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5

Method of magnetic transfer for perpendicular recording medium

[Detailed Description of the Invention]

[0001]

[Technical field of the invention]

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The present invention relates to a method for writing servo signals for positioning a read-write head into a magnetic disk surface by means of magnetic transfer technique in a hard disk drive (hereinafter abbreviated to HDD). The HDD, which uses magnetic film as recording material, is now a main stream of external memory. In particular, the present invention relates to magnetic transfer technique in a perpendicular magnetic recording medium, in which the direction of recorded magnetization is perpendicular to the medium surface.

15

[0002]

[Background of the invention]

20

The recording density of a magnetic recording medium for HDD is as high as 20 Gbit/in² in the development stage at present and the memory capacity is increasing in the rate of 60 % a year. With the enhancement of recording density, the size per bit of the magnetic material is diminishing. It is becoming difficult to read-write data by so-called longitudinal magnetic recording system, in which the direction of recorded magnetization is a longitudinal direction, that is, a direction in the surface of the magnetic recording medium. Accordingly, a so-called perpendicular magnetic recording system has been proposed, in which the direction of recorded magnetization is perpendicular to the surface of the magnetic recording medium. A perpendicular magnetic recording medium

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comprises a magnetic recording layer of hard magnetic substance and a backing layer of soft magnetic material that serves to concentrate the magnetic flux generated by the magnetic head and used for recording to the magnetic recording layer.

5 [0003]

In a common HDD, recording and reproduction of data are performed with a magnetic head floating over the surface of the rotating magnetic recording medium of a hollow disk shape. The floating is effected by a floating mechanism called slider and the ~~fly height~~ ^(flying height) is several tens of nm. Bit information on the magnetic recording medium is stored in the data tracks concentrically positioned on the medium. In the recording and reproduction of data, a read-write head moves to the target data track with high speed and positioned. The recording surface of the magnetic recording medium contains preformat information that includes tracking servo signals for detecting relative position between the head and the data track, and address signals or regenerative clock signals. The preformat information corresponding to a data track is recorded on a circle concentric with the data track at certain angular intervals. The preformat information of the whole magnetic recording medium is recorded on preformat sections with a sector form, which is substantially a linear form, arranged at certain angular intervals as shown in Figure 11. For preventing the center of the row of preformat signals from diverting from the center of the magnetic recording medium or from the center of the orbit of the read-write head, the preformat information has been conventionally recorded using a special writing apparatus called a ~~servo slider~~ ^(track writer) after mounting the magnetic recording medium on the HDD.

25 [0004]

Accompanying with the above-described enhancement of recording density, recording density of the preformat information is also increasing, to prolong the time for writing the preformat information. This is becoming a serious factor to lower efficiency in HDD production and to raise HDD cost.

30 [0005].

Recently, a method for writing the preformat information to a magnetic recording medium has been proposed, in which the information is written to the

recording medium with areal manner by means of magnetic transfer technique using a master disk carrying the preformat information, in place of writing to each of the tracks with linear manner using the signal-writing head of a servo slider. For example, Japanese Unexamined Patent Application Publication (KOKAI) No. H10-40544 discloses a method for transferring preformat information to a longitudinal magnetic recording medium using a master disk that has protrusions and recesses, the protrusions being composed of ferromagnetic material. Japanese Unexamined Patent Application Publication (KOKAI) No. H11-25455 discloses a method for close contact between a master disk and a magnetic recording medium in the magnetic transfer process by means of supplying and exhausting air in the groove of the master disk. However, these references don't disclose a magnetic transfer method for a perpendicular magnetic recording medium.

[0006]

A kind of technology for magnetic transfer to a perpendicular magnetic recording medium that is a recording medium where the direction of magnetization for recording is perpendicular to the medium surface has ever been devised. Fig. 3(A) and Fig. 3(B) show an initialization step and a transfer step, respectively, in a devised magnetic transfer method to a perpendicular recording medium. The structure of the master disk used in the method is the same as that in the case of longitudinal magnetic recording medium. In the step for initializing the perpendicular magnetic recording medium, a magnetic field perpendicular to the magnetic recording medium surface is applied using single magnetic pole heads as illustrated in the Fig. 3(A). Two single magnetic pole heads are symmetrically arranged such that the two magnetic poles of different polarity are opposing with the medium put between the poles. This arrangement is taken because (1) spread of magnetic field in the longitudinal direction is smaller than in the case using one single magnetic pole head, and (2) only perpendicular component of magnetic field is applied to the medium. In the step for transferring, the master disk is closely contacted to the medium, and two single magnetic pole heads are likewise symmetrically arranged such that the two magnetic poles of different polarity are opposing with the master disk and

the medium put between the poles, as shown in Fig. 3(B). Here, the direction of the magnetic field is reversed in the transfer step from in the initialization step.
✓[0007]

Fig. 4 also shows a prior art, in which one single magnetic pole head having
5 a yoke is used. In the opposite side of the medium to the head, a thick plate made of soft magnetic substance called a back pole is provided in place of a single magnetic pole head. This arrangement leads the magnetic flux generated by the permanent magnet through the yoke and the back pole so that the magnetic field is perpendicular to the medium surface.

