

DESCRIPTION

[Title of Invention]

METHOD FOR MANUFACTURING NONMAGNETIC SUBSTRATE

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[Technical Field]

[0001] The present invention relates to a method for manufacturing a nonmagnetic substrate, and specifically, to a method for manufacturing a substrate including a step of polishing an edge surface of the nonmagnetic substrate.

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[Background Art]

[0002] Nowadays, in order to record data, hard disk apparatuses are incorporated in personal computers, laptop personal computers, DVD (Digital Versatile Disc) recording apparatuses, and the like. In particular, a magnetic disk obtained by providing a magnetic layer on a magnetic-disk glass substrate is used in a hard disk apparatus used in a device for which portability is a prerequisite, such as a laptop personal computer. On the surface of the magnetic disk, magnetic recording information is recorded in or read from the magnetic layer of the magnetic disk with a magnetic head (DFH (Dynamic Flying Height) head) that flies slightly away from the surface of the magnetic disk. A glass substrate is preferably used as a nonmagnetic substrate for the magnetic disk substrate due to the fact that it has a property of being unlikely to undergo plastic deformation compared to a metal substrate or the like.

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[0003] Nowadays, in order to meet the demand for an increase in the storage capacity of hard disk drive apparatuses, attempts have been made to increase the magnetic recording density. Accompanying this, the magnetic recording information area has been made smaller by making the flying height of the magnetic head from the magnetic recording surface extremely low. In such a magnetic-disk glass substrate, the substrate is produced such that surface unevenness of the substrate is reduced as much as possible.

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In the magnetic head used in the hard disk apparatus, if the surface of the magnetic disk has minute unevenness, there is a risk that a known thermal asperity failure will occur, malfunction will occur in reproduction, or reproduction will not be able to be performed. This thermal asperity failure is caused by a protruding portion that is formed on the surface of the magnetic disk by foreign matter on the glass substrate causing adiabatic compression and adiabatic expansion of air in the vicinity of the head due to high-speed rotation of the magnetic disk, resulting in the generation of heat in the magnetic head. That is, the thermal asperity failure may occur in the case where the magnetic head does not come into contact with the magnetic disk.

Therefore, in order to prevent this thermal asperity failure, the surfaces of the magnetic disk need to be extremely smooth and to be finished into surfaces that do not have foreign matter and are highly clean.

[0004] It is conceivable that the reason why foreign matter attaches to the surfaces of the magnetic-disk glass substrate is not only because of the surface shape of the glass substrate but also because of the surface shape of edge surfaces of the glass substrate. That is, in the case where an edge portion of the magnetic-disk glass substrate is sharp, or in the case where the surface shape of an edge surface is not smooth, the edge portion scratches a wall surface of a resin case, and minute particles of the resin or glass are generated due to this scratching. Such minute particles and minute particles in the atmosphere are then captured by and accumulated on the edge surface of the magnetic-disk glass substrate. The minute particles accumulated on the edge surface of the magnetic-disk glass substrate serve as a dust generation source in the later steps or after the glass substrate is mounted in a hard disk apparatus, and cause the attachment of foreign matter to the surfaces of the disk substrate.

Therefore, when the magnetic-disk glass substrate is manufactured, chamfered surfaces are formed between the main surfaces and side wall surfaces of a circular glass substrate and processing for polishing the side wall

surfaces and the chamfered surfaces is performed.

[0005] Incidentally, there is known to be a magnetic polishing method in which a magnetosensitive polishing agent and a first magnet are placed in this order on a processing target surface of a nonmagnetic material such as aluminum or glass, a second magnet is disposed below the nonmagnetic material, the first magnet is revolved while being rotated above the processing target surface via the magnetic force generated between the first magnet and the second magnet, and the magnetosensitive polishing agent is moved relative to the processing target surface (Patent Literature 1). Such a magnetic polishing method is assumed to increase surface accuracy and shape accuracy of the processing target surface at the same time with a simple method.

[0006] Also, a magnetic polishing method is known as a method for polishing the edge surfaces of the circular glass substrate. For example, Patent Literature 2 discloses that polishing is performed with a magnetic polishing method in which, in a step of polishing an inner circumferential edge surface of the glass substrate, the inner circumferential side edge surface of a central circular hole is polished by forming a magnetic field on the inner circumferential side of the central circular hole, causing the magnetic field to hold a polishing agent including magnetic particles and polishing abrasive particles in this circular hole, and moving the magnetic field with respect to the inner circumferential side edge surface of the circular hole, thereby causing the polishing agent to move with respect to the inner circumferential side edge surface of the circular hole. According to such a magnetic polishing method, it is assumed that the inner circumferential side edge surface of the circular hole in the central portion of the glass substrate can be easily and preferably polished.

[Citation List]

[Patent Literature]

[0007] [PLT1]: JP 2008-290162A

[PLT2]: JP 2005-50501A

[Summary of Invention]

[Technical Problem]

[0008] When the inventor of the present invention performed processing for polishing an edge surface of the glass substrate by forming a magnetic field such that magnetic field lines advance in the thickness direction of the glass substrate using a magnetic field generation means, causing the magnetic field to hold magnetic functional fluid containing polishing abrasive particles, and moving the edge surface of the glass substrate relative to the magnetic functional fluid in a state in which the edge surface is in contact with the magnetic functional fluid, it was confirmed that the processing rate was high and a glass substrate having excellent edge surface properties could be obtained.

However, in the case where the above-described edge surface polishing processing is performed continuously on many glass substrates using single-substrate processing, it was found that the processing rate for chamfered surfaces in particular gradually decreased. It is conceivable that this problem arises in not only the glass substrate, but also similarly arises in a nonmagnetic substrate made of another material (an aluminum alloy, for example).

[0009] In view of this, an object of the present invention is to provide a method for manufacturing a substrate according to which a decrease in the processing rate for chamfered surfaces can be suppressed when the edge surfaces of substrates are polished continuously.

[Solution to Problem]

[0010] The inventor of the present invention conducted intensive studies on the cause of a decrease in the processing rate for the edge surface of the glass substrate in the case where the processing for continuously polishing the edge surfaces of the glass substrates using magnetic functional fluid is performed. As a result, the cause of a decrease in the processing rate was inferred as follows. That is, in the above-described edge surface polishing processing, the magnetic flux density decreases in a region in which a portion of the edge

surface of the glass substrate crosses the magnetic field lines. The force of the magnetic field holding the magnetic functional fluid is likely to decrease in such a region. That is, a pressing force of the magnetic functional fluid against the processing target portion of the substrate is likely to decrease. In the case where a side wall surface and a chamfered surface are formed in the edge portion of the substrate, such a tendency is more prominent in the chamfered surface. On the other hand, because the polishing abrasive particles contributing to polishing are nonmagnetic, basically, the polishing abrasive particles are not held by the magnetic field, but are held by a pressing force between the magnetic particles and the processing target substrate. Thus, if the pressing force decreases, the polishing abrasive particles easily come out of the magnetic functional fluid. Also, the concentration of polishing abrasive particles gradually decreases over time in a portion in which the pressing force is small. It was inferred that the processing rate of polishing decreased as a result. Also, it was inferred that because the pressing force against the chamfered surface had a tendency to be lower than the processing force against the side wall surface, such a decrease in the processing rate was more prominent on the chamfered surface. The inventor of the present invention further advanced the research based on this inferred cause, and found that a decrease in the processing rate for the chamfered surface in edge surface polishing could be suppressed with a method for manufacturing a magnetic-disk glass substrate according to the present invention.

[0011] A first aspect of the present invention is a method for manufacturing a nonmagnetic substrate, the method including edge surface polishing processing for polishing an edge surface of a plate-like nonmagnetic substrate having a side wall surface and a chamfered surface formed between a main surface and the side wall surface.

The edge surface polishing processing is processing for polishing the edge surface of the substrate by forming a magnetic field such that magnetic field lines advance in a thickness direction of the substrate using a magnetic

field generation means, bringing the edge surface of the substrate and magnetic functional fluid into contact with each other in a state in which the magnetic functional fluid containing polishing abrasive particles is held by the magnetic field, and moving the substrate and the magnetic functional fluid relative to each other. Here, the polishing abrasive particles are supplied to the magnetic functional fluid during the edge surface polishing processing.

Note that it is sufficient that the magnetic functional fluid is functional fluid that responds to the magnetic field, and the magnetic function fluid may be a MRF (Magneto-rheological Fluid), a MF (Magnetic Fluid), a MCF (Magnetic Compound Fluid), or the like.

[0012] In this time, the polishing abrasive particles may be supplied by supplying a liquid containing polishing abrasive particles during the above-described edge surface polishing processing.

[0013] A temperature of the liquid to be supplied during the above-described edge surface polishing processing may be less than or equal to room temperature.

[0014] In the above-described edge surface polishing processing, the polishing abrasive particles may be supplied to a position at which the edge surface of the substrate comes into contact with the magnetic functional fluid along a movement direction of the edge surface of the substrate that comes into contact with the magnetic functional fluid. A supplying method includes a method for allowing the polishing abrasive particles or the liquid containing the polishing abrasive particles to flow out toward the above-described position (ejection method, for example), a dropping method, and the like.

[0015] A second aspect of the present invention is a method for manufacturing a nonmagnetic substrate, the method including edge surface polishing processing for polishing an edge surface of a plate-like nonmagnetic substrate having a side wall surface and a chamfered surface formed between a main surface and the side wall surface.

The edge surface polishing processing is for polishing the edge surface

of the substrate by forming a magnetic field such that magnetic field lines advance in a thickness direction of the substrate using a magnetic field generation means in a state in which magnetic functional fluid containing polishing abrasive particles and the substrate are immersed in a liquid containing polishing abrasive particles, bringing the edge surface of the substrate and the magnetic functional fluid into contact with each other in a state in which the magnetic functional fluid containing the polishing abrasive particles is held by the magnetic field, and moving the substrate and the magnetic functional fluid relative to each other.

[0016] In the first and second aspects of the present invention, the magnetic field generation means may include a pair of magnets disposed in a state in which an N-pole surface and an S-pole surface are disposed apart from each other and facing each other in the thickness direction of the substrate.

[0017] In the first or the second aspect of the present invention, a spacer made of a nonmagnetic material may be provided between the N-pole surface and the S-pole surface of the pair of magnets.

