hard to fabricate a medium having a higher thermal stability and an excellent recording property by simply adding an oxide such as SiO_2 or O when a medium capable of addressing 400 Gbits/inch^2 or more is intended.

In other words, it was found that the coercive force Hc and the vertical magnetic anisotropy are deteriorated when an amount of the SiO_2 is increased up to a certain amount or more, for example.

[0008] For the demand, it is also possible to propose a method of increasing an amount of Pt in the magnetic recording layer, thereby increasing a magnetic anisotropic energy. However, it is apparent that there is also a new problem in that sufficient recording cannot be carried out with an increase in the magnetic anisotropic energy.

In a recording density region of 100 Gbits/inch^2 or more, particularly, a recording capability of a magnetic head itself is remarkably reduced with a reduction in tracking. For this reason, it is necessary to make an improvement for enhancing the recording capability on the magnetic recording layer side. This leads to a new problem.

There is no end to demand for an increase in an information recording density, and the demand has been increased yearly. In order to achieve the high recording density, it is demanded to enhance the magnetic property of the magnetic disk still more.

Embodiments of the ~~The~~ present invention ~~has been made in consideration of the conventional problems, and has an object to~~ provide a method of manufacturing a vertical magnetic recording disk and the vertical magnetic recording disk which can increase an information recording density by implementing a more enhancement in a magnetic property.

MEANS FOR SOLVING THE PROBLEMS

[0009] One of the applicants previously proposed a vertical magnetic recording disk,

greater mass than a conventional Ar gas, for example, a Kr gas for a sputtering film forming gas of the exchange energy control layer, and completed the present invention.

More specifically, embodiments of the present invention comprise ~~has~~ the following structures to solve the problems.

[0012]

~~(Structure 1) In a method of manufacturing a vertical magnetic recording disk comprising at least a magnetic recording layer on a substrate and used for vertical magnetic recording, in a step of forming, on the substrate, the magnetic recording layer composed of a ferromagnetic layer having a granular structure and an exchange energy control layer formed on the ferromagnetic layer, at least the exchange energy control layer is formed through sputtering in an atmosphere of a rare gas having a greater mass than an argon gas.~~According to an aspect, there is provided a method of manufacturing a vertical magnetic recording disk comprising at least a magnetic recording layer on a substrate and used for vertical magnetic recording at a density greater than 100 Gb/in^2, said method comprising:

a step of providing a substrate; and

a step of forming, on the substrate, the magnetic recording layer , said forming step further comprising (a) forming a ferromagnetic layer having a granular structure and (b) forming an exchange energy control layer on the ferromagnetic layer,

wherein at least the exchange energy control layer is formed through sputtering in an atmosphere of a rare gas having a greater mass than an argon gas, said sputtering being conducted at a gas pressure in a range of 1-10 mTorr and producing said energy control layer having a thickness of 2-5 nm,

wherein the exchange energy control layer is a laminated layer composed of a first layer containing Co or a Co-alloy and a second layer containing palladium (Pd) or platinum (Pt) with said rare gas embedded therein,

whereby the surface roughness of the disk having an exchange energy control layer that is formed through sputtering in an atmosphere of a rare gas having a greater mass than an argon gas, as determined by Ra and Rmax as measured by AFM, is less than that where an exchange energy control layer is formed through sputtering in an atmosphere of argon, and

whereby the coercive force (Hc) of the resulting structure is equal to or greater than 4300 Oe.

In an embodiment, ~~(Structure 2) In the method according to structure 1,~~ the rare gas has ~~having~~ a greater mass than the argon gas is a krypton (Kr) gas.

~~(Structure 3) In the method according to structure 1 or 2, the exchange energy control layer is a laminated layer composed of a first layer containing Co or a Co alloy and a second layer containing palladium (Pd) or platinum (Pt).~~

In an embodiment, ~~(Structure 4) In the method according to any one of structures 1 to 3,~~ the ferromagnetic layer has a crystal grain containing cobalt (Co) as a main constituent and a grain boundary portion containing an oxide, silicon (Si) or a silicon (Si) oxide as a main constituent.

