

## DESCRIPTION

METHOD OF MANUFACTURING SILICON SUBSTRATES FOR MAGNETIC  
RECORDING MEDIUM, SILICON SUBSTRATE FOR MAGNETIC RECORDING  
5 MEDIUM, MAGNETIC RECORDING MEDIUM, AND  
MAGNETIC RECORDING APPARATUS

## TECHNICAL FIELD

The present invention relates to a silicon substrate for a small-sized magnetic  
10 recording medium, which is used as a recording medium for a data processing apparatus.

Priority is claimed on Japanese Patent Application No. 2004-237340, filed  
August 17, 2004, and US Provisional Patent Application No. 60/603,566, filed August 24,  
2004, the contents of which are incorporated herein by reference.

## 15 BACKGROUND ART

Accompanying recent progress in data processing apparatuses, data recording  
capacity of a magnetic recording medium has increased more and more. In particular,  
in magnetic disks, which are important media as external memory for computers, both  
storage capacity and data recording density increase every year, and development for  
20 recording data with higher density is required. For example, in accordance with  
development of notebook computers or palmtop computers, small-sized and  
impact-resistant magnetic recording media are required, and therefore small-sized  
magnetic recording media for recording data with higher density, which also have high  
mechanical strength, are required. More recently, navigation systems or portable music  
25 reproducing systems may employ ultra-small-sized magnetic recording media.

A substrate made of aluminum alloy, which may be plated with NiP, or a glass substrate, is conventionally used as a substrate for a magnetic disk which is a magnetic recording medium as described above. A substrate made of aluminum alloy has inferior abrasion resistance and processibility, and plating with NiP is performed so as to solve this problem. However, a substrate which has been subjected to NiP plating tends to be warped, and may be magnetized when being processed at a high temperature. In addition, when the glass substrate is processed so as to be strengthened, a distortion layer may be produced in a surface of the substrate and the substrate may receive compressive stress, and the glass substrate also tends to be warped when being processed at a high temperature.

Regarding an ultra-small-sized magnetic recording medium having a diameter of 1 inch (i.e., 25.4 mm) or 0.85 inches (i.e., 21.6 mm) which requires higher recording density, warp of the substrate is a fatal problem. Therefore, as a substrate for an ultra-small-sized recording medium, a thinner material, which is not easily deformed by external force and has a smooth surface on which a magnetic recording layer can be easily formed, is required.

Accordingly, it has been proposed that a silicon substrate, which is popular as a substrate for semiconductor devices, be used as a magnetic recording medium (see, for example, Reference 1: Japanese Unexamined Patent Application, First Publication No. H06-076282).

In comparison with aluminum, single crystal silicon has a larger specific gravity, a larger Young's modulus, a smaller coefficient of thermal expansion, a superior high-temperature characteristic, and electrical conductivity. Such single crystal silicon having many advantages is preferable as a material for a substrate for a magnetic recording medium. In addition, the smaller the diameter of the substrate, the smaller

impact force the substrate receives, and a magnetic recording device having durability can be produced even from a silicon substrate.

In order to manufacture the silicon substrate for a magnetic recording medium, generally, a single crystal silicon ingot is first produced by a pulling method, and the  
5 ingot is sliced into blank materials having a specific thickness.

Each blank material is subjected to a lapping process, and a circular through hole is formed at the center of the blank material. The inner and outer peripheral edges are subjected to chamfering using a grindstone or the like. The inner and outer end faces and the chamfered portions are then subjected to polishing, so as to produce  
10 mirror-finished surfaces. Finally, the main surface is polished, and the substrate is used.

The material for the silicon substrate is fragile; thus, cracks or chips tend to be produced in the above manufacturing processes. When cracks or chips are produced, the yield rate for manufacturing the magnetic recording medium is reduced, and generated particles may cause errors in a write/read process, or a crash of the magnetic  
15 head in the write/read process.

In order to obtain a silicon substrate for the magnetic recording medium, which has no cracks or chips, from a fragile material, a method has been proposed in which for the inner periphery of the circular center hole and for the outer periphery of the substrate, the chamfering angle is set to be from  $20^\circ$  to  $24^\circ$ , and the chamfering length is set to be  
20 from 0.03 mm to 0.15 mm (see, for example, Reference 2: Japanese Unexamined Patent Application, First Publication No. H07-249223).