[0018] The substrate may have a disk shape having a circular inner hole. In this case, the magnetic field generation means may include an inner circumferential side means that is provided in the inner hole of the substrate and that forms a magnetic field around an inner circumferential edge surface, which is the side wall surface of the inner hole, such that inner circumferential side magnetic field lines advance in the thickness direction of the substrate, and/or an outer circumferential side means that is provided on an outer circumferential side of the substrate and that forms a magnetic field around an outer circumferential edge surface of the substrate such that outer circumferential side magnetic field lines advance in the thickness direction of the substrate. Furthermore, the inner circumferential edge surface and/or the outer circumferential edge surface of the substrate may be polished in a state in which the magnetic functional fluid is held by the magnetic fields respectively formed by the inner circumferential side means and/or the outer

circumferential side means.

[0019] Also, from a viewpoint different from that above, the inventor of the present invention conducted intensive studies on the cause of a decrease in the processing rate for the chamfered surface of the glass substrate in the case where the processing for continuously grinding the edge surfaces of the glass substrates using the magnetic functional fluid is performed. As a result, the cause of a decrease in the processing rate for the chamfered surface of the glass substrate is inferred as follows. That is, in the above-described edge surface polishing processing, the side wall surface of the edge surfaces of the glass substrate is polished by a mass of magnetic functional fluid, which is present in a region (referred to as a "region A1") in which the glass substrate does not cross magnetic field lines in plan view. Since the magnetic field lines are not disconnected, the mass of the magnetic functional fluid present in the region A1 has a strong force of holding the mass resulting from the magnetic field, and polishing is stably performed by polishing abrasive particles, and thus the processing rate of polishing is high. On the other hand, the chamfered surfaces of the edge surfaces of the glass substrate are polished by a mass of the magnetic functional fluid in a region (referred to as "region A2") in which the glass substrate crosses the magnetic field lines in plan view. Since the magnetic field lines are at least partially disconnected, the mass of the magnetic functional fluid present in this region A2 has a relatively weak holding force resulting from the magnetic field, the mass comes apart and deforms (plastic deformation), and a pressing force against the glass substrate is likely to decrease. Therefore, it was thought that polishing was not stably performed by the polishing abrasive particles in the region A2, and thus the processing rate of polishing the chamfered surface was lower than in the case of the processing rate of polishing the side wall surface. The inventor of the present invention further advanced the research based on this inferred cause, and found that a decrease in the processing rate for the chamfered surface could be suppressed by modifying the shape of the magnetic functional fluid

that had deformed due to contact with the substrate such that the pressing force against the substrate is kept constant.

[0020] A third aspect of the present invention is a method for manufacturing a nonmagnetic substrate, the method including edge surface polishing processing for polishing an edge surface of a plate-like nonmagnetic substrate having a side wall surface and a chamfered surface formed between a main surface and the side wall surface.

The edge surface polishing processing is processing for polishing the edge surface of the substrate by forming a magnetic field such that magnetic field lines advance in a thickness direction of the substrate using a magnetic field generation means, forming a mass of magnetic functional fluid by causing the magnetic field to hold the magnetic functional fluid containing polishing abrasive particles, bringing the edge surface of the substrate and the mass of the magnetic functional fluid into contact with each other, and moving the substrate and the mass of the magnetic functional fluid relative to each other. Here, a shape of the mass of the magnetic functional fluid that has deformed due to contact with the substrate is modified such that a pressing force against the substrate is kept constant.

[0021] At this time, the shape of the mass of the magnetic functional fluid may be modified by bringing a jig into contact with the deformed magnetic functional fluid. Also, the shape of the mass of the magnetic functional fluid may be modified by supplying an additional mass of the magnetic functional fluid.

[0022] A fourth aspect of the present invention is a method for manufacturing a nonmagnetic substrate, the method including edge surface polishing processing for polishing an edge surface of a plate-like nonmagnetic substrate having a side wall surface and a chamfered surface formed between a main surface and the side wall surface.

The edge surface polishing processing is processing for polishing the edge surface of the substrate by forming a magnetic field such that magnetic

field lines advance in a thickness direction of the substrate using a magnetic field generation means, forming a mass of magnetic functional fluid by causing the magnetic field to hold the magnetic functional fluid containing polishing abrasive particles, bringing the edge surface of the substrate and the mass of the magnetic functional fluid into contact with each other, and moving the substrate and the mass of the magnetic functional fluid relative to each other.

A shape of the mass of the magnetic functional fluid deformed due to contact with the substrate is modified so as to return to an original shape.

[0023] A fifth aspect of the present invention is a method for manufacturing a nonmagnetic substrate, the method including edge surface polishing processing for polishing an edge surface of a plate-like nonmagnetic substrate having a side wall surface and a chamfered surface formed between a main surface and the side wall surface.

The edge surface polishing processing is processing for polishing the edge surface of the substrate by forming a magnetic field such that magnetic field lines advance in a thickness direction of the substrate using a magnetic field generation means, forming a mass of magnetic functional fluid by causing the magnetic field to hold the magnetic functional fluid containing polishing abrasive particles, bringing the edge surface of the substrate and the mass of the magnetic functional fluid into contact with each other, and moving the substrate and the mass of the magnetic functional fluid relative to each other, and

a shape of the mass of the magnetic functional fluid is changed by bringing a jig into contact with the mass of the magnetic functional fluid.

[0024] The jig may be brought into contact with the mass of the magnetic functional fluid by inserting a tip of the jig into the mass of the magnetic functional fluid.

[0025] In the third to fifth aspects of the present invention, the magnetic field generation means may include a pair of magnets disposed in a state in which an N-pole surface and an S-pole surface are disposed apart from each other and

facing each other in the thickness direction of the substrate.

[0026] In the third to fifth aspects of the present invention, a spacer made of a nonmagnetic material may preferably be provided between the N-pole surface and the S-pole surface of the pair of magnets.

5 [0027] In the third to fifth aspects of the present invention, the substrate may have a disk shape having a circular inner hole. In this case, the magnetic field generation means may include an inner circumferential side means that is provided in the inner hole of the substrate and that forms a magnetic field around an inner circumferential edge surface, which is the side wall surface of
10 the inner hole, such that inner circumferential side magnetic field lines advance in the thickness direction of the substrate, and/or an outer circumferential side means that is provided on an outer circumferential side of the substrate and that forms a magnetic field around an outer circumferential edge surface of the substrate such that outer circumferential side magnetic
15 field lines advance in the thickness direction of the substrate. Furthermore, the inner circumferential edge surface and/or the outer circumferential edge surface of the substrate may be polished in a state in which the mass of the magnetic functional fluid is held by the magnetic fields respectively formed by the inner circumferential side means and/or the outer circumferential side
20 means.

[Brief Description of Drawings]

[0028] FIG. 1A is a diagram showing the external shape of a magnetic-disk glass substrate according to a first embodiment.

FIG. 1B is an enlarged cross-sectional view of an outer circumferential
25 side edge portion of the magnetic-disk glass substrate of the first embodiment.

FIG. 2 is a diagram showing the flow of an embodiment of a method for manufacturing a magnetic-disk glass substrate.

FIG. 3 is a diagram illustrating a polishing method for polishing an edge surface of the first embodiment.

30 FIG. 4 is a diagram illustrating a polishing method for polishing an

edge surface of the first embodiment.

FIG. 5 is a diagram illustrating a polishing method for polishing an edge surface of the first embodiment.

FIG. 6 is a diagram illustrating a polishing method for polishing an
5 edge surface of the first embodiment.

FIG. 7 is a diagram illustrating a polishing method for polishing an edge surface according to a modified example of the first embodiment.

FIG. 8 is a diagram illustrating a polishing method for polishing an edge surface according to a modified example of the first embodiment.

10 FIG. 9 is a diagram illustrating a reason why the processing rate for the chamfered surface decreases in the case where the shape of polishing fluid is not modified in polishing of the edge surface of the glass substrate in a second embodiment.

FIG. 10 is a diagram showing a configuration example in the case where
15 the shape of the polishing fluid is modified using a shape modification apparatus in the second embodiment.

FIG. 11 is a diagram illustrating processing for modifying the shape of the polishing fluid using a shape modification apparatus in the second embodiment.

20 FIG. 12 is a diagram showing a configuration example in the case where the shape of the polishing fluid is modified using a supplying apparatus in the second embodiment.

FIG. 13 is a diagram showing a configuration example in the case where the shape of the polishing fluid is modified using a supplying apparatus when
25 the edge surfaces of the glass substrates that constitute a stacked body are polished in the second embodiment.

FIG. 14 is a diagram illustrating a method for obtaining the radius of curvature of a shape of a portion between the side wall surface and a chamfered surface.

30 [Description of Embodiments]

[0029] (First embodiment)

Hereinafter, a method for manufacturing a magnetic disk substrate will be described in detail as an embodiment of a method for manufacturing a nonmagnetic substrate of the present invention. Note that although the case
 5 where a glass substrate is used as a magnetic disk substrate will be described in the description below, there is no limitation thereto, and an aluminum composite substrate may be used.

[Magnetic-disk glass substrate]

Aluminosilicate glass, soda-lime glass, borosilicate glass, and the like
 10 can be used as material for a magnetic-disk glass substrate in the present embodiment. In particular, aluminosilicate glass can be preferably used because chemical strengthening can be performed, and a magnetic-disk glass substrate that is excellent in the flatness of main surfaces and substrate strength can be produced.

15 [0030] Although there is no limitation on the composition of glass material used for the magnetic-disk glass substrate of the present embodiment, the glass substrate of the present embodiment may preferably be amorphous aluminosilicate glass containing, as essential components, SiO_2 , Li_2O , Na_2O , and at least one alkaline earth metal oxide selected from the group consisting of
 20 MgO , CaO , SrO , and BaO , a molar ratio of a CaO content with respect to a total content of MgO , CaO , SrO , and BaO ($\text{CaO}/(\text{MgO}+\text{CaO}+\text{SrO}+\text{BaO})$) being less than or equal to 0.20, and a glass transition temperature being greater than or equal to 650°C .

Also, the glass substrate may be crystallized glass containing, in terms
 25 of oxide amount in mass%, SiO_2 in an amount of 45.60 to 60%, Al_2O_3 in an amount of 7 to 20%, B_2O_3 in an amount of 1.00 to less than 8%, P_2O_5 in an amount of 0.50 to 7%, TiO_2 in an amount of 1 to 15%, RO in a total amount of 5 to 35% (note that R indicates Zn and Mg), CaO in an amount of 3.00% or less, BaO in an amount of 4% or less, no PbO component, no As_2O_3 component, no
 30 Sb_2O_3 component, no Cl^- component, no NO^- component, no SO^{2-} component, no

F⁻ component, and one or more selected from RAl_2O_4 and R_2TiO_4 (note that R indicates one or more selected from Zn and Mg) as a main crystal phase, the particle size of crystals in the main crystal phase being in a range of 0.5 nm to 20 nm, the degree of crystallization being less than or equal to 15%, and the specific gravity being less than or equal to 2.95.