In an embodiment, ~~(Structure 5) In the method according to any of structures 1 to 4,~~ a spacer layer is formed between the ferromagnetic layer and the exchange energy control layer.

[0013]

~~(Structure 6) In a magnetic disk for use in vertical magnetic recording, the~~

~~magnetic disk comprises: a substrate; a ferromagnetic layer formed on the substrate and having a granular structure and containing an oxide, silicon (Si) or a silicon (Si) oxide; and an exchange energy control layer formed on the ferromagnetic layer. The exchange energy control layer includes a laminated layer composed of a first layer containing cobalt (Co) or a Co alloy and a second layer containing palladium (Pd) or platinum (Pt), or the exchange energy control layer includes a single layer containing the Co alloy. The exchange energy control layer contains a krypton (Kr) element.~~

[0013a] In an embodiment, Rmax is 6nm or less and Ra is 0.6nm or less.

[0013b] In an embodiment, the spacer layer is formed in said atmosphere of a rare gas having a greater mass than an argon gas at a thickness of the spacer layer within a range of 0.1 nm to 2.0 nm.

[0013c] In an embodiment, the ferromagnetic layer also is produced in said atmosphere of a rare gas having a greater mass than argon gas.

[0013d] In an embodiment, the sputtering is conducted at a gas pressure in a range of 3-4 mTorr.

[0013e] In an embodiment, the magnetization reversal nucleation field (Hn) of the disk is -1300 Oe or smaller

[0014] As in the above aspect ~~structure 1~~, in a method of manufacturing a vertical magnetic recording disk comprising at least a magnetic recording layer on a substrate and used for vertical magnetic recording, in a step of forming, on the substrate, the magnetic recording layer composed of a ferromagnetic layer having a granular structure and an exchange energy control layer formed on the ferromagnetic layer, at least the exchange energy control layer is formed through sputtering in an atmosphere of a rare gas having a greater mass than an argon gas.

According to embodiments of the present invention, it is possible to suppose, as follows in accordance with considerations by the inventors, the reason why a deterioration in the interface state of the formed film can be suitably suppressed by using the rare gas having a greater mass than the conventional Ar gas. For example, the Kr gas is used for the sputtering film forming gas of the exchange energy control layer formed on the ferromagnetic layer having the granular structure constituting the magnetic recording layer.

When the Kr gas is used as the sputtering film forming gas of the exchange energy control layer, the energy of the gas atom colliding with the target, reflected from the target and reaching the substrate is smaller than that of the Ar gas.

Therefore, it is possible to relieve the effect of mixing atoms over the interface

magnetic recording layer can be reduced to decrease the medium noises, and furthermore, the S/N ratio in the high recording density can be enhanced.

[0016] When the Si or Si oxide is added to the CoPt based or CoPtCr based magnetic material, moreover, a crystal grain size can be reduced.

However, there is caused a problem in that the crystal grain size is excessively reduced and the thermal fluctuation is thus increased if an amount of addition of the Si or Si oxide is large. Therefore, the amount of addition of the Si oxide has been conventionally reduced to be 5 atomic% or less, for example.

For this reason, an increase in the recording density was naturally limited.

On the other hand, in embodiments of the present invention, it is possible to prevent a deterioration in a thermal stability by providing the exchange energy control layer on the ferromagnetic layer containing the oxide, the silicon (Si) or the silicon (Si) oxide even if the amount of addition of the Si or Si oxide is increased. Therefore, it is possible to increase the recording density without deteriorating the thermal stability.

[0017] In embodiments of the present invention, the ferromagnetic layer has a crystal grain containing Co as a main constituent and a grain boundary portion containing an oxide, silicon (Si) or an silicon (Si) oxide as a main constituent.

Consequently, it is possible to magnetically shield the crystal grains which are made fine.

[0018] A content of the silicon (Si) in the ferromagnetic layer is preferably equal to or higher than 6 atomic % and more preferably is in a range of 8 to 15 atomic %.

If the content of the silicon (Si) in the ferromagnetic layer is equal to or larger than 6 atomic %, the S/N ratio is rapidly enhanced. However, 8 to 15 atomic % is preferable for the following reasons.

