

PERPENDICULAR MAGNETIC RECORDING MEDIUM AND METHOD OF MANUFACTURING SAME

CROSS-REFERENCE TO RELATED APPLICATION

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This application is based on, and claims priority to, Japanese Application No. 2004-066422, filed March 02, 2004.

BACKGROUND OF THE INVENTION

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1. Field of the Invention

The present invention relates to a perpendicular magnetic recording medium, in particular to a perpendicular magnetic recording medium that exhibits high recording density and excellent read-write performance. The invention also relates to a method of manufacturing such a medium.

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2. Description of the Related Art

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Accompanying with higher performance of personal computers and work stations in recent years, the mounted magnetic recording devices are required having high capacity and small size. According to this background, a magnetic disk of a recording device needs higher recording density.

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Practically employed magnetic recording system at present is “an in-plane (or longitudinal) magnetic recording system”, in which the axis of easy magnetization is parallel to the surface of the magnetic recording medium. To enhance magnetic recording density in this in-plane magnetic recording system, enhancement of coercivity (H_c) is required as well as reduction the product of the residual magnetization (B_r) and the thickness (t) of the magnetic film of the recording medium. Accordingly, attempts have been made to decrease the thickness and control the grain size of the magnetic film.

However, the in-plane magnetic recording system involves a problem that the regeneration output decreases because the demagnetizing field increases with reduction of the bit length and decreases the residual magnetic flux density. In addition, “a problem of thermal fluctuation” becomes prominent accompanying with reduction of the grain size and the thickness of the magnetic film. For these reasons, it is now deemed technically difficult to obtain a high density magnetic disk under the in-plane magnetic recording system.

To solve these problems and enhance the surface recording density, “a perpendicular magnetic recording system” has been studied. A magnetic recording medium in the perpendicular magnetic recording system is designed for the axis of easy magnetization of the magnetic film to align perpendicularly to the substrate surface. Since adjacent magnetizations in a magnetization

transition region are not opposite to each other, the magnetization is stable even with a shortened bit length, and the magnetic flux is not decreased. Therefore, the perpendicular magnetic recording system is suitable to a magnetic recording system for a high density magnetic
5 recording medium.

Contrary to this advantage, a perpendicular magnetic recording medium may involve a problem of high media noise that is liable to occur because precipitation of nonmagnetic elements to a region
10 between magnetic grains in the magnetic layer is not enough and thus, the magnetic interaction between the magnetic grains increases. Thus, achievement of high density recording that is accompanied by reduction of the media noise and enhancement of the SN ratio is demanded, through development of a material control technology
15 promoting the grain boundary precipitation of nonmagnetic elements.

A perpendicular magnetic recording medium called “a double layer perpendicular magnetic recording medium” is known that comprises a soft magnetic backing layer formed on a nonmagnetic
20 substrate of aluminum or glass, an underlayer formed on the backing layer for perpendicular alignment of a magnetic layer, and further, a perpendicular magnetic recording layer and a protective layer that are formed on the underlayer. Various multilayer structures have been studied as the perpendicular magnetic layer, including
25 perpendicular magnetic films of a cobalt-based alloy such as Co-Cr, Co-Cr-Ta, or Co-Cr-Pt, multilayer perpendicular magnetic films of

Pt/Co and Pd/Co, and amorphous perpendicular magnetic films of Tb-Co and Tb-Fe-Co.

Among the multilayer structures, the multilayer perpendicular
5 magnetic films of Pt/Co and Pd/Co are extensively studied for a future
high recording density medium since the type of the magnetic films
exhibits large perpendicular magnetic anisotropy, high thermal
stability, large coercivity, and in addition, a squareness ratio that is
easily approaches 1.0. These multilayered media, however, generate
10 a large amount of so-called media noise, reduction of which is a
problem to be solved before practical application.

To reduce the media noises, a granular layer has been applied to
the underlayer. Besides, Japanese Unexamined Patent Application
15 Publication No. 2002-025032 discloses a perpendicular magnetic
recording medium that contains boron or oxygen in the multilayer
perpendicular magnetic film composed of alternately laminated Co
and Pt films or Co and Pd films.

20 The perpendicular magnetic recording medium disclosed in
Japanese Unexamined Patent Application Publication No. 2002-
025032, however, causes deterioration of thermal stability of the
recorded magnetization since the addition of boron or oxygen to the
cobalt layer, platinum layer or palladium layer in the multilayer
25 lamination film causes decrease of the perpendicular magnetic
anisotropy constant K_u (also called simply "Ku" in this specification).

It is consequently important to reduce the media noise while keeping the perpendicular magnetic anisotropy constant K_u sufficiently large, for securing thermal stability.

5 As is clarified above, the perpendicular magnetic recording medium still involves problems to be solved although the type of medium is deemed promising for achieving high density recording. Especially, thermal stability must be improved while simultaneously reducing media noise.

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SUMMARY OF THE INVENTION

The present invention has been made in view of the problems, and an object of the invention is to provide a perpendicular magnetic
15 recording medium that exhibits high recording density and excellent read-write performance through improving thermal stability of the recorded magnetization as well as reducing media noise. Another object of the invention is to provide a method of manufacturing such a medium.

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To effect the objects, the invention as claimed in claim 1 is a perpendicular magnetic recording medium that comprises a magnetic film provided on a nonmagnetic substrate and is characterized in that the magnetic film is composed of alternately laminated first magnetic
25 layers of cobalt layers and second magnetic layers of palladium layers, the second magnetic layer containing silicon oxide.