Fig. 12 is a longitudinal sectional view of a conventional silicon substrate for a magnetic recording medium. In Fig. 12, between an end face 4 and each of main surfaces 2 and 3 of the substrate 1, a chamfered portion 5 is formed, which is inclined at  
25 an angle from  $20^\circ$  to  $24^\circ$ . Similar chamfered portions (not shown) are also formed in

the inner periphery of the substrate.

According to the above form for the substrate, defects in the substrate, such as cracks or chips due to handling or dropping the substrate in the manufacturing process, are reduced, and the yield rate is remarkably improved.

5           In addition, regarding the glass substrate, lower floating of the magnetic head has been planned so as to implement high density data recording, and the write/read method has been gradually switched from the CSS (contact start stop) method to the load and run method (or the ramp load method). These write/read methods also require a substrate which can be reliably installed and does not cause write/read errors, or a crash  
10 of the magnetic head in the write/read process.

In order to satisfy the above requirements, a substrate has been proposed in which inner and outer peripheral end faces of the substrate are polished using a polishing liquid in which grains are suspended so that the arithmetic average roughness Ra for the surface roughness comes to 0.001 to 0.04  $\mu\text{m}$ , and the maximum height Rmax for the  
15 surface roughness comes to 0.5  $\mu\text{m}$  or less (see, for example, Reference 3: Japanese Unexamined Patent Application, First Publication No. H11-221742).

According to such a substrate, no cracks or chips are produced even when a substrate contained in a processing cassette (which is a case for storing and transferring a substrate in a manufacturing process) is transferred, and no write/read errors or crash of  
20 the magnetic head in the write/read process occurs, thereby providing a magnetic recording medium which can be reliably installed.

In order to write or read data on the magnetic recording medium, the medium is rotated at a high speed while a center circular hole of the medium is fit around a spindle. Therefore, the accuracy for processing the center circular hole is important, and if this  
25 accuracy is inadequate, a problem may occur in assembling of a hard disk drive which

can be rotated at high speed.

The silicon substrate is fragile; thus, a hard disk drive having high accuracy cannot be obtained by only limiting the surface roughness of the finished inner peripheral end face as shown in Reference 3.

5 In order to mass-producing hard disk drives having consistent quality and high performance, it is necessary to improve the accuracy and reduce dimensional variation of inner diameters of the center circular holes of the silicon substrates as respective magnetic recording media which are built into the hard disk drive. With inadequate accuracy in dimensions of the inner diameters, it is impossible to mass-produce hard disk  
10 drives having consistent quality and high performance.

However, no trial or attempt for regulating the accuracy relating to the dimensional variation of the inner diameters of the center circular holes has been implemented.

## 15 DISCLOSURE OF INVENTION

In view of the above circumstances, an object of the present invention is to improve the accuracy and reduce dimensional variation of the inner diameters of the center circular holes of the silicon substrates, to efficiently manufacture silicon substrates suitable for hard disk drives which have consistent quality and can be rotated at high  
20 speed, and to provide a magnetic recording apparatus in which a magnetic recording medium using such silicon substrates is mounted.

Therefore, the present invention provides a manufacturing method for silicon substrates for a magnetic recording medium, comprising the steps of:

forming a stack body of a number of silicon substrates which are stacked via  
25 spacers therebetween, wherein each silicon substrate has a circular hole at a center of the

substrate;

immersing the stack body of the silicon substrates in a polishing liquid in which grains are suspended; and

polishing inner peripheral end faces of the circular holes of the silicon substrates,  
5 wherein in polishing, a polishing brush contacts the end faces while performing a relative rotation between the end faces and the polishing brush, and the stack body of the silicon substrates is inverted during polishing.

The step of polishing the inner peripheral end faces may be performed before inner and outer peripheries of the silicon substrate are subjected to chamfering.

10 Preferably, the polishing brush is made of polyamide resin.

Typically, the difference between a maximum inner diameter and an minimum inner diameter of the circular hole of each silicon substrate of the stack body is 10  $\mu\text{m}$  or less.

Preferably, the difference between a maximum inner diameter and an minimum  
15 inner diameter of the circular hole of each silicon substrate of the stack body is 4  $\mu\text{m}$  or less.