10 [0008]

Fig. 5(A), Fig. 5(B) and Fig. 5(C) show a principle of magnetic transfer in a perpendicular magnetic recording medium. Fig. 5(B) and Fig. 5(C) show magnetic field distribution when a magnetic field is applied to the master disk and the recording medium closely contacted each other, with the field direction perpendicular to their surfaces, using lines of magnetic force and a graph showing the distribution of perpendicular component of the magnetic field. When a uniform and perpendicular magnetic field is applied to the master disk, the uniform flux is concentrated to the embedded soft-magnetic layer having high permeability. Hence, magnetic flux density or magnetic field intensity in
20 the recording medium is large in the position the soft-magnetic pattern is arranged and small in the position in the space between the soft-magnetic pattern, as shown in Fig. 5(B). If a perpendicular magnetic recording medium having coercive force H_c of proper value is used, the direction of magnetization in the region of the medium beneath the soft-magnetic pattern can be reversed in
25 the transfer step from the direction in the initialization step; in Fig. 5(A), the direction is reversed from upward to downward. In the region of the medium beneath the space area where the soft-magnetic pattern does not exist, the magnetization is not reversed and the direction of magnetization holds. Fig. 5(A) illustrates above-described situation and the distribution of intensity of signals
30 when the magnetization transferred to the perpendicular magnetic recording medium is read out.

[0009]

[Problem to be solved by the invention]

According to the principle of magnetic transfer in a perpendicular magnetic recording medium shown in Fig. 5(A), Fig. 5(B) and Fig. 5(C), if the difference in values of magnetic field intensity at the soft-magnetic pattern and magnetic field intensity at the space without the soft-magnetic pattern is significant, in other words, if almost entire magnetic flux is concentrated in the soft-magnetic pattern so that the magnetic field intensity is large at the soft-magnetic pattern and nearly zero at the space without the soft-magnetic pattern, the magnetization in the recording layer beneath the soft-magnetic pattern is reversed and the initial magnetization in the recording layer beneath the space without the soft-magnetic pattern is conserved, which is an ideal circumstance for the magnetic transfer.

[0010]

Concentrating large portion of magnetic flux in the soft-magnetic pattern requires thicker soft-magnetic embedded layer, as well as higher permeability of the soft magnetic substance. Thickness of the soft-magnetic layer is generally from 300 nm to 500 nm at present. The line width in the longitudinal direction of the soft-magnetic embedded layer pattern is 1 μm , or the width of the space without the soft-magnetic pattern is 1 μm . To raise the density of the servo information that is written by magnetic transfer, the length of the soft-magnetic pattern along the circumferential direction of the magnetic recording medium must become finer. However, to obtain finer pattern, the thickness of the soft-magnetic layer is necessary to be thinner. Therefore, coexistence of the fine pattern and the ideal magnetic transfer is difficult.

[0011]

It is therefore an object of the present invention to provide a method of magnetic transfer for a perpendicular magnetic recording medium without increasing the thickness of the soft-magnetic layer than the present value.

[0012]

[Means to solve the problem]

First aspect of a method of magnetic transfer for a perpendicular magnetic recording medium of the present invention is a method magnetically transferring preformat information to a magnetic recording layer of the magnetic recording

medium by applying an external magnetic field in an arrangement where a master disk is in close contact with or in proximity to the magnetic recording medium, the master disk having a non-magnetic substrate and a multiple of isolated soft magnetic material on a surface or in a surface portion of the non-magnetic substrate, the soft magnetic material having a pattern corresponding to the preformat information and being disposed in a linear periodic region, the method comprising:

(1) an initialization step, in which a magnetic field is applied to the magnetic recording medium in a direction perpendicular to a surface of the magnetic recording medium so that direction of magnetization of whole surface of the magnetic recording medium is aligned to one direction perpendicular to the magnetic recording medium, and

(2) a magnetic transfer step, in which a magnetic field in a longitudinal direction is applied to both of the master disk and the magnetic recording medium in an arrangement where the master disk is in close contact with or in proximity to one surface or both surfaces of the magnetic recording medium.

[0013]

Preferably, in the initialization step, a magnetic field is applied to the magnetic recording medium in perpendicular direction (with respect to the medium surface) of the medium using a single magnetic pole head, and in the magnetic transfer step, a magnetic field in a longitudinal direction is applied to the magnetic recording medium and the master disk using one or more ring heads each having a gap.

[0014]

Second aspect of a method of magnetic transfer for a perpendicular magnetic recording medium of the present invention is a method magnetically transferring preformat information to a magnetic recording layer of the magnetic recording medium by applying an external magnetic field in an arrangement where a master disk is in close contact with or in proximity to the magnetic recording medium, the master disk having a non-magnetic substrate and a multiple of isolated soft magnetic material on a surface or in a surface portion of the non-magnetic substrate, the soft magnetic material having a pattern

corresponding to the preformat information and being disposed in a linear periodic region, the method comprising:

- (1) a step for preparing as the magnetic recording medium an uninitialized magnetic recording medium as obtained from a manufacturing step, and
- 5 (2) a magnetic transfer step, in which a magnetic field in a longitudinal direction is applied to both of the master disk and the magnetic recording medium in an arrangement where the master disk is in close contact with or in proximity to one surface or both surfaces of the magnetic recording medium.

[0015]

- 10 Preferably, in the magnetic transfer step, a magnetic field in a longitudinal direction is applied to the magnetic recording medium and the master disk using one or more ring heads each having a gap.

