare earth-transition metal alloy noncrystalline film having a film thickness of 2 nm or more and no more than 15 nm, and in that, when the film thickness of the CoCr alloy crystalline film is a, and the film thickness of the rare earth-transition metal alloy noncrystalline film is b, the film thickness ratio a/b is equal to or more than 2.

Similarly, the second aspect of the present invention is a perpendicular magnetic recording medium, a first aspect thereof being a perpendicular magnetic recording medium, which is constituted by sequentially stacking, on a nonmagnetic substrate, at least an orientation control layer, a magnetic domain control layer, a soft magnetic under layer, an intermediate layer, a bilayer magnetic recording layer, a protective layer, and a liquid lubricant layer, characterized in that the first layer of the bilayer magnetic recording layer is a magnetic layer composed from a CoCr alloy crystalline film, and the second layer thereof is a magnetic layer composed from a rare earth-transition metal alloy noncrystalline film, the CoCr alloy crystalline film having a film thickness of 10nm or more and no more than 30 nm, and the rare earth-transition metal alloy noncrystalline film

having a film thickness of 2 nm or more and no more than 15 nm, and in that, when the film thickness of the CoCr alloy crystalline film is a, and the film thickness of the rare earth-transition metal alloy noncrystalline film is b, the film thickness ratio a/b is equal to or more than 2.

Furthermore, the rare earth-transition alloy noncrystalline material of the magnetic recording medium of the present invention contains at least from 10 atom percent to 35 atom percent of at least one or more elements from among Pr, Nd, Gd, Tb, Dy, Ho, the remainder containing at least one or more transition metals from among Ni, Fe, Co.

A second [invention] of the present invention relates to a fabrication method for the magnetic recording medium of the above first and second aspects.

Specifically, a fabrication method for the perpendicular magnetic recording medium of the first aspect is a fabrication method comprising the steps of depositing, on a nonmagnetic substrate, a soft magnetic under layer, an intermediate layer, a magnetic layer composed from a CoCr alloy crystalline film which is a first layer of the bilayer magnetic recording layer, a rare earth-transition metal alloy

noncrystalline film which is a second layer of the bilayer magnetic recording layer, a protective layer, and a liquid lubricant layer, characterized in that, more particularly, the gas pressure employed during the deposition of the rare earth-transition metal alloy noncrystalline film is 10 mTorr or more and no more than 200 mTorr, and is preferably 20 mTorr or more and no more than 100 mTorr.

Furthermore, a fabrication method for the perpendicular magnetic recording medium of the second aspect is a fabrication method comprising the steps of depositing, on a nonmagnetic substrate, an orientation control layer, a magnetic domain control layer, a soft magnetic underlayer, an intermediate layer, a magnetic layer composed from a CoCr alloy crystalline film which is a first layer of the bilayer magnetic recording layer, a rare earth-transition metal alloy noncrystalline film which is a second layer of the bilayer magnetic recording layer, a protective layer, and a liquid lubricant layer, characterized in that the gas pressure employed during the deposition of the rare earth-transition metal alloy noncrystalline film is 10 mTorr or more and no more than 200 mTorr, and is preferably 20 mTorr or more and no more than 100 mTorr.

The present invention includes a perpendicular magnetic recording medium that is fabricated using a fabrication method relating to the above second invention.

Brief Description of the Drawings

Fig. 1 is a cross-sectional schematic diagram showing the constitution of the magnetic recording medium according to Example 1 of the present invention;

Fig. 2 is a cross-sectional schematic diagram showing the constitution of the magnetic recording medium according to Example 2 of the present invention;

Fig. 3 is a graph which serves to illustrate the Examples of the present invention, and which shows values of the coercive force when the concentration of the rare earth elements is varied, where the material of the rare earth-transition metal alloy noncrystalline film of the perpendicular recording medium fabricated in the Examples is taken to be TbCo, PrCo, DyFeCo, NdFeNi, HoFe, GdCoNi, TbGdCo; and

Fig. 4 is a graph which serves to illustrate the Examples of the present invention, and which shows SNR values when the gas pressure during the deposition of the rare earth-transition metal alloy noncrystalline film is varied,

where the material during the deposition of the rare earth-transition metal alloy noncrystalline film is taken to be TbCo, PrCo, DyFeCo, NdFeNi, HoFe, GdCoNi, TbGdCo.

Embodiments of the Invention

The embodiments of the present invention will be described hereinbelow.

The first [invention] of the present invention relates to a perpendicular magnetic recording medium. A description will be provided hereinbelow for a first aspect and a second aspect of the magnetic recording medium of the present invention with reference to Fig. 1 and Fig. 2. Figs. 1 and 2 serve to illustrate examples of the present invention, and the present invention is not limited to or by these figures.

Fig. 1 is a cross-sectional schematic diagram showing the constitution of a perpendicular magnetic recording medium which is a first aspect of the first invention. This perpendicular magnetic recording medium has a structure in which a soft magnetic under layer 4, an intermediate layer 5, a bilayer magnetic recording layer 6, and a protective layer 7 are deposited sequentially on a nonmagnetic substrate 1, and a liquid lubricant layer 8 is further deposited thereon.

In the present invention, an NiP-plated Al alloy, chemical strengthened glass or crystallized glass, for example, which are used for ordinary magnetic recording media, can be used for the nonmagnetic substrate 1.

