TITLE OF THE INVENTION

Method of Manufacturing a Perpendicular Magnetic Recording Medium, Method of Manufacturing a Substrate for Said Recording Medium, a Medium and a Substrate Manufactured by the Methods

CROSS-REFERENCE TO RELATED APPLICATION

This application is based on, and claims priority to, Japanese Patent Application No. 2006-292757, filed on October 27, 2006, the contents of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a method of manufacturing a perpendicular magnetic recording medium, a method of manufacturing a substrate for a perpendicular magnetic recording medium, and a medium and a substrate manufactured by the method

2. Description of the Related Art

A perpendicular magnetic recording system has been practically applied to achieve high density magnetic recording medium in place of a

to achieve high density magnetic recording medium in place of a conventional longitudinal magnetic recording system.

In a conventional longitudinal magnetic recording medium, texture processing is done to facilitate alignment of magnetization in circumferential direction and prevent a magnetic head from adhering to the surface of a magnetic recording medium. The texture processing gives fine streaks in the circumferential direction on a Ni-P plating layer of a nonmagnetic substrate. The texture processing is normally carried out by pressing a polishing tape against the rotating nonmagnetic substrate having a Ni-P plating layer while supplying slurry of abrasive material.

In a perpendicular magnetic recording system, in which magnetization is aligned vertically, texture traces in the circumferential direction aligns magnetization in that direction and may inhibit from achieving low noise performance required by magnetic recording. It is known in a perpendicular magnetic recording system in general that higher accuracy in flatness of a substrate surface results in less magnetic noise and better vertical alignment of magnetization. Accordingly, it has been proposed in a series of steps of manufacturing a magnetic recording medium to implement a polishing step on the surface of a nonmagnetic substrate having a Ni-P plating layer composing a magnetic recording medium to achieve a flat surface with high accuracy, while omitting the texturing step in a circumferential direction, as disclosed in Japanese Unexamined Patent Application Publication No. 2005-216465 and Japanese Unexamined Patent Application Publication No. 2005-149603, for example.

When the texturing step is omitted in the series of steps of manufacturing a magnetic recording medium, and the polishing step is carried out to obtain a flat surface with high accuracy on the surface of a nonmagnetic substrate having a Ni-P plating layer, probability of contact increases between the magnetic head and the recording plane of the magnetic recording medium leading to degradation of reliability, because of lack of the texturing step that would have prevented the magnetic head from adhering to the recording plane of the magnetic recording medium. Meanwhile, flying height of a magnetic head is decreasing recently accompanying along with enhancement of recording density of a magnetic recording medium. A recording plane of such a magnetic recording medium may suffer from head crash due to abnormal protrusions that may be formed by the polishing step. The head crash damages the recording plane of the magnetic recording medium. On a recording plane of a magnetic recording medium of a perpendicular magnetic recording system that is not processed by texturing, minute protrusions may be formed, which do not lead to head crash, but cause various types of noises in read / write of information by the magnetic head.

Japanese Unexamined Patent Application Publication No. 2005-353177, for example, has proposed a method for solving this problem and stabilizing flying characteristic of a magnetic head, in which after a polishing step on the surface of a soft magnetic underlayer, fine streaks of irregularities are formed in the circumferential direction on the smoothed surface of the soft magnetic underlayer. In this method, fine streaks of irregularities in the radial direction are first formed on the surface of a nonmagnetic substrate

composing a magnetic recording medium. Then, a soft magnetic underlayer is formed on this surface by an electroless plating method or the like. Next, the surface of the soft magnetic underlayer is smoothed by polishing. Subsequently on the smoothed surface of the soft magnetic underlayer, the fine streaks of irregularities are formed in the circumferential direction.

In a series of steps of manufacturing a conventional recording medium of a longitudinal magnetic recording system, purposes of the texture processing include enhancing magnetization alignment in the circumferential direction and preventing a magnetic head from adhering to the surface of the magnetic recording medium. The texture processing for those purposes gives fine streaks in the circumferential direction on a Ni-P plating layer of the nonmagnetic substrate, as disclosed in Japanese Unexamined Patent Application Publication No. 2003-49159. The fine streaks in the circumferential direction are formed by pressing a polishing tape against the rotating nonmagnetic substrate having a Ni-P plating layer while supplying slurry of abrasive material. For the case the texture processing generates protrusions or burrs, a means for suppress these faults has been proposed, which uses slurry containing abrasive material, organic acid, and water. Japanese Unexamined Patent Application Publication No. 2003-173517 proposes a texture processing that polishes a nonmagnetic substrate, after polishing treatment on the substrate surface, using a foamed polyurethane tape and slurry containing abrasive grains of colloidal silica (a mean grain diameter in the range of 0.03 to 0.5 μm and a concentration in the range of 3 to 30 wt%) and an additive such as carboxylic acid.

In a series of steps of manufacturing a perpendicular magnetic recording medium, that is, a magnetic recording medium in a perpendicular magnetic recording system, when a polishing step is employed for smoothing the surface of the underlayer of Ni-P alloy without doing texture processing, and fine streaks of irregularities in the circumferential direction are formed on the smoothed surface of the underlayer, an additional step must be done to remove remaining particles (scraped dust), which are abnormal protrusions that can be formed in the polishing step. The polishing step, which leaves random surface configuration, further involves a problem of difficulty in flying of the magnetic head

SUMMARY OF THE INVENTION

In view of the above problems, it is an object of the present invention to provide a method of manufacturing a perpendicular magnetic recording medium and a method of manufacturing a substrate for a perpendicular magnetic recording medium, in which abnormal protrusions on an underlayer composed of a Ni-P alloy are automatically eliminated while assuring a flat surface with high accuracy on the underlayer, and appropriate texture traces are formed that do not give adverse effect on the magnetization alignment in the perpendicular magnetic recording medium and facilitate magnetization alignment in the vertical direction.