[0016]

- 15 In a magnetic transfer step of first and second aspects of the method of magnetic transfer for a perpendicular magnetic recording medium of the present invention, as heads for transfer magnet, preferably, two ring heads each having a gap are opposed each other, and the magnetic recording medium and the master disk are positioned in a center of the gaps of the two ring heads.

[0017]

- 20 In a magnetic transfer step of first and second aspects of the method of magnetic transfer for a perpendicular magnetic recording medium of the present invention, preferably, the magnetic recording medium has an axis of easy magnetization in a direction perpendicular to a surface of the medium.

[0018]

- 25 In a magnetic transfer step of first and second aspects of the method of magnetic transfer for a perpendicular magnetic recording medium of the present invention, preferably, direction of recorded magnetization in said magnetic recording medium is perpendicular to said magnetic recording medium.

[0019]

- 30 [Aspects of the embodiments of the invention]

A perpendicular magnetic recording medium used in the present invention comprises a non-magnetic substrate, and at least a soft-magnetic layer and a

magnetic recording layer sequentially formed on the substrate. A protective layer and liquid lubricant layer may further be formed on the magnetic recording layer. A structure of a typical perpendicular magnetic recording medium is shown in Fig. 12.

5 [0020]

As a non-magnetic substrate 41, a hollow disk that is a disk having a round hole in the central portion thereof, which is commonly used in a longitudinal magnetic recording medium, may be used. The hollow disk may be made of NiP plated Al alloy, reinforced glass, or crystallized glass. Amorphous cobalt alloy is preferably used for soft-magnetic layer 42, while NiFe alloy or Sendust alloy that is a FeSiAl alloy may also be used. The amorphous cobalt alloy may be obtained by adding metal element or elements selected from the group consisting of Zr, Nb, Ta, Hf, Ti and W, to cobalt. Ferromagnetic material of an alloy containing at least cobalt and chromium is favorably used in magnetic recording layer 44. For the ferromagnetic material to be used in a perpendicular magnetic recording medium, it is necessary that the c-axis of hexagonal closest packed structure of the ferromagnetic material takes orientation in the direction perpendicular to recording surface of the magnetic recording medium. Namely, the axis of easy magnetization of the ferromagnetic material is required to be in the direction perpendicular to the recording surface. It is also important for the material of magnetic recording layer 44 that the coercive force in the perpendicular direction is extremely larger than the coercive force in the longitudinal direction. In order to favorably control crystalline orientation and grain size of the magnetic recording layer 44, an under-layer 43 made of Ti or TiCr alloy, for example, may be provided between the soft magnetic layer 42 and the magnetic recording layer 44. A thin film consisting principally of carbon may be used for protective layer 45. Perfluoropolyether lubricant may be used for liquid lubricant layer 46.

[0021]

A master disk 33 illustrated in Fig. 10 that is used in a conventional longitudinal magnetic recording medium may be used as a master disk in the present invention. A master disk 33 comprises non-magnetic substrate 32 and a plurality of soft magnetic material that are isolated each other, disposed in

periodical and linear region 31, and have a patterns corresponding to the preformat information on the surface or in the surface portion of the non-magnetic substrate.

[0022]

5 Here, "a pattern corresponding to the preformat information" means a pattern used for magnetically transferring the preformat information to the magnetic recording medium. The pattern depends on the specifications of the HDD, and the pattern used in a conventional longitudinal magnetic recording medium may also be used. The pattern is generally disposed in the linear
10 regions 31 extending radially in the master disk and arranged periodically at a certain angular interval as shown in Fig. 10.

[0023]

The non-magnetic substrate 32 of the master disk may be made of glass, silicon, or resin depending on a method for forming the soft-magnetic material
15 pattern. The non-magnetic substrate has a size corresponding to the magnetic recording medium to be transferred, and preferably has the same shape and size as those of the magnetic recording medium. Thickness of the non-magnetic substrate is preferably from 0.2 mm to 0.5 mm depending on the production conditions including the magnetic recording medium to be used and magnetic
20 field intensity.

[0024]

The soft-magnetic material of the master disk preferably has permeability that is substantially larger than longitudinal permeability of the magnetic recording layer of the magnetic recording medium. Namely, relative
25 permeability value of 100 or larger is preferable. By selecting such material, a large magnetic field can be generated in the perpendicular direction of the magnetic recording layer of the magnetic recording medium when a longitudinal magnetic field is applied by a head for magnetic transfer, as described later in detail. Preferable soft-magnetic material includes pure cobalt. As previously
30 described, thickness of the soft-magnetic material is preferably large from the viewpoint of magnetic flux concentration, while the thickness is required to be small for higher density of preformatted information. Thus, the optimum value

of the thickness exists, and preferably in the range from 200 nm to 500 nm, more preferably 250 nm to 350 nm, most preferably 300 nm. The soft-magnetic material of the master disk may be placed on the surface of the non-magnetic substrate 32 or in the surface region of the substrate. To place on the surface means to deposit the soft-magnetic material on the surface of the substrate in a certain pattern. To place in the surface region of the substrate means to form depressions with a certain desired pattern on the surface region of the substrate and to embed the soft-magnetic material in the depressions.