A noncrystalline Co alloy, an NiFe alloy, a Sendust (FeSiAl) alloy, or similar, can be used for the soft magnetic under layer 4. More particularly, favorable electromagnetic conversion characteristics can be obtained by using a noncrystalline Co alloy, for example CoNbZr, CoTaZr, or similar. The film thickness of the soft magnetic under layer 4 is modified to an optimum value depending on the structure and characteristics of the magnetic head used for recording. In view of productivity, the soft magnetic under layer 4 desirably has a film thickness of 10 nm or more and no more than 300 nm.

In the present invention, the intermediate layer 5 is used to magnetically isolate the soft magnetic under layer 4 and the bilayer magnetic recording layer 6, and also to control the properties of the CoCr alloy crystalline film which is the first layer of the bilayer magnetic recording layer 6. As the material of the intermediate layer 5, a nonmagnetic element such as Ti, Ru, or a nonmagnetic alloy such as TiCr, CoCr, may be

suitably employed. The intermediate layer 5 desirably has a film thickness of from 5 to 30 nm.

In the present invention, the bilayer magnetic recording layer 6 is provided as a magnetic recording layer. This bilayer magnetic recording layer has a bilayer structure comprising a first layer 9 and a second layer 10.

In the present invention, the first layer 9 is a magnetic layer of which a CoCr alloy crystalline [material] is the raw material, and the second layer 10 is a magnetic layer of which a rare earth-transition metal alloy noncrystalline [material] is the raw material. With the perpendicular magnetic recording medium of the present invention, examples of preferable materials which can be employed as the CoCr alloy crystalline film are CoCr alloys such as CoCr, CoCrTa, CoCrPt, CoCrPtTa, CoCrPtB.

The above-mentioned CoCr alloy crystalline film of the first layer desirably has a film thickness of 10nm or more and no more than 30 nm. This is because, with a film thickness of less than 10 nm, favorable magnetic characteristics are not obtained, and the SNR (ratio between the electromagnetic conversion characteristic signals and noise) drops, and, with

a film thickness of more than 30 nm, the increased film thickness results in a drop in the SNR as a result of a noise increase.

The film of the second layer composed from a rare earth-transition metal alloy noncrystalline [material] preferably contains at least 10 atom percent and no more than 35 atom percent of at least one or more elements from among at least Pr, Nd, Gd, Tb, Dy, Ho. The remainder of this second layer contains at least one or more transition metals from among Ni, Fe, Co. Tb alloys such as TbCo and TbFeCo are examples of materials which can be employed in the second layer.

The rare earth-transition metal alloy noncrystalline film preferably has a film thickness of 2 nm or more and no more than 15 nm. This is because, with a film thickness of less than 2 nm, the characteristics for the rare earth-transition metal noncrystalline film are not obtained, and, with a film thickness of more than 15 nm, the rare earth-transition metal noncrystalline film properties become too strong, and the SNR drops as a result of the production of fluctuations in the written signals.

In the present invention, in order to maintain the

favorable properties of the bilayer magnetic recording layer 6, there is the condition that the ratio between the film thickness of the CoCr alloy crystalline film of the first layer 9 of the bilayer magnetic recording layer 6, and the film thickness of the rare earth-transition metal alloy noncrystalline film of the second layer 10, should be constant.

The first and second layers are preferably formed such that, when the film thickness of the CoCr alloy crystalline film is a , and the film thickness of the rare earth-transition metal alloy noncrystalline film is b , the film thickness ratio a/b is equal to or more than 2. This is because, when the film thickness ratio a/b is smaller than 2, the rare earth-transition metal alloy noncrystalline film properties are then strong, and the SNR drops.

The protective layer 7 can be deposited using a material employed conventionally. For example, the protective layer 7 can be formed from a material of which the main constituent is carbon. As for the conditions for the film thickness or similar of the protective layer 7, all conditions used for ordinary magnetic recording media can be employed as is.

A material employed conventionally can also be used for the liquid lubricant layer 8. For example, perfluoropolyethyl lubricants can be used. As for the conditions for the film thickness or similar of the liquid lubricant layer 8, all conditions used for ordinary magnetic recording media can be employed as is.

Fig. 2 is a cross-sectional schematic diagram showing the constitution of the perpendicular magnetic recording medium that is the second aspect of the present invention. This magnetic recording medium has a structure in which an orientation control layer 2, a magnetic domain control layer 3, a soft magnetic under layer 4, an intermediate layer 5, a bilayer magnetic recording layer 6, and a protective layer 7 are deposited sequentially on a nonmagnetic substrate 1, and a liquid lubricant layer 8 is further deposited thereon.

A material like that for the perpendicular storage medium described in the above first aspect can be used for the nonmagnetic substrate 1.

For the magnetic domain control layer 3, an antiferromagnetic film, such as PtMn, IrMn or similar composed from an alloy containing Mn, or a hard magnetic film of CoCrTa, CoCrPt, CoCrPtB or similar in which

magnetization is oriented in a radial direction of the nonmagnetic substrate 1, can be employed. The magnetic domain control layer 3 preferably has a film thickness on the order of 5 to 300 nm.

For the orientation control layer 2, in cases where an Mn alloy antiferromagnetic film is used for the magnetic domain control layer 3, a nonmagnetic pure metal such as Cu, Ir, which has a face-centered cubic structure, or a nonmagnetic alloy or similar such as NiFeCr, are desirably used. In such a case, a primary coat of Ta, Zr, Nb, or similar, which has a film thickness of 3 nm to 30 nm, and preferably 5 to 10 nm, may be provided between the nonmagnetic substrate 1 and the orientation control layer 2, in order to control the fine structure of the orientation control layer 2. Further, in cases where a hard magnetic film is used as the magnetic domain control layer 3, a Cr alloy such as CrMo, CrW, or similar, can be used for the orientation control layer 2. In this case also, a primary coat governed by the condition of being like that described above which serves to control the fine structure of the orientation control layer 2 may be provided between the nonmagnetic substrate 1 and the orientation control layer 2. The orientation control layer 2 preferably has a film thickness of 3 nm to 30 nm.