The invention of claim 2 is the perpendicular magnetic recording medium according to claim 1 characterized in that: crystalline magnetic anisotropy energy of the magnetic film is approximated by $E \approx Ku_1 \sin^2\theta + Ku_2 \sin^4\theta$, where Ku_1 and Ku_2 are uniaxial anisotropy constants, θ is an angle between spontaneous magnetization and an axis of easy magnetization of the magnetic film, and a crystalline magnetic anisotropy constant Ku holds a relation $Ku = Ku_1 + Ku_2$; and the Ku and the Ku_2 obtained by magnetic anisotropy measurement using a torque magnetization meter under a condition of approximately saturated magnetization of the magnetic film satisfy a relation $Ku_2 / Ku \geq 0.25$.

The invention of claim 3 is the perpendicular magnetic recording medium according to claim 1 or claim 2, characterized in that an amount of the added silicon oxide is in the concentration range of 2 to 8 mol%.

The invention of claim 4 is the perpendicular magnetic recording medium according to any one of claims 1 through 3, characterized in that a thickness of the first magnetic layer is in the range of 0.2 to 0.5 nm and a thickness of the second magnetic layer is in the range of 0.6 to 1.0 nm.

The invention of claim 5 is the perpendicular magnetic recording medium according to any one of claims 1 through 4, characterized in that an underlayer is provided between the magnetic film and the

substrate, and the magnetic film is disposed directly on the underlayer.

The invention of claim 6 is the perpendicular magnetic recording
5 medium according to claim 5, characterized in that the underlayer is a ruthenium film.

The invention of claim 7 is the perpendicular magnetic recording
medium according to claim 5 or claim 6, characterized in that a
10 thickness of the underlayer is in the range of 5 to 20 nm.

The invention of claim 8 is the perpendicular magnetic recording
medium according to any one of claims 5 through 7, characterized in
that a surface of the underlayer is adsorbed with oxygen.
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The invention of claim 9 is the perpendicular magnetic recording
medium according to any one of claims 5 through 8, characterized in
that an alignment control layer is provided between the substrate
and the underlayer for C-axis alignment of crystal alignment of the
20 underlayer.

The invention of claim 10 is the perpendicular magnetic
recording medium according to claim 9, characterized in that the
alignment control layer is composed by laminating a first alignment
25 control layer and a second alignment control layer.

The invention of claim 11 is the perpendicular magnetic recording medium according to claim 10, characterized in that the first alignment control layer is a tantalum layer and the second alignment control layer is selected from a NiFeNbB layer, a NiFeCr layer, and a NiFeSi layer.

The invention of claim 12 is the perpendicular magnetic recording medium according to claim 11, characterized in that: a composition of the NiFeNbB layer is in the range of 64 to 86 at% Ni, 10 to 20 at% Fe, 2 to 10 at% Nb, and 2 to 6 at% B; a composition of the NiFeCr layer is in the range of 50 to 70 at% Ni, 10 to 20 at% Fe, 20 to 30 at% Cr; a composition of the NiFeSi layer is in the range of 70 to 88 at% Ni, 10 to 20 at% Fe, 2 to 10 at% Si; and a total of the compositions of elements composing each second alignment control layer is 100 %.

The invention of claim 13 is the perpendicular magnetic recording medium according to any one of claims 10 through 12, characterized in that a thickness of the first alignment control layer is in the range of 1 to 5 nm and a thickness of the second alignment control layer is in the range of 5 to 30 nm.

The invention of claim 14 is the perpendicular magnetic recording medium according to any one of claims 10 through 13, characterized in that a soft magnetic backing layer is provided between the substrate and the first alignment control layer.

The invention of claim 15 is the perpendicular magnetic recording medium according to claim 14, characterized in that the backing layer is composed of an alloy of CoZrNb or CoZrTa, and has a thickness in the range of 50 to 300 nm.

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The invention as claimed in claim 16 is a method of manufacturing a perpendicular magnetic recording medium characterized in that the method comprises: an underlayer deposition step of depositing an underlayer of a ruthenium film on a nonmagnetic substrate, and a deposition step of depositing a magnetic film of multilayered lamination film directly on the underlayer by alternately laminating first magnetic layers of cobalt layers and second magnetic layers of palladium layers containing silicon oxide.

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The invention of claim 17 is the method of manufacturing a perpendicular magnetic recording medium according to claim 16, characterized in that the deposition step of depositing the magnetic film is conducted by a sputtering method using a target of cobalt and a target of palladium containing silicon oxide in a concentration range of 2 to 8 mol%.

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The invention of claim 18 is the method of manufacturing a perpendicular magnetic recording medium according to claim 16 or claim 17, characterized in that, in the underlayer deposition step, oxygen is adsorbed on a surface of the underlayer by exposing the

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surface of the underlayer to argon gas at a gas pressure in the range of 0.1 to 10 Pa containing oxygen in the mass flow range of 1 to 10 % for a time duration in the range of 1 to 10 sec.

5 The invention of claim 19 is the method of manufacturing a perpendicular magnetic recording medium according to any one of claims 16 through 18, characterized in that the method further comprises, prior to the underlayer deposition step, an alignment control layer deposition step in which a first alignment control layer
10 of tantalum layer and a second alignment control layer of a layer selected from an NiFeNbB layer, an NiFeCr layer, and an NiFeSi layer are deposited for aligning crystal alignment of the underlayer in C-axis alignment; and in the alignment control layer deposition step, the first alignment control layer and the second alignment control
15 layer are laminated.

 The invention of claim 20 is the method of manufacturing a perpendicular magnetic recording medium according to any one of claims 16 through 19, characterized in that the method further
20 comprises, prior to the alignment control layer deposition step, a backing layer deposition step in which a soft magnetic backing layer of a CoZrNb layer or a CoZrTa layer is deposited on the substrate.

 As described above, in the perpendicular magnetic recording
25 medium of the invention, a magnetic film is a multilayer lamination film composed of alternately laminated first magnetic layers of cobalt

layers and second magnetic layers of palladium layers, the second magnetic layer containing silicon oxide. Consequently, thermal stability of magnetization recorded in the perpendicular magnetic recording medium is improved and excellent recording and
5 regeneration performance is achieved.