The present invention also provides a silicon substrate for a magnetic recording medium, manufactured by a manufacturing method as described above.

The present invention also provides a magnetic recording medium made using a  
20 silicon substrate as described above, wherein at least a magnetic layer is formed on a main surface of the silicon substrate.

The present invention also provides a magnetic recording apparatus into which a magnetic recording medium as described above is mounted.

According to the present invention, the accuracy in dimensions in center circular  
25 holes of silicon substrates is strictly regulated. Therefore, it is possible to easily

mass-produce hard disk drives which have consistent quality and can be rotated at high speed.

## BRIEF DESCRIPTION OF THE DRAWINGS

5           Fig. 1 is a perspective view of a silicon substrate for a magnetic recording medium according to the present invention, which is cut and viewed from the cut face.

          Fig. 2 is a diagram for explaining the dimension of each portion of the silicon substrate in Fig. 1 according to the present invention.

          Fig. 3 is an enlarged view of an outer peripheral of the silicon substrate in Fig. 1  
10   according to the present invention.

          Fig. 4 is a diagram for explaining the method of measuring the radius  $R$  of the curved surface.

          Fig. 5 is a diagram for explaining the processes for manufacturing silicon substrates for a magnetic recording medium according to the present invention.

15           Fig. 6 is a diagram for explaining the processes for manufacturing a conventional silicon substrate for a magnetic recording medium.

          Fig. 7 is a diagram showing a portion of a stack body of silicon substrates used according to the present invention.

          Fig. 8 is a diagram for explaining the method of brush-polishing the inner  
20   peripheries of the center circular holes of the silicon substrates.

          Fig. 9 is a diagram showing frequencies for differences between the maximum value and the minimum value of the inner diameters of the silicon substrates.

          Fig. 10 is a diagram showing another example for the frequencies for differences between the maximum value and the minimum value of the inner diameters of the silicon  
25   substrates.

Fig. 11 is a diagram for explaining the method of brush-polishing the outer peripheries of the silicon substrates.

Fig. 12 is a longitudinal sectional view of a conventional silicon substrate.

## 5 BEST MODE FOR CARRYING OUT THE INVENTION

Hereinbelow, the present invention will be explained in detail.

Fig. 1 is a perspective view of a silicon substrate for a magnetic recording medium according to the present invention, which is cut and viewed from the cut face.

Fig. 2 is a diagram for explaining the dimension of each portion of the silicon substrate in

10 Fig. 1 according to the present invention.

As shown in Fig. 1, the silicon substrate 1 for a magnetic recording medium according to the present invention forms a doughnut-shaped circular disk. The main surfaces 2 and 3 for implementing magnetic recording are formed on the front and back faces of the circular disk. The outer peripheral end face 4 is positioned at the outermost periphery of the circular disk, and the inner peripheral end face 7 is positioned at the inside of the center circular hole of the disk. Between the outer peripheral end face 4 and the main surfaces 2 and 3, outer peripheral chamfered portions 5 are formed, and inner peripheral chamfered portions 6 are formed between the inner peripheral end face 7 and the main surfaces 2 and 3.

20 The main surfaces 2 and 3, the outer peripheral end face 4, the inner peripheral end face 7, the outer peripheral chamfered portions 5, and the inner peripheral chamfered portions 6 are subjected to polishing so as to produce mirror-finished surfaces.

Preferably, in the silicon substrate 1 for a magnetic recording medium according to the present invention, it is preferable to form curved surfaces having a radius R (of curvature) from 0.01 mm to 0.3 mm at edges between the main surfaces 2 and 3 and the

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outer peripheral chamfered portions 5, and also at edges between the main surfaces 2 and 3 and the inner peripheral chamfered portions 6.

According to such curved surfaces, even in a silicon substrate made of a fragile material, the corner portion does not break, and dust particles are not produced due to cracks or rubbing against a processing cassette and are not included in the substrate. Therefore, a smaller number of substandard magnetic recording media and a smaller number of write/read errors are produced.