To achieve the above object, a method of manufacturing a perpendicular magnetic recording medium and a method of manufacturing a substrate for the medium comprises a step of texturing process in which a

plurality of grooves are formed on an underlayer made of a Ni-P alloy of a substrate having the underlayer using a first polishing tape made of non woven fabric while supplying first slurry containing a surfactant and a first abrasive material; and a step of texture polishing in which a surface of the underlayer processed by the step of texturing process is polished to such a surface roughness that leaves texture traces promoting magnetization alignment in a vertical direction, using a second polishing tape made of a porous material while supplying second slurry containing an organic acid and a second abrasive material having a grain diameter smaller than a mean diameter of perforations of the second polishing tape.

A perpendicular magnetic recording medium and a substrate for the medium of the invention are manufactured by the methods as stated above.

As described above, in the method of manufacturing a perpendicular magnetic recording medium and in the method of manufacturing a substrate for a perpendicular magnetic recording medium according to the invention, a step of texture polishing is carried out in which the surface of the underlayer made of a Ni-P alloy that has been processed by a preceding step of texturing process is polished to such a surface roughness that leaves texture traces promoting magnetization alignment in the vertical direction, using a second polishing tape made of a porous material while supplying second slurry containing an organic acid and a second abrasive material having a grain diameter smaller than a mean diameter of perforations of the second polishing tape. By virtue of this featured constitution of the invention, abnormal protrusions on the underlayer are automatically

eliminated while maintaining a flat surface with a high accuracy on the underlayer, and appropriate texture traces remains to promote magnetization alignment in the vertical direction in a perpendicular magnetic recording medium without adversely affecting the magnetization alignment.

BRIEF DESCRIPTION OF THE DRAWINGS

Figs. 1 is an enlarged partial sectional view showing a part of a polishing tape and a part of a substrate that are used in an embodiment of a method of manufacturing a perpendicular magnetic recording medium according to the invention;

Fig. 2 shows manufacturing steps in an embodiment of a method of manufacturing a perpendicular magnetic recording medium according to the invention;

Figs. 3(A) and 3(B) are partial sectional views showing different embodiments of a method of manufacturing a perpendicular magnetic recording medium according to the invention for the cases of a nonmagnetic underlayer of Ni-P alloy and a soft magnetic underlayer of Ni-P alloy, respectively;

Fig. 4 shows a schematic construction of an essential part of a texture processing apparatus used in an embodiment of a method of manufacturing a perpendicular magnetic recording medium according to the invention;

Fig. 5 is a side view of the texture processing apparatus shown in Fig. 4;

Fig. 6 illustrates operation of the texture processing apparatus shown in Fig. 4;

Fig. 7 shows relationship between surface roughness and processing time in substrates of comparative examples and embodiment examples;

Fig. 8 shows relationship between noise performance and surface roughness of a substrate in perpendicular magnetic recording media of comparative examples and embodiment examples;

Fig. 9 shows measured values of touchdown height on perpendicular magnetic recording media of comparative examples;

Fig. 10 shows measured values of touchdown height on perpendicular magnetic recording media of embodiment examples;

Figs. 11(A), 11(B), 11(C), and 11(D) are pictures of substrate surfaces taken by an atomic force microscope, wherein Figs. 11(A), 11(B), and 11(C) are of embodiment examples processed by texture polishing for 5 sec, 10 sec, and 30 sec, respectively, and Fig. 11(D) is of a comparative example processed by texture processing only;

Figs. 12(A), 12(B), 12(C), and 12(D) show surface roughness data corresponding to Figs. 11(A), 11(B), 11(C), and 11(D), respectively;

Figs. 13(A) and 13(B) are pictures of surface configuration of substrates taken by an atomic force microscope, wherein Fig. 13(A) is of a comparative example processed by polishing poly, and Fig. 13(B) is of an embodiment example processed by D processing; and

Figs. 14(A), 14(B), and 14(C) are pictures of surface configuration of substrates take by an atomic force microscope in comparative and embodiment examples processed by A processing, B processing, and C processing, respectively.

DETAILED DESCRIPTION OF THE INVENTION

Fig. 2 shows a series of steps in a method of manufacturing a perpendicular magnetic recording medium of an embodiment according to the invention.

Figs. 3(A) and 3(B) show perpendicular magnetic recording media manufactured by a method of the invention, in which Fig. 3(A) shows an embodiment with a nonmagnetic underlayer 6 of Ni-P alloy and Fig. 3(B) shows an embodiment with a soft magnetic underlayer 6. A perpendicular magnetic recording medium 10 manufactured by the series of steps shown in Fig. 2 comprises a pretreatment layer 4, an underlayer 6 made of a Ni-P alloy, a soft magnetic backing layer 7 (in the case of Fig. 3(A)), a nonmagnetic seed layer 8, a perpendicular magnetic recording layer 12, and a protective layer 14 sequentially laminated on the surface of a nonmagnetic base plate 2,

The nonmagnetic base plate 2 is preferably a disk having a through hole in the center. An aspect of embodiment of a substrate for a perpendicular magnetic recording medium according to the invention is a disk-shaped substrate 22 including a nonmagnetic base plate 2 and an underlayer 6 of Ni-P alloy provided on the nonmagnetic base plate 2. Figs. 3(A) and 3(B) schematically show a partial cross-section along the radial direction of a perpendicular magnetic recording medium 10 composed of a perpendicular magnetic recording layer 12 and other layers formed on the substrate 22. Every layer over the nonmagnetic base plate 2 can be formed similarly on

the other side of the base plate, though not shown in the figures.