With the ratio of K_{u2} to K_u of at least a specified value, the ease of writing-in onto a perpendicular magnetic recording medium by a head and the thermal stability of recorded magnetization are
10 improved at the same time.

Embodiment of the invention will be described in detail in the following referring to the accompanying drawings.

15 BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 illustrates an example of structure of a perpendicular magnetic recording medium according to an embodiment of the invention;
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Fig. 2 illustrates the coercivity H_c of perpendicular magnetic recording media provided with a multilayered lamination film composed of Co layers or Co-SiO₂ layers and Pd layers or Pd-SiO₂ layers in the dependence on the thickness of the Pd layer or Pd-SiO₂
25 layer; and

Fig. 3 illustrates the gradient α of the magnetization curve at the vicinity of H_c of perpendicular magnetic recording media provided with a multilayered lamination film composed of Co layers or Co-SiO₂ layers and Pd layers or Pd-SiO₂ layers in the dependence on the
5 thickness of the Pd layer or Pd-SiO₂ layer.

DETAILED DESCRIPTION OF THE INVENTION

(Items that were studied in the course of carrying out the invention)

10 A conventional perpendicular magnetic recording medium, although it has many advantages for a high density recording medium, involves a problem that precipitation of a nonmagnetic substance to a region between magnetic grains in the magnetic layer is not enough and the interaction between the magnetic grains is
15 large, leading to high media noise.

Considering this point, perpendicular magnetic recording medium is manufactured in which the basic structure of the multilayer perpendicular magnetic film is Co/Pd, the cobalt layer
20 containing SiO₂.

In the cobalt layer containing SiO₂, the nonmagnetic SiO₂ precipitates between the cobalt particles. As a result, the cobalt particles are made fine and isolated, thereby reducing media noise.
25 Since the reduction of media noise raises SN ratio, recording and regeneration performance can be improved and high density

recording can be attained.

In addition to the reduction of media noises, a perpendicular magnetic recording medium is also desired to exhibit excellent
5 recording and regeneration performance and improvement in thermal stability of the recorded magnetization.

Embodiment of the invention has been carried out in view of the above study items. Some preferred embodiments of the invention are
10 described in the following.

An embodiment of the invention is a perpendicular magnetic recording medium comprising a multilayered lamination film composed of alternately laminated first magnetic layers of cobalt
15 layers and second magnetic layers of palladium layers, the palladium layers containing silicon oxide. By adding the silicon oxide in the palladium layers and laminating the palladium layers and the cobalt layers, the crystalline magnetic anisotropy constant K_u is increased. Further, a uniaxial anisotropy constant K_{u2} is also increased.

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(Principle of the invention)

A principle of the invention is described below.

To improve thermal stability of magnetization recorded in a
25 perpendicular magnetic recording medium, the perpendicular magnetic anisotropy constant K_u must be increased. The increase of

the perpendicular magnetic anisotropy constant K_u , however, generally accompanies increase of coercivity H_c and a switching field H_k . Since too large value of the coercivity H_c or the switching field H_k causes difficulty in writing-in onto the magnetic recording medium by a head, the value must be in an appropriate range. K_u is given by $K_u = K_{u1} + K_{u2}$, where each of K_{u1} and K_{u2} is a uniaxial anisotropy constant (also called “ K_{u1} ” and “ K_{u2} ” in this specification). The switching field in the process of recording into a magnetic recording medium is given by $H_k = 2K_{u1} / M_s$, where M_s is saturation magnetization. Consequently, small value of the K_{u1} results a small H_k , so making writing into the magnetic recording medium easy to be performed.

On the other hand, to improve thermal stability of the recorded magnetization, the large K_u value is favorable. Magnetization, recorded in the magnetic recording medium, of a magnetic grain with a volume V has a magnetic anisotropy energy represented by $K_u V$. Thermal energy in the environment at an absolute temperature T is represented by kT , where k is the Boltzmann constant. Consequently, thermal stability can be represented by $K_u V / kT$, which indicates that the K_u value should be large for improving thermal stability.

Therefore, K_{u1} should be small to obtain excellent recording and regeneration performance, and K_u should be large for improving thermal stability of recorded magnetization.

Because $K_u = K_{u1} + K_{u2}$, K_{u1} can be small if K_{u2} is large, even with a large K_u value. Therefore, when K_u is large and the proportion of K_{u2} in K_u is large, thermal stability of the recorded magnetization is improved and, at the same time, the switching filed remains in a proper range, thus achieving excellent read-write performance. In perpendicular magnetic recording media that are manufactured in various conditions but have an equal K_u value, it is important to make the K_{u2} value large and the proportion of K_{u2} in K_u large.

To improve thermal stability of the recorded magnetization and retain the H_k in a proper range, the proportion of the uniaxial anisotropy constant K_{u2} in the perpendicular magnetic anisotropy constant K_u is the larger the more favorable. Specifically, K_{u2} / K_u is preferably at least 25 %.

To achieve excellent read-write performance and at the same time, to improve thermal stability of the recorded magnetization, that is, in order to hold a large value of perpendicular magnetic anisotropy constant K_u and at the same time, to make a uniaxial anisotropy constant K_{u2} large, the magnetic film of a perpendicular magnetic recording medium of an embodiment of the invention is, as shown in Fig. 1, a multilayered lamination film composed of cobalt layers and palladium layers that contains silicon oxide.

(Structure of the perpendicular magnetic recording medium)

Fig. 1 illustrates a concept of a basic structure of a perpendicular magnetic recording medium of an embodiment of the invention. The medium comprises a backing layer 2, alignment control layers 3 and 4, an underlayer 5, and a magnetic film 6 sequentially laminated on a nonmagnetic substrate 1 of aluminum, glass, or the like. On the magnetic film 6, a protective layer 7 is provided.