[0025]

The initialization step of the present invention is performed by applying a magnetic field to the perpendicular magnetic recording medium with the field direction perpendicular to the medium surface, as is conventionally employed. For example, two opposing single magnetic pole heads may be used as shown in Fig. 3(A), or a head having a yoke and a back pole may be used as shown in Fig. 4(A). The magnetic field applied in the initialization step is necessary to be larger than coercive force in the perpendicular direction of the magnetic recording layer of the perpendicular magnetic recording medium, and the magnetic field with the intensity of 0.4 to 1 T (Tesla) is generally employed. Although the field to be applied may contain a component in the longitudinal direction of the perpendicular magnetic recording medium, the intensity is preferably smaller than the coercive force in the longitudinal direction of the magnetic recording layer of the perpendicular magnetic recording medium.

[0026]

The magnetic transfer step of the present invention is performed by applying a magnetic field to a combination of the perpendicular magnetic recording disk and a master disk with the field direction in the longitudinal direction of the medium surface, in which the combination consists of the recording medium and a master disk that is in close contact with or in proximity to a surface of the medium or consists of the recording medium and two master disks that are in close contact with or in proximity to two surfaces of the medium. Fig. 1 shows the arrangement in which a master disk is disposed on a surface of the recording medium, and Fig. 2 shows the arrangement, in which two master

disks are disposed on both surfaces of the recording medium.

[0027]

A magnetic head used for applying a longitudinal magnetic field in the magnetic transfer step of the present invention may be a ring head comprising a permanent magnet 4 and yoke 3 attached to both poles of the magnet as shown in Fig. 1. A gap is formed between the tips of the yoke 3. The gap is opposite to the master disk in operation. The width of the gap of the ring head is preferably in the range from 3 mm to 6 mm depending on the master disk and the magnetic recording medium that are used. Although the ring head provided with a permanent magnet is illustrated in Fig. 1 and Fig. 2, the permanent magnet may, of course, be replaced by a solenoid coil with an appropriate size or other means known by the skilled person. The magnetic head generates a magnetic field in the longitudinal direction of the magnetic recording medium in the magnetic transfer step of the invention. The intensity of the generated magnetic field is preferably in the range from 0.4 to 1 T, depending on the coercive force and permeability in perpendicular and longitudinal directions of the magnetic recording layer of the magnetic recording medium, permeability of the soft-magnetic layer of the master disk, and the shape of the magnetic head.

[0028]

The master disk is disposed in close contact with or in proximity to the perpendicular magnetic recording medium. The surface of the master disk opposite to the perpendicular magnetic recording medium is the surface that includes soft-magnetic material portions carrying the preformat information. "To dispose the master disk in proximity to the recording medium" means here that the distance between the surface of the master disk and the opposite surface of the perpendicular magnetic recording medium is controlled to be 1 mm ^{or} ~~to~~ less.

[0029]

In the magnetic transfer step of the invention, the two ring heads are preferably positioned opposite each other and generate a magnetic field in the longitudinal direction of the magnetic recording medium. Physical shape and intensity distribution of the generated magnetic field need to be identical between the two ring heads. In the case in which one master disk is placed on

one surface of the perpendicular magnetic recording medium as illustrated in Fig. 1, the surface of the perpendicular magnetic recording medium in close contact with or in proximity to the master disk is positioned in the center of two ring heads, in more detail, in the center of the two gaps. In other words, the two ring heads are positioned symmetrical each other with respect to the surface of the perpendicular magnetic recording medium in close contact with or in proximity to the master disk. In the case in which two master disks are placed on both surfaces of the perpendicular magnetic recording medium as illustrated in Fig. 2, a plane at the center of the perpendicular magnetic recording medium, which is in equal distance from the both surfaces of the magnetic recording medium is positioned in the center of the two ring heads.

[0030]

The important point of these arrangement is that each of the polarity and the intensity distribution of the magnetic field generated by the two ring heads are symmetrical with respect to the surface of the magnetic recording medium opposing the master disk or with respect to the center plane of the perpendicular magnetic recording medium. A magnetic field generated by single ring head contains a perpendicular component as well as a longitudinal component as shown in Fig. 9(A). By arranging the ring heads symmetrical as shown in Fig. 1 and Fig. 2, the perpendicular magnetic field component can be cancelled around the of the perpendicular magnetic recording medium surface or around the plane disposing the soft-magnetic embedded pattern of the master disk. Consequently, this arrangement allows to apply only longitudinal magnetic field to the surface of the perpendicular magnetic recording medium opposite to the master disk.

[0031]

Distance D_m between the surface of the perpendicular magnetic recording medium opposite to the master disk and a medium-side plane of the gap of the ring head and distance D_m' between the center plane of the perpendicular magnetic recording medium and a medium-side plane of the gap of the ring head are to be optimized depending on the intensity of the magnetic field generated by the ring head, the shape of the soft-magnetic pattern of the master disk, substance of the soft-magnetic layer, and magnetic property of the recording

medium. Preferable ranges of D_m and D_m' are from 1 mm to 4 mm.

[0032]

The magnetic transfer step of the invention is performed by moving the thus arranged ring heads to the place to which preformat information is to be recorded.

5 These movement of the ring heads is necessary to be done along the longitudinal magnetic field generated by the ring head. The ring head may be moved from N-pole to S-pole or S-pole to N-pole of the generated magnetic field. Specifically, the ring head is arranged such that the gap of the ring head is parallel to the radial direction of the recording medium to which preformat information is
10 transferred. The ring head generates a magnetic field while the medium is rotating or the ring head is moving in the direction of the circumference of the medium.

