

MASTER DISK FOR MAGNETIC PRINTING AND MANUFACTURING METHOD THEREOF

Technical Field of the Invention

The present invention relates to a master disk for magnetic printing and a manufacturing method thereof and, more in detail, to a master disk for magnetic printing which is provided so as to write servo signals for positioning a head or specified data onto a surface of a magnetic disk by using magnetic printing technology, and a manufacturing method thereof. The head carries out writing of data to/reading of written data from the surface of the magnetic recording disk in a hard disk drive (hereinafter referred to as an "HDD") with the magnetic recording disk using a magnetic film as a recording material which drive currently becomes main stream as external storage of a computer.

Prior Art

In the above-described HDD, recording and reproducing of data are carried out while a magnetic head is made floated on a surface of a rotating magnetic disk as a magnetic recording medium by a floating mechanism known as a slider with a distance of several tens nanometers kept from the surface of the disk. On the magnetic recording medium, bit information is stored in data tracks arranged in concentric

circles on the magnetic recording medium. The data recording/reproducing head is moved and positioned at a high speed onto a target data track on the magnetic recording medium to carry out recording and reproducing of the data.

On the surface of the magnetic recording medium, positioning signals (servo signals) for detecting a relative position of the head to the data track are written in concentric circles for making the head carrying out recording and reproduction of data detect its own position at fixed time intervals. The servo signal is written by using a specialized device known as a servo writer after the magnetic recording medium is mounted in an HDD device so that the center of the written servo signal causes no eccentricity to the center of the magnetic recording medium (or the center of the orbit of the head).

At present, a recording density in a development stage reaches up to 100Gbits/in² and, along with this, a recording density is increasing at an annual rate of 60%. Accompanied with this, the density of the servo signal for the head detecting its own position is increasing and the writing time of the servo signal also tends to increase year by year. The increase in the writing time of the servo signal becomes one of the major causes of bringing reduction in

productivity and increase in cost of the HDDs.

Recently, in contrast with the above-described method of writing the servo signal using a writing head of the servo writer, a technological development is carried out about a method for far reducing the writing time of servo information by writing the servo signal in a lump by magnetic printing.

Figures 3(a) to 3(c) and Figures 4(a) and 4(b) are views for explaining a magnetic printing technology. Figures 3(a) to 3(c) are views for explaining process steps of magnetic printing in a magnetic recording medium. Figures 4(a) and 4(b) are views for explaining the principle of the magnetic printing in the magnetic recording medium.

Figure 4(a) is a view from the direction of a cross section of a substrate, a state in which a permanent magnet moves on the surface of a magnetic recording medium while keeping a fixed distance (1mm or less) thereto. A magnetic film 42 deposited on a substrate 41 forming a magnetic recording medium 40 is initially not in a state of being magnetized in a definite direction. However, the film 42 is magnetized in the definite direction by a leakage magnetic flux from the gap of a permanent magnet 43 (arrows drawn in the

magnetic film in the drawing indicate the direction of magnetization). The step is referred to as an initial demagnetization step.

The initial demagnetization step shown in Fig. 4(a) corresponds to an initial demagnetization step shown in Fig. 3(a). An arrow in Fig. 3(a) represents the moving path of the permanent magnet 43 in Fig. 4(a), by which magnet the magnetic film 42 is uniformly magnetized. Figure 3(b) is a view showing a state in which a master disk for magnetic printing (hereinafter referred to as a "master disk") is laid on the magnetic recording medium to carry out positioning. Figure 3(c) is a view showing a state of carrying out magnetic printing by bringing the master disk into intimate contact with the surface of the magnetic recording medium and by moving the permanent magnet for magnetic printing along the moving path in the figure (shown by an arrow).

Moreover, Fig. 4(b) is a view showing the step of writing a printing pattern, and corresponds to Fig. 3(c). The master disk has a structure in which, as shown in the figure, soft magnetic films (cobalt family soft magnetic films) 44 are embedded on the side of a face of a silicon substrate 45 contacting the surface of the magnetic recording medium 40.