In the perpendicular magnetic recording medium of an embodiment of the invention, the magnetic film 6 has a basic structure of a multilayered lamination film composed of multiple of cobalt layers and palladium layers, the palladium layers containing silicon oxide. This magnetic film 6 is formed on an underlayer that is provided for reducing magnetic interaction between magnetic grains constructing the magnetic film 6. The underlayer 5 is preferably composed of a ruthenium film, though a Pt film, a Pd film, and a Pt/Pd lamination film can also be used. The composition of the silicon oxide contained in the magnetic film 6 is preferably a stoichiometric composition, that is, in the composition SiO_x ($0 < x \leq 2$), SiO_2 is preferable. The backing layer 2 and the alignment control layers 3 and 4 are preferably provided between the underlayer 5 and the substrate 1 to enhance crystal alignment (C-axis alignment) of the underlayer 5. A perpendicular magnetic recording medium without these layers is also possible.

More specifically, the underlayer 5 is composed of a ruthenium film having an hcp (hexagonal closest packed) crystal structure. The

thickness is in the range of 5 to 20 nm. When the surface of the underlayer 5 is subjected to oxygen adsorption treatment before forming the magnetic film 6, magnetic performance of the magnetic film 6 can be improved. The oxygen adsorption on the surface of the underlayer 5 suppresses magnetic interaction between magnetic grains in the magnetic film 6 formed on the underlayer 5 and makes a gradient α (also called simply " α " in this specification) of a magnetization curve around H_c less steep, to facilitate recording and regeneration. The oxygen adsorption to the underlayer 5 is conducted after formation of the underlayer by exposing the surface of the underlayer to argon gas containing 1 to 10 % of oxygen in mass flow proportion at a pressure of 0.1 to 10 Pa for 1 to 10 seconds.

The α is an index representing magnitude of magnetic interaction between magnetic grains composing the magnetic film 6. A small α means little magnetic interaction between the magnetic grains and thus, little media noise.

The magnetic film 6 has a basic structure of a multilayered lamination film of Co/Pt. The multilayered lamination film consists of first magnetic layers 6a of cobalt layers containing no additive and second magnetic layers 6b of palladium layers containing an additive of silicon oxide (SiOx). The multilayered lamination film has a composition of Co/Pd-SiO₂, for example. The SiO₂ in the palladium layer of an embodiment of the invention is preferably contained in the concentration range of 2 to 8 mol%. A thickness of the cobalt layer is

in the range of 0.2 to 0.5 nm, and a thickness of the palladium layer is in the range of 0.6 to 1.0 nm.

By containing no additive in the cobalt layer and SiO₂ in the
5 palladium layer, and laminating these layers, a crystalline magnetic
anisotropy constant K_u is held large and a uniaxial anisotropy
constant K_{u2} is also made large. As a result, thermal stability of the
recorded magnetization is improved and switching field H_k is kept in
an appropriate range, achieving excellent recording and regeneration
10 performance.

By adding SiO₂ in the palladium layer, the nonmagnetic SiO₂
precipitates between the magnetic grains making the particles
minute and isolated. Therefore, the coercivity H_c is held in a proper
15 range and the media noise is reduced.

An underlayer 5 with oxygen adsorbed on the surface thereof is
provided in a perpendicular magnetic recording medium of an
embodiment of the invention for the purpose of controlling the
20 gradient α of a magnetization curve around coercivity (H_c) of the
magnetic film 6 formed on the underlayer 5. The magnetic film is
composed of a multilayered lamination film of Co/Pt for the purpose
of forming a magnetic film with a higher H_c and with a squareness
ratio readily approaching 1 as compared with a magnetic film of a Co-
25 Cr alloy, and also obtaining large crystalline magnetic anisotropy by
taking advantage of interface magnetic anisotropy. Large crystalline

magnetic anisotropy not only improves thermal stability of recorded magnetization, but also aligns the axis of easy magnetization perpendicularly to the magnetic film surface easily, increases the coercivity for the perpendicular magnetic field, and facilitates
5 retaining a residual magnetization.

Alignment control layers 3 and 4 are provided for the purpose of enhancing crystal alignment (C-axis alignment) of the underlayer 5 of a ruthenium layer. The alignment control layers have preferably a
10 double layer structure consisting of a first alignment control layer 3 of a tantalum layer and a second alignment control layer 4 of a NiFeNbB layer. The second alignment control layer can also be a NiFeCr layer or a NiFeSi layer. By enhancing C-axis alignment of the underlayer 5, crystal alignment of the magnetic film 6 formed on
15 the underlayer 5 is also improved, thereby improving magnetic performance of the magnetic film 6. Thickness of the first alignment control layer 3 of a tantalum layer is in the range of 1 to 5 nm, and thickness of the second alignment control layer 4 of a NiFeNbB layer, a NiFeCr layer, or a NiFeSi layer is in the range of 5 to 30 nm. A
20 composition of the NiFeNbB layer is in the range of 64 to 86 at% Ni, 10 to 20 at% Fe, 2 to 10 at% Nb, and 2 to 6 at% B. A composition of the NiFeCr layer is in the range of 50 to 70 at% Ni, 10 to 20 at% Fe, and 20 to 30 at% Cr. A composition of the NiFeSi layer is in the range of 70 to 88 at% Ni, 10 to 20 at% Fe, and 2 to 10 at% Si. Here,
25 the total of compositions of the elements for each layer is 100 %.

The backing layer 2 is provided for the purpose of enhancing writing capability by a recording head. The backing layer can be, for example, a soft magnetic film of CoZrNb or CoZrTa having thickness of 50 to 300 nm.