The same materials as for the perpendicular storage medium described in the above first aspect can be employed for the soft magnetic under layer 4, the intermediate layer 5, the bilayer magnetic recording layer 6, the protective layer 7 and the liquid lubricant layer 8.

Next, a description will be provided for a fabrication method for the perpendicular magnetic recording medium of the first invention above, which method relates to a second invention.

A fabrication method for the perpendicular magnetic recording medium relating to the first aspect of the first invention is described hereinbelow.

This perpendicular magnetic recording medium fabrication method comprises the steps of depositing, on a nonmagnetic substrate 1, a soft magnetic under layer 4, an intermediate layer 5, a first layer 9 of a bilayer magnetic recording layer 6, a second layer 10 of the bilayer magnetic recording layer 6, a protective layer 7, and a liquid lubricant layer 8.

The first step is a step of depositing a soft magnetic

under layer 4 on a nonmagnetic substrate 1. An NiP-plated Al alloy, chemical strengthened glass or crystallized glass, for example, which are used for ordinary magnetic recording media, can be used for the nonmagnetic substrate 1 used in this step. To permit the stacking of layers on the nonmagnetic substrate 1, the surface of the nonmagnetic substrate 1 is preferably smooth and free of impurities.

The step of depositing the soft magnetic under layer 4 on such a nonmagnetic substrate 1 is performed using a sputtering method or plating method. A noncrystalline Co alloy, an NiFe alloy, a Sendust (FeSiAl) alloy, or similar, can be used for the soft magnetic under layer 4. In particular, by using a noncrystalline Co alloy, for example, CoNbZr, CoTaZr, or similar, for example, it is possible to obtain favorable electromagnetic conversion characteristics. The film thickness of the soft magnetic under layer 4 is modified to an optimum value depending on the structure and characteristics of the magnetic head used for recording. However, in view of productivity, the soft magnetic under layer 4 desirably has a film thickness of 10 nm or more and no more than 300 nm.

Next, the second step is a step of depositing the intermediate layer 5. In this step, after heating the

substrate surface temperature as far as 250°C, the intermediate layer 5 is similarly deposited using a sputtering method. The intermediate layer 5 is used to magnetically isolate the soft magnetic under layer 4 and the bilayer magnetic recording layer 6, and also to control the properties of the CoCr alloy crystalline film which is the first layer 9 of the bilayer magnetic recording layer 6. As the material of the intermediate layer 5, a nonmagnetic element such as Ti, Ru, or a nonmagnetic alloy such as TiCr, CoCr, may be suitably employed. The intermediate layer 5 desirably has a film thickness of from 5 to 30 nm.

Next, the third step is a step of depositing the bilayer magnetic recording layer 6. This bilayer magnetic recording layer 6 is constituted by a first layer 9 and a second layer 10, these layers being deposited sequentially. First, the first layer 9 is formed by means of a sputtering method using a CoCr alloy crystalline [material] as the target. The material for this first layer is a CoCr alloy crystalline [material], it being possible to employ an alloy group such as CoCr, CoCrTa, CoCrPt, CoCrPtTa, CoCrPtB. The sputtering method of the present invention is capable of performing sputtering using the target of being able to form a crystalline film of a desired composition.

The film thickness when a CoCr alloy crystalline film is employed is preferably 10nm or more and no more than 30 nm. This is because, with a film thickness of less than 10 nm, favorable magnetic characteristics are not obtained, and the SNR drops, and, with a film thickness of more than 30 nm, the increased film thickness results in a drop in the SNR on account of a noise increase. The sputtering conditions are preferably that, for example, Ar gas, which is generally used in sputtering, is employed, and that, by adjusting the flow amount of Ar gas or adjusting the degree of opening/closing of a valve provided at an interval from a vacuum pump, the gas pressure is on the order of 2 mTorr to 10 mTorr.

Subsequently, the second layer 10 of the bilayer magnetic recording layer 6 is deposited. The deposition of the second layer 10 is performed using a sputtering method employing, for example, an $RE_{(1-x)} - TM_x$ target (rare earth element (RE) = Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm / transition metal (TM) = Co, Fe, Ni; $x = 0.5$ to 0.95). As described in the first invention above, the rare earth-transition metal alloy noncrystalline film preferably contains at least 10 atom percent and no more than 35 atom percent of at least one or more elements from among Pr, Nd, Gd, Tb, Dy, Ho, the remainder of the film containing at least one or more

transition metals from among Ni, Fe, Co. Therefore, the conditions for the sputtering method are controlled so as to obtain such a composition. For example, it is desirable that Ar gas, which is generally used in sputtering, should be employed as the gas employed during the deposition of the rare earth-transition metal alloy noncrystalline film, and that by adjusting the flow amount of Ar gas or adjusting the degree of opening/closing of a valve provided at an interval from a vacuum pump, the gas pressure is 10 mTorr or more and no more than 200 mTorr, and preferably 20 mTorr or more and no more than 100 mTorr. Such a range is adopted because, with a gas pressure of less than 10 mTorr, the exchange coupling in the film is extremely strong, and, in particular, signals in high frequency regions undergo a phase shift or annihilation, with the result that the SNR is of a small value on the order of 5dB, and also since, with a high gas pressure of more than 200 mTorr, a film whose magnetization is in plane is produced, and characteristics are radically adversely affected.