When the content is smaller than 8 atomic %, the effect of reducing the

medium noises is small and the S/N ratio in the high recording density cannot be enhanced sufficiently. When the content is larger than 15 atomic %, moreover, a vertical magnetic anisotropy is started to be deteriorated so that a deterioration in a thermal stability and an increase in a DC noise in the high recording density are caused.

For the same reasons, the content is particularly preferably in a range of 10 to 15 atomic % and is further preferably in a range of 12 to 15 atomic %.

In embodiments of the present invention, the ferromagnetic layer has a granular structure containing Si or a Si oxide between the magnetic crystal grains containing Co.

Moreover, it is preferable that a film thickness of the ferromagnetic layer should be equal to or smaller than 20 nm. A range of 8 to 16 nm is desirable,

[0019] The exchange energy control layer has the function of carrying out magnetic coupling to the ferromagnetic layer adjacently to the ferromagnetic layer or through the spacer layer and the function of aligning easy directions of magnetization in mutual layers to be almost identical to each other.

The exchange energy control layer has crystal grains coupled magnetically therein.

It is advantageous that the exchange energy control layer should be specifically composed of a film formed by alternately laminating cobalt (Co) or a Co-alloy and palladium *Q?d)* or a film formed by alternately laminating the cobalt (Co) or the Co-alloy and platinum (Pt) for the ferromagnetic layer formed by the Co-based magnetic material. The alternate laminated film composed of the above materials has great magnetic Ku. Therefore, it is possible to reduce a width of a magnetic domain wall formed on the laminated film. It is preferable that a film thickness should be 1 to 8 nm.

It is desirable that the film thickness should be 2 to 5 nm. Even if a single layer film such as CoCrPt having a large Pt content, CoPt, CoPd, FePt, $CoPt_3$ or $CoPd_3$ is

provided adjacently to each other or through the spacer layer, it is preferable that the exchange energy control layer should be disposed on the ferromagnetic layer as viewed from the substrate in respect of an Head Disk Interface (HDI).

Moreover, the ferromagnetic layer is not restricted to a single layer but may be constituted by a plurality of layers. In this case, Co based magnetic layers containing the Si or Si oxide may be combined with each other or the Co based magnetic layer containing the Si or Si oxide and a Co based magnetic layer containing neither the Si nor the Si oxide may be combined with each other.

It is preferable that the Co based magnetic layer containing the Si or Si oxide should be disposed on an adjacent side to the exchange energy control layer.

[0022] As a method of forming the vertical magnetic recording layer according to embodiments of the present invention, it is preferable that the film should be formed by a sputtering method.

When the film is formed by a DC magnetron sputtering method, particularly, the film can be uniformly formed, which is preferable.

In embodiments of the present invention, when the vertical magnetic recording layer composed of the ferromagnetic layer and the exchange energy control layer is to be formed on the substrate, the ferromagnetic layer is formed on the substrate through sputtering in an argon gas atmosphere and the exchange energy control layer is then formed through the sputtering in an atmosphere of a rare gas having a greater mass than an argon gas, for example, a krypton (Kr) gas atmosphere.

[0023] A film forming gas to be used for forming the exchange energy control layer is not restricted to the krypton (Kr) gas if a rare gas having a greater mass than the argon gas is used, but the krypton gas can easily be handled and is therefore preferable.

Moreover, it is preferable that a gas pressure should be low in the film formation of the exchange energy control layer. As a reason, if the ferromagnetic layer

is not provided adjacently, it is necessary to cause the exchange energy control layer to be magnetically uniform in order to fix a magnetic domain wall (a magnetization transition point) by a pinning force generated from a magnetic particle of the ferromagnetic layer everywhere in such a manner that the magnetic domain wall can be moved freely. For this purpose, it is suitable that the film should be formed at a low gas pressure.

In this case, for example, the film is formed through the sputtering at the gas, pressure in a range of 1 to 10 mTorr, preferably, in a range of 3 to 4 mTorr.

