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Substrate for Perpendicular Magnetic Recording Medium,

**Perpendicular Magnetic Recording Medium using the Substrate, and
Method for those Production**

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Field of the Invention

This invention concerns a substrate for a perpendicular magnetic recording medium, a
perpendicular magnetic recording medium using the substrate, and a method for
10 those production.

Prior Art

A perpendicular magnetic recording medium is classified roughly into two sorts of
15 media, namely a single-layer type and a double-layer type, from the structure of a
magnetic layer formed on a substrate. The one comprises a perpendicular magnetic
recording layer only. The other comprises a double-layered magnetic layer consisting
of a perpendicular magnetic recording layer and a back layer including a soft magnetic
layer. Information is written and read out these perpendicular magnetic recording
20 media with magnetic recording heads, a ring type thin film magnetic recording head
applied in longitudinal magnetic recording and a single-pole magnetic recording
head. This requires strengthening the perpendicular magnetization of these heads so as
to conform to the perpendicular magnetic recording, There are limits, however, to
strengthening the perpendicular magnetic field of these heads for their proper
25 adaptability to the longitudinal magnetic recording. Thus, limitations in the measures

taken to deal with magnetic recording heads require the magnetic recording medium of a structure enabling to improve perpendicular magnetic recording. The double-layer type perpendicular magnetic recording medium with the back layer for enhancing the effect of head magnetic field on the magnetic recording layer, is becoming the main stream from such a viewpoint.

Further, as everyone knows, it is necessary to improve linear density and track density, to improve area density in the perpendicular magnetic recording medium. Linear density refers to density in the circumferential direction of the recording medium, and track density refers to density in the radial direction of the recording medium. Increasing both densities improves effectively area density because both contribute to the area density. However, the current ratio of linear densities to track densities is 12 to 1, and high area density is depended mostly on linear density. Thus, it is indispensable to increase track density, that is information density in the radial direction of the recording medium, in order to achieve high area density in the future.

Then, methods to improve track density have to be devised. First, the magnetic pole width of a corresponding magnetic recording head is narrowed. Recorded track width, the size of a recorded track in the radial direction, is narrowed as a result of the narrowed magnetic pole, improving track density. Track 20 is part of a medium surface, a concentric circle of prescribed width, altered magnetically with a magnetic pole 14 of a magnetic recording head as shown in Figure 8(a).

At a prescribed position above the rotating perpendicular magnetic recording medium is placed the magnetic pole 14 of the magnetic recording head. Skew angle must be taken

into account when the recorded track 20 is formed with the head in this way. Skew angle is formed where an outline of the magnetic pole 14 and an outline of a recording section on the recorded track 20 cross each other as shown in Fig. 8(a). Represented is the outline of the magnetic pole 14 by a front edge 18 and a side edge 19, and the outline of the recorded track 20 by borderlines 21 and 22 in the circumferential direction of the track. Interval between the borderline 21 and the borderline 22 corresponds to recorded track width T_w . On condition that the side edge 19 of the magnetic pole 14 and the borderlines 21, 22 of the recorded track cross each other at a skew angle of zero degrees, the width M_w of the magnetic pole 14 parallels the width of a recording section (a recorded bit) 23 on the recorded track 20, that is recorded track width T_w .

However, the magnetic recording head of the conventional hard disk drive (HDD) is often designed to have skew angles -30 to +30 degrees, assuming that the central, internal, and outer circumference of a magnetic disk has a skew angle of zero, a negative, and a positive in degrees respectively. And hence, the magnetic recording head of an actual HDD works above the rotating perpendicular magnetic recording medium with skew angles varied over the range of some -30 to +30 degrees, causing some recorded bits to have a width equal to and others different from magnetic pole width.

Therefore, when the magnetic recording head works with the skew angle of the magnetic pole 14 varied, the recorded track 20 is formed with both the front edge 18 and the side edge 19 in the magnetic pole 14 as shown in Fig. 8(b). That is, the actual recorded track formed by the magnetic pole 14 differs from an interval between two sides of the magnetic pole in width. Nearly equal, however, is the recorded track width to the magnetic pole's diagonal M_w' . As a result, a recorded bit 24 of a distorted polygon is

formed as shown in the figure. Larger is recorded track width referred to as effective recorded track width T than width T_w mentioned earlier, making it difficult to achieve high recording density.

5 Object of the Invention

The purpose of the present invention is to offer a substrate for perpendicular magnetic recording, a perpendicular magnetic recording medium using the substrate, and the method of manufacturing the substrate and the medium. Of double layer type is the perpendicular magnetic recording medium, is written into and read out with a current
10 ring type thin film magnetic recording head and a single-pole magnetic recording head. The substrate, medium, and method of the present invention provides an increase in the recording density of a magnetic recording layer, keeping recorded track width from growing when the magnetic recording head works with the skew angle of the magnetic pole varied.