The nonmagnetic base plate 2 is made of a nonmagnetic material, for example, an aluminum alloy. Useful nonmagnetic materials other than the aluminum alloy include strengthened glass, crystallized glass, polycarbonate, polyolefin, and other plastic resins. A nonmagnetic base plate 2 can be manufactured from such plastic resins by injection molding.

The pretreatment layer 4 formed on the surface of a nonmagnetic base plate 2 of aluminum alloy is a zinc film formed by dipping in zincate solution (a liquid containing zinc oxide and caustic soda solution).

A pretreatment layer, when formed on a nonmagnetic base plate made of strengthened glass, crystallized glass, or plastics is generally treated for activation in which palladium nuclei are precipitated on the surface of the base plate by sequentially dipping in tin chloride acidic solution with hydrochloric acid and palladium chloride acidic solution with hydrochloric acid. Physical evaporation techniques such as sputtering and ion plating can also be used to form a film of Ni, Ni-P, Cu, Cr, Fe, or Pd.

An underlayer 6 laminated on the pretreatment layer 4 is composed of a nonmagnetic or soft magnetic N-P alloy and laminated by principally an electroless plating method. An electroless plating layer of Ni-P alloy is substantially nonmagnetic in a phosphorus concentration higher than about 10 wt% and exhibits soft magnetic property in the lower phosphorus concentration. An underlayer 6 composed of a soft magnetic Ni-P alloy can

be used as at least a part of a soft magnetic backing layer of a perpendicular magnetic recording medium as shown in Fig. 3(B). A structure is yet possible in which a soft magnetic Ni-P alloy layer is provided on a nonmagnetic Ni-P layer. In that structure, the present invention can be applied to either one or both of the nonmagnetic Ni-P alloy layer and the soft magnetic Ni-P alloy layer. The Ni-P alloy layer is preferably laminated by the electroless plating technique from the view point of mass production at a low cost. However, other general techniques for film deposition including physical evaporation techniques such as sputtering and ion plating can also be employed depending on required characteristics. In the present specification, a substrate 22 is defined by a structure including a nonmagnetic base plate 2 and an underlayer 6 composed of a nonmagnetic or soft magnetic Ni-P alloy layer formed on the base plate 2.

A nonmagnetic seed layer 8 is formed, on the underlayer 6, of a material that favorably control crystal alignment and grain size of a perpendicular magnetic recording layer 12 that is described later. Preferable materials in the case of a perpendicular magnetic recording layer 12 composed of a magnetization film of a lamination of cobalt alloy and platinum in particular, include Ti, Ru, Re, Os and alloys of these elements.

A perpendicular magnetic recording layer 12 can be formed of any material that performs recording and reproduction in a perpendicular magnetic recording medium. The examples include cobalt alloy and platinum. Preferable materials are a material having a granular structure consisting of a CoCrPt alloy and an oxide of silicon or titanium, and a

material having a lamination structure of multiple layers of cobalt layers and platinum or palladium layers.

A protective layer 14 can be a thin film of mainly carbon.

On the protective layer 14, a liquid lubricant layer (not shown in the figure) is preferably formed by applying a liquid lubricant such as perfluoropolyether.

The nonmagnetic seed layer 8, a perpendicular magnetic recording layer 12, and a protective layer 14 can be formed by any thin film formation method selected from a sputtering method, a CVD method, a vacuum evaporation method, a plating method and the like. In the case of the underlayer 6 of a nonmagnetic Ni-P alloy, a soft magnetic backing layer 7 (Fig. 3(A)) is preferably formed between the underlayer 6 and the nonmagnetic seed layer 8. Another nonmagnetic seed layer (composed of Pt, Pd, or Ta, for example) or a soft magnetic seed layer (composed of CoNiFe, for example) may be further provided (not shown in the figure) between the underlayer 6 of Ni-P alloy and the nonmagnetic seed layer 8 in the case without a soft magnetic backing layer (Fig. 3(B)), or between the soft magnetic backing layer 7 and the nonmagnetic seed layer 8 in the case with the soft magnetic backing layer 7 (Fig. 3(A)). Additional layers can be provided between the layers described above as far as it does not adversely affect the performance of the existing layers. Patent Document 2006-120231, for example, discloses a favorable example of a perpendicular magnetic recording medium in detail, though the names and representation of the

layers are different a little from those in the present specification.

Referring to Fig. 2, the process of manufacturing a perpendicular magnetic recording medium 10 described above is principally comprised of a step of Ni-P plating S1, a step of annealing S2, a step of polishing S3, a step of texturing S4, a step of sputtering S5, and a step of liquid lubricant application S6. The step of texturing S4 is featured in the present invention and includes a step of-texturing process S41 and a step of texture polishing S42. These steps will be described in the following.