Fig. 2 shows dimensions of each portion of the silicon substrate 1 for a magnetic recording medium according to the present invention. In the Figure, reference symbol D indicates the outer diameter of the substrate, reference symbol d indicates the inner diameter of the center circular hole of the substrate, reference symbol T indicates the thickness of the substrate, and reference symbol L indicates the length of each chamfered portion. Table 1 shows an example of the dimensions of each portion of the silicon substrate for a magnetic recording medium, according to the present invention. As shown in Table 1, an appropriate radius R of the curved surface is approximately from 0.01 mm to 0.3 mm for substrates having a diameter from 0.85 inches to 3.5 inches.

Table 1

unit: mm

| substrate name: inch | outer diameter of substrate (D) | diameter of inner hole of substrate (d) | thickness of substrate (T) | length of chamfered portion (L) | radius of curved surface (R) |
|----------------------|---------------------------------|-----------------------------------------|----------------------------|---------------------------------|------------------------------|
| 0.85                 | 21.6                            | 6.00                                    | 0.381                      | 0.07                            | 0.01 to 0.3                  |
| 1.                   | 25.4                            | 7.00                                    | 0.381                      | 0.07                            |                              |
| 1.89                 | 48.0                            | 12.00                                   | 0.508                      | 0.12                            |                              |
| 2.5                  | 65.0                            | 20.00                                   | 0.635                      | 0.15                            |                              |
| 3.3                  | 84.0                            | 25.00                                   | 1.27                       | 0.15                            |                              |
| 3.5                  | 95.0                            | 25.00                                   | 1.27                       | 0.15                            |                              |

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Here, an enlarged view of an outer peripheral portion of the silicon substrate 1 for a magnetic recording medium according to the present invention is shown in Fig. 3.

Between the outer peripheral end face 4 and the main surfaces 2 and 3 of the silicon substrate 1, the chamfered portions 5 are formed, and it is preferable to form curved surfaces having a radius  $R$  from 0.01 mm to 0.3 mm at edges between the main surfaces 2 and 3 and the outer peripheral chamfered portions 5.

5 Similarly, it is preferable to form curved surfaces having a radius  $R$  from 0.01 mm to 0.3 mm at edges between the main surfaces 2 and 3 and the inner peripheral chamfered portions.

Below, the method of measuring the radius  $R$  of the curved surface will be described with reference to Fig. 4. As shown in Fig. 4, an extension line  $S1$  from the  
10 main surface is defined, and a start point  $A$  is defined at the position where the curved surface  $S2$  is separated from the extension line  $S1$ . Point  $C$  on the extension line  $S1$  is away from the start point  $A$  by 10  $\mu\text{m}$ , and point  $B$  on the curved surface  $S2$  is away from the start point  $A$  by 10  $\mu\text{m}$ . The radius of a circle on which points  $A$ ,  $B$ , and  $C$  are present is defined as the radius  $R$  of the curved surface. When the radius  $R$  of the  
15 curved surface is set to be from 0.01 mm to 0.3 mm, it is possible to prevent the relevant corner portion of the silicon substrate from breaking. When  $R < 0.01$  mm, the corner is too sharp and is weak to impact, and chips tend to be produced when the substrate is handled or hits something. When  $R > 0.3$  mm, the data recording area on the main surface is reduced, which is not preferable. In addition, it is preferable to provide  
20 curved surfaces of radius  $R$  on either between the main surfaces and the outer peripheral chamfered portions and between the main surfaces and the inner peripheral chamfered portions.

Such curved surfaces having a radius  $R$  from 0.01 mm to 0.3 mm can be formed in silicon substrates of any size. In the silicon substrate, appropriately, the length of the  
25 chamfered portions 5 or 6 is 0.05 mm to 0.16 mm, so as to secure a sufficient data

recording area on each main surface.

Additionally, in the silicon substrate 1 for a magnetic recording medium according to the present invention, the main surfaces, the outer and inner peripheral end faces, and the outer and inner peripheral chamfered portions are subjected to polishing so as to create mirror-finished surfaces.

Regarding the surface roughness of the main surfaces, the maximum height  $R_{\max}$  is 10 nm or less, and for the surface roughness of the outer peripheral end faces and the outer peripheral chamfered portions, the maximum height  $R_{\max}$  is 10  $\mu\text{m}$  or less.

The accuracy for the inner diameter of the center circular hole of each silicon substrate for a magnetic recording medium must be 3  $\mu\text{m}$  or less as a difference between the maximum and the minimum values of the inner diameter.