[0033]

Preformat information of the master disk is transferred to a perpendicular
15 magnetic recording medium by employing above-described initialization step and magnetic transfer step. A perpendicular magnetic recording medium to which preformat information is transferred from a master disk having a structure shown in Fig. 10, for example, records the preformat information in linear region
35 extending in the radial direction of the magnetic recording medium 34 and located periodically with a certain angular interval as shown in Fig. 11.

[0034]

Although above-described method comprises initialization step before magnetic transfer step, a method of the second aspect of the present invention does not comprise an initialization step and carries out magnetic transfer step
25 using a magnetic recording medium as obtained from a medium production process, that is, an uninitialized medium. The second aspect of the invention is possible because in the magnetic transfer using longitudinal magnetic field in the invented method, magnetic field for transfer in the perpendicular direction, the field being generated by longitudinal field applied to the master disk, has
30 intense peaks at both edges of the soft-magnetic pattern and opposite directions at the edges, as shown in Fig. 8(C), while details will be described later. Therefore, a pattern of magnetization transition can be recorded on the magnetic

recording medium only by a transfer step without initialization.

[0035]

The arrangement in which two ring heads oppose in the magnetic transfer step in the invention has mostly been described so far. However, magnetic transfer is possible using one ring head in the present invention. Arrangements in magnetic transfer using one ring head are shown in Fig. 13 and Fig. 14. The same conditions for the gap width and the magnetic field intensity as previously described may also be employed in a magnetic transfer using one ring head. Values for D_m and D_m' are preferably in the range from 0.6 to 2.4 mm in order to apply a desired magnetic field to the perpendicular magnetic recording medium by using one ring head. The ring head may be placed either by the side of the master disk or by the side of the recording medium. Use of one ring head is beneficial for avoiding complexity and high cost of the transfer devise.

[0036]

15 <Working>

Benefit of the magnetic transfer step of the present invention using two opposing ring heads will be described in the following in comparison with the case using one single magnetic pole head. The perpendicular magnetic recording medium in the following description is assumed to be magnetized in the initialization step uniformly upward on the drawings.

[0037]

Fig. 6 shows an arrangement of a magnetic recording medium, a master disk, and a single magnetic pole head in an experiment of a magnetic transfer step using one single magnetic pole head. We consider magnetic transfer in the arrangement of Fig. 6. In this experiment, the magnetic recording medium is fixed and not moved relative to the transferring magnet. So, magnetic transfer is done right under the transferring magnet or in their neighborhood. Since only one single magnetic pole head is used, the generated magnetic field spreads toward longitudinal direction as the lines of magnetic force shown in the figure, and includes a longitudinal component and a perpendicular component.

[0038]

Fig. 7(A) shows the width of the used single magnetic pole head and the

lines of magnetic force of the magnetic field generated by the head. Fig. 7(B) is a graph showing intensity distribution of the longitudinal component of the magnetic field generated by the single magnetic pole head on the magnetic recording medium surface. Fig. 7(C) is a graph showing a transfer signal in the transfer with the arrangement of Fig. 6. The transfer signal has two linearly symmetric peaks of signal intensity. The distance between the peaks is from 11.8 mm to 13.5 mm. On the other hand, peaks in longitudinal component of magnetic field intensity distribution generated by the single magnetic head on the medium surface are exist at the positions corresponding to the edges of the single magnetic pole head. The positions nearly agree with the positions of two peaks in the signal intensity.

[0039]

Fig. 9(B) shows longitudinal component and perpendicular component of a magnetic field generated by a single magnetic pole head. The magnetic field intensity distribution of a single magnetic pole head has two peaks in a longitudinal component (a component in X-axis direction), existing at the positions corresponding to the width of the magnet, and one peak in a perpendicular component (a component in Y-axis direction) at the position corresponding to the center of the magnet. The magnitude of the magnetic field intensity at the peak position of each of the longitudinal component and the perpendicular component is nearly the same. The distribution of transferred signal intensity in Fig. 7(C) shows that the two peaks strongly recording transfer signals corresponds to the two peaks in longitudinal magnetic field intensity, and that the transfer signals are recorded by a perpendicular magnetic field generated by application of magnetic field to the master disk. Effective transfer is not performed in the peak of the perpendicular component of the magnetic field at the magnet center although the magnetic field intensity is nearly the same magnitude as of the longitudinal component. The result shows that the perpendicular transferring field generated by application of a longitudinal field to the master disk is more effective for magnetic transfer than the perpendicular transferring field generated by application of a perpendicular field to the master disk.

[0040]

Fig. 8(A) shows a magnetic field that is generated by two ring heads and applied in the longitudinal direction of a laminate of a perpendicular magnetic recording medium and a master disk, and also shows intensity of transferred signals made by the field. Here, "a laminate of a perpendicular magnetic recording medium and a master disk" means a pair of a perpendicular magnetic recording medium and a master disk that are in close contact with or in proximity to each other. Fig. 8(B) shows lines of magnetic force of the longitudinal magnetic field and Fig. 8(C) shows the distribution of perpendicular magnetic field generated by the longitudinal magnetic field. A magnetic field applied around the soft-magnetic pattern of the master disk is concentrated to the soft magnetic material with high permeability and becomes a leakage flux in a space without the soft magnetic material. The magnetic field concentrated to the soft-magnetic material and the leakage flux have each component perpendicular to the laminate, thus, the perpendicular magnetic field is generated and transfer signals are recorded. The generated perpendicular magnetic field has maximum intensity at the edges of the pattern, while the directions are opposite. If we assume the magnetic recording medium is uniformly magnetized upward in the figure by initialization of the perpendicular magnetic recording medium, magnetization around right edge of the soft magnetic material is reversed by the downward perpendicular magnetic field component generated in the transfer step. On the other hand, around left edge of the soft magnetic material, the generated perpendicular magnetic field is upward, which is the same direction as in the initialization magnetization, consequently, the direction of initial magnetization is not reversed and held.