The step of Ni-P plating S1

In the step of Ni-P plating S1, when a nonmagnetic base plate 2 is an aluminum alloy base plate, the surface of the nonmagnetic base plate 2 cut in a disk shape is first cleaned by alkali rinsing and acid etching. The cleaned nonmagnetic base plate 2 is then dipped in zincate solution, thereby forming a pretreatment layer 4 of a zinc film having a predetermined thickness. In the case of a nonmagnetic base plate 2 of glass or silicon, a pretreatment layer 4 of an activation treatment layer is formed in which palladium nuclei are formed on the surface of the base plate by sequentially dipping in a tin chloride acidic solution with hydrochloric acid and a palladium chloride acidic solution with hydrochloric acid. Alternatively, a pretreatment layer 4 of Ni, Ni-P, Cu, Cr, Fe, or Pd is formed by means of a physical evaporation method such as a sputtering method or an ion plating method.

After that, an underlayer 6 is formed on the pretreatment layer 4 of the

nonmagnetic base plate 2 by Ni-P electroless plating.

A step of annealing S2

In the step of annealing S2, heat treatment is done on the nonmagnetic base plate 2 having the underlayer 6, that is, on a substrate 22, at a temperature in a predetermined range and for a predetermined period.

A step of polishing S3

Polishing processing is done on the surface of the underlayer 6 for smoothing the surface.

A step of texturing S4

A step of texturing process S41

In the step of texturing process S41, texture processing is done on the surface of the underlayer 6 of the substrate 22. The texture processing is carried out using a texture processing apparatus shown in Figs. 4, 5, and 6. Every phase of the texture processing is controlled by a control unit (not shown in the figures) for the texture processing apparatus.

The texture processing apparatus comprises: a chuck mechanism 24 detachably holding the substrate 22 that has a hole in the center and an underlayer formed thereon, a rotary driving device 26 rotating the chuck mechanism 24 together with the substrate 22 connected to the chuck mechanism 24, tape polishing mechanisms 28A and 28B that press a part of polishing tape 34 against the both surfaces of the substrate 22 that are to be polished and carry out polishing, a tape polishing mechanism shifting

devices 30A and 30B that bring the tape polishing mechanisms 28A and 28B approaching or separating one another along the center line of the chuck mechanism 24, an oscillation device 32 that oscillates the tape polishing mechanisms 28A and 28B simultaneously in the radial direction of the substrate 22, and slurry supply sections 42A and 42B that supply slurry to the surface of the substrate 22 to be processed.

The chuck mechanism 24 disposed along the common central axis with the through hole of the substrate 22 holds the substrate 22 so that the central axis crosses the flat surface of the substrate 22 nearly at right angle. The rotary driving device 26 is a drive motor, for example, and rotates the substrate 22 and the chuck mechanism 24 at a rotating speed in the range of 50 to 500 rpm.

The tape polishing mechanisms 28A and 28B opposing each other interposing the substrate 22 therebetween have the same structure. So, description is made on the tape polishing mechanism 28A only and a description on the tape polishing mechanism 28 B is omitted.

The tape polishing mechanism 28A comprises a feed roller 40c feeding a polishing tape 34 (described later), a wind roller 40b winding the polishing tape 34, a press roller 40a pressing a part of the continuously fed polishing tape 34 against the surface of the substrate 22 to be processed, and tension rollers 40d each gives tensional force on the part of the polishing tape 34 hung between the press roller 40a and the feed roller 40c and the part of the polishing tape 34 hung between the press roller 40a and the wind roller 40b.

The polishing tape 34 is non woven type processed fabric. The width of the polishing tape 34 is preferably a width covering the whole width in the radial direction of the surface of the substrate 22 to be processed.

The wind roller 40b is connected to an output shaft of a drive motor (not shown in the figures). By operation of the drive motor, the polishing tape 34 fed from the feed roller 40c is moved in the direction of the arrows in Fig. 4 and, through the press roller 40a, wound continuously by the wind roller 40b at a predetermined speed. As a result, a part of the polishing tape 34 continuously fed and wound on the outer peripheral surface of the press roller 40a is continuously made in new contact with the surface of the substrate 22 to be processed. The tape polishing mechanisms 28A and 28B are provided with slurry supply sections 42A and 42B, respectively, which supply slurry onto the surface of the substrate 22 to be processed. The slurry is a mixture of a surfactant and abrasive grains of polycrystalline diamond, for example.

The slurry supply sections 42A and 42B are arranged in the tape polishing mechanism 28A and 28B with the tips of the slurry supply sections opposing the surfaces of the substrate 22 to be processed. Accordingly, the slurry supply sections 42A and 42B are arranged opposing each other with the substrate 22 therebetween, as shown in the enlarged drawing of Fig. 6. The slurry supply sections 42A and 42B are moved together with the tape polishing mechanism 28A and 28B.

In texture processing, the tape polishing mechanisms 28A and 28B are

first moved from a waiting position separated from the surface of the substrate 22 to be processed, as indicated by the two-dot chain line in Fig. 4, to the polish execution position indicated by the solid line in Fig. 4 along the center line of the substrate 22 by a tape polishing mechanism transfer devices 30A and 30B. Then, a part of the polishing tape 34 is pressed to the surface of the substrate 22 being processed as shown in enlarged drawing of Fig. 6 while the substrate 22 is rotating in the direction of arrow with the slurry being supplied from the slurry supply sections 42A and 42B. At the same time, the tape polishing mechanisms 28A and 28B are oscillated by the oscillation device 32 as shown in Fig. 5 in the radial direction indicated by the double-headed arrow. In Fig. 5, the length of the double-headed arrow and the position of the polishing tape 34 indicated by the dotted line are exaggerated for clear expression of the oscillation.