[0031] FIG. 1A shows the external shape of a magnetic-disk glass substrate 1 of an embodiment. As shown in FIG. 1A, the magnetic-disk glass substrate 1 of the present embodiment is a donut-shaped thin glass substrate having an inner hole 2. Although there is no limitation on the size of the magnetic-disk glass substrate, this magnetic-disk glass substrate is preferable as a magnetic-disk glass substrate having a nominal diameter of 2.5 inches, for example.

FIG. 1B is a diagram showing an enlarged cross section of an outer circumferential side edge portion of a magnetic-disk glass substrate of an embodiment. As shown in FIG. 1B, the magnetic-disk glass substrate has a pair of main surfaces 1p, a side wall surface 1t disposed along the direction orthogonal to the pair of main surfaces 1p, and a pair of chamfered surfaces 1c disposed between the pair of main surfaces 1p and the side wall surface 1t. Although not shown, a side wall surface and chamfered surfaces are formed similarly on an inner circumferential side edge portion of the magnetic-disk glass substrate. The angle of each chamfered surface 1c with respect to the side wall surface 1t (chamfering angle) is the same, and is 40 to 50 degrees, for example. As shown in FIG. 1B, typically, the chamfering angle is 45 degrees. Note that the chamfered surface may be formed in an arc shape in a cross-sectional view.

[0032] Although there is no particular limitation on the thickness of the magnetic-disk glass substrate of the present embodiment, in the case of a magnetic-disk glass substrate having a nominal size of 2.5 inches, for example, the substrate thickness is 0.8 mm, 0.635 mm, or 0.5 mm, whereas in the case of a magnetic-disk glass substrate having a nominal size of 3.5 inches, the

substrate thickness is 0.5 to 3.0 mm, for example. Note that the same applies to the case where an aluminum alloy substrate is used as a nonmagnetic substrate.

[0033] (Method for manufacturing magnetic-disk glass substrate)

5 Next, the flow of a method for manufacturing a magnetic-disk glass substrate will be described with reference to FIG. 2. FIG. 2 is a diagram showing the flow of an embodiment of the method for manufacturing a magnetic-disk glass substrate.

As shown in FIG. 2, first, a plate-like glass blank having a pair of main
10 surfaces is molded (step S10). Next, the molded glass blank is scribed to produce an annular glass substrate (step S20). Accordingly, a magnetic-disk glass substrate (simply referred to as a glass substrate, hereinafter) having a circular through hole in the central portion can be obtained. Next, shape processing (chamfering processing) is performed on the scribed glass substrate
15 (step S30). Next, grinding is performed on the glass substrate using fixed abrasive particles (step S40). Next, an edge surface of the glass substrate is polished (step S50). Next, first polishing is performed on the main surfaces of the glass substrate (step S60). Next, chemical strengthening is performed on the glass substrate that has undergone first polishing (step S70). Next, second
20 polishing is performed on the chemically strengthened glass substrate (step S80). A magnetic-disk glass substrate that satisfies a required surface unevenness can be obtained through the above-described processing. Note that a circular glass substrate is produced from a glass blank by processes from the glass blank molding processing (step S10) to shape processing (step S30).
25 Hereinafter, each processing will be described in detail.

[0034] (a) Glass blank molding processing (step S10)

After plate-like glass is formed with a float method, for example, a glass blank that serves as the base for a magnetic-disk glass substrate and has a predetermined shape is cut out from this plate-like glass. Instead of the float
30 method, a glass blank may be molded by press molding using an upper mold

and a lower mold, for example. Note that a molding method is not limited to these, and a glass blank can also be manufactured using a known manufacturing method such as a downdraw method, a redraw method, a fusion method, or the like.

5 Note that rough grinding processing may be performed on both main surfaces of the glass blank as needed.

[0035] (b) Scribing processing (step S20)

Next, scribing processing will be described. After the glass blank molding processing, in the scribing processing, the scribing processing is performed on the molded glass blank using a scribe, as a result of which an annular glass substrate having a circular inner hole can be obtained. Note that an annular glass substrate can also be obtained by forming a circular inner hole on the glass blank using a core drill or the like.

[0036] (c) Shape processing (step S30)

15 Next, shape processing will be described. The shape processing includes processing for chamfering edge portions of the glass substrate that has undergone the scribing processing (processing for chamfering an outer circumferential edge surface and an inner circumferential edge surface). The chamfering processing is shape processing for chamfering the outer circumferential edge surface and the inner circumferential edge surface of the glass substrate that has undergone the scribing processing, using a diamond grindstone. An inclination angle of chamfering with respect to the main surface is 40 to 50 degrees, for example, and is preferably approximately 45 degrees. A glass substrate having a predetermined cross-sectional shape is produced by this shape processing.

[0037] (d) Precision grinding processing (step S40)

In precision grinding processing, grinding processing is performed on the main surfaces of the glass substrate using a double-side grinding apparatus having a known planetary gear mechanism provided with an upper surface plate, a lower surface plate, an internal gear, a carrier, and a sun gear.

Specifically, the main surfaces on both sides of the glass substrate are ground while the outer circumferential edge surface of the glass substrate is held in a holding hole provided in a holding member of the double-side grinding apparatus. The machining allowance for grinding is about several μm to about 100 μm , for example. The particle size of the fixed abrasive particles used in precision grinding processing is about 10 μm , for example. The double-side grinding apparatus has a pair of upper and lower surface plates (an upper surface plate and a lower surface plate), and the glass substrate is sandwiched between the upper surface plate and the lower surface plate. Sandwiching the glass substrate is performed such that a disk-shaped carrier is sandwiched between the upper surface plate and the lower surface plate in a state in which the glass substrate is held in a holding hole provided in the carrier. The glass substrate and the surface plates are moved relative to each other by moving one or both of the upper surface plate and the lower surface plate, and thereby both main surfaces of the glass substrate can be ground.

[0038] (e) Edge surface polishing processing (step S50)

Next, edge surface polishing processing will be described. In edge surface polishing, a magnetic field is formed using a magnetic field generation means such that magnetic field lines advance in the thickness direction of the glass substrate, and magnetic functional fluid (referred to as "polishing fluid", hereinafter) containing polishing abrasive particles is held by the magnetic field, and the glass substrate is moved relative to the polishing fluid in a state in which the edge surface of the glass substrate is in contact with the polishing fluid so as to polish the edge surface of the glass substrate. A mass of the polishing fluid is formed in the magnetic field. Minute particles of cerium oxide, zirconium oxide, or the like, for example, are used as the polishing abrasive particles included in the polishing fluid. Also, the machining allowance for edge surface polishing is less than or equal to 10 μm , and is more preferably less than or equal to 5 μm . By performing the edge surface polishing, contamination caused by attachment of dirt and the like and

impairment such as scratches on the edge surface of the glass substrate can be eliminated, and thermal asperity and deposition of ions such as sodium and potassium that causes corrosion can be prevented. Edge surface polishing of the present embodiment enables polishing in a shorter time compared to a conventional magnetic polishing method in which the edge surfaces of the glass substrate are polished with a polishing slurry using a brush, for example, and has excellent production efficiency. Edge surface polishing will be described later.

[0039] (f) First polishing processing (step S60)

Next, first polishing processing is performed on the main surfaces of the glass substrate. In the first polishing processing, polishing is performed on the main surfaces on both sides of the glass substrate using a double-side polishing apparatus provided with a planetary gear mechanism. Loose abrasive particles such as cerium oxide abrasive particles, or zirconia abrasive particles, for example, and a resin polisher are used in the first polishing processing. Cracks and warping remaining on the main surfaces in the case where the precision grinding processing is performed, for example, is removed by first polishing.

[0040] (g) Chemical strengthening processing (step S70)

The glass substrate can be chemically strengthened as appropriate. A molten liquid obtained by heating potassium nitrate, sodium nitrate, or a mixture thereof can be used as a chemical strengthening liquid. Then, by immersing the glass substrate in the chemical strengthening liquid, lithium ions and sodium ions in the glass composition in the surface layer of the glass substrate are respectively substituted with sodium ions and potassium ions with relatively large ion radii in the chemical strengthening liquid, and a compressive stress layer is formed in a surface layer portion, as a result of which the glass substrate is strengthened.

Although the time at which the chemical strengthening processing is performed is determined as appropriate, the polishing processing is

particularly preferably performed after the chemical strengthening processing, because the surface can be smoothed and foreign matter adhering to the surfaces of the glass substrates can be removed by the chemical strengthening processing. Also, it is sufficient that the chemical strengthening processing is performed as needed, and need not be performed.

[0041] (h) Second polishing (final polishing) processing (step S80)

Next, second polishing is performed on the glass substrate that has undergone the chemical strengthening processing. An object of second polishing is to perform mirror-polishing on the main surfaces. A double-side polishing apparatus having a configuration similar to that of the double-side polishing apparatus used in first polishing is also used in second polishing. It is preferable that in the second polishing processing, the particle size of loose abrasive particles and the hardness of a resin polisher of a polishing pad are smaller than in the first polishing processing. Doing so makes it possible to extremely reduce the surface roughness of the glass substrate.

[0042] Colloidal silica minute particles or the like, for example, are used as the loose abrasive particles used in the second polishing processing.

Although the second polishing processing is not necessarily essential processing, the second polishing processing is preferably performed because the level of surface unevenness of a main surface of the glass substrate can be made more preferable. Thereafter, a magnetic-disk glass substrate is obtained by performing cleaning. Note that it is preferable to polish the glass substrate such that an arithmetic average roughness R_a for the surface roughness of the glass substrate that has undergone the second polishing processing is less than or equal to 0.15 nm because a magnetic-disk glass substrate having small surface roughness is produced.

[0043] [Edge surface polishing]

Edge surface polishing performed in step S50 will be described in detail. FIGS. 3 and 4 are diagrams illustrating a polishing method for polishing an edge surface according to the present embodiment such that the polishing

method can be easily understood.