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Means to Solve the Problems

Experiments made wholeheartedly to solve the problems reveal that processing the side of a substrate as set forth below improves the recording density of a medium's magnetic layer without an increase in recorded track width even when a magnetic
20 recording head works above a rotating medium with the skew angle of the magnetic pole varied. Used is the substrate in a perpendicular magnetic recording medium of a double-layer type. Grooved is the side of the substrate to give a land and a groove alternated in respective concentric circles with each of the land and the groove arranged at regular intervals. Equalized is the total of land width and groove width with the track pitch
25 of the magnetic recording head used in magnetic recording. And formed is the land to

have width equal to or less than the effective recorded track width of the magnetic recording head, and the groove to have depth 200 nm or more.

The present invention was accomplished according to the findings set forth earlier.

5 Characterized is a substrate for a perpendicular magnetic recording medium of the present invention by a land and a groove the side of the substrate provides. Alternated is the land and the groove in respective concentric circles with each of the land and the groove arranged at regular intervals. Equal is the total of land width and groove width to the track pitch of the magnetic recording head used in magnetic recording. Provided is the
10 side of the substrate with the land equal to or less than the effective record track width of the magnetic recording head in width, and the groove 200 nm or more in depth.

Further, the method of manufacturing a substrate for a perpendicular magnetic recording medium of the present invention is characterized by the process of making a
15 land and a groove set forth below. Grooved is the side of the substrate in concentric circles to form grooves 200 nm or more in depth, arranged at regular intervals in the radial direction. Thus, provided is the side of the substrate with the land and the groove alternated in respective concentric circles with each of the land and the groove arranged at regular intervals. Flat part is the land between grooves 200 nm or more in depth. Grooved
20 is the side of the substrate in concentric circles to give the land and groove equal to the track pitch of a magnetic recording head in total width, and the land equal to or less than the effective recorded track width of the magnetic recording head in width.

Further, a perpendicular magnetic recording medium of the present invention is
25 characterized by a seed layer, an antiferromagnetic layer, a soft magnetic layer, a

under layer, an intermediate layer, a perpendicular magnetic recording layer, a protective layer, and a lubricative layer formed one on top of another on a non-magnetic substrate mentioned below. Provided is the side of the substrate with a land and a groove alternated in respective concentric circles with each of the land and the groove arranged at regular intervals. Equal is the total of land width and groove width to the track pitch of the magnetic recording head. Provided is the side of the substrate with the land equal to or less than the effective recorded track of the magnetic recording head in width, and the groove 200 nm or more in depth.

And further, the method of manufacturing a perpendicular magnetic recording medium of the present invention is characterized by making a non-magnetic substrate as set forth below, and by forming an seed layer, an antiferromagnetic layer, a soft magnetic layer, a under layer, an intermediate layer, a perpendicular magnetic recording layer, a protective layer, and a lubricative layer one on top of another on the non-magnetic substrate. Grooved is the side of the substrate in concentric circles to form grooves 200 nm or more in depth, arranged at regular intervals in the radial direction. Provided is the side of the substrate with a land and a groove alternated in respective concentric circles with each of the land and the groove arranged at regular intervals. Flat part is the land between grooves 200 nm or more in depth. Grooved is the side of the substrate in concentric circles to give the land and groove equal to the track pitch of a magnetic recording head in total width, and the land equal to or less than the effective recorded track width of the magnetic recording head in width.

Brief Description of the Drawings

Fig. 1

Figure 1 is a typical chart of a substrate for a perpendicular magnetic recording medium referred to in the example of the present invention.

5 **Fig. 2**

Figure 2 is a principally sectional view of a substrate taken as indicated along the line II-II' of Fig. 1.

Fig. 3

Figure 3 is a typical chart representing the relation between the effective recorded track width T of a magnetic pole and skew angle θ referred to in the example.

Fig. 4

Figure 4 is a typical chart showing sectional composition of a perpendicular magnetic recording medium of the present invention.

Fig. 5

15 Figure 5 is a diagram representing amplitude TAA and noise in terms of land width referred to in the example.

Fig. 6

Figure 6 is a diagram showing the relation between land width and SN ratio referred to in the example.

20 **Fig. 7**

Figure 7 is a diagram showing the relation between groove depth and effective recorded track width referred to in the example.