As a result, predetermined multiple of grooves are formed in a nearly circumferential direction on the underlayer 6 that is a surface of the substrate 22 being processed.

After completion of the texture processing on the whole processed surface of the substrate 22, the slurry supply from the slurry supply sections 42A and 42B is stopped.

The tape polishing mechanisms 28A and 28B are stopped from working and returned to the waiting position separated from the processed surface of the substrate by the tape polishing mechanism transfer devices 30A and 30B.

A step of texture polishing S42

In the subsequent step of texture polishing S42 in Fig. 2, a processing of texture polishing is carried out for about 30 sec on the surface of the substrate 22 on which the step of texturing process S41 has been accomplished. The processing of texture polishing is carried out using the texture processing apparatus shown in Fig. 4 in which the polishing tape 34 is replaced by a polishing tape 36 the latter is described hereinafter.

The polishing tape 36 is made of a porous material, for example, a urethane foam pad, as shown in the enlarged view of Fig. 1. A mean diameter Da of perforations and a rate of perforations of the urethane foam pad are 40 μm and 25 %, respectively. The width of the polishing tape 36 is preferably a width covering the whole width in the radial direction of the surface of the substrate 22 to be processed.

Usable slurry contains at least an abrasive material 38 and an organic acid. The abrasive material 38 is preferably single crystal or polycrystalline diamond or colloidal silica having a grain diameter smaller than the mean diameter Da of perforations of the polishing tape 36. The organic acid is citric acid, for example. The organic acid can also be selected from maleic acid, malic acid, phosphoric acid, succinic acid, formic acid, a mixture of these acids, and a mixture of the mixed acid and a surfactant.

This processing of texture polishing forms an appropriate texture trace on the surface of the underlayer 6 of the substrate 22. A surface roughness (arithmetic mean roughness) Ra of the obtained underlayer 6 of the substrate

22 can be made no larger than 0.5 nm (5 Å), more preferably in a range of 0.05 nm to 0.2 nm.

A step of sputtering S5

Subsequently, after cleaning and drying (not shown in Fig. 2), the sputtering step S5 in Fig. 2 forms a nonmagnetic seed layer 8, a perpendicular magnetic recording layer 12, and a protective layer 14 by sequentially laminating on the polished surface of the underlayer 6 by means of a sputtering method, for example.

A step of liquid lubricant application S6

Finally, a liquid lubricant layer is applied and formed on the protective layer 14 in the step of liquid lubricant application S6. Thus, a perpendicular magnetic recording medium 10 is obtained.

Examples

Example 1

Manufacturing a substrate

A disk of 3.5 inch diameter of an Al-5 wt% Mg alloy was prepared for a nonmagnetic base plate 2. After cleaning the surface by alkali cleaning and acid etching, zincate (substitution zinc plating) was made for a pretreatment layer of electroless Ni-P plating. Then, a nonmagnetic underlayer of Ni-P alloy with a thickness of about 13 μm was formed using a commercially available electroless Ni-P plating solution for hard disk substrates (Nimuden HDX manufactured by C.Uyemura & Co., Ltd.) in a plating bath controlled

at a Ni concentration of 6.0 ± 0.1 g/L, pH 4.5 ± 0.1, and liquid temperature 92 ± 1°C. The average phosphorus concentration of the nonmagnetic Ni-P plating film was 12 wt%. Then, annealing was done at 250 °C for 30 min and the surface was smoothened by polishing.

Then, texture processing was carried out according to the step of texturing process S41 as described previously using a polishing tape of non woven fabric of nylon with a width of about 4 cm and slurry containing about 0.1 wt% of polycrystalline diamond with a mean grain diameter of 0.05 μm and a coolant material. The conditions in the texture processing were a rotating speed of the disk substrate of 400 rpm, a press roller made of nitrile rubber with a hardness of 50 duro, and a pressure on the polishing tape of 1.5 kgf/cm^2. The winding speed of the polishing tape was 35 mm/min, the oscillation frequency was 5 Hz, oscillation amplitude was 1 mm, and the slurry supply rate was 20 mL/min. The time for the texture processing was 20 sec for a disk including simultaneous processing on both front and back surfaces. Arithmetic mean roughness Ra was measured on the surface of the obtained disk substrate having texture traces, resulting in Ra of 0.15 nm.

Then processing of texture polishing was done on the substrate 22 varying polishing time and type of slurry according to the step of texture polishing S42 as described previously to obtain several substrates 22. The conditions in the texture polishing were a rotating speed of the disk substrate of 400 rpm, a press roller made of nitrile rubber with a hardness of 50 duro, and a pressure on the polishing tape of 1.5 kgf/cm^2. The winding speed of

the polishing tape was 35 mm/min, the oscillation frequency was 5 Hz, oscillation amplitude was 1 mm, and the slurry supply rate was 20 mL/min.

Evaluation 1: Surface roughness of the substrate (Ra values obtained by AFM)

Fig. 7 shows the experimental result.

In Fig. 7, the ordinate represents the surface roughness (arithmetic mean roughness Ra), and the abscissa represents polishing time (sec). The characteristic lines L1 and L2 show surface roughness on the underlayer 6 of a nonmagnetic Ni-P alloy layer of the substrates 22 processed by the texture polishing for various times using two types of slurry.