[0041]

To increase perpendicular magnetic field intensity that involves recording of transfer signals, the flux density in the soft magnetic material is required to be large. As the magnetic flux density in the soft magnetic material increases, the leakage flux in a space without the soft magnetic pattern can be made large, and hence, enough transfer signal can be written. When a magnetic field is applied to a laminate including soft magnetic material, as permeability of the soft

magnetic material is higher and as a dimension of the pattern along the direction of the applied magnetic field, that is, length along the circumference of the magnetic recording medium is larger, the magnetic flux is more concentrated to the soft magnetic pattern, and accordingly, the magnetic flux density in the soft magnetic pattern becomes larger. As a result, leakage flux from the soft magnetic pattern, which is leakage flux for transferring, also is made larger. We consider a case where a magnetic field is applied to a master disk in the longitudinal direction or in the perpendicular direction. Because a thick soft magnetic layer is difficult to be processed with a fine pattern, the thickness of the soft magnetic pattern in the perpendicular direction can not be larger than the present value. The pattern size in the longitudinal direction, that is, length along the circumference of the magnetic recording medium is easier to be increased. When a magnetic field with the same intensity is to be applied to a master disk, larger perpendicular magnetic field for transfer is generated by application of longitudinal field according to the present invention than by application of perpendicular field as in the conventional technology.

[0042]

Superiority of the use of longitudinal field to the use of perpendicular field in transferring to a perpendicular magnetic recording medium will be described in the following based on the difference of perpendicular magnetic field distribution impressed to the magnetic recording medium shown in Fig. 5(C) and Fig. 8(C).

[0043]

As previously described, a perpendicular magnetic field applied to a soft magnetic pattern is focussed to the soft magnetic pattern in the place the soft magnetic pattern exists, and the field becomes leakage flux in the place the soft magnetic pattern does not exist. Thus, the magnetic field intensity impressed to the perpendicular magnetic recording medium has periodically strong and weak values corresponding to existence and non-existence of the soft magnetic pattern. However, since the direction of the impressed magnetic field is not different between the places with and without the soft magnetic pattern, magnetic transfer takes effect based on the difference of magnetic field intensity between

the places with and without the soft magnetic pattern, and does not takes effect simply based on the value of intensity of the perpendicular magnetic field generated by the soft magnetic pattern. If the coercive force H_c in perpendicular direction of the perpendicular magnetic recording medium is smaller than the magnetic field intensity in the place without soft magnetic pattern, the direction of magnetization of initialization is reversed in both places with and without the soft magnetic pattern, and signal transfer does not take effect. Therefore, the coercive force H_c in perpendicular direction of the perpendicular magnetic recording medium, specifically in the magnetic recording layer, is restricted to a value that is smaller than the impressed magnetic field intensity in the place with the soft magnetic pattern and larger than the impressed magnetic field intensity in the place without the soft magnetic pattern. In other words, even when a magnetic field of large magnetic field intensity is simply applied, if large difference in magnetic field intensity is not produced between the places with and without the soft magnetic pattern, magnetic transfer of signals is not effectively accomplished.

[0044]

In contrast, when a longitudinal magnetic field is applied to the soft magnetic pattern, the directions of the perpendicular component of generated magnetic field are opposite at the right edge and the left edge of the soft magnetic pattern. Merely when perpendicular component of the magnetic field generated by application of the longitudinal field exceeds the coercive force of the perpendicular magnetic recording medium, then initialized magnetization can be reversed. That is, signals corresponding to the soft magnetic pattern can be transferred. Magnetic transfer here is performed simply based on intensity of perpendicular component of the generated magnetic field, and not based on the difference in the magnetic field intensity between the places with and without the soft magnetic pattern. This makes the previously described restriction unnecessary that is implied to the magnetic recording layer of the perpendicular magnetic recording medium when the magnetic transfer is conducted by applying magnetic field in perpendicular direction. Thus, the range of material selection for the magnetic recording layer is extended.

[0045]

The above description is a basis to explain the experimental result that larger transfer signals are easily obtained by transfer using longitudinal magnetic field in comparison with transfer using perpendicular magnetic field.

5 [0046]

<Example 1>

A perpendicular magnetic recording medium was prepared, the medium being composed of a NiP-plated aluminum substrate and the layers laminated on the substrate including a soft magnetic layer of NiFe alloy having thickness of 30
10 nm, an under-layer of Ti alloy having thickness of 10 nm, a magnetic recording layer of CoCr alloy having thickness of 30 nm, a protective layer of carbon having thickness of 10 nm, and a liquid lubricant layer of perfluoropolyether lubricant having thickness of 1 nm. A master disk is produced by arranging soft magnetic material 500 nm thick with a pattern corresponding to the desired preformat
15 information on a surface of a silicon substrate having thickness of 500 μm . The pattern of soft magnetic material is provided in the linear region extending in radial direction as shown in Fig. 10.