In addition, in order to produce a hard disk drive having high performance and stable quality, which is an object of the present invention, a difference between the maximum inner diameter and the minimum inner diameter for the center circular holes of the respective silicon substrates must be 10  $\mu\text{m}$  or less. If the difference between the maximum inner diameter and the minimum inner diameter exceeds 10  $\mu\text{m}$ , it is difficult to mass-produce hard disk drives which have consistent quality and operate stably. According to the method of the present invention, it is possible to obtain silicon substrates for a magnetic recording medium, in which the difference between the maximum inner diameter and the minimum inner diameter for the center circular holes is 4  $\mu\text{m}$  or less.

In order to form the center circular hole of the silicon substrate for a magnetic recording medium, a stack body of silicon substrates is used, in which a number of silicon substrates are stacked via spacers, and it is important to reduce variation among the inner diameters of the center circular holes of the silicon substrates which constitute

the batch.

The above-described silicon substrate having a center circular hole formed with a high dimensional accuracy is obtained by using a stack body in which a number of disk-formed silicon substrates (having center circular holes) are stacked via spacers, and  
5 immersing the circular hole portions in a polishing liquid in which grains are suspended, and performing polishing of the inner peripheral end faces of the circular holes, in which a polishing brush contacts the end face while performing a relative rotation between the end face and the polishing brush.

In the above process in which a number of silicon substrates are stacked and  
10 simultaneously polished in batch processing, it is inevitable to have variation among dimensions of the inner diameters of the silicon substrates which constitute a batch. If the variation can be reduced as much as possible, hard disk drives having stable quality can be efficiently manufactured.

As shown in Fig. 6, conventional silicon substrates are manufactured in the  
15 following processes. First, in order to improve accuracies for shapes and dimensions, a disk-shaped silicon material is subjected to lapping which is performed in two steps by using a lapping apparatus, thereby achieving the conditions in which the surface accuracy is 1  $\mu\text{m}$  or less, and  $R_{\text{max}}$  for the surface roughness is 4  $\mu\text{m}$  or less.

According to the first lapping step,  $R_{\text{max}}$  for the surface roughness of the inner  
20 and outer peripheral end faces comes to approximately 6 $\mu\text{m}$ , and according to the successive second lapping step, the surface accuracy comes to 1  $\mu\text{m}$  or less, and  $R_{\text{max}}$  for the surface roughness comes to 4  $\mu\text{m}$  or less (see steps (a) and (b) in Fig. 6).

Next, after a circular hole is formed at a center of the substrate by using a cylindrical grindstone, a specific chamfering process is applied to the inner and outer  
25 peripheries (see steps (c2) and (c3) in Fig. 6).

Next, the inner and outer peripheral end faces and chamfered portions are subjected to polishing so as to produce mirror-finished surfaces (see step (d) in Fig. 6). The above processes are performed for every substrate (i.e., for each piece).

Finally, the main surface on which a magnetic recording medium is provided is subjected to polishing. This polishing process is performed in two steps. The first polishing step is performed for removing scars or distortions produced in the previous processes, and the second polishing step is performed for producing mirror-finished surfaces (see steps (e) and (f) in Fig. 6).

The silicon substrate after polishing is sufficiently cleaned, and then transferred to an inspection process (see steps (g) and (h) in Fig. 6).

According to the above processes, a conventional silicon substrate for a magnetic recording medium is obtained.

In the processes according to the present invention, as shown in Fig. 5, first, in order to improve accuracies for shapes and dimensions, a disk-shaped silicon material is subjected to lapping which is performed in two steps by using a lapping apparatus, so that the surface accuracy comes to 1  $\mu\text{m}$  or less, and  $R_{\text{max}}$  of the surface roughness comes to 5  $\mu\text{m}$  or less (see steps (a) and (b) in Fig. 5).

Next, a number of silicon substrates are bundled via spacers, so that a stack body of the silicon substrates is prepared, and a circular hole is formed at a center portion of the stack body by using a cylindrical grindstone, and then a specific chamfering process is applied to inner and outer peripheries of the substrates (see steps (c1), (c2), and (c3) in Fig. 6).

Next, the end faces of the stack body of the silicon substrates are brush-polished. In this brush polishing, when half of a period of time necessary for producing target mirror-surface-finished end faces has elapsed, the stack body is inverted (i.e., turned

upside down), and then polishing is again performed until the end faces acquire target mirror surfaces (see step (d) in Fig. 5).