A polishing apparatus 10 that performs edge surface polishing polishes an edge surface of the glass substrate using a magnetic field generation means and polishing fluid. FIGS. 3 and 4 illustrate polishing of an outer circumferential edge surface of the glass substrate. An overview of the polishing apparatus 10 that performs edge surface polishing will be described. As shown in FIG. 3, the polishing apparatus 10 includes a pair constituted by a magnet 12 (N-pole) and a magnet 14 (S-pole), which are cylindrical permanent magnets, and a spacer 16. A magnetic field in which magnetic field lines advance from the magnet 12 to the magnet 14 around the spacer 16 is formed between the pair constituted by the magnet 12 (N-pole) and the magnet 14 (S-pole). In an example shown in FIG. 3, the pair of magnets disposed in a state in which the N-pole surface and the S-pole surface are disposed apart from each other and facing each other in the thickness direction of the glass substrate G is used as a magnetic field generation means. In order that a clearance between the N-pole edge surface of the magnet 12 and the S-pole edge surface of the magnet 14 is set to a predetermined distance, the spacer 16 made of a nonmagnetic material is provided between the magnets 12 and 14.

[0044] As shown in FIG. 4, in the case where edge surface polishing is performed using the polishing apparatus 10, the glass substrate G that is to be an edge surface polishing target is held by a rotary body (not shown) and is rotated about the central axis.

The magnetic field is formed such that magnetic field lines advance from the magnet 12 to the magnet 14, the outer circumferential edge portion of the glass substrate G held by the rotary body is repeatedly brought into contact with a mass F of the polishing fluid in a state in which the mass F of the polishing fluid is held by the magnetic field, and the glass substrate G and the mass F of the polishing fluid are moved relative to each other, and thereby the outer circumferential edge surface of the glass substrate G is polished. As shown in FIG. 4, the mass F of the polishing fluid contains magnetic minute

particles 5a and polishing abrasive particles 5b.

The polishing apparatus 10 and the rotary body (not shown) that holds the glass substrate G are mechanically connected to a driving motor (not shown). For example, it is preferable to rotate the polishing apparatus 10 and the rotary body that holds the glass substrate G such that the rotation directions thereof are mutually opposite directions by setting the relative speed of circumferential speeds of the polishing apparatus 10 and the rotary body to 40 to 500 m/minutes. Note that the polishing apparatus 10 is fixed and thereby the mass F of the polishing fluid is fixed, and the outer circumferential edge surface of the glass substrate G and the mass F of the polishing fluid may be moved relative to each other by rotating the glass substrate G.

[0045] Note that although permanent magnets are used as a magnetic field generation means in the examples shown in FIGS. 3 and 4, electromagnets can also be used.

[0046] A fluid containing nonpolar oil that contains magnetic minute particles having an average particle diameter (D50) of 0.1 to 10 μm in a concentration of 3 to 5 g/cm³ containing Fe (iron) elements, for example, and a surfactant is used as the polishing fluid used to polish the edge surface. The nonpolar oil or polar oil has a viscosity of 100 to 1000 (mPa·sec) at room temperature (20°C), for example.

The polishing fluid serves as the mass F having a relatively high elastic property due to the magnetic field in which magnetic field lines advance from the magnet 12 to the magnet 14, and therefore, polishing can be efficiently performed by pressing the edge surface of the glass substrate against the mass of the polishing fluid. That is, the processing rate can be made greater than with the conventional method, and polishing can be efficiently performed.

[0047] Known polishing abrasive particles for the glass substrate, such as cerium oxide, colloidal silica, zirconia oxide, alumina abrasive particles, and diamond abrasive particles, can be used as the polishing abrasive particles included in the polishing fluid. The average particle diameter (D50) of the

polishing abrasive particles are 0.5 to 10 μm , for example. Using polishing abrasive particles in this range makes it possible to preferably polish the edge surface of the glass substrate. The polishing fluid contains the polishing abrasive particles in an amount of 3 to 15 [Vol%], for example.

5 Note that the average particle diameter (D50) means a particle diameter at which a cumulative volume frequency calculated with volume fraction reaches 50% when calculated starting from a smaller particle diameter. [0048] In order to form the mass F of the polishing fluid and efficiently polish the edge surface, the viscosity of the polishing fluid is preferably 1000 to 2000
10 [mPa $\cdot$ sec] at room temperature (20°C). If the viscosity is low, it is difficult to form the mass F, and it is difficult to polish the edge surface of the glass substrate G by relative movement in a state in which the mass F is pressed against the edge surface. On the other hand, in the case where the viscosity of the polishing fluid is extremely high, the mass F of the polishing fluid is formed
15 along the shape of the edge portion of the glass substrate G during polishing, and thus it is difficult to form an even pressing state. Also, in order to form the mass F of the polishing fluid and efficiently polish the edge surface, the magnetic flux density of the magnetic field generated by the magnetic field generation means is preferably 0.3 to 0.9 [tesla]. Also, the yield stress of the
20 magnetic functional fluid is preferably greater than or equal to 30 kPa in a state in which the magnetic field having a magnetic flux density of 0.4 [tesla] is applied, and is more preferably 30 to 60 kPa.

[0049] Here, the yield stress (yield shearing stress) of the polishing fluid, or in other words, the magnetic functional fluid, can be obtained with the following
25 method, for example. The yield stress of the magnetic functional fluid can be obtained by obtaining a relationship between the shear velocity and the shearing stress of the magnetic functional fluid using an apparatus obtained by incorporating a magnetic field generation means (a permanent magnet, an electromagnet, and the like) that is capable of applying a magnetic field having
30 a magnetic flux density of 0.4 [tesla] in a rotational viscometer, and

approximating the obtained relationship between the shear velocity and the shearing stress using a known Casson equation.

The above-described yield stress affects the pressure that the glass substrate receives from the polishing fluid when the polishing fluid held by the magnetic field and the outer circumferential edge surface of the glass substrate are moved relative to each other, that is, the shearing stress. Therefore, the higher the yield stress of the polishing fluid is (the higher the shearing stress while the polishing fluid flows is), the more efficiently polishing resulting from contact between the polishing abrasive particles and the glass substrate is performed, and the more the processing rate of polishing the edge surface can be increased.

[0050] In polishing of the edge surface of the glass substrate using the above-described polishing fluid, in the case where edge surfaces of a plurality of glass substrates, which are workpieces, are polished continuously using single-substrate processing, there is a risk that the processing rate will decrease. The cause of the decrease in the processing rate will be described with reference to FIG. 5. FIG. 5 is a diagram schematically showing magnetic field lines when the outer circumferential edge surface of the glass substrate G is polished.

While the edge surface of the glass substrate is polished, the mass of the polishing fluid comes into contact with the edge portion of the glass substrate G while being rotated at a relatively high speed accompanying the rotation of the polishing apparatus 10, and a portion thereof is ejected little by little to the outside. The polishing abrasive particles that are held by the magnetic field and included in the polishing fluid are also released to the outside due to the ejection of the polishing fluid. In particular, as shown in FIG. 4, in the case where polishing is performed with an edge portion of the glass substrate, which is the nonmagnetic material, being interposed between the N-pole magnet and the S-pole magnet, the polishing abrasive particles included in the polishing fluid are easily released to the outside (that is, the concentration of the

polishing abrasive particles in the polishing fluid decreases), and the reason for this will be described with reference to FIG. 5.

[0051] In FIG. 5, in edge surface polishing in which the glass substrate G is pushed into the polishing fluid, and the glass substrate G and the polishing fluid are moved relative to each other, the edge portion of the glass substrate is interposed so as to cross lines of magnetic flux generated between the N-pole magnet 12 and the S-pole magnet 14. At this time, in the region A1 of FIG. 5, the magnetic field has a strong force of holding the polishing abrasive particles due to a state in which the magnetic minute particles in the polishing fluid are arranged along the lines of magnetic flux, and the glass substrate G is likely to receive an opposing force (that is, a pressing force against the glass substrate G) from the polishing fluid. On the other hand, in the region A2, the arrangement of the magnetic minute particles in the polishing fluid comes apart due to the edge portion of the glass substrate crossing the lines of magnetic flux, and the force of the magnetic field holding the polishing abrasive particles thereby locally decreases, as a result of which the polishing abrasive particles are likely to be released to the outside.

As a result, in the case where edge surface polishing is continuously performed on a plurality of glass substrates G, the concentration of the polishing abrasive particles in the polishing fluid located in the region A1 in which the holding force of the magnetic field is high is kept high, whereas the concentration of the polishing abrasive particles in the polishing fluid located in the region A2 in which the holding force of the magnetic field decreases. Therefore, even if polishing is performed continuously, the processing rate does not decrease for a side wall surface Co1 of the glass substrate G included in the region A1, but in the case where polishing is performed continuously, the processing rate decreases for chamfered surfaces Co2 and Co3 of the glass substrate G included in the region A2, accompanying the reduction in the amount of the polishing abrasive particles in the polishing fluid.

[0052] In view of this, the edge surface polishing processing of the present

embodiment is polished while the polishing abrasive particles are supplied from the outside during polishing. That is, by supplying new polishing abrasive particles from the outside to the region A2 in which the slurry concentration is likely to decrease in continuous processing in FIG. 5, it is possible to suppress a decrease in the processing rate for chamfered surfaces in the case where edge surface polishing is performed continuously. Supplying of the polishing abrasive particles during polishing may be performed by supplying the polishing abrasive particles, or may be performed by supplying a liquid containing the polishing abrasive particles. A supplying method includes a method of allowing the polishing abrasive particles or the liquid containing the polishing abrasive particles to flow out toward the region A2 (ejection method, for example), a dropping method, and the like, but there is no limitation thereto.

An example of the method for supplying the polishing abrasive particles by supplying the liquid containing the polishing abrasive particles is shown in FIG. 6. FIG. 6 shows an example in which the polishing fluid is supplied to the polishing apparatus 10 from a nozzle of a supplying apparatus 30 in plan view. In the example shown in FIG. 6, the liquid containing additional polishing abrasive particles is supplied to a position at which the mass of the polishing fluid held by the magnetic field and the outer circumferential edge portion of the glass substrate G come into contact with each other. Preferably, as shown in FIG. 6, the liquid containing the additional polishing abrasive particles is supplied along the movement direction of the edge surface of the glass substrate that comes into contact with the mass of the polishing fluid. Note that water can be used as the above-described liquid, for example.

[0053] Although there is no particular limitation on the time at which the liquid containing the additional polishing abrasive particles is supplied, the liquid may be supplied at any time during the edge surface polishing processing, the liquid may be supplied during a period from the end of polishing of the glass substrate to the start of polishing of the next glass substrate, the liquid may be

supplied at a predetermined time, or at a time between lots into which a predetermined number of glass substrates are divided, for example. Also, the liquid may be continuously supplied without designating a specific time.