The characteristic line L1 was obtained on the substrates 22 of comparative examples that were polished using slurry of citric acid (3 % solution) only; the characteristic line L2 was obtained on the substrates 22 of embodiment examples that were polished using slurry additionally containing 0.2 wt% of polycrystalline diamond (mean grain diameter of 0.05 μm) in the citric acid solution. The Ra values were obtained using results of surface configuration measurement by means of an atomic force microscope (AFM) over a surface area of 10μm square and in conformity with the arithmetic mean roughness Ra specified in Japanese Industrial Standards JIS B0601.

As shown by the characteristic line L1 and the characteristic line L2 in Fig. 7, the arithmetic mean roughness Ra (nm) saturates at a processing time

(polishing time) of about 30 sec in the both cases. The arithmetic mean roughness Ra has been reduced twice the more effectively in the characteristic line L2 than in the characteristic line L1 from the texture roughness before the step of texture polishing.

Manufacturing perpendicular magnetic recording media

Perpendicular magnetic recording media 10 as shown in Fig. 3(A) were manufactured by forming a perpendicular magnetic recording layer 12 and other layers on various types of disk substrates 22 on which the steps to the step of texture polishing S42 have been carried out. (The layers except for the substrates were the same as those of "Example 1" in Japanese Unexamined Patent Application Publication No. 2006-120231.)

A substrate 22 after completion of the steps to texture polishing S42 was cleaned and dried, and introduced into a sputtering apparatus, and a CoZrNb amorphous soft magnetic backing layer 7 was deposited to a thickness of 160 nm using a target of Co3Zr5Nb (the numeral represents content of the element after the numeral in at%; representing 3 at% of zirconium, 5 at% of niobium, and the remainder of cobalt; applicable hereinafter). Then, a CoNiFe soft magnetic seed layer 6 nm thick (not shown in the figure) was deposited using a target of Co35Ni4Fe. Subsequently, a Ru nonmagnetic seed layer 8 was deposited to a thickness of 10 nm using a Ru target under an argon gas pressure of 4.0 Pa. Subsequently, a perpendicular magnetic recording layer 12 of CoCrPt-SiO_2 10 nm thick was deposited under a gas pressure of 5.3 Pa using a target of 90 mol% (Co12Cr14Pt) – 10 mol% (SiO_2). Finally, a protective layer 14 of

carbon 7 nm thick was deposited using a target of carbon, and extracted from the vacuum chamber. Deposition of the layers except for the Ru nonmagnetic seed layer 8 and the perpendicular magnetic recording layer 12 of CoCrPt-SiO_2 was carried out under an argon gas pressure of 0.67 Pa. The perpendicular magnetic recording layer 12 of CoCrPt-SiO_2 was formed by means of an RF magnetron sputtering method; and other layers were formed by means of a DC magnetron sputtering method. After that, a liquid lubricant layer 2 nm thick was formed of perfluoropolyether by a dipping method. Thus, a perpendicular magnetic recording medium 10 was manufactured.

Evaluation 2: noise performance of magnetic recording media

Fig. 8 shows results of comparative experiments on perpendicular magnetic recording media 10 studied by the inventors. Fig. 8 shows noise performance of the perpendicular magnetic recording media 10 using substrates 22 that were polished with the types of slurry mentioned previously. In Fig. 8, the ordinate represents the noise performance (S/N ratio [dB]) and the abscissa represents arithmetic mean roughness Ra after processing of texture polishing on the substrate 22. The graph L1 consists of measured values on the substrates of comparative examples that were polished with a slurry of citric acid (3 % solution) only, and the graph L2 is for substrates 22 of embodiment examples that were polished using slurry additionally containing 0.2 wt% of polycrystalline diamond (mean grain diameter of 0.05 μm) in the citric acid solution. The noise performance (S/N ratio [dB]) was measured by a noise measuring instrument (RWA2002 manufactured by Guzik Technical Enterprises Corporation).

As is apparent from the graph L1 and graph L2 in Fig. 8, the noise performance is in correlation with the arithmetic mean roughness Ra after the processing of texture polishing; reduction of the arithmetic mean roughness Ra improves the noise performance. As is apparent from Figs. 7 and 8, it has been confirmed, in the processing of texture polishing using an acid, that the addition of abrasive grains of diamond achieves mirror finish more efficiently and brings about aimed performance in a shorter time.

Example 2

A comparative study was done by the inventors on the effect of the type of slurry replacing the slurry of a citric solution containing 0.2 wt% of polycrystalline diamond (having a mean grain diameter of 0.05 μm) by a slurry containing colloidal silica in place of the polycrystalline diamond.

The abrasive grains of colloidal silica used in this slurry was a mixture of a colloidal silica with a grain diameter of 40 nm and a colloidal silica with a grain diameter of 10 nm in the proportion of 80 % to 20 %. Acid in the slurry was maleic acid. Other conditions were the same as in the example of Fig. 7.

The substrates 22 studied in this experiment were subjected to four types of different processing: A, B, C, and D processing. The A processing includes two times of conventional longitudinal texturing processing, which uses a non woven fabric and a slurry containing cluster diamond and a coolant material. The B processing includes the conventional longitudinal texture processing once and following polishing processing using the

polishing tape 36 (of the urethane foam pad), abrasive grains of minute polycrystalline diamond, and a coolant material for slurry. The C processing includes the conventional longitudinal texture processing once and a following polishing processing using the polishing tape 36, the abrasive grains of minute polycrystalline diamond, and the slurry using 3 % citric acid. The D processing includes the conventional longitudinal texture processing once and following two times of polishing using the polishing tape 36, the abrasive grains of colloidal silica, and the slurry using 3 % citric acid, the processing being carried out by means of the texture processing apparatus.