The rare earth-transition metal alloy noncrystalline film desirably has a film thickness of 2 nm or more and no more than 15 nm. This is because, with a film thickness of less than 2 nm, the properties for the rare earth-transition

metal alloy noncrystalline film are not obtained, and, with a film thickness of more than 15 nm, the rare earth-transition metal alloy noncrystalline film properties become too strong, and the SNR drops as a result of the production of fluctuations in the written signals.

As described above, the bilayer magnetic recording layer 6 is deposited by means of two steps, namely the deposition step for the first layer 9 and the deposition step for the second layer 10. As described by the first invention, with the perpendicular magnetic recording medium of the present invention, it is therefore necessary, also in the fabrication method for the perpendicular magnetic recording medium of the present invention, to set deposition conditions so as to fulfil the condition that the film thickness ratio between the first layer 9 and the second layer 10 should be in some range. In other words, deposition conditions are set so that the first layer 9 and the second layer 10 are formed such that, when the film thickness of the CoCr alloy crystalline film constituting the first layer 9 is a , and the film thickness of the rare earth-transition metal alloy noncrystalline film constituting the second layer 10 is b , the film thickness ratio a/b is equal to or more than 2. The regulation of the film thickness has, as targets, regulation of the sputtering power

and of the deposition time interval such that a film of a desired thickness may be formed. Control of the film thickness ratio in this manner is so that, in a case where the film thickness ratio a/b is smaller than 2, the rare earth-transition metal alloy noncrystalline film properties are then strong and the SNR drops.

The subsequent step is a step of depositing the protective layer 7. Methods for depositing the protective layer 7 include sputtering methods, CVD methods, and cathodic arc carbon methods. Such methods can be used to deposit the protective layer 7 on the bilayer magnetic recording layer 6. The protective layer 7 can be deposited using a material which is employed conventionally. An employable material can be formed from a material of which the main constituent is carbon, for example. As for the conditions for the film thickness or similar of the protective layer 7, all conditions used for ordinary magnetic recording media can be employed as is.

When the above-described steps of the present invention are performed using sputtering, it is desirable that all the gas pressures during deposition other than the gas pressure employed during deposition of the rare earth-transition

metal alloy noncrystalline film should be adjusted to be from 2 mTorr to about 10 mTorr. The gas pressure adjustment method is like the gas pressure adjustment method during deposition of the rare earth-transition metal alloy noncrystalline film. Conditions other than this [gas pressure condition] such as temperature conditions, may be suitably selected to suit the conditions of deposition for each layer.

In the present invention, the sputtering method can be principally employed as far as the above steps. This method is preferable since it is possible to perform serial reactions all together in a sputtering machine. However, the present invention is not limited to the fulfillment of all the conditions for the bilayer magnetic recording layer 6, it being possible to employ other conventional methods.

Next, the magnetic recording medium for which each of the layers is deposited is removed from the sputtering machine, and, finally, the liquid lubricant layer 8 is deposited [thereon].

The liquid lubricant layer 8 can be deposited using a material employed conventionally. As an employable material,

a perfluoropolyethyl lubricant can be used. The liquid lubricant layer 8 may be deposited on the magnetic recording medium obtained in the earlier steps by means of a dip method, a spray method, a spin-coating method using a solution produced by dissolving the above liquid lubricant in a prescribed solvent. As for the conditions for the film thickness or similar of the liquid lubricant layer 8, all conditions used for ordinary magnetic recording media can be employed as is.

Next, a description is provided hereinbelow for the fabrication method of the perpendicular magnetic recording medium of the second aspect of the first invention above. The fabrication method of the perpendicular magnetic recording medium of the second aspect is a method comprising the steps of depositing, on a nonmagnetic substrate 1, an orientation control layer 2, a magnetic domain control layer 3, a soft magnetic underlayer 4, an intermediate layer 5, a first layer 9 of a bilayer magnetic recording layer 6, a second layer 10 of the bilayer magnetic recording layer 6, a protective layer 7, and a liquid lubricant layer 8.

The fabrication method of the present invention is substantially the same as the fabrication method of the

perpendicular magnetic recording medium of the first aspect above, with the exception of the provision, on the nonmagnetic substrate, of the orientation control layer 2 and the magnetic domain control layer 3. Therefore, this second step will be described hereinbelow, the other steps being the same as in the fabrication method of the perpendicular magnetic recording medium of the first aspect above.

The step of depositing the orientation control layer 2 can be performed by introducing the nonmagnetic substrate 1 to a sputtering machine and depositing the orientation control layer 2 using the sputtering method. As for the material of the orientation control layer 2, when an Mn alloy antiferromagnetic film is used for the magnetic domain control layer 3 deposited in the next step, a nonmagnetic pure metal having a face-centered cubic structure such as Cu, Ir, or a nonmagnetic alloy or similar such as NiFeCr, is desirably used. In such a case, a primary coat of Ta, Zr, Nb, or similar, may be provided between the nonmagnetic substrate and the orientation control layer 2, in order to control the fine structure of the orientation control layer 2. The primary coat preferably has a film thickness of 3 to 30 nm, and more preferably 5 to 10 nm. The primary coat can be deposited using a conventional method such

as a sputtering method. Further, in cases where a hard magnetic film is used as the magnetic domain control layer 3, a Cr alloy such as CrMo, CrW, or similar, can be used for the orientation control layer 2. In this case also, a primary coat governed by the condition of being like that described above which serves to control the fine structure of the orientation control layer 2 may be provided between the nonmagnetic substrate 1 and the orientation control layer 2.