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As described above, in an embodiment of the invention, a magnetic film has a basic structure of a multilayered lamination film of Co/Pd and consists of first magnetic layers of cobalt layers containing no additive and second magnetic layers of palladium layers containing an additive of SiO₂. As a result, a perpendicular magnetic anisotropy constant K_u is large and a proportion of a uniaxial anisotropy constant K_{u2} in the K_u is large as well. Therefore, thermal stability of magnetization recorded in a perpendicular magnetic recording medium is improved and excellent read-write performance is achieved as well.

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Since the nonmagnetic SiO₂ is locally distributed in the second magnetic layer 6b, magnetic interaction between the magnetic grains is decreased, reducing media noise.

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In addition, by the ruthenium underlayer 5 with oxygen adsorption on the surface thereof, the gradient α of a magnetization curve around H_c is made less steep and magnetic interaction between the grains in the magnetic film 6 is decreased, facilitating recording and regeneration.

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The present invention is described more in detail according to some specific embodiment examples. Needless to say, the invention shall not be limited to the specific examples, but various modifications are possible within the spirit and scope of the invention.

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(Example 1) (E1)

A perpendicular magnetic recording medium of Example 1 comprises a substrate 1 of a glass substrate, a backing layer 2 of a CoZrNb film, a first alignment control layer 3 of a tantalum layer, a
10 second alignment control layer 4 of a NiFeNbB layer, an underlayer 5 of a ruthenium layer, a protective layer 7 of a nitrogen-doped carbon film, and a magnetic film 6 of a multilayered lamination film consisting of first magnetic layers 6a of cobalt layers with a composition of cobalt and second magnetic layers 6b of Pd-SiO₂ layers
15 with a composition of Pd-SiO₂.

A manufacturing method of the perpendicular magnetic recording medium is as follows. The substrate 1 is a glass substrate having a thickness of 0.635 mm and a diameter of 2.5 inches.
20 However, the diameter and the thickness are not essential, and the material is not essential, too; an aluminum substrate can also be used for the substrate 1.

After cleaning the substrate well, a soft magnetic layer of a
25 CoZrNb film was deposited by a sputtering method to form a backing layer 2. The sputtered target used in this example had a composition

of 87 at% Co - 5 at% Zr - 8 at% Nb. Using a sputtering gas of argon, a film about 200 nm thick was deposited under argon gas pressure of about 1 Pa at room temperature. The CoZrNb film exhibits satisfactory soft magnetic characteristic even though in an
5 amorphous condition deposited at room temperature.

On this CoZrNb film, subsequently deposited by sputtering was a first alignment control layer 3 of tantalum, using a target of pure tantalum. A film 3 nm thick was deposited by sputtering with argon
10 gas at room temperature under gas pressure of about 1 Pa.

On this tantalum film, subsequently deposited by sputtering was a second alignment control layer 4 of NiFeNbB. The composition of the target used was 79 at% Ni - 12 at% Fe - 3 at% Nb - 6 at% B. A
15 film about 25 nm thick was deposited by sputtering with argon gas at room temperature under gas pressure of about 1 Pa.

The thus deposited alignment control layers 3 and 4 were used to obtain an hcp crystal structure in the underlayer 5 of a ruthenium
20 layer to be deposited in the subsequent step. For the purpose of increasing coercivity by C-axis alignment of the crystals of the ruthenium underlayer 5, a first alignment control layer 3 of a tantalum layer and a second alignment control layer 4 of NiFeNbB were used for crystal alignment control.

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On the thus deposited NiFeNbB layer, an underlayer 5 of a

ruthenium film was deposited by sputtering. Target used was pure ruthenium. A film about 10 nm thick was deposited by sputtering with argon gas. The deposition temperature was room temperature and the gas pressure was about 4 Pa. The surface of the thus
5 deposited ruthenium underlayer 5 having the hcp crystal structure was exposed to an atmosphere of argon gas containing oxygen in a mass flow fraction of 2 % under a pressure of 1 Pa for 10 sec, to adsorb an appropriate amount of oxygen on the ruthenium surface.

10 By using an underlayer 5 of ruthenium with oxygen adsorbed thereon, the gradient of magnetization curve around H_c is made less steep and magnetic interaction between the grains in the perpendicular magnetic film is reduced, to facilitate recording and regeneration.

15 On the ruthenium underlayer, a perpendicularly aligned magnetic film 6 of a multilayered lamination film of Co/Pd-SiO₂ was formed by sputtering. Targets used are a target of pure cobalt and a target of palladium containing 5 mol% of SiO₂. By discharging and
20 sputtering simultaneously these two targets while rotating, each of the cobalt layers and each of the Pd-SiO₂ layers were alternately laminated. The composition of the deposited Pd-SiO₂ layer was 95 mol% Pd - 5 mol% SiO₂ reflecting the target used. Argon gas was used for the sputtering. Thickness of the cobalt layer was 0.3 nm and
25 thickness of the Pd-SiO₂ layer was 0.8 nm. The deposition was conducted at room temperature and under gas pressure of 5 Pa.

By using a magnetic film 6 of a multilayered lamination film of Co/Pd-SiO₂ composed of alternately laminated first magnetic layers 6a of cobalt layers and second magnetic layers of Pd-SiO₂ layers, the Ku value is made large and the proportion of Ku₂ in the Ku is made large. By adding SiO₂ in palladium, the nonmagnetic SiO₂ precipitates between the palladium particles making the palladium particles minute and isolated.

Finally, a protective layer 7 of a nitrogen-doped carbon (C: N) film was deposited by sputtering. The target used was carbon. A film about 7 nm thick was formed by sputtering with argon gas in the atmosphere of argon gas containing nitrogen gas in a mass flow fraction of 4 %. The deposition was conducted at room temperature and under gas pressure of about 1 Pa.