Fig. 8

25 Figure 8 is a typical chart showing the relation between skew angle of a magnetic pole in a conventional magnetic recording head and recorded track width formed by the head, Fig.

8 (a) being a typical chart when the magnetic pole has a skew angle of zero degrees, and Fig. 8 (b) skew angles more than zero degrees.

Preferred Embodiment of the Present Invention

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One selected from the group of ceramic, glass, plastics, and metal including aluminum, titanium, and silicon can be used as the substrate of the present invention.

Copying from stamper grooves the side of a substrate on injection molding the plastic
10 substrate to give more than one land and groove.

Further, the side of a metal substrate and a ceramic substrate is grooved with photolithography to give more than one land and groove.

15 Use is made of the more than one land and groove of the perpendicular magnetic recording medium of the present invention to carry ROM information including servo information and confidential information.

Examples

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The following describes an example of the present invention with reference to accompanying drawings. Figure 1 is a typical chart referring to the example of a substrate for a perpendicular magnetic recording medium of the present invention.

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Side of the substrate 1 is provided with more than one groove of prescribed depth in concentric circles at regular intervals. Thus, provided is the side of the substrate 1 with the land 3 and the groove 2 alternated in concentric circles with each of them arranged at regular intervals. Flat part is the land between the grooves.

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Figure 2 is a principally sectional view of a substrate taken as indicated along the line II-II' of Fig. 1. Represented below is the depth of groove 2 by H, groove width Gw, the land width of land 3 Lw, and track pitch Tp as shown in the figure.

10 Further, Fig. 3 is a typical chart representing the relation between the effective recorded track width T of a magnetic pole and skew angle θ . Recorded track width, referred to as effective recorded track width, T equals the track width Y of the front edge 18 plus the track width X of the side edge 19 in a magnetic pole 14, when skew angle θ is larger than zero degrees as shown in Fig. 3.

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Substrate referred to in the example sets the total of groove width Gw and land width Lw equal to track pitch Tp. Effective recorded track width T formed by the head of a recording medium is given in terms of skew angle θ of the magnetic pole 14 of a magnetic recording head.

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It follows that,

$$\text{effective recorded track width } T = X + Y = \delta \sin \theta + Tw \cos \theta ,$$

wherein δ represents the side edge size of the magnetic pole and Tw recorded track width.

To recorded track width Tw, which is equal to magnetic pole width Mw, is reduced

25 recorded track width T when the magnetic pole has a skew angle θ of zero degrees.

As is apparent from the foregoing equation, the larger the skew angle θ of the magnetic recording head, the wider is the effective recorded track width. For instance, track pitch, which implies an adjacent track interval, T_p results in $0.254 \mu\text{m}$, assuming a linear density of 1000 kBPI and a track density of 100 kTPI for an area density of 100Gb/in².

5 Then, track pitch T_p provides the magnetic pole 14 of a magnetic recording head with a magnetic pole width M_w of $0.216 \mu\text{m}$, magnetic pole width M_w being equal to some 85 percent of track pitch. Hence, a land 3, flat part between grooves of the substrate 1, is formed to have land widths L_w of $0.216 \mu\text{m}$ or less, and groove 2 to have groove widths G_w of $0.038 \mu\text{m}$ or more.

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Width G_w of groove 2 has relation to width L_w of land 3 as set forth below.

It follows that,

land width L_w (μm) $\leq 25.4/A \times 1000 \times B$, and

15 groove width G_w (μm) = $T_p - L_w \geq 25.4/A \times 1000 \times (1-B)$,

wherein A (kTPI) is track density, and B is the distribution ratio of land width L_w to groove width G_w under prescribed track pitch T_p .

As mentioned earlier, the magnetic recording head in a HDD is conventionally designed to
 20 have skew angles -30 to +30 degrees, assuming that the central, internal, and outer circumference of a magnetic disk, that is a magnetic recording medium, the head floats over, provides a skew angle of zero, a negative, and a positive in degrees respectively. Polarity of skew angle has no effect on effective recorded track width, and a skew angle of -30 degrees and +30 degrees gives the same effective recorded track width under skew
 25 angles of -30 to +30 degrees. Hence, it is appropriate to design land width L_w and groove

width $Tp-Lw$ with a large absolute value of skew angle θ . The following describes the process of forming the land and the groove of a substrate with land width Lw and groove width $Tp-Lw$ designed in this way under prescribed track density.