The orientation control layer 2 preferably has a film thickness of 3 nm to 30 nm.

Next, the step of depositing the magnetic domain control layer 3 can be performed using the sputtering method. Sputtering conditions may include the example of heating the substrate surface temperature to 250°C using a lamp heater or similar, and performing deposition using a CoCrPt target.

As the material of the magnetic domain control layer 3, an antiferromagnetic film, such as PtMn, IrMn or similar composed from an alloy containing Mn, or a hard magnetic film of CoCrTa, CoCrPt, CoCrPtB or similar in which magnetization

is oriented in a radial direction of the nonmagnetic substrate 1, can be employed. The magnetic domain control layer 3 preferably has a film thickness on the order of 5 to 300 nm.

Further, when a primary coat is provided between the orientation control layer and the nonmagnetic substrate, a material such as Ta, Zr, Nb, can be used for the primary coat, it being possible to provide a film thickness of 3 to 30 nm, and preferably 5 to 10 nm.

The materials for the soft magnetic under layer 4, the intermediate layer 5, the bilayer magnetic recording layer 6, the protective layer 7 and the liquid lubricant layer 8, and other materials, are the same as those described in the fabrication method for the magnetic recording medium of the first aspect of the invention.

A description will be provided for a third invention of the present invention. The third invention of the present invention relates to a perpendicular magnetic recording medium which is fabricated using the above fabrication method. The perpendicular magnetic recording medium of the third invention of the present invention has a structure like that of the first aspect and the second aspect of the first invention of

the present invention above.

Examples

Examples of the present invention will be described hereinbelow. The Examples below are merely suitable representative examples serving to describe the present invention, and do not limit the present invention in any way.

Example 1

A chemically strengthened glass substrate having a smooth surface (an N-5 glass substrate manufactured by HOYA, for example) is used as the nonmagnetic substrate 1. After cleaning this substrate, same is introduced to a sputtering machine, and a 200 nm CoZrNb noncrystalline soft magnetic under layer 4, and then, after heating using a lamp heater such that the substrate surface temperature reaches 250°C, a 15 nm TiCr intermediate layer 5, are sequentially deposited [on the substrate]. A bilayer magnetic recording layer 6 is formed by depositing a first layer 9 of 20 nm using CoCrPt as the target, and a second layer 10 of 10 nm using an $RE_{(1-x)} - TM_x$ target (rare earth element (RE) = Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm / transition metal (TM) = Co, Fe, Ni; $x = 0.5$ to 0.95). After finally depositing a 5 nm protective layer 7 composed of

carbon, [the substrate formed with layers] is removed from the sputtering machine. Deposition, other than that of the rare earth-transition metal alloy constituting the second layer 10 of the bilayer magnetic recording layer 6, is entirely performed using a DC magnetron sputtering method with a gas pressure (Ar gas) of 5 mTorr. During deposition of the second layer 10 of the bilayer magnetic recording layer 6, the gas pressure (Ar gas) within the sputtering machine was adjusted to a desired value (the gas pressure in Fig. 4 is 5 mTorr to 300 mTorr) by adjusting the overall flow amount of the deposition gas employed and the degree of opening of a valve provided between the sputtering machine and the vacuum pump.

Thereafter, a liquid lubricant layer 8 of 2 nm composed of perfluoropolyethyl is deposited using a dip method, to thereby produce the perpendicular magnetic recording medium.

Example 2

A chemically strengthened glass substrate having a smooth surface (an N-5 glass substrate manufactured by HOYA, for example) is used as the nonmagnetic substrate 1. After cleaning this substrate, same is introduced to a sputtering machine, and a 5 nm Ta primary coating, a 5 nm NiFeCr

orientation control layer 2, a 10 nm IrMn magnetic domain control layer 3, a 200 nm CoZrNb noncrystalline soft magnetic under layer 4, and then, after heating using a lamp heater such that the substrate surface temperature reaches 250°C, a 15 nm TiCr intermediate layer 5, are sequentially deposited [on the substrate]. A bilayer magnetic recording layer 6 is formed by depositing a first layer 9 of 20 nm using CoCrPt as the target, and a second layer 10 of 10 nm using an $RE_{(1-x)} - TM_x$ target (rare earth element (RE) = Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm / transition metal (TM) = Co, Fe, Ni; $x = 0.5$ to 0.95). After finally depositing a 5 nm protective layer 7 composed of carbon, [the substrate formed with layers] is removed from the sputtering machine. Deposition, other than that of the rare earth-transition metal alloy constituting the second layer 10 of the bilayer magnetic recording layer 6, is entirely performed using a DC magnetron sputtering method under a gas pressure (Ar gas) of 5 mTorr. During deposition of the second layer 10 of the bilayer magnetic recording layer 6, the gas pressure (Ar gas) within the sputtering machine was adjusted to a desired value (the gas pressure in Fig. 4 is 5 mTorr to 300 mTorr) by adjusting the overall flow amount of the deposition gas employed and the degree of opening of a valve provided between the sputtering machine and the vacuum pump.

Thereafter, a liquid lubricant layer 8 of 2 nm composed of perfluoropolyethyl is deposited using a dip method, to thereby produce the perpendicular magnetic recording medium.

Comparative Example

A magnetic recording medium was fabricated using a procedure like that of Example 1 except for the fact that, in the fabrication method according to Example 1, following the deposition of the first layer 9 of the bilayer magnetic recording layer 6 using a CoCrPt target, the second layer 10 was not deposited.