Thus, a perpendicular magnetic recording medium was manufactured comprising a magnetic film of a multilayered lamination film of Co/95 mol% Pd - 5 mol% SiO₂.

Fig. 2 illustrates coercivity H_c in the dependence on the thickness of a palladium layer or the Pd -SiO₂ layer of the perpendicular magnetic recording media each comprising a magnetic film of a multilayered lamination film. Each medium comprises a magnetic film of a multilayered lamination film of Co / 95 mol% Pd - 5 mol% SiO₂ (in medium A), 94 mol% Co - 6 mol% SiO₂ / Pd (in medium B), 94 mol% Co - 6 mol% SiO₂ / 95 mol% Pd - 5 mol% SiO₂ (in

medium C), or pure Co / pure Pd (in medium D). In Fig. 2, the ordinate represents the coercivity H_c and the abscissa represents the thickness of the palladium layer or the Pd - SiO_2 layer.

5 The perpendicular magnetic recording media B, C, and D were manufactured in the same compositions and deposition processes as in medium A except for the construction of the magnetic film described above.

10 Fig. 2 shows that the H_c becomes large in all of the four types of media up to the thickness of 0.8 nm of the Pd or Pd- SiO_2 film. At this thickness of 0.8 nm, H_c of the medium C is about 4,000 Oe. The medium A according to the invention exhibits the H_c value of about 7,000 Oe, which is sufficient for performing excellent recording and
15 regeneration. The H_c of the medium B is about 7,500 Oe. The medium D, which does not contain SiO_2 in the cobalt layer and in the palladium layer, resulted a too large H_c value of 10,000 Oe. When the H_c value is excessively large, a magnetic field generated by a ring
20 head for recording and regeneration is insufficient for reversing the magnetization direction, thus adequate recording and regeneration cannot be performed.

 In a perpendicular magnetic recording medium comprising a multilayered lamination film of basically composed of cobalt layers
25 and palladium layers, the magnitude of H_c can be controlled by addition or no addition of the SiO_2 into the cobalt layers and the

palladium layers as described above. The medium A according to the invention exhibits an H_c value that is not too large, not too small, and just appropriate, to obtain an excellent recording and regeneration characteristic.

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(Example 2)

Fig. 3 illustrates gradient α around H_c in a magnetization curve in the dependence on the thickness of a palladium layer or a Pd-SiO₂ layer of the perpendicular magnetic recording media each comprising a magnetic film of a multilayered lamination film. Each medium comprises a magnetic film of a multilayered lamination film of Co / 95 mol% Pd - 5 mol% SiO₂ (in medium A₁), 94 mol% Co - 6 mol% SiO₂ / Pd (in medium B₁), 94 mol% Co - 6 mol% SiO₂ / 95 mol% Pd - 5 mol% SiO₂ (in medium C₁), or pure Co / pure Pd (in medium D₁). In Fig. 3, the ordinate represents the gradient α and the abscissa represents the thickness of the Pd or Pd-SiO₂ layer. The gradient α of a magnetization curve is an index representing magnitude of magnetic interaction between magnetic grains composing the magnetic film 6, and is favorably a small value.

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The medium A₁ according to the invention in this Example 2 was manufactured in the same method and conditions as in Example 1, and description is omitted. The perpendicular magnetic media of B₁, C₁, and D₁ were manufactured with the same composition and through the same deposition processes as in the medium A₁ except for the construction of the magnetic films as described above.

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Fig. 3 shows that the thicker the Pd or the Pd-SiO₂ film is, the smaller the α value is, in all four types of media. While medium D₁ resulted the α values not smaller than 1.5 in the range of thickness not larger than 0.9 nm, media A₁, B₁, and C₁ show smaller α values than medium D₁ in the whole thickness range, and the α values of the media A₁, B₁, and C₁ are approximately in the same magnitude. Thus, addition of SiO₂ into the cobalt layers or the palladium layers in a perpendicular magnetic recording medium comprising a multilayered lamination film basically composed of cobalt layers and palladium layers, suppresses magnetic interaction between magnetic grains, and results reduction of media noise.

(Example 3)

Table 1 shows measurement results of the perpendicular magnetic anisotropy constant Ku, the uniaxial anisotropy constants Ku₁ and Ku₂, and the ratio of Ku₂ to Ku, that is, Ku₂/Ku, on the perpendicular magnetic recording media each comprising a magnetic film of a multilayered lamination film. Each medium comprises a magnetic film of a multilayered lamination film of Co/95 at% Pd - 5 mol% SiO₂ (in medium A₂), 94 mol% Co - 6 mol% SiO₂ / Pd (in medium B₂), 94 mol% Co - 6 mol% SiO₂ / 95 mol% Pd - 5 mol% SiO₂ (in medium C₂), or pure Co / pure Pd (in medium D₂).

The medium A₂ according to the invention in this Example 3 was manufactured in the same method and conditions as in Example 1, and description is omitted. The perpendicular magnetic recording

media of B₂, C₂ and D₂ were manufactured with the same composition and through the same deposition processes as in the medium A₂ except that the magnetic films had the constructions as described above, and the thickness of the Co or Co-SiO₂ layer composing the
5 multilayered lamination film was 0.3 nm and the thickness of the Pd or Pd-SiO₂ layer was 0.8 nm.