- 5 First, copying from a stamper of a injection molding machine grooves the side of a substrate on injection molding the plastics substrate, including polycarbonate, polyolefine, and polyimide, to give a land and a groove. Patterned is the stamper in advance with land width Lw and groove width $Tp-Lw$ designed as set forth earlier.
- 10 Second, photo-resist $1\ \mu\text{m}$ thick was applied to the side of a metal substrate, including Al, Al/NiP, Ti, and Si, a carbon substrate, and a ceramic substrate such as Al_2O_3 . Loaded was the substrate with a mask, exposed, and developed to give photo-resist of a prescribed pattern.
- 15 Grooved was the side of the substrate by reactive ion etching (RIE) of the processed substrate with a mixed gas of argon and chlorofluorocarbon, for example $CClF_3$. And provided was the substrate with a land and a groove by exfoliating the patterned photo-resist.
- 20 Third, the photolithography technique used in the metal substrate and the ceramic substrate, and the melt process used in the plastics substrate can be applied to the formation of a glass substrate with a land and a groove. Melted is glass at temperatures 700 to 800°C

Besides, the land and the groove can store patterned ROM information as well as recording data. Included by ROM information is servo information on the address of recorded data, and confidential information for protecting copyright. Thus, the medium with the land and the groove can be used as a magnetic recording medium with high recording density and security.

The following describes the method of manufacturing a perpendicular magnetic recording medium of a double type by using these substrates.

A plastic substrate was degassed in a vacuum oven. Then, the plastic substrate was put in a vacuum chamber, and the vacuum chamber was pumped to 10^{-5} Pa or less. On the unheated substrate, a seed layer 6, an antiferromagnetic layer 7, a soft magnetic layer 8, an under layer 9, a non-magnetic intermediate layer 10, a perpendicular magnetic recording layer 11, and a protective layer 12 were formed one on top of another with DC magnetron sputtering technique as shown in Fig. 4. Made was a single-layered or multi-layered seed layer 6, the back layer, of Ta, Cu, NiFeCr, etc. Antiferromagnetic layer 7 was made of IrMn, NiMn, PtMn, etc. Soft magnetic layer 8 was made of CoZrNb, CoZrTa, CoFeNi, FeCo, etc. In addition, the under layer 9 was made of Ti, TiCr, Pd, Ru, etc. Non-magnetic intermediate layer 10 was made of CoCr, CoCrTa, CoCrRu, etc. Perpendicular magnetic recording layer 11 was made of CoCrPt, CoCrPtB, TbCo, TbFeCo, TbCoCr, TbFeCoCr, etc. Protective layer 12 was made of DLC carbon, nitrogenous carbon, etc. The substrate was taken out of the vacuum chamber, and lubricative layer 13 was formed by applying fluorocarbon polymer, tetraol, etc. to give the perpendicular magnetic recording medium of a double-layer type. Each layer optimized in layer thickness was formed according to the condition that each layer

material dictates.

DC sputtering, RF magnetron sputtering, face-to-face target type sputtering, ECR sputtering, ion beam sputtering (IBS), and CVD technique can be used instead of the DC magnetron sputtering technique mentioned earlier to give characteristics similar to that obtained with the DC magnetron sputtering technique.

Further, a metal, glass, and ceramic substrate was heated, and layers similar to those in plastics substrate were formed to give a perpendicular magnetic recording medium of a double-layer type.

Figure 5 is a diagram representing Amplitude TAA and noise in terms of land width. Specified is that a magnetic recording head has a magnetic pole width of $0.36\ \mu\text{m}$, a side edge size of $0.30\ \mu\text{m}$, a skew angle of 30 degrees, and a track density of 60 kTPI. Measurement demonstrates that land widths equal to or more than magnetic pole width $0.36\ \mu\text{m}$ increase noise considerably. This is ascribed to an increase in recorded track width of a recorded bit, the formation of a polygon recorded bit, the influence of adjacent recorded tracks, etc. Further, land widths less than magnetic pole width diminishes noise a little. Amplitude, on the contrary, decreases due to the reduction of recorded magnetization.

Figure 6 is a diagram showing the relation between land width and SN ratio. Measurement indicates that the land is required to have land widths 0.32 to $0.36\ \mu\text{m}$ in order to obtain SN ratios 20dB or more. Land has to be minimized to have land widths equal to or less than magnetic pole width, and optimized according to the kind of a

magnetic recording head used and medium characteristic.

Figure 7 is a diagram showing the relation between groove depth and effective recorded track width. Specified is that the magnetic recording head has a skew angle of 20 degrees, other conditions remaining the same. Measurement reveals that shallow groove depth causes the signal recorded in grooves to be detected, increasing effective recorded track width. Groove depths 200nm or more results in an effective recorded track width equal to magnetic pole width $0.36 \mu\text{m}$. Hence, groove widths 200nm or more suffice.