As shown in Fig. 4(b), intervention of the substrate, embedded with patterns of the soft magnetic films, between the permanent magnet 43 and the magnetic recording medium 40, allows the leakage magnetic flux from the permanent magnet 43 that entered the silicon substrate 45 (the direction of a magnetic field for writing printed signal is opposite to the direction of the magnetic field for demagnetization) to pass through the silicon substrate 45 again and magnetize the magnetic film 42 at a position without the soft magnetic film 44. However, at a part with presence of the soft magnetic pattern, the leakage magnetic flux passes through the soft magnetic film 44 so as to form a magnetic circuit with low magnetic resistance. This makes the leakage magnetic flux from the silicon substrate 45 become small at a position with the soft magnetic film 44, by which no writing by magnetization is carried out. With the mechanism as above, magnetic printing of the servo signal is carried out.

Figures 5(a) to 5(e) are views for explaining the manufacturing process steps of the master disk with Fig. 5(a) showing the step of applying a resist, Fig. 5(b) showing the step of patterning the magnetic pattern, Fig. 5(c) showing the step of etching the silicon substrate, Fig. 5(d) showing the step of sputtering soft magnetic material, and

Fig. 5(e) showing the step of lift-off. In the following, explanation will be made specifically about each step.

First step: On the surface of a silicon substrate (substrate thickness of about $500\mu\text{m}$) 51, a resist (thickness of $1.2\mu\text{m}$) 52 is applied by using a spin coater (Fig. 5(a)). Thereafter, patterning is carried out to the resist 52 by employing an optical lithography method similar to that in a manufacturing method of a normal silicon semiconductor (Fig. 5(b)). The resist 52 is used as a mask for etching in a second step, and is of a material of novolak family which is not so strong against etching. Therefore, it is important for the resist 52 to have such a thickness that the resist 52 does not disappear even by etching.

Second step: By employing a reactive plasma-etching method (reaction gas: methane trichloride), the silicon substrate 51 is subjected to dry etching to the depth of 500nm (Fig. 5(c)).

Third step: By employing a sputtering method, deposition of a soft magnetic film 53 of Co is carried out by a thickness of 500nm (Fig. 5(d)).

Fourth step: After the deposition of the Co soft

magnetic film 53, the silicon substrate 51 is immersed in a solvent that dissolves the resist 52 (while employing ultra sound and the like as necessary), by which the resist 52 between the Co soft magnetic film 53 and the silicon substrate 51 is dissolved to be removed (Fig. 5(e)).

Official gazettes describing prior art relating to the invention are shown as follows.

The art described in the patent JP-A-2001-34938 relates to a master information carrier, by which high density information signals can be uniformly and stably recorded over the whole face of a magnetic recording medium, and a manufacturing method of the carrier. The carrier is provided with a substrate and a ferromagnetic thin film disposed on the substrate so as to form a pattern arranged to correspond to a magnetic pattern with the surface of the ferromagnetic film made approximately flat. Moreover, the art described in International Publication No.00/26904 Pamphlet relates to a master information carrier and a magnetic recording method using the carrier, in which a figure pattern corresponding to an arrangement of information signals for being recorded in a magnetic recording medium is provided by an arrangement of ferromagnetic thin films deposited on the surface of a

non-magnetic substrate.

Problems to be Solved by the Invention

Figures 6(a) and 6(b) are views showing shapes of servo patterns with Fig. 6(a) showing a part of the servo pattern. In the figure, regions surrounded by closed curves (although the lines, being magnified in the figure, look like straight lines, they are actually curved lines) show areas in which soft magnetic films are formed. Figure 6(b) shows patterns of contents. In the figure, regions surrounded by closed curves (although the lines, being magnified in the figure, look like straight lines, they are actually curved lines) show areas in which soft magnetic films are formed.

Line widths of the patterns range from 1 line to several lines. In order to carry out magnetic printing of the servo patterns, the same patterns as the servo patterns must be formed on a master disk as patterns of soft magnetic films. The thickness of the soft magnetic film is very important. A thin film thickness causes magnetic saturation when a magnetic field to be printed is applied, which results in leakage of a magnetic flux to the magnetic recording media facing the soft magnetic film. This, in the worst case, causes inversion in magnetization to produce a problem that makes a region where the data must be "0" have

data of "1".