Finally, the main surface on which a magnetic recording medium is provided is subjected to polishing. This polishing process is performed in two steps. The first  
5 polishing step is performed for removing scars or distortions produced in the previous processes, and the second polishing step is performed for producing mirror-finished surfaces (see steps (e) and (f) in Fig. 5).

The silicon substrate, after polishing of the main surface, is sufficiently cleaned, and then transferred to an inspection process (see steps (g) and (h) in Fig. 5).

10 Processing of the inner and outer peripheral end faces is performed as batch processing applied to a stack body 12 of a number of silicon substrates, as shown in Fig. 7. The stack body 12 includes 100 to 200 silicon substrates 1, and spacers 11 are inserted between the silicon substrates 1.

The spacers 11 are provided for reliably preventing (i) insufficient polishing in  
15 the brush polishing process applied to the inner peripheral chamfered portions 6 of the inner peripheral end face 7 and the outer peripheral chamfered portions 5 of the outer peripheral end face 4, and (ii) breakage of the silicon substrate in the polishing process. Each spacer 11 has a circular disk shape having a center circular hole, similar to the shape of the silicon substrate. More specifically, the spacers are installed in a manner  
20 such that an end face (i.e., a side face) of each spacer 11 is positioned at approximately 0 to 2 mm (preferably, 0.5 to 2 mm) inward from the end face 4 of the silicon substrate 1. When the end face of the spacer is positioned further inward from the end of the chamfered portion of the substrate, brush hairs reach the main surface areas of the silicon substrate (though depending on the thickness of the spacer and the diameter of the brush  
25 hair), and a ridge portion between the main surface and the chamfered portion is rounded.

In addition, the thickness of the spacer 11 is appropriately adjusted according to the diameter of the hair of the polishing brush. Preferably, the thickness is approximately 0.1 to 0.3 mm. In addition, a preferable material for the spacers 11 is polyurethane, acryl, epoxy, the same material as that of a polishing pad used in the polishing process, or  
5 the like, which is softer than the silicon substrate. That is, it is preferable to use spacers 11 made of a soft material adapted to prevent the silicon substrate from breaking due to pressure from the polishing brush or the polishing pad.

In the polishing process, first, a number of silicon substrates 1 and a number of spacers 11 are alternately inserted into a specific jig (not shown), and this body is bound  
10 tight and clamped using a binding cover, thereby forming a stack body 12 of the silicon substrates. Next, as shown in Fig. 8, a polishing brush 13 is inserted into the center circular hole of the silicon substrate 1, and the amount of pressing by the polishing brush 13 is adjusted so that the hairs 14 of the brush contact the inner peripheral end face of each substrate. Preferably, the polishing brush 13 is formed by tying up polyamide  
15 resin fibers into a corkscrew form, in which the diameter and the length of the brush hairs are respectively 0.05 mm to 0.3 mm, and 1 to 10 mm.

In the next step, a case in which the substrates are contained is filled with an appropriate amount of a polishing liquid. As shown in Fig. 8, a relative vertical motion between the stack body 12 of the silicon substrates 1 and the polishing brush 13 is  
20 performed while respectively rotating the stack body 12 and the brush 13 in opposite rotational directions, thereby brush-polishing the inner peripheral faces of the substrates. Preferably, the rate of rotation of the stack body 12 of the silicon substrates is approximately 60 rpm, and the rate of rotation of the polishing brush 13 is approximately 1000 to 3000 rpm.

25 Due to the brush polishing for the inner peripheral faces, the contact line

between the main surface and the inner peripheral end face is made into a curved surface having a radius of 0.01 to 0.05 mm, and the form of the inner peripheral end faces has high circularity.

In substantially the middle of the brush polishing process of the inner peripheral  
5 faces, it is preferable to invert the stack body 12 of the silicon substrates. Effects of the polishing are rapidly apparent after approximately 3 minutes of polishing; thus, 5 minutes of polishing is sufficient. For example, after 5 minutes of polishing, the stack body of the silicon substrates is inverted, and a further 5 minutes of polishing is performed, thereby sufficiently obtaining a target surface roughness and a target accuracy  
10 for the inner diameters.