Note that in addition to the polishing abrasive particles, magnetic
5 minute particles or magnetic functional fluid may be added to the
above-described liquid supplied while the edge surface of the glass substrate G
is polished. Because the magnetic minute particles also gradually decrease
slightly due to polishing processing, a decrease in the processing rate can be
suppressed over a longer term. However, the magnetic minute particles are
10 more unlikely to be reduced compared to the polishing abrasive particles, and
thus there are cases where supplying the magnetic minute particles gradually
increases the amount of magnetic minute particles included in the polishing
fluid during edge surface polishing. In this case, there are cases where the
magnetic minute particles that cannot be held by the magnetic field are
15 scattered around the polishing apparatus, which causes contamination of the
substrate surface. Therefore, it is necessary to adjust the supply amount of
the magnetic minute particles or the magnetic functional fluid so that the
amount does not become excessive.

[0054] It is preferable that the temperature of the polishing fluid, or the
20 polishing abrasive particles, or the liquid containing the polishing abrasive
particles, which are supplied during the edge surface polishing processing, is
less than or equal to room temperature. Specifically, the temperature is less
than or equal to 25°C, and is more preferably less than or equal to 20°C. In
the edge surface polishing processing of the present embodiment, frictional
25 heat is generated due to the relative movement of the glass substrate G with
respect to the mass of the polishing fluid due to crossing the magnetic field
lines formed by the magnetic field generation means, a moisture amount in the
polishing fluid decreases due to this frictional heat, and lubricity deteriorates
in a processing target portion, which causes minute scratches on the surface of
30 the processing target portion. In view of this, setting the temperature of the

polishing fluid supplied during polishing to room temperature or less makes it possible to suppress the generation of the above-described frictional heat and maintain the quality of polishing the processing target portion.

[0055] Hereinafter, a modified example of the first embodiment will be described.

[Modified Example 1]

Although polishing of the outer circumferential edge surface of the glass substrate G has been described with reference to FIGS. 3 to 6, the inner circumferential edge surface of the glass substrate can also be polished with a similar method. Modified Example 1 (not shown) is an example in which the inner circumferential edge surface is polished at the same time as the outer circumferential edge surface of the glass substrate G is polished.

In Modified Example 1, a polishing apparatus (not shown) having a configuration similar to that of FIG. 3 is disposed in the vicinity of the inner circumferential edge surface of the glass substrate G, and a magnetic field is generated by a pair of N-pole and S-pole magnets. A mass of the polishing fluid is formed by causing the magnetic field to hold the polishing fluid. The inner circumferential edge surface of the glass substrate G is polished by moving the mass and the glass substrate G relative to each other in the state in which the mass and the inner circumferential edge surface of the glass substrate G are in contact with each other. At this time, an additional polishing fluid is supplied to a position at which the mass of the polishing fluid held by the magnetic field comes into contact with the inner circumferential edge portion of the glass substrate G.

[0056] That is, a magnetic field generation means of Modified Example 1 includes an outer circumferential side means and an inner circumferential side means, the outer circumferential side means generating a magnetic field such that magnetic field lines (outer circumferential side magnetic field lines) advance in the thickness direction of the glass substrate G by providing magnets 12 and 14 shown in FIGS. 3 and 4 on the outer circumferential side of

the glass substrate G, and the inner circumferential side means generating a magnetic field such that magnetic field lines (inner circumferential side magnetic field lines) advance in the thickness direction of the glass substrate G by providing a pair of magnets (N-pole and S-pole) on the inner circumferential side of the glass substrate G (that is, an inner hole of the glass substrate G). Edge surface polishing is performed by polishing both the inner circumferential edge surface and the outer circumferential edge surface at the same time by causing magnetic fields formed by the above-described inner circumferential side means and the above-described outer circumferential side means to hold the mass of polishing fluid, and moving the inner circumferential edge surface and the outer circumferential edge surface of the glass substrate G relative to each other in a state of being in contact with the mass of the polishing fluid. Therefore, in Modified Example 1, the inner circumferential edge surface is polished at the same time as the outer circumferential edge surface of the glass substrate G shown in FIGS. 3 and 4 is polished, and efficient edge surface polishing can be realized.

Note that it is not necessary to polish both the inner circumferential edge surface and the outer circumferential edge surface at the same time. That is, it is sufficient that at least one of the above-described inner circumferential side means and the above-described outer circumferential side means is provided. Also, even in the case where both the above-described inner circumferential side means and the above-described outer circumferential side means are provided, the inner circumferential edge surface and the outer circumferential edge surface may be polished in order without polishing both the inner circumferential edge surface and the outer circumferential edge surface at the same time.

[0057] [Modified Example 2]

FIG. 7 is a diagram showing Modified Example 2 of polishing the outer circumferential edge surface of the glass substrate G. Modified Example 2 is an example in which inner circumferential edge surfaces of a plurality of glass

substrates are polished at once, instead of only one glass substrate being polished.

A polishing apparatus 10A shown in FIG. 7 includes N-pole magnets 121, 122, 123, 124..., S-pole magnets 140, 141, 142, 143..., and spacers 161, 162, 163... The N-pole magnets, the S-pole magnets, and the spacers respectively have the same configurations as those of the magnet 12, the magnet 14, and the spacer 16 of FIG. 3.

That is, in the polishing apparatus 10A, an N-pole edge surface of a magnet and an adjacent S-pole edge surface are arranged stacked so as to oppose each other at a fixed distance apart from each other. In the polishing apparatus 10A, a magnetic field in which magnetic field lines advance from the N-pole magnet to the S-pole magnet is formed, the N-pole and the S-pole facing each other with a spacer interposed therebetween. That is, a plurality of pairs of magnets disposed in a state in which the N-pole surface and the S-pole surface are disposed apart from each other and facing each other in the thickness direction of the glass substrate G are used as a magnetic field generation means. For example, a magnetic field in which magnetic field lines advance from the magnet 121 to the magnet 141 is formed. Masses F of polishing fluid are held by the magnetic fields at the circumferential edges of the spacers 161, 162, 163... A driving motor (not shown) is used to rotate the polishing apparatus 10A as shown in FIG. 7 during edge surface polishing.

[0058] The plurality of glass substrates G are integrated as a stacked body using an adhesive or the like with spacers 151, 152, 153, 154... sandwiched therebetween. Here, any adhesive may be used as the adhesive used to form the stacked body as long as it can attach the main surfaces of the plurality of glass substrates G to the spacers or can be separated from the spacers. For example, an ultraviolet curable resin adhesive is easily set with irradiation of ultraviolet rays having a predetermined wavelength, and therefore, an adhesion operation can be easily performed. Also, a resin according to which the plurality of glass substrates G that are attached to each other can be easily

separated from each other with warm water or an organic solvent is preferable as the ultraviolet curable resin. In addition to the ultraviolet curable resin adhesive, wax, a photocurable resin, a visible light curable resin, and the like can be used as the adhesive. Because the wax softens at a predetermined temperature and becomes a liquid, and is a solid at room temperature, the tasks of attaching and separating the plurality of glass substrates G can be easily performed. Instead of the adhesive, a spacer may be sandwiched and attached. In the case where spacers are attached between the plurality of glass substrates G, instead of the adhesive, thin spacers made of a resin material, a fiber material, rubber material, metal material, ceramic material, or the like may be used. A stacked body including the plurality of glass substrates G is held by a rotary body (not shown), and is rotated as shown in FIG. 7 using a driving motor (not shown) during edge surface polishing.

[0059] The outer circumferential edge surfaces of the plurality of glass substrates G can be polished at the same time by bringing the outer circumferential edge surfaces of the glass substrates G included in the stacked body into contact with the mass F of the polishing fluid, and moving the mass F of the polishing fluid and the outer circumferential edge surfaces of the plurality of glass substrates G relative to each other. That is, since the outer circumferential edge surfaces of the plurality of glass substrates can be polished at the same time, the processing rate can be increased more than with the conventional method, and polishing can be efficiently performed.

[0060] Note that it is preferable that a formation position of the mass F of the polishing fluid is adjusted by adjusting spacers provided between magnets such that the length of each glass substrate G matches the length of the mass F of the polishing fluid, and the outer circumferential edge surfaces of the glass substrates G come into contact with the masses F of the polishing fluid at the same time. It is preferable that the plurality of magnets and the stacked body of the glass substrates G swing relative to each other during polishing with respect to the stacking direction of the stacked body, with consideration given to

the case where the outer circumferential edge surfaces of the plurality of glass substrates G do not come into contact with the masses F of the polishing fluid at the same time. By swinging, the outer circumferential edge surfaces uniformly come into contact with the masses F of the polishing fluid during
5 polishing, and the outer circumferential edge surfaces of the plurality of glass substrates G can be evenly polished. This swinging is not necessarily used only in polishing the edge surfaces of the stacked body of the glass substrates of Modified Example 2, and can also be applied to the case of polishing an edge surface of one glass substrate, such as that shown in FIG. 4.

[0061] Also, the edge surface polishing processing of Modified Example 2 is
10 polished while the liquid containing polishing abrasive particles is supplied from the outside during polishing. Accordingly, polishing abrasive particles lost during the polishing processing can be compensated for, and in the case where edge surface polishing is performed continuously, a decrease in the
15 processing rate for the chamfered surfaces can be suppressed. In the example shown in FIG. 7, the additional polishing fluid is supplied from the nozzle of a supplying apparatus 30A to a position at which the mass F of the polishing fluid held by the magnetic field and the outer circumferential edge portion of the glass substrate G come into contact with each other. The liquid containing
20 the polishing abrasive particles falls downward from above, and therefore, the additional polishing fluid is supplied to the plurality of masses F of polishing fluid that comes into contact with the outer circumferential edge portions of the glass substrates. Also, a configuration is possible in which, as was shown in FIG. 6, a liquid containing the polishing abrasive particles is supplied from a
25 plurality of nozzles in the latitudinal direction toward a position at which the masses F of the polishing fluid and the outer circumferential edge portions of the glass substrates G come into contact with each other, although this is not shown in the drawing.

[0062] Although FIG. 7 shows the case where the outer circumferential edge
30 surfaces of the plurality of glass substrates G, which is integrated as a stacked

body, are polished, the inner circumferential edge surfaces of the plurality of glass substrates G may be polished similarly. Also, the outer circumferential edge surfaces and the inner circumferential edge surfaces of the plurality of glass substrates G, which are integrated as a stacked body, may be polished at the same time.

[0063] [Modified Example 3]

FIG. 8 is a diagram showing Modified Example 3 of edge surface polishing. Although a polishing apparatus 10 similar to that of FIG. 4 is used in Modified Example 3, the edge surface of the glass substrate G is polished in a state in which both the polishing apparatus 10 and the glass substrate G, which is a polishing target, are immersed in a bath 90 filled with a liquid containing the polishing abrasive particles. The concentration of the polishing abrasive particles in the bath may be a value equal to the value described in the embodiment, and may be set to 1 to 50 wt%, for example. Also, water can be used as the above-described liquid, for example.