Figures 7(a) and 7(b), and Figures 8(a) and 8(b) are views each showing magnetic field strength distributions around the magnetic film of a magnetic recording medium at printing with Fig. 7(a) showing magnetic field strength distributions on the surface of a magnetic recording medium in the case of ($P = 1.4$, $W = 0.7\mu\text{m}$), Fig. 7(b) showing magnetic field strength distributions on the surface of a magnetic recording medium in the case of ($P = 0.4$, $W = 0.2\mu\text{m}$), Fig. 8(a) showing magnetic field strength distributions on the surface of a magnetic recording medium in the case of ($P = 0.7$, $W = 0.35\mu\text{m}$), and Fig. 8(b) showing magnetic field strength distributions on the surface of a magnetic recording medium in the case of ($P = 0.2$, $W = 0.1\mu\text{m}$) where P is pitch of the soft magnetic film, W is width of the soft magnetic film.

Namely, Figs. 7(a) and 7(b), and Figs. 8(a) and 8(b) are views each showing magnetic field strength distributions at the magnetic film of a magnetic recording medium with a printing magnetic field kept constant and the width (the pattern width) and the film thickness of the soft magnetic film of the master disk made varied. When printing is carried out, the magnetic field strength must be 4kOe or

more in a region where magnetization is made inverted and must be 2kOe or less in a region where magnetization is not made inverted. The thickness of the soft magnetic film for satisfying the conditions becomes as follows.

Pattern width: $0.7\mu\text{m}$ $\rightarrow$

Thickness of the soft magnetic film: $0.20\mu\text{m}$ or more

Pattern width: $0.35\mu\text{m}$ $\rightarrow$

Thickness of the soft magnetic film: $0.20\mu\text{m}$ or more

Pattern width: $0.2\mu\text{m}$ $\rightarrow$

Thickness of the soft magnetic film: $0.075\mu\text{m}$ or more

Pattern width: $0.1\mu\text{m}$ $\rightarrow$

Thickness of the soft magnetic film: $0.050\mu\text{m}$ or more

When the pattern width of the servo pattern is from 0.1 to $0.7\mu\text{m}$, the thickness of the soft magnetic film necessitates to be $0.20\mu\text{m}$ or more for causing no magnetic saturation in all of the regions. Practically, however, within film nonuniformity arisen in a photo-process and deposition of the soft magnetic film must be taken into consideration. Therefore, the thickness of the soft magnetic film necessitates to be $0.30\mu\text{m}$ or more. Cross sectional shapes in each of which a Co soft magnetic film is embedded in a groove etched in a photo-process are shown in Figs. 9(a) to 9(g), and a relationship between groove width and film thickness at the groove section is shown in Fig. 10.

Figure 9(a) is a view showing a 0.5 μ m groove width section, Fig. 9(b) is a view showing a 1.0 μ m groove width section, Fig. 9(c) is a view showing a 1.5 μ m groove width section, Fig. 9(d) is a view showing a 2.0 μ m groove width section, Fig. 9(e) is a view showing a 2.5 μ m groove width section, Fig. 9(f) is a view showing a 3.0 μ m groove width section, and Fig. 9(g) is a view showing a 3.5 μ m groove width section. In the figures, reference numeral 91 denotes a silicon substrate, 92 denotes a resist, and 93 denotes a soft magnetic film.

From Fig. 9 and Fig. 10, it is known that as the groove width becomes smaller, thickness nonuniformity of the soft magnetic film deposited in the groove becomes noticeable. In Fig. 10, it is shown that the nonuniformity becomes not negligible for groove widths of 1 μ m or less and there is a problem in that the narrower the pattern width becomes, the more difficult it becomes to embed the soft magnetic film in a deep groove. Therefore, a method of manufacturing a master disk is long awaited which facilitates magnetic printing even for groove widths of 1 μ m or less.

In view of such a problem, the invention was made with an object of providing a master disk for magnetic printing that enables control of an aspect ratio of a width

of a groove vs. a depth thereof, and along with this, facilitates embedding of a soft magnetic film in the groove for stabilizing magnetic printability by the master disk, and a manufacturing method of the master disk.

Means for Solving the Problems

In order to accomplish such an object, the invention as claimed in claim 1 is characterized in that, in a master disk for forming a magnetic pattern in a magnetic recording medium by magnetic printing, at least two or more kinds of depths of grooves for embedding magnetic materials are provided on a substrate of the master disk.