Although the temperature of the substrate in forming the exchange energy control layer is not particularly restricted, moreover, it is preferable that the temperature should range from a room temperature to 150°C in respect of suppression of diffusion over a lamination interface, for example.

In embodiments of the present ~~the~~ invention, the exchange energy control layer is formed by the sputtering in the krypton gas atmosphere, for example. Consequently, a krypton (Kr) element is contained in the formed exchange energy control layer.

[0024] On the other hand, it is preferable that the ferromagnetic layer should be formed at a high gas pressure.

This is because a magnetic grain size in the ferromagnetic layer can be reduced and the Si or Si oxide can be subjected to a grain boundary segregation in a uniform thickness between the magnetic crystal grains containing Co in order to decrease the medium noises.

It is preferable that the ferromagnetic layer should be formed by the sputtering at a gas pressure of 15 to 30 mTorr, for example.

In embodiments of the present invention, while the krypton gas is used as the film forming gas of the exchange energy control layer, for example, it is also possible to use the krypton

gas in place of the argon gas for the film forming gas of the ferromagnetic layer,

[0025] While the vertical magnetic recording disk according to the present invention comprises at least the vertical magnetic recording layer on the substrate, it is preferable that various other functional layers should be provided.

For example, it is also possible to provide, on the substrate, a soft magnetic layer for suitably regulating a magnetic circuit of the vertical magnetic recording layer.

In embodiments of the present invention, if the soft magnetic layer is formed by a magnetic body having a soft magnetic property, there is not particular restriction. However, a magnetic property preferably has a coercive force (He) of 0.01 to 80 oersteds and more preferably 0.01 to 50 oersteds.

Moreover, it is preferable that the magnetic property should have a saturation magnetic flux density (Bs) of 500 emu/cc to 1920 emu/cc.

Examples of a material of the soft magnetic layer include an Fe based material and a Co based material.

For example, it is possible to use an Fe based soft magnetic material such as an FeTaC based alloy, an FeTaN based alloy, an FeNi based alloy, an FeCoB based alloy or an FeCo based alloy, a Co based soft magnetic material such as a CotaZr based alloy or a CoNbZr based alloy, or an FeCo based alloy soft magnetic material.

In addition to a single layer structure of the alloy materials, it is also possible to employ a lamination structure in which an Ru layer is interposed between a plurality of layers formed by the alloy materials, for example.

[0026] In embodiments of the present invention, the thickness of the soft magnetic layer is preferably 30 nm to 1000 nm, and is desirably 50 nm to 200 nm.

In some cases in which the film thickness is smaller than 30 nm, it is hard to form a suitable magnetic circuit among the magnetic head, the vertical magnetic

recording layer and the soft magnetic layer. In some cases in which the film thickness is greater than 1000 nm, a surface roughness Is increased.

In some cases in which the film thickness is greater than 1000 nm, moreover, it is hard to carry out the sputtering film formation.

[0027] In the present invention, it is preferable to provide, on the substrate, a non-magnetic ground layer for setting a crystal orientation of the vertical magnetic recording layer in a perpendicular direction to a substrate surface.

As a material of the non-magnetic ground layer, Ru, Pd, Pt and Ta based alloys and a Ti based alloy are preferable. Examples of the non-magnetic ground layer formed by the Ta based alloy include a CoCrTa based alloy and an NiTa based alloy in addition to a Ta single substance.

Examples of the non-magnetic ground layer formed by the Ti based alloy include a TiCr based alloy and a TiCo based alloy in addition to a Ti single substance.

It is suitable that a film thickness of the non-magnetic ground layer should be 2 nm to 30 nm. The function of controlling a crystal axis of the vertical magnetic recording layer is insufficient when the film thickness of the ground layer is smaller than 2 nm. The size of the magnetic crystal grain constituting the vertical magnetic recording layer is increased and thus the noise is increased when the film thickness exceeds 30 nm, which is not preferable.

[0028] In embodiments of the present invention, it is preferable that the substrate should be a glass if annealing in a magnetic field is required to control a magnetic domain of the soft magnetic layer.