It has been confirmed in the study by the inventors that the A processing, which is a comparative example, generated a surface configuration having large arithmetic mean roughness Ra and sharp texture traces, which are not suited for perpendicular magnetic recording media but suited for longitudinal (in-plane) magnetic recording media. The B processing, which is a comparative example, has also been confirmed to generate a surface configuration having rather low arithmetic mean roughness Ra but leaving sharp texture traces, which tends to make in-plane alignment of magnetization.

The C processing and the D processing, which are embodiment examples according to the invention, have been confirmed to produce a surface configuration achieving a low arithmetic mean roughness Ra and eliminating a sharp texture trace, and thus, demonstrating favorable for perpendicular magnetic recording media.

Figs. 14(A), 14(B), 14(C), and 13(B) show surface roughness Ra (nm) obtained by measuring the surface roughness by means of an atomic force microscope (AFM) in a square area of 1 x 1 (μm) on a surface of the substrates 22 processed by the A processing, B processing, C processing, and D processing, respectively.

Fig. 14(A) shows a surface roughness of a substrate 22 of a comparative example processed by the A processing; Fig. 14(B) shows a surface roughness of a substrate 22 of a comparative example processed by the B processing; Fig. 14(C) shows a surface roughness of a substrate 22 of an embodiment example processed by C processing; and Fig. 13(B) shows a surface roughness of a substrate 22 of an embodiment example processed by D processing. Fig. 13(A) shows a surface roughness (arithmetic mean roughness Ra: 0.230 (nm)) of a substrate 22 of a comparative example processed by polishing only.

The values of arithmetic mean roughness Ra were 0.262 nm and 0.230 nm in the substrates 22 of comparative examples processed by A processing (shown in Fig. 14(A)) and B processing (shown in Fig. 14(B)), respectively. These values are larger than 0.2 nm and rather large values. Employing the C processing and the D processing, in contrast, the values of arithmetic mean roughness Ra were 0.101 nm and 0.119 nm in the substrates 22 of embodiment examples shown in Fig. 14(C) and Fig. 13(B), respectively. These values are a little larger than 0.1 nm and significantly small values, exhibiting a surface configuration of a substrate that is appropriate for perpendicular magnetic recording media. It has been therefore

demonstrated that the mirror finishing of a substrate surface is possible using abrasive grains of colloidal silica similarly to or even better than the abrasive grains of diamond.

Evaluation 3: surface roughness of substrates (AFM observation)

Figs. 11(A), 11(B), 11(C) and Figs. 12(A), 12(B), 12(C) show results of the studies by the inventors about the effects of processing time of the texture polishing on the surface roughness on the substrates 22.

Figs. 11(A), 11(B), and 11(C) are pictures taken by an atomic force microscope on the surface of the substrates 22 of embodiment examples obtained after the texture polishing for processing time of 5 sec, 10 sec, and 30 sec, respectively. Figs. 12(A), 12(B), and 12(C) show the data of surface roughness obtained on the respective substrates. Figs. 11(D) and 12(D) show an AFM picture and a surface roughness data, respectively, on the surface of a substrate 22 of a comparative example processed by the texture processing only.

As is apparent from Figs. 11(A), 11(B), 11(C) and Figs. 12(A), 12(B), 12(C), the step of texture polishing S42 has eliminated flaws on the surface of the Ni-P plating layer (an underlayer) 6. The texture traces in the circumferential direction can be left in an appropriate degree even after the step of texture polishing using an acid and a urethane foam pad as described previously. Thus, a surface configuration has been obtained having slightly remained texture traces. It has been confirmed by the inventor that the arithmetic mean roughness Ra of the surface configuration on the substrate

can be adjusted by controlling the processing time of the step of texture polishing.

Evaluation 4: evaluation of touch-down height of a perpendicular magnetic recording medium

A touch-down height is used in some cases for evaluating a recording density of a magnetic recording medium and presence of abnormal protrusions on a substrate surface.

A touch-down height is a height at which a test head first comes in contact with the magnetic recording medium during the rotating speed of the medium is gradually decreased while the test head flying over the medium.

The touch-down height was measured by a testing machine (RQ7800 manufactured by Hitachi DECO Company). The testing machine has a collision signal generator that is attached on the test head and generates a voltage on collision with the test piece. The test head is set at a predetermined radial position of the magnetic recording medium. Variation of the voltage is measured during the rotating speed of the medium is gradually decreased. The flying height of the magnetic head has been measured in advance as a function of the rotating speed of the medium by an instrument for measuring a flying height of the test head. Consequently, the flying height of the test head can be obtained from a rotating speed value.

Concerning the relationship between the flying height of a magnetic

head and the recording density of a magnetic recording medium, a relationship is applicable that the higher recording density needs the lower flying height of a magnetic head. Accordingly, a recording density can be evaluated by measuring the touch-down height as described above. It can be considered that the lower touch-down height means possibility of the higher recording density.

When the abnormal protrusions such as particles are present on the substrate surface, the touch-down height is detected high because of collision of the abnormal protrusions on the test head. Therefore, presence of abnormal protrusions can also be evaluated by measuring the touch-down height.

Accordingly, measurement of touch-down height was carried out on the perpendicular magnetic recording media of comparative experimental examples studies by the inventors.