The invention as claimed in claim 2 is characterized in that, in the invention as claimed in claim 1, the depth of the groove for embedding the magnetic material is proportional to a pattern width in a sector direction of a servo pattern.

The invention as claimed in claim 3 is characterized in that, in the invention as claimed in claim 2, the depth of the groove for embedding the magnetic material is made shallow in a region where the pattern width of the servo pattern is narrow and made deep in a region where the pattern width is wide.

The invention as claimed in claim 4 is characterized in that, in the invention as claimed in claim 2, the depth of the groove for embedding the magnetic material is made varied in stepwise with respect to the pattern width.

The invention as claimed in claim 5 is a method of manufacturing a master disk for magnetic printing and is characterized in that the groove for embedding the magnetic material as claimed in any one of claim 1 to 4 is formed by repetition of photolithography.

With respect to the above-described subject, the problem caused at the deposition can be eliminated by taking measures that make the depth of the groove for embedding the soft magnetic film in the silicon substrate of the master disk varied depending on the pattern width of the soft magnetic film in the sector direction. The depth of the groove is not required to be varied in an analog way, but may be varied stepwise. When classification of the depths of the grooves is determined with the magnetic field strengths shown in Figs. 7(a) and 7(b) and Figs. 8(a) and 8(b) taken as examples, the depths can be classified into two groups, 0.075 μm or more depths for the grooves with the pattern widths being 0.1 to 0.2 μm , and 0.2 μm or more depths for the grooves with the pattern widths being 0.35 to 0.7 μm . For forming grooves

with different depths, the first step and the second step shown in Fig. 5 can be repeatedly carried out. However, when the process is made to return from the second step to the first step, lift-off of the resist is necessary.

Brief Description of the Drawings

Fig. 1 are views showing shapes of servo patterns and shapes of grooves for embedding soft magnetic films in the invention with (a) and (b) being views showing the shapes of the servo patterns, and (c) and (d) being views showing the shapes of the embedding grooves.

Fig. 2 are views for explaining a manufacturing process steps of a master disk according to the invention with (a) showing the preparation step of a silicon substrate, (b) showing the application step of a resist, (c) showing the patterning step of a magnetic pattern with a narrow line width, (d) showing the etching step of the silicon substrate, (e) showing the removing step of the resist, (f) showing the application step of a resist, (g) showing the patterning step of a magnetic pattern with a wide line width, (h) showing the etching step of the silicon substrate, (i) showing the removing step of the resist, (j) showing the deposition step of a soft magnetic film, and (k) showing the polishing step by CMP.

Fig. 3 (a) to (c) are views for explaining process steps of magnetic printing in a magnetic recording medium.

Fig. 4 (a) and (b) are views for explaining the principle of the magnetic printing in the magnetic recording medium.

Fig. 5 are views for explaining the manufacturing process steps of manufacturing the master disk with (a) showing the step of applying a resist, (b) showing the step of patterning the magnetic pattern, (c) showing the step of etching the silicon substrate, (d) showing the step of sputtering soft magnetic material, and (e) showing the step of lift-off.

Fig. 6 are views showing shapes of servo patterns with (a) showing a part of the servo pattern and (b) showing patterns of contents.

Fig. 7(a) and (b) are views (1) each showing a magnetic field strength distributions on a surface of a magnetic film at printing.

Fig. 8(a) and (b) are views (2) each showing a magnetic field strength distributions on a surface of a magnetic film

at printing.

Fig. 9(a) to (g) are views each showing a cross section where a soft magnetic film is embedded in a recess.

Fig. 10 is a view showing the groove width dependence of the film thickness.

Mode for Carrying Out the Invention

In the following, explanations will be made to a mode for carrying out the invention with reference to the drawings.

Figures 1(a) to 1(d) are views showing the shapes of the servo patterns and the shapes of the grooves for embedding soft magnetic films in the invention with Figs. 1(a) and 1(b) being views showing the shapes of the servo patterns and Figs. 1(c) and 1(d) being views showing the shapes of the embedding grooves. Figure 1(a) and Figure 1(c) correspond to each other and Figure 1(b) and Figure 1(d) correspond to each other. In the figures, reference numeral 11 denotes a silicon (Si) substrate and 12 denotes a soft magnetic film.