Since the glass substrate is excellent in a heat resistance, it is possible to increase a heating temperature of the substrate.

Examples of the glass for the substrate include an aluminosilicate glass, an

alminoborosilicate glass and a soda thyme glass. Above all, the aluminosilicate glass is suitable. Moreover, it is possible to use an amorphous glass and a crystallized glass.

In the case in which the soft magnetic layer is amorphous, it is preferable that the substrate should be an amorphous glass. The use of a chemical strengthened glass is preferable because of a high rigidity

In embodiments of the present invention, it is preferable that a surface roughness of a main surface of the substrate should have Rmax of 6 nm or less and Ra of 0.6 nm or less.

By forming a smooth surface, it is possible to set a gap between the vertical magnetic recording layer and the soft magnetic layer to be constant. Therefore, it is possible to form a suitable magnetic circuit among the magnetic head, the vertical magnetic recording layer and the soft magnetic layer.

[0029] In the present invention, it is also preferable to form a bonding layer between the substrate and the soft magnetic layer.

By forming the bonding layer, it is possible to enhance a bonding property between the substrate and the soft magnetic layer. Therefore, it is possible to prevent the soft magnetic layer from being peeled.

As a material of the bonding layer, it is possible to use a Ti containing material, for example.

From a practical viewpoint, it is preferable that a film thickness of the bonding layer should be set to be 1 nm to 50 *nm*.

[0030] In the vertical magnetic recording disk according to embodiments of the present invention, it is suitable that a protecting layer should be provided on the vertical magnetic recording layer.

By providing the protecting layer, it is possible to protect the surface of the magnetic disk from the magnetic recording head floating and flying over the magnetic

disk.

As a material of the protecting layer, for example, a carbon based protecting layer is suitable. Moreover, it is suitable that a film thickness of the protecting layer should be approximately 1.5 nmto 7 nm.

Moreover, it is preferable that a lubricating layer should be further provided on the protecting layer.

By providing the lubricating layer, it is possible to suppress an abrasion between the magnetic head and the magnetic disk, thereby enhancing durability of the magnetic disk. As a material of the lubricating layer, PFPE (perfluoropolyether) is preferable, for example.

Furthermore, it is suitable that a film thickness of the lubricating layer should be approximately 0.5 nm to 1.5 nm.

[0031] It is preferable that the soft magnetic layer, the ground layer, the bonding layer and the protecting layer should also be formed by the sputtering method.

In particular, a film can be uniformly formed by a DC magnetron sputtering method, which is preferable.

It is also preferable to use an inline type film forming method.

It is also preferable that the protecting layer should be formed by a plasma CVD method. Moreover, it is preferable that the lubricating layer should be formed by a dip coating method, for example.

ADVANTAGE OF TFIE INVENTION

[0032] According to embodiments of the present invention, it is possible to provide a method of manufacturing a vertical magnetic recording disk and the vertical magnetic recording disk which can enhance a magnetic property still more, thereby increasing an

3. The method according to claim 1 or 2, wherein the ferromagnetic layer has a crystal grain containing cobalt (Co) as a main constituent and a grain boundary portion containing an oxide, silicon (Si) or a silicon (Si) oxide as a main constituent.

4. The method according to any one of claims 1 to 3, wherein a spacer layer is formed between the ferromagnetic layer and the exchange energy control layer.

5. The method according to any one of claims 1 to 4, wherein Rmax is 6nm or less and Ra is 0.6nm or less.

6. The method according to claim 4, wherein the spacer layer is formed in ~~in~~ said atmosphere of a rare gas having a greater mass than an argon gas at a thickness of the spacer layer within a range of 0.1 nm to 2.0 nm.

7. The method according to any one of claims 1 to 6, wherein the ferromagnetic layer also is produced in said atmosphere of a rare gas having a greater mass than argon gas.

8. The method according to any one of claims 1 to 7, wherein the sputtering is conducted at a gas pressure in a range of 3-4 mTorr.

9. The method according to any one of claims 1 to 8, wherein the magnetization reversal nucleation field (Hn) of the disk is -1300 Oe or smaller