Similarly to the case of FIG. 4, the outer circumferential edge portion of the glass substrate G is polished by forming a magnetic field in the bath 90 such that magnetic field lines advance from the magnet 12 to the magnet 14, repeatedly bringing the outer circumferential edge portion of the glass substrate G to come into contact with the mass F of the polishing fluid in a state in which the polishing fluid around the magnetic field is held by the magnetic field as the mass F, and moving the glass substrate G and the mass F of the polishing fluid relative to each other. At this time, as described above, in part of a region (a region A2 of FIG. 5), the arrangement of the magnetic minute particles in the polishing fluid comes apart due to an edge portion of the glass substrate crossing the lines of magnetic flux, and thereby the force of the magnetic field holding the polishing abrasive particles decreases locally, as a result of which the polishing abrasive particles are likely to be released to the outside. However, in this modified example, polishing is performed in the bath 90 filled with the liquid containing the polishing abrasive particles, and thus

the released polishing abrasive particles are supplied by the surrounding polishing abrasive particles in the bath, avoiding a situation in which the concentration of the polishing abrasive particles decreases in the case where polishing is performed continuously. Therefore, the processing rate does not decrease over time.

Note that although FIG. 8 shows the case where the outer circumferential edge surface of one glass substrate G is ground in the bath 90 filled with the polishing fluid, there is no limitation to this case. The inner circumferential edge surface of the glass substrate G may be polished in the bath 90 filled with the polishing fluid, or edge surfaces of the stacked body of a plurality of glass substrates G may be polished as shown in Modified Example 2.

[0064] [Working Examples]

In order to check the effect of the present invention, an edge surface of a produced glass substrate was polished.

An outer diameter of the produced glass substrate was 65 mm and the thickness was 0.8 mm, and in the shape processing, 0.15-mm chamfering was performed in the thickness direction of the glass substrate at an inclination angle of 45 degrees with respect to the main surface.

[0065] (Comparative Example)

As shown in FIG. 4, an outer circumferential edge portion of a 2.5-inch magnetic-disk glass substrate was inserted in a polishing apparatus in which a pair of magnets are disposed apart from each other by a spacer made of stainless steel. The magnet has a diameter of 19 mm and a thickness of 15 mm, as the dimensions. The magnetic field formed by the magnets with the polishing fluid provided between the magnets was caused to hold the mass of a magnet slurry, and the outer circumferential edge surface of the glass substrate was polished. The polishing apparatus was rotated such that the edge surface of the glass substrate was rotated in the opposite direction, and the rotation rates thereof were set to 700 rpm. 100 glass substrates were polished, and the

processing time for one glass substrate was set to 3 minutes.

Polishing fluid obtained by dispersing Fe (iron) minute particles having an average particle diameter (D50) of 2 μm at a concentration of 3 $[\text{g}/\text{cm}^3]$ in nonmagnetic oil (silicone oil) and dispersing cerium oxide having an average particle diameter of 2 μm as the polishing abrasive particles was used as the polishing fluid used to polish the outer circumferential edge surface of the glass substrate. The polishing fluid contained cerium oxide in a concentration of 5 $[\text{vol}\%]$. A permanent magnet having a magnetic flux density of 0.5 $[\text{tesla}]$ was used as the magnet.

10 [0066] (Working Example 1)

In addition to the polishing conditions of Comparative Example, polishing was performed while a liquid containing polishing abrasive particles was supplied. Specifically, as shown in FIG. 6, the liquid containing polishing abrasive particles was supplied along the movement direction of the edge surface of the glass substrate that comes into contact with the mass of the polishing fluid every time polishing of the outer circumferential edge surface of one glass substrate ended. Water was used as the liquid. Similarly to Comparative Example, 100 glass substrates were polished, and the processing time for one glass substrate was set to 3 minutes.

20 [0067] (Evaluation of Comparative Example and Working Example 1)

With regard to the chamfered surfaces of the outer circumferential edge surfaces of the glass substrates after edge surface polishing in Comparative Example and Working Example 1, the results of measurement of the processing rates for a first glass substrate and for a 100th glass substrate are shown in Table 1. In Table 1, the percentage of decrease in the processing rate is a value calculated using Equation (1) below.

Percentage of decrease in the processing rate (%) = $100 - (\text{processing rate for 100th glass substrate}) / (\text{processing rate for first glass substrate}) \times 100 \dots$
Equation (1)

30 [0068] As shown in Table 1, in Working Example 1, in the case where glass

substrates are polished continuously, it was confirmed that a decrease in the processing rate was significantly suppressed compared to Comparative Example. Note that although not shown in Table 1, the percentage of decrease in the processing rate for the side wall surface was less than or equal to 2% in both Comparative Example and Working Example 1, which was a level of not being problematic.

[0069] [Table 1]

	Processing rate for 1st glass substrate [$\mu\text{m}/\text{min}$]	Processing rate for 100th glass substrate [$\mu\text{m}/\text{min}$]	Percentage of decrease in processing rate
Comp. Ex.	27	10	63%
Work. Ex. 1	27	25	7%

[0070] (Working Example 2)

Similarly to Comparative Example described above, the processing for polishing the outer circumferential edge surface of the glass substrate was performed except that the liquid containing the polishing abrasive particles was continuously supplied to the mass of the polishing fluid during the polishing processing. At that time, the above-described liquid was dropped from above to the mass of the polishing fluid immediately before reaching the polishing processing target portion (processing point).

As a result, the percentage of decrease in the processing rate for the chamfered surfaces of the glass substrate was 5%, and a more preferable result was obtained than in Working Example 1. Note that, similarly to Working Example 1, the percentage of decrease in the processing rate for the side wall surface of the glass substrate was less than or equal to 2%.

[0071] (Working Example 3)

As shown in FIG. 8, the processing for polishing the outer circumferential edge surface of the glass substrate was performed in a state in which the glass substrate, which is a polishing target, was immersed in a bath

filled with the liquid containing the polishing abrasive particles. Water was used as the liquid in the bath, and the concentration of the polishing abrasive particles was set to 20 wt%. The above-described liquid was not supplied to the bath during polishing.

5 As a result, the percentage of decrease in the processing rate for the chamfered surfaces of the glass substrate was 0%, and a more preferable result was obtained than in Working Example 2.

[0072] (Second embodiment)

 Hereinafter, a method for manufacturing a magnetic disk substrate will
10 be described as a second embodiment of the method for manufacturing a nonmagnetic substrate of the present invention. Note that although the case where a glass substrate is used as a magnetic disk substrate will be described similarly to the first embodiment, the substrate is not limited thereto and an aluminum composite substrate may be used.

15 In the present embodiment, a magnetic-disk glass substrate, the flow of overall processing of the method for manufacturing a magnetic-disk glass substrate, and a method for polishing an edge surface using a magnetic field generation means and polishing fluid (the content described in association with FIGS. 3 and 4) are similar to those in the first embodiment. Hereinafter, the
20 content of the edge surface processing, which is different from that in the first embodiment, will mainly be described.

[0073] In the second embodiment, in glass substrate edge surface polishing using polishing fluid, in the case where edge surfaces of a plurality of glass substrates, which are workpieces, are polished continuously using
25 single-substrate processing, processing for modifying the shape of a mass of the polishing fluid is performed so as to eliminate a significant decrease in the processing rate for the chamfered surfaces. Here, the reason why the processing rate for the chamfered surfaces decreases in the case where the shape of the polishing fluid is not modified in glass substrate edge surface
30 polishing will be described with reference to FIG. 9.

In FIG. 9, the mass F of the polishing fluid is stably held by the magnetic field formed by the magnets 12 and 14 in a state S1, which is an initial state of the edge surface polishing processing. The side wall surface and the chamfered surfaces that constitute the outer circumferential edge surface of the glass substrate G are pressed by the mass F at a fixed pressing force immediately after contact of the glass substrate G with the mass F of this polishing fluid starts, and the processing rate for both the side wall surface and the chamfered surfaces are high.

However, in the case where edge surface polishing is performed continuously on a plurality of glass substrates using single-substrate processing, the processing rate for the side wall surface is unlikely to decrease, but the processing rate for the chamfered surfaces significantly decreases. That is, the side wall surface of the outer circumferential edge surface of the glass substrate is polished by the mass F of the polishing fluid located in a region A1 in which the glass substrate G does not cross the magnetic field lines in plan view. The magnetic field has a strong force of holding the mass F of the polishing fluid located in the region A1 because the magnetic field lines are not disconnected, and polishing is performed stably by the polishing abrasive particles, and therefore the polishing rate of polishing is high. On the other hand, the chamfered surfaces of the outer circumferential edge surface of the glass substrate are polished by the mass F of the polishing fluid located in a region A2 in which the glass substrate G crosses the magnetic field lines in plan view. The magnetic field has a relatively weak force of holding the mass F of the polishing fluid located in this region A2. Therefore, if edge surface polishing is continuously performed on the plurality of glass substrates G using single-substrate processing, as shown in the state S2 of FIG. 9, the mass F of the polishing fluid comes apart and deforms (plastic deformation) in the region A2, and a pressing force against the chamfered surfaces on the outer circumferential side of the glass substrate G is likely to decrease. If the pressing force against the chamfered surfaces of the glass substrate G

decreases, polishing is unlikely to be stably performed with the polishing abrasive particles, and therefore the processing rate of polishing the chamfered surfaces decreases.

[0074] In view of this, in the edge surface polishing processing of the present embodiment, the shape of the mass F of the polishing fluid that has deformed due to contact with the glass substrate G is modified such that the pressing force against the glass substrate G is kept constant.

Hereinafter, in the edge surface polishing processing of the present embodiment, a method for modifying the mass of the polishing fluid using a shape modification apparatus will be described with reference to FIGS. 10 and 11. FIG. 10 is a diagram showing a configuration example in the case of modifying the shape of the polishing fluid using the shape modification apparatus. FIG. 11 is a diagram illustrating processing for modifying the shape of the polishing fluid using the shape modification apparatus.