In this Example 3, the K_u and K_{u2} were obtained depending on applied magnetic field by a method described below. A magnetic
10 torque curve was measured in the dependence on applied magnetic field H in the range of 10 kOe to 25 kOe using a torque magnetometer under a condition of approximately saturated magnetization of the magnetic film. Fourier analysis was carried out on this magnetic torque curve. Using an approximation relation on the crystalline
15 magnetic anisotropy energy E of the magnetic film: $E \approx K_{u1} \sin^2\theta + K_{u2} \sin^4\theta$ (θ is an angle between the spontaneous magnetization and the axis of easy magnetization of the magnetic film), the K_u and K_{u2} were derived. Thus obtained K_u and K_{u2} were plotted against the reciprocal of the applied magnetic field (1/H) and straight lines were
20 obtained as approximation. From the approximation line of K_u versus 1/H, the K_u value was determined as the sum of the value of K_u at 1/H = 0 (the section with the ordinate of the extrapolated straight line) and 2 π M_s² (M_s is the saturation magnetization). The K_{u2} was defined by the extrapolated value itself of the above-
25 described straight line. From the relation $K_u = K_{u1} + K_{u2}$, the K_{u1} value was determined as $K_u - K_{u2}$.

Table 1

	Ku (erg/cm ³)	Ku ₁ (erg/cm ³)	Ku ₂ (erg/cm ³)	Ku ₂ /Ku (%)
medium A ₂	5.1 x 10 ⁶	3.76 x 10 ⁶	1.38 x 10 ⁶	27.1
medium B ₂	3.6 x 10 ⁶	2.84 x 10 ⁶	0.73 x 10 ⁶	20.3
medium C ₂	2.1 x 10 ⁶	1.83 x 10 ⁶	0.24 x 10 ⁶	11.5
medium D ₂	3.8 x 10 ⁶	2.95 x 10 ⁶	0.82 x 10 ⁶	21.8

Table 1 clearly shows that the Ku is largest in the medium A₂ according to the invention. Because thermal stability of recorded magnetization is represented by KuV/kT , the medium A₂, exhibiting the largest Ku value, is the best in the thermal stability of recorded magnetization.

Table 1 also shows that the Ku values of medium A₂ and medium D₂ without addition of SiO₂ in the cobalt layer are larger than the Ku values of medium B₂ and medium C₂ with addition of SiO₂ in the cobalt layer in the multilayered lamination film basically composed of cobalt layers and palladium layers. Therefore, SiO₂ is advantageously not added in the cobalt layer for the thermal stability of recorded magnetization.

The ratio Ku_2/Ku is the largest in the medium A₂ according to the invention while simultaneously achieving the highest Ku. Since a switching field H_k in a recording process is represented by $H_k = 2Ku_1/M_s$ as described previously, only the Ku_1 affects the switching field H_k . On the other hand, thermal stability of recorded magnetization depends on $Ku = Ku_1 + Ku_2$. Therefore, by making the

Ku value large and the Ku_2 value also large, that is, making the Ku value large and the ratio Ku_2/Ku large, writing-in to a perpendicular magnetic recording medium is facilitated and thermal stability of recorded magnetization is improved.

5

(Example 4)

Table 2 shows the recording and regeneration performances of SN ratio (SNR) and OW (overwrite) characteristics obtained on perpendicular magnetic recording media each comprising a magnetic
10 film of a multilayered lamination film. Each medium comprises a magnetic film of a multilayered lamination film of Co/95 at% Pd - 5 mol% SiO₂ (in medium A₃), 94 mol% Co - 6 mol% SiO₂ / Pd (in medium B₃), or pure Co / pure Pd (in medium C₃).

15 The medium A₃ according to the invention in this Example 3 was manufactured in the same method and conditions as in Example 1, and description is omitted. The perpendicular magnetic recording media of B₃ and C₃ were manufactured in the same composition and through the same deposition processes as in the medium A₃ except
20 that the magnetic films had the constructions as described above, and the thickness of the Co or Co-SiO₂ layer composing the multilayered lamination film was 0.3 nm.

Evaluation of SNR was conducted at the linear recording density
25 of 470 kFCI using a ring head for an in-plane medium.

Evaluation of two OW characteristics OW1 and OW2 were made on the perpendicular magnetic recording media. The OW1 is an OW characteristic in the case high linear recording density signals are written-in over low linear recording density signals. Evaluation of the OW1 was conducted by overwriting high linear recording density signals over signals that were written with a low linear recording density and taking the ratio of the initially written low linear recording density signals to the remained low linear recording density signals after the overwriting process. Recording densities used in the evaluation of the OW1 was 53.5 kFCI (12T) for the low linear recording density and 642 kFCI (1T) for the high linear recording density. The OW2 is an OW characteristic in the case low linear recording density signals are written-in over high linear recording density signals. Evaluation of the OW2 was conducted, similarly to the evaluation of the OW1, by taking the ratio of the initially written high linear recording density signals to the remained high linear recording density signals after the overwriting process. Recording densities used in the evaluation of the OW2 was 321 kFCI (2T) for the high linear recording density and 42.8 kFCI (15T) for the low linear recording density.

Table 2

	OW1 (dB)	OW2 (dB)	SNR (dB) (470 kFCI)
medium A ₃	40.8	40.6	20.0
medium B ₃	38.3	38.5	19.1
medium C ₃	33.6	36.2	18.8

Table 3 shows that the SNR is highest in the medium A₃ according to the invention, followed by in medium B₃, and the lowest in medium C₃. Large SNR achieves lowered noise and enhanced recording density. The medium A₃ has attained high SNR as compared with the media B₃ and C₃, thus enhances recording density and improves recording and regeneration performance.

The medium A₃ according to the invention exhibited the OW1 of 40.8 dB and the OW2 of 40.6 dB, which are larger than the respective OW characteristics of the medium B₃ and the medium C₃. Therefore, the medium A₃ achieves higher OW characteristics than the medium B₃ and the medium C₃, demonstrating improvement in the recording and regenerating characteristics.

As described above, the medium A₃ in which SiO₂ is not added in the cobalt layers and added in the palladium layers according to the invention has achieved higher SNR and OW characteristics and improvement in recording and regeneration performance as compared with the medium B₃ described previously in the section of studied items and the medium C₃ according to the conventional technology.