Fig. 9 shows the results of the touch-down height measurement on the perpendicular magnetic recording media of comparative examples with an underlayer 6 of the substrate 22 on which polishing processing was solely executed and texture processing was not executed. Fig. 10 shows the results of the touch-down height measurement on the perpendicular magnetic recording media 10 of embodiment examples with an underlayer 6 of the substrate 22 which is subjected to D processing of Example 2.

In each of the Figs. 9 and 10, the ordinate represents the voltage from

the collision signal generator and the abscissa represents the flying height (nm) of the test head. Figs. 9 and 10 illustrates the characteristic lines L1, L2 and L3 representing touch-down height values measured at radial positions of the test head of 20 mm, 30 mm, and 40 mm, respectively.

As is clearly shown by the characteristic lines of L1, L2, and L3 in Fig. 9, the perpendicular magnetic recording media of comparative examples generated the voltage due to collision of the test head at the flying height of the test head around 8 to 10 nm. In contrast, the perpendicular magnetic recording media of embodiment examples, as is apparent from the characteristic lines L1, L2, and L3 in Fig. 10, exhibited stable flying performance at the flying height of the test head down to 4 to 6 nm.

The results demonstrate that crash due to flaws and adhesion of a magnetic head on a recording plane of a magnetic recording medium are prevented because the step of texturing process S41 eliminates the flaws on the Ni-P plating layer (an underlayer) 6 generated in the step of polishing S3, and further, the following step of texture polishing S42 using the acid eliminates abnormal protrusions to form a plane having appropriate texture traces in the circumferential direction. Therefore, magnetization alignment in the vertical direction is possible while maintaining good flying performance. By making texture traces with an arithmetic mean roughness Ra of at most 0.5 nm (5 Å), preferably in the range of 0.05 nm to 0.2 nm on the substrate 22, a perpendicular magnetic recording medium can be provided that exhibits higher recording density than conventional one and improved flying performance.

CLAIMS

What is claimed is:

1. A method of manufacturing a perpendicular magnetic recording medium comprising:

a step of texturing process in which a plurality of grooves are formed on an underlayer made of a Ni-P alloy of a substrate having the underlayer using a first polishing tape made of non woven fabric while supplying first slurry containing a surfactant and a first abrasive material; and

a step of texture polishing in which a surface of the underlayer processed by the step of texturing process is polished to such a surface roughness that leaves texture traces promoting magnetization alignment in a vertical direction, using a second polishing tape made of a porous material while supplying second slurry containing an organic acid and a second abrasive material having a grain diameter smaller than a mean diameter of perforations of the second polishing tape.

2. The method of manufacturing a perpendicular magnetic recording medium according to claim 1, wherein

the step of texture polishing is carried out until the surface of the underlayer is polished to an arithmetic mean roughness Ra in the range of 0.05 nm to 0.2 nm.

3. The method of manufacturing a perpendicular magnetic recording medium according to claim 1 or claim 2, wherein

the organic acid is selected from the group consisting of citric acid, maleic acid, malic acid, phosphoric acid, succinic acid, formic acid, and a mixture of these acids.

4. The method of manufacturing a perpendicular magnetic recording medium according to any one of claims 1 through 3, wherein

the second abrasive material is abrasive grains of single crystal diamond, polycrystalline diamond, cluster diamond, or colloidal silica.

5. The method of manufacturing a perpendicular magnetic recording medium according to any one of claims 1 through 4, wherein

the second polishing tape made of a porous material is a urethane pad.

6. A perpendicular magnetic recording medium manufactured by the method defined by any one of claims 1 through 5.

7. The perpendicular magnetic recording medium according to claim 6, wherein

a touch-down height of the perpendicular magnetic recording medium is at most 8 nm.

8. A method of manufacturing a substrate for a perpendicular magnetic recording medium comprising:

a step of texturing process in which a plurality of grooves are formed on an underlayer made of a Ni-P alloy of a substrate having the underlayer using a first polishing tape made of non woven fabric while supplying first

slurry containing a surfactant and a first abrasive material; and

a step of texture polishing in which a surface of the underlayer processed by the step of texturing process is polished to such a surface roughness that leaves texture traces promoting magnetization alignment in a vertical direction, using a second polishing tape made of a porous material while supplying second slurry containing an organic acid and a second abrasive material having a grain diameter smaller than a mean diameter of perforations of the second polishing tape.

9. The method of manufacturing a substrate for a perpendicular magnetic recording medium according to claim 8, wherein

the step of texture polishing is carried out until the surface of the underlayer is polished to an arithmetic mean roughness Ra in the range of 0.05 nm to 0.2 nm.

10. The method of manufacturing a substrate for a perpendicular magnetic recording medium according to claim 8 or claim 9, wherein

the organic acid is selected from the group consisting of citric acid, maleic acid, malic acid, phosphoric acid, succinic acid, formic acid, and a mixture of these acids.

11. The method of manufacturing a substrate for a perpendicular magnetic recording medium according to any one of claims 8 through 10, wherein

the second abrasive material is abrasive grains of single crystal diamond, polycrystalline diamond, cluster diamond, or colloidal silica.

12. The method of manufacturing a substrate for a perpendicular magnetic recording medium according to any one of claims 8 through 11, wherein

the second polishing tape made of a porous material is an urethane pad.

13. A substrate for a perpendicular magnetic recording medium manufactured by the method defined by any one of claims 8 through 12.