A characteristic of the invention is that the width of

the groove is equal to the width in the sector direction of the servo pattern and the depth is varied. Namely, the servo pattern width "a" in Fig. 1(a) and the width "c" of the groove in Fig. 1(c) are equal to each other ($a = c$) in the sector direction with the depth "c1" of the groove in Fig. 1(c) being proportional to the servo pattern width "a" in Fig. 1(a). Meanwhile, the servo pattern width "b" in Fig. 1(b) and the width "d" of the groove in Fig. 1(d) are equal to each other ($b = d$) in the sector direction with the depth "d1" of the groove in Fig. 1(d) being proportional to the servo pattern width "b" in Fig. 1(b).

The depths are required to be those with which the soft magnetic films have such thicknesses that no magnetic saturation occurs due to printing magnetic fields therein. According to the results of analyses of magnetic field strengths on the surface of the magnetic recording medium as shown in Figs. 7(a) and 7(b) and Figs. 8(a) and 8(b) by employing a method of magnetic field analysis, following thicknesses become necessary.

Pattern widths: $0.35\mu\text{m}$ to $0.7\mu\text{m}$ →

Thickness of the soft magnetic film: $0.20\mu\text{m}$

Pattern width: $0.1\mu\text{m}$ to $0.2\mu\text{m}$ →

Thickness of the soft magnetic film: $0.075\mu\text{m}$

The magnetic field analyses about the surface of the magnetic recording medium shown in Figs. 7(a) and 7(b) and Figs. 8(a) and 8(b) treat the pattern widths only in the range from 0.1 μ m to 0.7 μ m to determine two kinds of thicknesses of the soft magnetic film. However, since servo track addresses included in the servo patterns are represented by 18 bits, the pattern width becomes up to 1.8 μ m. This requires further increase in the kinds of the thicknesses of the soft magnetic film.

Figures 2(a) to 2(k) are process drawings for explaining a manufacturing method of a master disk according to the invention with Fig. 2(a) showing the preparation step of a silicon substrate, Fig. 2(b) showing the application step of a resist, Fig. 2(c) showing the patterning step of a magnetic pattern with a narrow line width, Fig. 2(d) showing the etching step of the silicon substrate, Fig. 2(e) showing the removing step of the resist, Fig. 2(f) showing the application step of a resist, Fig. 2(g) showing the patterning step of a magnetic pattern with a wide line width, Fig. 2(h) showing the etching step of the silicon substrate, Fig. 2(i) showing the removing step of the resist, Fig. 2(j) showing the deposition step of a soft magnetic film, and Fig. 2(k) showing the polishing step by CMP (Chemical Mechanical Polishing).

A plurality of photomasks become necessary beforehand which correspond to the number of the kinds of the film thicknesses of the soft magnetic films (the kinds of the depths of the grooves). Namely, in the example, the required kinds become two kinds, a photomask only for a region with the thickness of the soft magnetic film being $0.075\mu\text{m}$, and a photomask only for a region with the thickness of the soft magnetic film being $0.20\mu\text{m}$. In the following, explanations will be made in order about the process steps.

First step: A silicon substrate (substrate thickness of about $500\mu\text{m}$) 21 is prepared (Fig. 2(a)).

Second step: A resist 22 is applied (Fig. 2(b)).

Third step: Patterning is carried out by using a photomask only for a region with a thickness of a soft magnetic film being $0.075\mu\text{m}$ (Fig. 2(c)).

Moreover, in the unillustrated development step, parts of the resist irradiated with light are removed to make the pattern of the photomask printed on the resist.

Fourth step: By employing a reactive plasma-etching method (reaction gas: methane trichloride), dry etching of the

silicon substrate 21 is carried out to the depth of 75nm to form grooves (Fig. 2(d)).

Fifth step: The resist 22 is removed by resist stripper to expose the face of the silicon substrate 21 (Fig. 2(e)).

Sixth step: A resist is applied again (Fig. 2(f)).

Seventh step: Patterning is carried out by using a photomask only for a region with a thickness of a soft magnetic film being $0.2\mu\text{m}$ (Fig. 2(g)).