Evaluation

In the above method, perpendicular magnetic recording media were fabricated after changing the target composition for the second layer 10 of the bilayer magnetic recording layer 6 as well as the gas pressure during deposition. The magnetic characteristics of the perpendicular magnetic recording media thus fabricated were calculated by measuring the magnetization curves using a

vibration-test-type magnetometer with respect to a sample fabricated without the deposition of the soft magnetic under layer 4 in Example 1 above, and with respect to a sample fabricated without the deposition of the orientation control layer 3 and the soft magnetic under layer 4 in Example 2 above. The electromagnetic conversion characteristics of the perpendicular recording media with all layers deposited in the methods illustrated in the above Examples were measured using a spin stand tester and by means of a GMR head.

Since a disparity with regard to all the characteristics described hereinafter was not discerned in the perpendicular magnetic recording medium fabricated in the method of Example 1 and in the perpendicular magnetic recording medium fabricated in the method of Example 2, the results are taken to represent the characteristics of the perpendicular magnetic recording medium shown in Example 1. However, by means of the layer constitution shown in Example 2, it is possible to completely suppress spike noise of which the main cause is the magnetic domain formed by the soft magnetic under layer 4.

SNRs, at a recording density of 300 kFCI for perpendicular magnetic recording media fabricated by modifying the film

thickness and the film thickness ratio of the first layer 9 (CoCr alloy crystalline film) and the second layer 10 (rare earth-transition metal alloy crystalline film) of the bilayer magnetic recording layer 6, are shown in Tables 1 to 6. Tables 1 to 6 illustrate cases where the material of the second layer 10 (rare earth-transition metal alloy crystalline film) has been changed to TbCo, PrCo, NdFeNi, GdCoNi, DyFeCo, HoFe, respectively. The results of a judgement of whether this [material] is good or not based on SNR = 15dB are combined and shown in the tables. According to the tables, when the film thickness of the CoCr alloy crystalline film is a film thickness of less than 10 nm, the SNR falls since favorable magnetic characteristics cannot be obtained. Conversely, when the film thickness of the CoCr alloy crystalline film is a film thickness that is thicker than 30 nm, since the film thickness is then thicker, noise increases, and the SNR actually falls. Therefore, it was discovered that the film thickness of the CoCr alloy crystalline film is required to be 10 nm or more and no more than 30 nm. With regard to the film thickness of the rare earth-transition metal alloy noncrystalline film, when this film thickness is thinner than 2 nm, the properties for the rare earth-transition metal alloy noncrystalline film are not obtained, and when the film thickness is thicker than 15 nm, the rare earth-transition

metal alloy noncrystalline film properties become too strong, and the SNR drops as a result of the production of fluctuations in the written signal. Thus, it was discovered that when a favorable SNR is to be obtained at 15 dB or more, the film thickness is required to be 2 nm or more and no more than 15 nm. Furthermore, with regard to the film thickness ratio a/b of both magnetic recording layers when the film thickness of the CoCr alloy crystalline film is a , and the film thickness of the rare earth-transition metal alloy noncrystalline film is b , when a/b is less than 2, the SNR drops. It was thus discovered that a/b is required to be 2 or more. This condition range is common throughout the Tables 1 to 6, and it is illustrated that the same condition range can be applied also when different materials are used for the rare earth-transition metal alloy noncrystalline film.

Table 1

CoCrPt film thickness a	TbCo film thickness b	a/b	SNR (@300kFCI)	Good?
(nm)	(nm)		(dB)	
5	2	2.5	10.6	No
5	5	1	11.8	No
10	1	10	13.4	No
10	2	5	20.8	Yes
10	5	2	21.3	Yes
10	10	1	12.4	No
20	1	20	13.9	No
20	2	10	22.5	Yes
20	5	4	22.3	Yes
20	10	2	18.3	Yes
20	15	1.3	13.2	No
20	20	1	9.9	No
30	2	15	20.1	Yes
30	5	6	20.5	Yes
30	10	3	18.3	Yes
30	15	2	16.4	Yes
40	2	20	13.2	No
40	10	4	11.5	No
40	15	2	7.2	No

Table 2

CoCrPt film thickness a	PrCo film thickness b	a/b	SNR(@300kFCI)	Good?
(nm)	(nm)		(dB)	
5	2	2.5	11.6	No
10	5	2	22.1	Yes
10	10	1	12.7	No
20	2	10	22.0	Yes
20	5	4	21.8	Yes
20	15	1.3	12.9	No
30	1	30	12.8	No
30	5	6	19.9	Yes
40	10	4	12.3	No

Table 3

CoCrPt film thickness a	NdFeNi film thickness b	a/b	SNR(@300kFCI)	Good?
(nm)	(nm)		(dB)	
5	2	2.5	8.7	No
10	1	10	10.1	No
10	5	2	20.5	Yes
20	2	10	23.2	Yes
20	5	4	22.7	Yes
20	15	1.3	13.1	No
30	1	30	13.3	No
30	5	6	18.3	Yes
40	20	2	9.8	No

Table 4

CoCrPt film thickness a	GdCoNi film thickness b	a/b	SNR(@300kFCI)	Good?
(nm)	(nm)		(dB)	
5	5	1	7.9	No
10	1	10	13.7	No
10	2	5	18.7	Yes
20	2	10	22.4	Yes
20	5	4	23.1	Yes
20	10	2	19.3	Yes
30	2	15	20.1	Yes
30	20	1.5	13.3	No
40	10	4	13.2	No