In a more specific example, in brush-polishing of the inner peripheral faces of silicon substrates having an outer diameter of 48.0 mm and an inner diameter of 12.00 mm (i.e., substrates called 1.89 inch), when the stack body of the silicon substrates was inverted after 5 minutes of polishing and a further 5 minutes of polishing was performed,  
15 the maximum value and the minimum value of the inner diameters of the circular holes of the silicon substrates which constitute a stack body were measured using a hole tester. Regarding this example, frequencies for differences between the maximum value and the minimum value are shown in Fig. 9. As shown in Fig. 9, the difference between the maximum and the minimum values of the inner diameters when the stack of the silicon  
20 substrates was inverted was 3 or 4  $\mu\text{m}$  while the difference when no inversion was performed was up to 10  $\mu\text{m}$ . Therefore, the accuracy for the inner diameters of the circular holes is remarkably improved by performing the inversion of the stack body of the silicon substrates.

The inversion of the stack body of the silicon substrates is remarkably effective  
25 for the silicon substrates, and is also effective for glass substrates. Fig. 10 shows results

of another example of similar brush-polishing applied to silicon substrates and glass substrates having the same size as that of the silicon substrates. As shown in Fig. 10, in comparison with the silicon substrates having the difference (between the maximum and the minimum values of the inner diameters) of 4 to 5  $\mu\text{m}$ , the glass substrates have a wider distribution but the values are within 2 to 10  $\mu\text{m}$ .

After brush polishing of the inner peripheral end faces, the outer peripheral end faces of the substrates are polished using a brush.

As shown in Fig. 11, a cylindrical brush 15 is pushed against the end faces of the silicon substrates 1 of the stack body 12. Preferably, the cylindrical brush 15 is formed by tying up polyamide resin fibers into a corkscrew form, in which the diameter and the length of the brush hairs are respectively 0.05 mm to 0.3 mm, and 1 to 30 mm, and the diameter of the cylindrical brush 15 is 200 to 500 mm. This cylindrical brush is pushed against the outer peripheral portion of the stack body 12 of the silicon substrates 1, and a relative vertical motion is performed between the stack body 12 of the silicon substrates and the cylindrical brush 15 which are simultaneously respectively rotated in opposite rotational directions at respective rates of rotation of 60 rpm and 700 to 1000 rpm while supplying a polishing liquid to a contact face between the outer periphery of the stack body 12 and the polishing brush 15. Thereby, the outer peripheral end faces of the silicon substrates 1 are brush-polished.

After the brush polishing, each silicon substrate is cleaned using water, and the main surface of the substrate is subjected to a first polishing step which is performed for removing scars or distortions produced in the previous processes.

In this first polishing step, a polishing apparatus which is usually used is used. In polishing using the polishing apparatus, a polishing liquid obtained by adding colloidal silica to water is used; the load is approximately 100  $\text{g}/\text{cm}^2$ ; the rate of rotation

of the lower surface plate is 40 rpm; the rate of rotation of the upper surface plate is 35 rpm; the rate of rotation of the sun gear is approximately 14 rpm; and the rate of rotation of the internal gear is approximately 29 rpm. After the first polishing step, the silicon substrate is cleaned using water, and is transferred to a second polishing step.

5           That is, the second polishing step as a finishing process is applied to the main surfaces of each silicon substrate which was subjected to the first polishing step. As conditions for the second polishing step as finish polishing, a polishing liquid obtained by adding colloidal silica to water is used; the load is approximately  $100 \text{ g/cm}^2$ ; a target removal amount in polishing is  $1 \text{ }\mu\text{m}$ ; the rate of rotation of the lower surface plate is 40  
10 rpm; the rate of rotation of the upper surface plate is 35 rpm; the rate of rotation of the sun gear is approximately 14 rpm; and the rate of rotation of the internal gear is approximately 29 rpm.

After the second polishing step, the silicon substrate is immersed in neutral detergent, pure water, pure water and IPA (isopropyl alcohol), and IPA (for vapor drying)  
15 in turn, which are respectively contained in cleaning tanks, thereby performing ultrasonic cleaning of the silicon substrate.

According to the above-described processes, a silicon substrate for a magnetic recording medium is obtained, in which the end faces and the chamfered portions are mirror surfaces, and curved surfaces having a radius from 0.01 mm to 0.3 mm are  
20 provided between the main surfaces and the chamfered portions of the substrate.