[0047]

At first, initialization of the magnetic recording medium was done by
20 applying a uniform upward magnetic field of intensity of 0.5 T to the magnetic recording medium in the direction perpendicular to the medium surface using two opposite single magnetic pole heads, to orient the magnetization of the magnetic recording layer of the magnetic recording medium uniformly upward.

[0048]

25 Then, a master disk was made closely contact with a surface of the initialized perpendicular magnetic recording medium such that the surface on which soft magnetic material is arranged opposed to the medium surface. A laminate of the perpendicular magnetic recording medium and the master disk was placed between two opposing ring heads. The ring head had a gap at the tip,
30 the width of the gap being 5 mm. Each of the ring heads is disposed with its gap parallel to the radial direction of the perpendicular magnetic recording medium, at a distance of 1.5 mm from the contact surface between the perpendicular

magnetic recording medium and the master disk, in a symmetric arrangement with respect to the contact surface. The magnetic field intensity generated by the ring heads was 0.5 T. Magnetic transfer was conducted keeping the distance and the relative position between the ring heads and the contact surface of the laminate and moving the ring head along the longitudinal magnetic field generated by the ring head, that is, circumferential direction of the perpendicular magnetic recording medium covering whole surface of the perpendicular magnetic recording medium.

[0049]

10 Preformat information was transferred to specified positions on the obtained perpendicular magnetic recording medium.

[0050]

<Example 2>

15 A perpendicular magnetic recording medium was prepared being provided with a soft magnetic layer, an under-layer, a magnetic recording layer, a protective layer, and a liquid lubricant layer in this order on each of the both surfaces of the non-magnetic substrate that was the same as that used in Example 1. Material and thickness of each layer was the same as in Example 1. Two master disks that are the same as that used in Example 1 were prepared.

20 [0051]

Initialization step was conducted in the same manner as in Example 1. The two ring heads used in Example 1 were utilized in a magnetic transfer step. The ring heads were positioned at 1.5 mm from a center plane of the perpendicular magnetic recording medium. Except the position of the ring head, magnetic transfer was conducted in the same manner as in Example 1.

25 [0052]

Preformat information was transferred to specified positions on the both surfaces of the obtained perpendicular magnetic recording medium.

[0053]

30 <Example 3>

Magnetic transfer was conducted in the same manner as in Example 1 except that an uninitialized perpendicular magnetic recording medium as

obtained from a medium manufacturing process was utilized and that an initialization step was not conducted. Preformat information was transferred to specified positions on the surface of the obtained perpendicular magnetic recording medium.

5 [0054]

<Example 4>

Magnetic transfer was conducted in the same manner as in Example 1 except that only one ring head in the master disk side of Example 1 was used and that the ring head was positioned such that the gap of the ring head was at a
10 distance of 1 mm from the contact surface between the perpendicular magnetic recording medium and the master disk. Preformat information was transferred to specified positions on the surface of the obtained perpendicular magnetic recording medium.

[0055]

15 [Effect of the invention]

Preformat information is allowed to be easily recorded on a perpendicular magnetic recording medium by means of magnetic transfer using a master disk carrying the preformat information according to a method of the present invention. Magnetic transfer in the method of the invention is performed by
20 applying a longitudinal magnetic field in place of a conventional perpendicular magnetic field. Such a method does not need thick soft magnetic material corresponding to the preformat information in the master disk. Consequently, fine pattern of the soft magnetic material, or a pattern with high density is made possible corresponding to the high-density preformat information.

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[Brief description of the drawings]

Fig. 1 shows a transfer step in an example of embodiments of the present invention.

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Fig. 2 shows a transfer step in an example of embodiments of the present invention.

Fig. 3(A) and Fig. 3(B) explain a conventional magnetic transfer method to a perpendicular magnetic recording medium using a single magnetic pole head; Fig. 3(A) shows an initialization step and Fig. 3(B) shows a transfer step.

Fig. 4(A) and Fig. 4(B) explain a conventional magnetic transfer method to a perpendicular magnetic recording medium using a single magnetic pole head having a soft magnetic yoke; Fig. 4(A) shows an initialization step and Fig. 4(B) shows a transfer step.

Fig. 5(A), Fig. 5(B) and Fig. 5(C) explain a conventional magnetic transfer method to a perpendicular magnetic recording medium; Fig. 5(A) shows a positional relationship between transfer signals and soft magnetic material, Fig. 5(B) shows lines of magnetic force in a perpendicular magnetic recording medium and a master disk, and Fig. 5(C) is a graph showing density distribution of perpendicular component of magnetic flux on the surface of the perpendicular magnetic recording medium.

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Fig. 6 shows lines of magnetic force in magnetic transfer using a single magnetic pole head.

Fig. 7(A), Fig. 7(B) and Fig. 7(C) show lines of magnetic force, perpendicular component of magnetic flux on the surface of a magnetic recording medium, and transfer signals in the magnetic transfer using a single magnetic pole head; Fig. 7(A) shows lines of magnetic force in the neighborhood of the single magnetic

pole head, Fig. 7(B) is a graph showing longitudinal component of magnetic flux on the surface of the magnetic recording medium, and Fig. 7(C) shows transfer signals.

5 Fig. 8(A), Fig. 8(B) and Fig. 8(C) explain a method for magnetic transfer to a perpendicular magnetic recording medium according to the present invention; Fig. 8(A) shows a positional relationship between transfer signals and soft magnetic material, Fig. 8(B) shows lines of magnetic force in a perpendicular magnetic recording medium and a master disk, and Fig. 8(C) is a graph showing
10 density distribution of perpendicular component of magnetic flux on the surface of the perpendicular magnetic recording medium.