Table 5

CoCrPt film thickness a	DyFeCo film thickness b	a/b	SNR(@300kFCI)	Good?
(nm)	(nm)		(dB)	
5	2	2.5	10.2	No
10	5	2	21.4	Yes
10	10	1	11.9	No
20	1	20	12.4	No
20	2	10	21.9	Yes
20	15	1.3	13.2	No
30	1	30	13.5	No
30	10	3	19.1	Yes
40	10	4	11.4	No

Table 6

CoCrPt film thickness a	HoFe film thickness b	a/b	SNR(@300kFCI)	Good?
(nm)	(nm)		(dB)	
5	1	5	8.5	No
10	1	10	11.6	No
10	2	5	18.7	Yes
20	2	10	22.3	Yes
20	5	4	23.4	Yes
20	10	2	20.8	Yes
30	1	30	13.4	No
30	10	3	19.9	Yes
40	20	2	9.3	No

The orientation of the magnetic anisotropy (perpendicular or in-plane) and values of the coercive force H_c of perpendicular orientation, when the transition metal of the rare earth-transition metal alloy noncrystalline film is Co and when the rare earth element material is varied, are shown in Table 7. In the group of materials examined on this occasion, Pr, Nd, Gd, Tb, Dy, Ho exhibited perpendicular magnetic anisotropy, and it was found that a favorable H_c in a perpendicular direction as required for the perpendicular magnetic recording medium had been obtained. Moreover, favorable characteristics for the perpendicular magnetic recording

medium can also be obtained when two or more of these elements are combined.

Table 7

Rare earth element	Magnetic anisotropy	H _{c1} (Oe)	Good?
Ce	in plane	-	No
Pr	perpendicular	5890	Yes
Nd	perpendicular	4860	Yes
Pm	in plane	-	No
Sm	in plane	-	No
Eu	in plane	-	No
Gd	perpendicular	3580	Yes
Tb	perpendicular	8700	Yes
Dy	perpendicular	7930	Yes
Ho	perpendicular	4090	Yes
Er	in plane	-	No
Tm	in plane	-	No

Next, the variation of H_c, when the rare earth-transition metal alloy noncrystalline film material is TbCo, PrCo, DyFeCo, NdFeNi, HoFe, GdCoNi, TbGdCo, and the rare earth element (RE) concentration is varied, is shown in Fig. 3. With a rare earth element concentration (RE) in the region of 10 atom percent or more and no more than 35 atom percent in all the rare

earth-transition metal alloy noncrystalline film materials subjected to testing, a coercive force of 10000e or more was obtained which can be used for a perpendicular magnetic recording medium.

Fig. 4 is a graph showing SNR values at 300kFCI when the rare earth-transition metal alloy noncrystalline film material is TbCo, PrCo, DyFeCo, NdFeNi, HoFe, GdCoNi, TbGdCo and when the gas pressure during deposition of the rare earth-transition metal alloy noncrystalline film of the perpendicular magnetic recording medium fabricated in the Examples is varied.

In all the rare earth-transition metal alloy noncrystalline films subjected to testing, with a gas pressure of less than 10 mTorr, since the exchange coupling in the film is extremely strong, and, in particular, as a result of signals in high frequency regions undergoing a phase shift or annihilation, the SNR is of a small value on the order of 5dB. On the other hand, with a gas pressure of 10 mTorr or more, the coercive force/squareness S^* (an indicator which aims to evaluate the extent of inclination of the magnetization curves in the vicinity of the coercive force H_c , and which is such that, the larger the inclination of the magnetization curves, the smaller S^*

becomes. Generally, the larger the inclination of the magnetization curves, the smaller the medium noise becomes, and the SNR increases) tends to fall. Accordingly, the SNR increases abruptly, and a favorable characteristic on the order of 15 dB is exhibited. Further, in a range of from 20 mTorr to 100 mTorr, irrespective of which material is used, a preferable characteristic of 15 dB or more is exhibited, and in particular for TbCo, PrCo, DyFeCo, TbGdCo, a superior characteristic is exhibited, namely that the SNR is 20dB or more. However, with a high gas pressure that is more than 200 mTorr, since a film whose magnetization is in plane is produced, characteristics abruptly deteriorate.

Therefore, it was discovered that, as a result of performing deposition with the gas pressure during deposition at 10 mTorr or more and no more than 200 mTorr, favorable characteristics are exhibited even at a high recording density, and that a more preferable gas pressure is 20 mTorr or more and no more than 100 mTorr.

Next, an investigation was conducted with regard to thermal stability using a magnetic recording medium fabricated in the method of Example 1, and using a magnetic recording medium fabricated in the method of the Comparative Example.

Measurement to investigate thermal stability was carried out using the procedure below. Using a spin stand tester, after performing writing once of signals by means of a GMR head, playback waveform reading was performed continuously. The proportion of the output drop 1000 seconds afterwards with respect to an output value immediately after writing was expressed as a percentage, this being an indicator to show thermal stability.

The results are shown in Table 8 below. The magnetic recording medium, of the Comparative Example, which has only a magnetic layer composed from CoCrPt and does not possess a magnetic layer whose raw material is a rare earth-transition metal alloy noncrystalline [material], exhibited a large value of 3.2%/decade-sec, whereas the magnetic recording medium of Example 1 was capable of quite a small value of 0.1%/decade-sec by virtue of the bilayer magnetic recording layer. Therefore, thermal stability was markedly improved by the layer constitution illustrated by the present invention.