Moreover, in the unillustrated development step, parts of the resist irradiated with light are removed to make the pattern of the photomask printed on the resist.

Eighth step: By employing a reactive plasma-etching method (reaction gas: methane trichloride), dry etching of the silicon substrate 21 is carried out to the depth of 200nm to form grooves (Fig. 2(h)).

Ninth step: The resist 22 is removed by resist stripper to expose the face of the silicon substrate 21 (Fig. 2(i)).

Tenth step: A soft magnetic film 23 is deposited on the silicon substrate 21 by a sputtering device and the like. At this time, the soft magnetic film is made to have a thickness sufficiently exceeding the surface of the silicon substrate 21 from the bottom of the grooves (Fig. 2 (j)).

Eleventh step: The soft magnetic film 23 deposited above the surface of the silicon substrate 21 is polished by CMP (Chemical Mechanical Polishing) to be removed (Fig. 2(k)).

In the above-explained eleventh step, by grasping the polishing rate of the silicon (Si) substrate and the polishing rate of the magnetic film of Co and the like by CMP beforehand and by knowing the thickness of the soft magnetic film deposited on the silicon substrate, it becomes possible to estimate the polishing time using CMP. Actually, however, the polishing is carried out with some margin given to the estimated polishing time. At the early stage of the polishing, the soft magnetic film deposited on the silicon substrate is polished. When the polishing reaches the silicon substrate, the speed of the polishing becomes slow to allow only a little amount to be polished in a unit time.

In the invention, the resist was used as an etching mask, but an SiO₂ film can be taken as an etching mask. This,

however, requires complicated processes as shown below, in which the first step to the fourth step and the fifth step to the eighth step are substituted by the respective steps shown below. Characteristic of using the mask of the SiO_2 film is that polishing selectivity of Co to SiO_2 film is increased at the eleventh step and the SiO_2 film is hard to polish to provide an advantage in that the depth of the groove embedding the soft magnetic film is kept accurately.

First step and Fifth step: Thermal oxidation treatment of the silicon substrate is carried out to form an SiO_2 film on the silicon surface.

Second step and Sixth step: A resist is applied on the face of the SiO_2 film.

Third step and Seventh step: Patterning of the resist is carried out for development.

Fourth' step and Eighth' step: Etching of the SiO_2 film is carried out by using the mask of the resist.

Fourth'' step and Eighth'' step: Ashing of the resist is carried out.

Fourth''' step and Eighth''' step: Etching of the silicon substrate is carried out by using the mask of the SiO₂ film.

Advantageous Effect of the Invention

As was explained above, according to the invention, in a master disk for forming a magnetic pattern in a magnetic recording medium by magnetic printing, at least two or more kinds of depths of grooves for embedding magnetic materials are provided on a substrate of the master disk. Therefore, the depth of the groove for embedding the soft magnetic film can be provided so as to be made shallow in a region where the pattern width of the servo pattern is narrow and made deep in a region where the pattern width is wide. This enables control of an aspect ratio of a width of a groove vs. a depth thereof to facilitate embedding of the soft magnetic film in the groove, which can provide stabilization of magnetic printability by the master disk.

Claims

1. A master disk for magnetic printing characterized in that, in a master disk for forming a magnetic pattern in a magnetic recording medium by magnetic printing, at least two or more kinds of depths of grooves for embedding magnetic materials are provided on a substrate of the master disk.

2. The master disk for magnetic printing as claimed in claim 1 characterized in that the depth of the groove for embedding the magnetic material is proportional to a pattern width in a sector direction of a servo pattern.

3. The master disk for magnetic printing as claimed in claim 2 characterized in that the depth of the groove for embedding the magnetic material is made shallow in a region where the pattern width of the servo pattern is narrow and made deep in a region where the pattern width is wide.

4. The master disk for magnetic printing as claimed in claim 2 or claim 3 characterized in that the depth of the groove for embedding the magnetic material is made varied stepwise with respect to the pattern width of the servo

pattern.

5. A method of manufacturing a master disk for magnetic printing characterized in that the groove for embedding the magnetic material as claimed in any one of claim 1 to 4 is formed by repetition of photolithography.