This silicon substrate for a magnetic recording medium is made of fragile silicon; however, chips in end faces or cracks in the substrate are not easily produced, thereby preventing the occurrence of dust particles produced from end faces of the substrate, or due to rubbing with a processing cassette.

25           In addition, the dimensional accuracy for the inner diameters of the center

circular holes of the silicon substrates as described above is 4  $\mu\text{m}$  or less as the difference between the maximum and the minimum values, that is, variation is extremely small and the accuracy is very high. Therefore, a hard disk drive in which the silicon substrates are mounted can have stable performance.

5           Furthermore, the chamfering process for every substrate is omitted and brush polishing is instead performed in a batch processing. Therefore, the manufacturing processes are considerably simplified and production efficiency is improved, thereby contributing to cost reduction.

10           On either face of the silicon substrate obtained as described above, layers are deposited by a known method, for example, a CrMo base layer, a CoCrPtTa magnetic layer, and a carbon hydride protection layer are deposited in turn by using an in-line sputtering apparatus or the like, and then a perfluoropolyether liquid lubricating layer is further deposited using a dipping method, thereby obtaining a magnetic recording medium.

15           A hard disk drive is obtained by mounting known devices such as a driving device and a write/read head onto a magnetic recording medium as obtained above.

20           The magnetic recording medium according to the present invention, obtained by the above processes, has curved surfaces having a radius from 0.01 mm to 0.3 mm between the main surfaces and the chamfered portions; thus, chips in the end faces or cracks of the substrate are not easily produced, thereby preventing the occurrence of dust particles produced from an end face of the substrate, or due to rubbing with a processing cassette. Accordingly, it is effective for preventing write/read errors or a crash of the magnetic head in the write/read process.

25           In addition, dimensional accuracy of the inner diameter of the center circular hole of the substrate is extremely high and dimensional variation is very small.

Therefore, it is possible to mass-produce magnetic recording apparatuses having stable performance.

While preferred embodiments of the invention have been described and illustrated above, it should be understood that these are exemplary of the invention and  
5 are not to be considered as limiting. Additions, omissions, substitutions, and other modifications can be made without departing from the spirit or scope of the present invention. Accordingly, the invention is not to be considered as being limited by the foregoing description, and is only limited by the scope of the appended claims.

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#### INDUSTRIAL APPLICABILITY

The accuracy in dimensions in center circular holes of silicon substrates is strictly regulated; thus, it is possible to easily mass-produce hard disk drives which have consistent quality and can be rotated at high speed.

## CLAIMS

1. A manufacturing method for silicon substrates for a magnetic recording medium, comprising the steps of:

5 forming a stack body of a number of silicon substrates which are stacked via spacers therebetween, wherein each silicon substrate has a circular hole at a center of the substrate;

immersing the stack body of the silicon substrates in a polishing liquid in which grains are suspended; and

10 polishing inner peripheral end faces of the circular holes of the silicon substrates, wherein in polishing, a polishing brush contacts the end faces while performing a relative rotation between the end faces and the polishing brush, and the stack body of the silicon substrates is inverted during polishing.

15 2. The manufacturing method as claimed in claim 1, wherein the step of polishing the inner peripheral end faces is performed before inner and outer peripheries of the silicon substrate are subjected to chamfering.

3. The manufacturing method as claimed in claim 1, wherein the polishing brush is  
20 made of polyamide resin.

4. The manufacturing method as claimed in claim 1, wherein the difference between a maximum inner diameter and an minimum inner diameter of the circular hole of each silicon substrate of the stack body is 10  $\mu\text{m}$  or less.

5. The manufacturing method as claimed in claim 1, wherein the difference between a maximum inner diameter and an minimum inner diameter of the circular hole of each silicon substrate of the stack body is 4  $\mu\text{m}$  or less.
- 5 6. A silicon substrate for a magnetic recording medium, manufactured by a manufacturing method as claimed in claim 1.
7. A magnetic recording medium made using a silicon substrate as claimed in claim 6, wherein at least a magnetic layer is formed on a main surface of the silicon  
10 substrate.
8. A magnetic recording apparatus into which a magnetic recording medium as claimed in claim 7 is mounted.