Table 8

Sample	Thermostability (%/decade-sec)
Comparative example (CoCrPt alone)	3.2
Example 1 (CoCrPt/TbCo)	0.1

Advantageous Effects of the Invention

According to the present invention as described hereinabove, the magnetic recording layers of the perpendicular magnetic recording medium are constituted by stacking two magnetic layers, of which the first layer is a magnetic layer composed from a CoCr alloy crystalline film, and the second layer thereof is a rare earth-transition metal alloy noncrystalline film, the CoCr alloy crystalline film having a film thickness of 10 nm or more and no more than 30 nm, and the rare earth-transition metal alloy noncrystalline film having a film thickness of 2 nm or more and no more than 15 nm, and, when the film thickness of the CoCr alloy crystalline film is a , and the film thickness of the rare earth-transition metal alloy noncrystalline film is b , the film thickness ratio a/b is equal to or more than 2, and, as a result, a favorable SNR characteristic can be obtained even at a high recording density.

Furthermore, the rare earth-transition metal alloy noncrystalline material contains at least from 10 atom percent to 35 atom percent of at least one or more elements from among Pr, Nd, Gd, Dy, Ho, the remainder containing at least one or more transition metals from among Ni, Fe, Co, and the rare

earth-transition metal alloy noncrystalline film is deposited under the condition that the gas pressure is 10 mTorr or more and no more than 200 mTorr, and is preferably 20 mTorr or more and no more than 100 mTorr, and, consequently, in addition to it being possible to obtain favorable characteristics for the perpendicular magnetic recording medium, since such a stacked medium can be produced simply by using already existing manufacturing machines, such a medium is highly suited to mass production as a large capacity magnetic recording body hereinafter.

Claims

1. A perpendicular magnetic recording medium, which is constituted by sequentially stacking, on a nonmagnetic substrate, at least a soft magnetic under layer, an intermediate layer, a bilayer magnetic recording layer, a protective layer, and a liquid lubricant layer, characterized in that a first layer of said bilayer magnetic recording layer is a magnetic layer composed from a CoCr alloy crystalline film, and a second layer thereof is a magnetic layer composed from a rare earth-transition metal alloy noncrystalline film, said CoCr alloy crystalline film having a film thickness of 10nm or more and no more than 30 nm, and said rare earth-transition metal alloy noncrystalline film having a film thickness of 2 nm or more and no more than 15 nm; and in that, when the film thickness of the CoCr alloy crystalline film is a, and the film thickness of the rare earth-transition metal alloy noncrystalline film is b, the film thickness ratio a/b is equal to or more than 2.

2. A perpendicular magnetic recording medium, which is constituted by sequentially stacking, on a nonmagnetic substrate, at least an orientation control layer, a magnetic domain control layer, a soft magnetic under layer, an intermediate layer, a bilayer magnetic recording layer, a

protective layer, and a liquid lubricant layer, characterized in that a first layer of said bilayer magnetic recording layer is a magnetic layer composed from a CoCr alloy crystalline film, and a second layer thereof is a magnetic layer composed from a rare earth-transition metal alloy noncrystalline film, said CoCr alloy crystalline film having a film thickness of 10nm or more and no more than 30 nm, and said rare earth-transition metal alloy noncrystalline film having a film thickness of 2 nm or more and no more than 15 nm; and in that, when the film thickness of the CoCr alloy crystalline film is a, and the film thickness of the rare earth-transition metal alloy noncrystalline film is b, the film thickness ratio a/b is equal to or more than 2.

3. The perpendicular magnetic recording medium according to claims 1 and 2, characterized in that said rare earth-transition alloy noncrystalline material contains at least one or more elements from among Pr, Nd, Gd, Tb, Dy, and Ho.

4. The perpendicular magnetic recording medium according to claims 1 to 3, characterized in that said rare earth-transition alloy noncrystalline material contains at

least from 10 atom percent to 35 atom percent of one or more rare earth elements, the remainder containing at least one transition metal from among Ni, Fe, and Co.

5. A fabrication method for the perpendicular magnetic recording medium according to claim 1, comprising the steps of depositing, on a nonmagnetic substrate, at least a soft magnetic under layer, an intermediate layer, a magnetic layer composed from a CoCr alloy crystalline film which is a first layer of the bilayer magnetic recording layer, a rare earth-transition metal alloy noncrystalline film which is a second layer of said bilayer magnetic recording layer, a protective layer, and a liquid lubricant layer, characterized in that a gas pressure employed during the deposition of said rare earth-transition metal alloy noncrystalline film is 10 mTorr or more and no more than 200 mTorr.

6. A fabrication method for the perpendicular magnetic recording medium according to claim 2, comprising the steps of depositing, on a nonmagnetic substrate, at least an orientation control layer, a magnetic domain control layer, a soft magnetic under layer, an intermediate layer, a magnetic layer composed from a CoCr alloy crystalline film which is a first layer of the bilayer magnetic recording layer, a

rare earth-transition metal alloy noncrystalline film which is a second layer of said bilayer magnetic recording layer, a protective layer, and a liquid lubricant layer, characterized in that a gas pressure employed during the deposition of said rare earth-transition metal alloy noncrystalline film is 10 mTorr or more and no more than 200 mTorr.

7. The fabrication method for the perpendicular magnetic recording medium according to claims 5 and 6, characterized in that a gas pressure employed during the deposition of said rare earth-transition metal alloy noncrystalline film is 20 mTorr or more and no more than 100 mTorr.

8. A magnetic recording medium, which is fabricated by the methods according to claims 5 to 7.