In FIG. 10, the shape modification apparatus 20 includes jigs 21U, 21L, and 22 made of nonmagnetic material having an arc shape in plan view, and a driving mechanism (not shown) that drives the jigs. The driving mechanism (not shown) drives the jig 21U and the jig 21L in the horizontal direction and the vertical direction so as to be able to move on the surfaces of the magnets 12 and 14 respectively. Also, the driving mechanism drives the jig 22 in the horizontal direction so as to insert the jig 22 into the space between the magnet 12 and the magnet 14. It is preferable that the length of the jig 22 in the thickness direction of the glass substrate is the same as the clearance between the magnet 12 and the magnet 14, or is set slightly lower than the clearance. Note that depending on the degree of shape modification of the polishing fluid, the jig 21U and the jig 21L need not be provided in the shape modification apparatus 20.

[0075] FIG. 11 shows a positional relationship between the jigs of the shape modification apparatus 20 and the magnets 12 and 14 in the series of processes (steps S1 to S3) in which the shape of the mass F of the polishing fluid is

modified by the shape modification apparatus 20, in side view and plan view. Note that in the example shown in FIG. 11, it is assumed that positioning of the jig 22 in the vertical direction has been already performed.

First, in step S1, the jigs 21U and 21L are driven in the horizontal
 5 direction, and the jigs respectively come into contact with the side surfaces of the magnets 12 and 14. Next, in step S2, the jig 21U is driven downward, and the jig 21L is driven upward. Accordingly, polishing fluid that overflows and is attached to the side surfaces of the magnets 12 and 14 (that is, a portion of the deformed mass F of the polishing fluid) is pressed against the jigs, and is moved
 10 to a position between the magnets 12 and 14 in side view. Finally, in step S3, the jig 22 is driven in the horizontal direction, and the polishing fluid that has been moved in step S2 and the polishing fluid that has moved to the side surface edges of the magnets due to the deformation of the mass F move toward the center of the magnets by being pressed by the jig 22. The shape of the
 15 deformed mass F of the polishing fluid is modified through steps S1 to S3 described above such that the pressing force against the glass substrate is kept constant.

In the case where the polishing fluid that overflows the side surfaces of the magnets 12 and 14 is not present, the jig 21U and the jig 21L need not be
 20 used.

[0076] As described above, in the present embodiment, the shape of the mass F of the polishing fluid deformed due to contact with the glass substrate is modified using the shape modification apparatus 20 so as to return to the original shape. In other words, the shape of the mass of the polishing fluid F
 25 is changed by bringing the jig into contact with the mass F of the polishing fluid. Accordingly, the pressing force against the glass substrate is kept constant.

[0077] In the present embodiment, it is preferable that the jig is brought into contact with the mass F of the polishing fluid by inserting the tip of the jig into the mass F of the polishing fluid. For example, instead of the jig 22 shown in
 30 FIG. 10, using a jig in which the cross section of the tip has a protruding shape,

the tip of the jig is inserted into the mass F of the polishing fluid by driving the jig in the horizontal direction. The jig may have a rod shape, a plate shape, a flat shape, or a prismatic shape. That is, the cross section of the tip of the jig may be circular, elliptic, tabular, or polygonal. It is sufficient that the height in the vertical direction of such a jig (that is, the thickness direction of the glass substrate G that is subjected to polishing processing) is less than or equal to a space between the magnets 12 and 14. Similarly to the above-described jigs 21U, 21L, and 22, the jig is preferably made of a nonmagnetic material that is relatively hard, such as metal (aluminum, titanium, etc.) or ceramic.

The reason why the tip of the jig being inserted into the mass of the polishing fluid is preferable is as follows. That is, it is conceivable that in the case where the mass F of the polishing fluid comes apart and deforms (plastic deformation) in the region A2 and the pressing force against the chamfered surface on the outer circumferential side of the glass substrate G decreases as shown in the state S2 of FIG. 9, the density of magnetic minute particles is not uniform inside the mass of the polishing fluid. In other words, it is conceivable that the region A1 of FIG. 9 has a high density of magnetic minute particles due to the substrate being pushed, whereas the region A2 has a low density thereof, as a result of which a force of holding the polishing abrasive particles in the region A2 decreases. In view of this, re-arrangement of the magnetic minute particles inside the polishing fluid due to the magnetic field is promoted by inserting the tip of the jig into the mass of the polishing fluid and moving the magnetic minute particles forward that were pushed backward, resulting in a state in which the density of the magnetic minute particles before processing is uniform. Therefore, a decrease in the processing rate for the chamfered surfaces can be further suppressed.

[0078] The time at which the shape of the mass of the polishing fluid is modified may be any time during the edge surface polishing processing. As shown in FIG. 10, by disposing the shape modification apparatus 20 on the opposite side of the glass substrate G, which is a workpiece, using the polishing

apparatus 10 as a reference, the shape of the mass of the polishing fluid can be modified while the edge surface of the glass substrate G is polished. Also, shape modification may be performed during a period starting from the end of polishing of the edge surface of the glass substrate to the start of polishing of the edge surface of the next glass substrate, or shape modification may be performed at a predetermined time or at a time between lots in which a predetermined number of glass substrates are divided.

[0079] Next, a method for supplying additional polishing fluid to the deformed mass of the polishing fluid will be described as another method for modifying the shape of the mass of the polishing fluid with reference to FIG. 12.

FIG. 12 shows an example in which polishing fluid is supplied from a nozzle of the supplying apparatus 30 to the polishing apparatus 10 in plan view. Although in the example shown in FIG. 12, the additional polishing fluid is supplied to a position at which the mass of the polishing fluid held by the magnetic field and the outer circumferential edge portion of the glass substrate G come into contact with each other, and the additional polishing fluid is more preferably supplied to the mass of the polishing fluid located at a position after the position of coming into contact with the outer circumferential edge portion of the glass substrate G. Also, it is more preferable that the additional polishing fluid is supplied along the movement direction of the edge surface of the glass substrate that comes into contact with the mass of the polishing fluid. This additional polishing fluid is newly held by the magnetic field as the mass, and as a result, the shape of the mass of the polishing fluid is modified such that the pressing force against the glass substrate is kept constant.

[0080] Although there is no particular limitation on the supplying time of the additional polishing fluid, the additional polishing fluid may be supplied as appropriate during the edge surface polishing processing, may be supplied during a period starting from the end of polishing the edge surface of the glass substrate to the start of polishing the edge surface of the glass substrate, may be supplied at a predetermined time, or at a time between lots into which a

predetermined number of glass substrates are divided, for example. Also, the polishing fluid may be continuously supplied without designating a specific time.

[0081] It is preferable that the temperature of the polishing fluid supplied during the edge surface polishing processing is less than or equal to room temperature. In the edge surface polishing processing of the present embodiment, since the glass substrate G is moved relative to the mass of the polishing fluid so as to cross magnetic field lines formed by a magnetic field generation means, frictional heat is generated, and this frictional heat causes deterioration of the polishing fluid and a reduction in the processing rate of polishing. In view of this, setting the temperature of the polishing fluid supplied during polishing to room temperature or less makes it possible to suppress the generation of the above-described frictional heat and keep the processing rate of polishing high.

[0082] Hereinafter, a modified example of the second embodiment will be described.

[Modified Example 1]

Although polishing of the outer circumferential edge surface of the glass substrate G has been described with reference to FIGS. 9 to 12, the inner circumferential edge surface of the glass substrate can also be polished with a similar method. Modified Example 1 (not shown) is an example in which the outer circumferential edge surface of the glass substrate G and the inner circumferential edge surface thereof are polished at the same time, and is a polishing method similar to that of Modified Example 1 of the first embodiment, and therefore detailed description is omitted.

[0083] Note that in Modified Example 1 of the second embodiment, for example, by supplying additional polishing fluid using a supplying apparatus to a position at which the mass of the polishing fluid held by the magnetic field and the inner circumferential edge portion of the glass substrate G come into contact with each other, the shape of the mass of the polishing fluid for

performing inner circumferential edge surface polishing is modified such that the pressing force against the glass substrate is kept constant. Also, with regard to outer circumferential edge surface polishing, the shape of the mass of the polishing fluid for performing outer circumferential edge surface polishing is modified by performing shape modification on the mass of the polishing fluid using the above-described shape modification apparatus, or supplying additional polishing fluid such that the pressing force against the glass substrate is kept constant. Therefore, in this modified example, it is possible to polish both the inner circumferential edge surface and the outer circumferential edge surface at the same time and to suppress a decrease in the processing rate for a chamfered surface on the inner circumferential side and a chamfered surface on the outer circumferential side.

[0084] [Modified Example 2]

FIG. 13 is a diagram showing Modified Example 2 of polishing an outer circumferential edge surface of the glass substrate G. Modified Example 2 is an example in which outer circumferential edge surfaces of a plurality of glass substrates are polished at once, instead of only one glass substrate being polished.

A polishing apparatus 10A shown in FIG. 13 includes N-pole magnets 121, 122, 123, 124, ..., S-pole magnets 140, 141, 142, 143, ..., and spacers 161, 162, 163, The N-pole magnets, the S-pole magnets, and the spacers respectively have the same configurations as the magnet 12, the magnet 14, and the spacer 16 of FIG. 3.

That is, in the polishing apparatus 10A, an N-pole edge surface of a magnet and an adjacent S-pole edge surface are arranged stacked so as to oppose each other at a fixed distance apart from each other. In the polishing apparatus 10A, a magnetic field whose magnetic field lines advance from the N-pole magnet to the S-pole magnet is formed, the N-pole and the S-pole facing each other with a spacer interposed therebetween. That is, a plurality of pairs of magnets disposed in a state in which the N-pole surface and the S-pole

surface are disposed apart from each other and facing each other in the thickness direction of the glass substrate G are used as a magnetic field generation means. For example, a magnetic field in which magnetic field lines advance from the magnet 121 to the magnet 141 is formed. Masses F of the polishing fluid are held by the magnetic fields at the circumferential edges of the spacers 161, 162, 163... A driving motor (not shown) is used to rotate the polishing apparatus 10A as shown in FIG. 13 during edge surface polishing.

[0085] The plurality of glass substrates G are integrated as a stacked body using an adhesive with spacers 151, 152, 153, 154... sandwiched therebetween.

Here, the adhesive used to produce the stacked body may be similar to that described in Modified Example 2 of the first embodiment. A stacked body including the plurality of glass substrates G is held by a rotary body (not shown), and is rotated as shown in FIG. 13 using a driving motor (not shown) during edge surface polishing.

[0086] The outer circumferential edge surfaces of the plurality of glass substrates G can be polished at the same time by bringing the outer circumferential edge surfaces of the glass substrates G included in the stacked body into contact with the mass F of the polishing fluid, and moving the mass F of the polishing fluid and the outer circumferential edge surfaces of the plurality of glass substrates G relative to each other. That is, since the outer circumferential edge surfaces of the plurality of glass substrates can be polished at the same time, the processing rate can be increased more than with the conventional method, and polishing can be efficiently performed.