Findings reveals that land widths 0.32 to $0.36 \mu\text{m}$ and groove depths 200nm or more in the substrate provide an increase in recording density and an improvement in the RW characteristic (SN ratio $\geq 20\text{dB}$) of a perpendicular magnetic recording medium, assuming that the magnetic recording head has a magnetic pole width of $0.36 \mu\text{m}$, a magnetic pole's side edge size of $0.30 \mu\text{m}$, a skew angle of 30 degrees, and a track density of 60 kTPI.

Advantageous Effect of the Invention

A perpendicular magnetic recording medium with high recording density and an excellent RW characteristic can be efficiently manufactured with the present inventions as set forth above.

What is claimed is:

1. A substrate for a perpendicular magnetic recording medium is magnetically written and read out with a magnetic recording head comprising:
 - 5 (a) a land; and
 - (b) a groove,said land and groove being alternated in respective concentric circles with each of said land and groove arranged at regular intervals, said land and groove being equal to the track pitch of said magnetic recording head in total width, said land being equal to or less
10 than the effective recorded track width of said magnetic recording head in width, and said groove being 200 nm or more in depth.
2. A substrate for a perpendicular magnetic recording medium as set forth in claim 1, wherein said substrate is composed of one selected from the group of metal, including
15 aluminum, titanium, and silicon, ceramic, glass, and plastics.
3. A method for manufacturing a substrate for a perpendicular magnetic recording medium information is magnetically written into and read out with a magnetic recording head comprising the steps of:
 - 20 (a) grooving the side of said substrate in concentric circles to give a land and a groove, said land and groove being alternated in respective concentric circles with each of said land and groove arranged at regular intervals, said land and groove being equal to the track pitch of said magnetic recording head in total width, said land being equal to or less than the effective recorded track width of said magnetic recording head in width, and
25 said groove being 200 nm or more in depth.

4. A method for manufacturing a substrate for a perpendicular magnetic recording medium as set forth in claim 3, wherein said substrate is composed of one selected from the group of metal, including aluminum, titanium, and silicon, ceramic, glass, and plastics.

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5. A method for manufacturing a substrate for a perpendicular magnetic recording medium as set forth in claim 3 or 4, wherein the side of a plastic substrate is grooved by copying from a stamper on injection molding said substrate to give more than one land and groove.

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6. A method for manufacturing a substrate for a perpendicular magnetic recording medium as set forth in claim 3, or 4, wherein the side of a ceramic or a metal substrate is grooved by photolithography to give more than one land and groove.

15 7. A perpendicular magnetic recording medium including a substrate and a perpendicular magnetic recording layer information is magnetically written into and read out with a magnetic recording head comprising:

(a) a land and a groove of said substrate,

said land and groove being alternated in respective concentric circles with each of said

20 land and groove arranged at regular intervals, said land and groove being equal to the track pitch of said magnetic recording head in total width, said land being equal to or less than the effective recorded track width of said magnetic recording head in width, and said groove being 200 nm or more in depth.

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8. A perpendicular magnetic recording medium as set forth in claim 7, wherein a substrate is composed of one selected from the group of metal, including aluminum, titanium, and silicon, ceramic, glass, and plastics.

5 9. A perpendicular magnetic recording medium as set forth in claim 7 or 8, wherein ROM information, including servo information and confidential information, is formed with more than one land and groove.

10. A method for manufacturing a perpendicular magnetic recording medium including a orientation-control layer, an antiferromagnetic layer, a soft magnetic layer, a under layer, an intermediate layer, a perpendicular magnetic recording layer, a protective layer, and a lubricative layer formed one on top of another on a non-magnetic substrate comprising the steps of:

15 (a)grooving the side of said substrate in concentric circles to give a land and a groove,

said land and groove being alternated in respective concentric circles with each of said land and groove arranged at regular intervals, said land and groove being equal to the track pitch of a magnetic recording head in total width, said land being equal to or less than the effective recorded track width of said magnetic recording head in width, and
20 said groove being 200 nm or more in depth.

11. A method for manufacturing a perpendicular magnetic recording medium as set forth in claim 10, wherein a substrate is composed of one selected from the group of metal, including aluminum, titanium, and silicon, ceramic, glass, and plastics.

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12. A method for manufacturing a perpendicular magnetic recording medium as set forth in claim 10 or 11, wherein the side of a plastic substrate is grooved by copying from a stamper on molding said substrate to give more than one land and groove.

5 13. A method for manufacturing a perpendicular magnetic recording medium as set forth in claim 10 or 11, wherein the side of a ceramic or a metal substrate is grooved by photolithography to give more than one land and groove.

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