Fig. 9(A) and Fig. 9(B) show a perpendicular component and a longitudinal component of magnetic flux on the surface of a magnetic recording medium in a case using a ring head and in a case using a single magnetic pole head; Fig. 9(A)
15 shows a case using a ring head, and Fig. 9(B) shows a case using a single magnetic pole head.

Fig. 10 is a plan view of a master disk used in the present invention.
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Fig. 11 is a plan view of a magnetic recording medium manufactured by a magnetic transfer step of the present invention.

Fig. 12 is a bird's-eye view with a partial cross-section of a magnetic recording
25 medium used in the present invention.

Fig. 13 shows a transfer step in an example of embodiments of the present invention.

30 Fig. 14 shows a transfer step in another example of embodiments of the present invention.

[Description of symbols]

- 1 magnetic recording medium for perpendicular recording
- 2 master disk
- 3 soft magnetic yoke for a ring head
- 5 4 permanent magnet
- 5 movement direction of a transfer magnet
- 6 embedded soft magnetic layer carrying preformat information
- 7 soft magnetic yoke for single magnetic pole head
- 8 back pole
- 10 9 direction of magnetic flux
- 10 direction of applied magnetic field
- 13 lines of magnetic force
- 16 single magnetic pole head
- 17 shape of the gap portion of the ring head
- 15 18 longitudinal component of magnetic field that is generated by a single
magnetic pole head
- 19 perpendicular component of magnetic field that is generated by a single
magnetic pole head
- 20 longitudinal component of magnetic field that is generated by a ring head
- 20 21 perpendicular component of magnetic field that is generated by a ring head
- 32 non-magnetic substrate
- 33 master disk
- 34 perpendicular magnetic recording medium
- 35 preformat region
- 25 41 non-magnetic substrate
- 42 soft magnetic backing layer
- 43 under-layer
- 44 magnetic recording layer
- 45 protective layer
- 30 46 liquid lubricant layer



[Claims]

1 A method of magnetic transfer for a perpendicular magnetic recording medium, said method magnetically transferring preformat information to a magnetic recording layer of said magnetic recording medium by applying an external magnetic field in an arrangement where a master disk is in close contact with or in proximity to said magnetic recording medium, said master disk having a non-magnetic substrate and a multiple of isolated soft magnetic material on a surface or in a surface portion of said non-magnetic substrate, said soft magnetic material having a pattern corresponding to said preformat information and being disclosed in a linear periodic region, wherein said method comprising:

an initialization step, in which a magnetic field is applied to said magnetic recording medium in a direction perpendicular to a surface of said magnetic recording medium so that direction of magnetization of whole surface of said magnetic recording medium is aligned to one direction perpendicular to said magnetic recording medium, and
a magnetic transfer step, in which a magnetic field in a longitudinal direction is applied to both of said master disk and said magnetic recording medium in an arrangement where said master disk is in close contact with or in proximity to one surface or both surfaces of said magnetic recording medium.

2 A method of magnetic transfer for a perpendicular magnetic recording medium according to claim 1, wherein
in said initialization step, a magnetic field is applied to said magnetic recording medium in perpendicular direction of said medium using a single magnetic pole head, and in said magnetic transfer step, a magnetic field in a longitudinal direction is applied to said magnetic recording medium and said master disk using one or more ring heads each having a gap.

3 A method of magnetic transfer for a perpendicular magnetic recording medium, said method magnetically transferring preformat information to a magnetic recording layer of said magnetic recording medium by applying an



external magnetic field in an arrangement where a master disk is in close contact with or in proximity to said magnetic recording medium, said master disk having a non-magnetic substrate and a multiple of isolated soft magnetic material on a surface or in a surface portion of said non-magnetic substrate, said soft magnetic material having a pattern corresponding to said preformat information and being disposed in a linear periodic region, said method comprising:

a step for preparing as said magnetic recording medium an uninitialized magnetic recording medium as obtained from a manufacturing step, and a magnetic transfer step, in which a magnetic field in a longitudinal direction is applied to both of said master disk and said magnetic recording medium in an arrangement where said master disk is in close contact with or in proximity to one surface or both surfaces of said magnetic recording medium.

4 A method of magnetic transfer for a perpendicular magnetic recording medium according to claim 3, wherein in said magnetic transfer step, a magnetic field in a longitudinal direction is applied to said magnetic recording medium and said master disk using one or more ring heads having a gap.

5 A method of magnetic transfer for a perpendicular magnetic recording medium according to claim 2 or claim 4, wherein in said magnetic transfer step, two ring heads each having a gap are opposed each other, said magnetic recording medium and said master disk are positioned in a center of said gaps of said two ring heads.

6 A method of magnetic transfer for a perpendicular magnetic recording medium according to any one of claim 1 ^{through 5} ~~or claim 2~~, wherein said magnetic recording medium has an axis of easy magnetization in a direction perpendicular to a surface of said medium. ✓

7 A method of magnetic transfer for a perpendicular magnetic recording medium according to any one of claim 1 ^{through 5} ~~or claim 2~~, wherein direction of recorded magnetization in said magnetic recording medium is perpendicular to a surface of said magnetic recording medium. ✓