CLAIMS

What is claimed is:

1. A perpendicular magnetic recording medium comprising a
5 magnetic film formed on a nonmagnetic substrate, characterized in
that the magnetic film is a multilayered lamination film composed of
alternately laminated first magnetic layers of cobalt layers and
second magnetic layers of palladium layers, the second magnetic
layers containing silicon oxide.

10

2. The perpendicular magnetic recording medium according to
claim 1 characterized in that:

crystalline magnetic anisotropy energy of the magnetic film is
approximated by $E \approx Ku_1 \sin^2\theta + Ku_2 \sin^4\theta$, where Ku_1 and Ku_2 are
15 uniaxial anisotropy constants, θ is an angle between spontaneous
magnetization and an axis of easy magnetization of the magnetic film,
and a crystalline magnetic anisotropy constant Ku holds a relation
 $Ku = Ku_1 + Ku_2$, and

the Ku and the Ku_2 obtained by magnetic anisotropy
20 measurement using a torque magnetization meter under a condition
of approximately saturated magnetization of the magnetic film satisfy
a relation $Ku_2 / Ku \geq 0.25$.

3. The perpendicular magnetic recording medium according to
25 claim 1 or claim 2, characterized in that an amount of the added
silicon oxide is in the concentration range of 2 to 8 mol%.

4. The perpendicular magnetic recording medium according to any one of claims 1 through 3, characterized in that a thickness of the first magnetic layer is in the range of 0.2 to 0.5 nm and a thickness of
5 the second magnetic layer is in the range of 0.6 to 1.0 nm.

5. The perpendicular magnetic recording medium according to any one of claims 1 through 4, characterized in that an underlayer is provided between the magnetic film and the substrate, and the
10 magnetic film is provided directly on the underlayer.

6. The perpendicular magnetic recording medium according to claim 5, characterized in that the underlayer is a ruthenium film.

15 7. The perpendicular magnetic recording medium according to claim 5 or claim 6, characterized in that a thickness of the underlayer is in the range of 5 to 20 nm.

8. The perpendicular magnetic recording medium according to
20 any one of claims 5 through 7, characterized in that a surface of the underlayer is adsorbed with oxygen.

9. The perpendicular magnetic recording medium according to any one of claims 5 through 8, characterized in that an alignment
25 control layer is provided between the substrate and the underlayer for C-axis alignment of crystal alignment of the underlayer,.

10. The perpendicular magnetic recording medium according to claim 9, characterized in that the alignment control layer is composed by laminating a first alignment control layer and a second alignment control layer.

5

11. The perpendicular magnetic recording medium according to claim 10, characterized in that the first alignment control layer is a tantalum layer and the second alignment control layer is selected from a NiFeNbB layer, a NiFeCr layer, and a NiFeSi layer.

10

12. The perpendicular magnetic recording medium according to claim 11, characterized in that:

a composition of the NiFeNbB layer is in the range of 64 to 86 at% Ni, 10 to 20 at% Fe, 2 to 10 at% Nb, and 2 to 6 at% B;

15 a composition of the NiFeCr layer is in the range of 50 to 70 at% Ni, 10 to 20 at% Fe, and 20 to 30 at% Cr;

a composition of the NiFeSi layer is in the range of 70 to 88 at% Ni, 10 to 20 at% Fe, and 2 to 10 at% Si; and

20 a total of the compositions of elements composing each second alignment control layer is 100 %.

13. The perpendicular magnetic recording medium according to any one of claims 10 through 12, characterized in that a thickness of the first alignment control layer is in the range of 1 to 5 nm and a
25 thickness of the second alignment control layer is in the range of 5 to 30 nm.

14. The perpendicular magnetic recording medium according to any one of claims 10 through 13, characterized in that a soft magnetic backing layer is provided between the substrate and the first alignment control layer.

5

15. The perpendicular magnetic recording medium according to claim 14, characterized in that the backing layer is composed of an alloy of CoZrNb or CoZrTa, and has a thickness in the range of 50 to 300 nm.

10

16. A method of manufacturing a perpendicular magnetic recording medium, characterized in that the method comprises:

an underlayer deposition step of depositing an underlayer of a ruthenium film on a nonmagnetic substrate, and

15

a deposition step of depositing a magnetic film of multilayered lamination film directly on the underlayer by alternately laminating first magnetic layers of cobalt layers and second magnetic layers of palladium layers containing silicon oxide.

20

17. The method of manufacturing a perpendicular magnetic recording medium according to claim 16, characterized in that the deposition step of depositing the magnetic film is conducted by a sputtering method using a target of cobalt and a target of palladium containing silicon oxide in a concentration range of 2 to 8 mol%.

25

18. The method of manufacturing a perpendicular magnetic recording medium according to claim 16 or claim 17, characterized in that, in the underlayer deposition step, oxygen is adsorbed on a surface of the underlayer by exposing the surface of the underlayer to
5 argon gas at a gas pressure in the range of 0.1 to 10 Pa containing oxygen in the mass flow range of 1 to 10 % for a time duration in the range of 1 to 10 sec.

19. The method of manufacturing a perpendicular magnetic
10 recording medium according to any one of claims 16 through 18, characterized in that the method further comprises, prior to the underlayer deposition step, an alignment control layer deposition step in which a first alignment control layer of tantalum layer and a second alignment control layer of a layer selected from a NiFeNbB
15 layer, a NiFeCr layer, and a NiFeSi layer are deposited for aligning crystal alignment of the underlayer in C-axis alignment; and in the alignment control layer deposition step, the first alignment control layer and the second alignment control layer are laminated.

20. The method of manufacturing a perpendicular magnetic
20 recording medium according to any one of claims 16 through 19, characterized in that the method further comprises, prior to the alignment control layer deposition step, a backing layer deposition step in which a soft magnetic backing layer of a CoZrNb layer or a
25 CoZrTa layer is deposited on the substrate.