Note that the technical points (adjustment of a spacer between magnets, swinging of the plurality of magnets and the stacked body of the glass substrates G, and the like, for example) described in Modified Example 2 of the first embodiment can be applied to this modified example.

[0087] The edge surface polishing processing of Modified Example 2 is performed while new polishing fluid is supplied from the outside during polishing. In the example shown in FIG. 13, additional polishing fluid is

supplied from a plurality of nozzles 301, 302, 303, ... in the latitudinal direction to a position at which the masses F of the polishing fluid and the outer circumferential edge portions of the glass substrates G come into contact with each other. This additional polishing fluid is newly held by the magnetic field as the mass, and as a result, the shapes of the masses F of the polishing fluid are modified such that the pressing force against the glass substrate is kept constant. Accordingly, it is possible to suppress a decrease in the processing rate for chamfered surfaces of the glass substrates G in the case where edge surface polishing is continuously performed on the stacked body of the glass substrates G.

[0088] Although FIG. 13 shows, as an example, the case where the outer circumferential edge surfaces of the plurality of glass substrates G that are integrated as a stacked body are polished, the inner circumferential edge surfaces of the plurality of glass substrates G may be polished similarly. Also, the outer circumferential edge surfaces and the inner circumferential edge surfaces of the plurality of glass substrates G, which are integrated as a stacked body, may be polished at the same time.

[0089] [Working Examples]

In order to check the effect of the present invention, an edge surface of a produced glass substrate was polished.

An outer diameter of the produced glass substrate was 65 mm and the thickness was 0.8 mm, and in the shape processing, 0.15-mm chamfering was performed in the thickness direction of the glass substrate at an inclination angle of 45 degrees with respect to the main surface.

[0090] (Comparative Example)

As shown in FIG. 4, the outer circumferential edge portion of a 2.5-inch magnetic-disk glass substrate was inserted in a polishing apparatus in which a pair of magnets are disposed apart from each other by a spacer made of nonmagnetic stainless steel. The magnet has a diameter of 19 mm and a thickness of 15 mm, as the dimensions. The magnetic field that was formed by

the magnets with the polishing fluid provided between the magnets was caused to hold the mass of a magnet slurry, and the outer circumferential edge surface of the glass substrate was polished. The polishing apparatus was rotated such that the edge surface of the glass substrate was rotated in the opposite
5 direction, and the rotation rates thereof were set to 700 rpm. 100 glass substrates were polished, and processing time for one glass substrate was set to 3 minutes. Note that there was no polishing fluid that overflowed the side surfaces of the magnets.

Polishing fluid obtained by dispersing Fe (iron) minute particles having
10 an average particle diameter (D50) of 2 μm at a concentration of 3 $[\text{g}/\text{cm}^3]$ in nonmagnetic oil (silicone oil) and dispersing cerium oxide having an average particle diameter of 1.5 μm as the polishing abrasive particles was used as the polishing fluid used to polish the outer circumferential edge surface of the glass substrate. The polishing fluid contained cerium oxide in a concentration of 7
15 $[\text{vol}\%]$. A permanent magnet having a magnetic flux density of 0.5 $[\text{tesla}]$ was used as the magnet.

[0091] (Working Example 1)

Similarly to Comparative Example, 100 glass substrates were polished, and the processing time for one glass substrate was set to 3 minutes. In
20 Working Example 1, polishing was performed under conditions similar to the polishing conditions of Comparative Example, except that a shape modification apparatus was used every time 10 glass substrates were polished, and the shape of the deformed mass of the polishing fluid was modified.

[0092] (Evaluation of Comparative Example and Working Example 1)

25 With regard to the chamfered surfaces of the outer circumferential edge surfaces of the glass substrates after edge surface polishing in Comparative Example and Working Example 1, the results of measurement of the processing rates for a first glass substrate and for a 100th glass substrate are shown in Table 2. Here, Equation (1) described above was applied to a method for
30 calculating the percentage of decrease in the processing rate. As shown in

Table 2, in Working Example 1, in the case where glass substrates are polished continuously, it was confirmed that a decrease in the processing rate for the chamfered surfaces was significantly suppressed compared to Comparative Example. If the percentage of decrease in the processing rate is less than or equal to 10%, no problem in particular will occur in the manufacturing steps.

[0093] [Table 2]

	Processing rate for 1st glass substrate	Processing rate for 100th glass substrate	Percentage of decrease in processing rate
Comp. Ex.	25 [$\mu\text{m}/\text{min}$]	11.25 [$\mu\text{m}/\text{min}$]	55%
Work. Ex. 1	25 [$\mu\text{m}/\text{min}$]	24.25 [$\mu\text{m}/\text{min}$]	3%

[0094] (Working Example 2)

The outer circumferential edge surface of the glass substrate was polished under conditions similar to the polishing conditions of Comparative Example described above, except that a bar-like jig in which the cross section of the tip has a protruding shape and that is made of aluminum was used, and the tip of the jig was inserted into the mass of the polishing fluid during edge surface polishing. As a result, the percentage of decrease in the processing rate for the chamfered surfaces of the glass substrates was 1%, and a more preferable result was obtained than in Working Example 1.

[0095] (Working Example 3)

Instead of using a shape modification apparatus, polishing fluid was added during the polishing processing, and processing for polishing the outer circumferential edge surface of the glass substrate was performed. The percentage of decrease in the processing rate for the chamfered surfaces of the glass substrates in that case was 6%.

[0096] (Working Example 4)

In addition to the conditions of Working Example 1, polishing was performed while a liquid containing polishing abrasive particles was supplied.

Specifically, as shown in FIG. 6, the liquid containing polishing abrasive particles was supplied along the movement direction of the edge surface of the glass substrate that comes into contact with the mass of the polishing fluid every time polishing of the outer circumferential edge surface of one glass substrate ended. Water was used as the liquid.

The percentage of decrease in the processing rate for the chamfered surfaces of the glass substrates in that case was 0%, and a more preferable result was obtained than in Working Example 2.

[0097] Furthermore, with regard to 100 glass substrates, which are polishing targets, a radius of curvature of the shape of a portion between the side wall surface and the chamfered surface was measured.

Here, a method for obtaining the radius of curvature of the shape of a portion between the side wall surface and the chamfered surface will be described with reference to FIG. 14. In FIG. 14, R indicates a radius of a circle C2 that forms the curvature of the shape of a portion between a side wall surface 1t and a chamfered surface 1c, and indicates the radius of curvature of the shape of the portion. The radius of curvature R can be obtained as follows, for example. First, an intersection point of a virtual line L1 obtained by extending a linear portion of the chamfered surface 1c and a virtual line L2 obtained by extending a linear portion of the side wall surface 1t is given as P1. Next, a virtual line L3 passing through the intersection point P1 and extending perpendicularly to the linear portion of the chamfered surface 1c is set. Next, an intersection point of the virtual line L3 and the portion between the side wall surface 1t and the chamfered surface 1c is given as P2. Also, a circle C1 having a predetermined radius (50 μ m, for example) around the intersection point P2 is set on the cross-section of the glass substrate G. Also, two intersection points of an outer circumference of the circle C1 and the portion between the side wall surface 1t and the chamfered surface 1c are respectively given as P3 and P4. Furthermore, a circle C2 passing through three intersection points P2, P3, and P4 is set. By obtaining the radius of the circle

C2, the radius of curvature R of the shape of the portion between the side wall surface 1t and the chamfered surface 1c can then be obtained.

Note that the radius of curvature of a shape of a portion between the side wall surface 1t and the other chamfered surface 1c (not shown in FIG. 14) can also be obtained similarly to the above description.

[0098] When the above-described radii of curvature of the 100 glass substrates were measured (an average value of any two points on the respective circumferences of both surfaces) and variation in 100 glass substrates (defined as a difference between the maximum value and the minimum value, herein) was calculated, a ratio of the magnitude of variation of Working Example 4 with respect to the magnitude of variation of Working Example 1 was 0.5, which is significantly smaller. It is inferred that this is because not only a decrease in the polishing rate for chamfered surfaces is suppressed but also polishing of the portions between the side wall surface and the chamfered surfaces becomes stable due to the synergistic effect of supplying the liquid containing polishing abrasive particles. That is, in general, since the portion between the side wall surface and the chamfered surface is sharp, the shape of the portion is likely to change due to a slight change in processing conditions, but it was confirmed that the change was suppressed in Working Example 4.

[0099] Although a method for manufacturing a nonmagnetic substrate of the present invention has been described in detail above, the present invention is not limited to the above-described embodiments and modified examples, and it will be appreciated that various improvements and modifications can be made without departing from the gist of the present invention. For example, although a method for manufacturing a magnetic-disk glass substrate has been described as one embodiment of a method for manufacturing a nonmagnetic substrate of the present invention, this method is applicable to a nonmagnetic substrate made of other material, such as an aluminum alloy substrate, as long as a processing target is a nonmagnetic substrate.

[Descriptions of Reference Numerals]

5	[0100]	1	Magnetic-disk glass substrate
		G	Glass substrate
		10, 10A	Polishing apparatus
		5a	Magnetic minute particles
		5b	Polishing abrasive particles
		12, 14, 121 to 124, 140 to 143	Magnets
		16, 151 to 154, 161 to 163	Spacers
		F	Mass
		M	Magnetic field line
		20	Shape modification apparatus
10		21U, 21L, 22	Jig
		30, 30A	Supplying apparatus
		90	Bath

CLAIMS

1. A method for manufacturing a nonmagnetic substrate, comprising edge surface polishing processing for polishing an edge surface of a plate-like nonmagnetic substrate having a side wall surface and a chamfered surface formed between a main surface and the side wall surface, wherein

the edge surface polishing processing is processing for polishing the edge surface of the substrate by forming a magnetic field such that magnetic field lines advance in a thickness direction of the substrate using a magnetic field generation means, bringing the edge surface of the substrate and magnetic functional fluid into contact with each other in a state in which the magnetic functional fluid containing polishing abrasive particles is held by the magnetic field, and moving the substrate and the magnetic functional fluid relative to each other, and

the polishing abrasive particles are supplied to the magnetic functional fluid during the edge surface polishing processing.

2. The method for manufacturing a nonmagnetic substrate according to claim 1, wherein

the polishing abrasive particles are supplied by supplying a liquid containing the polishing abrasive particles during the edge surface polishing processing.

3. The method for manufacturing a nonmagnetic substrate according to claim 2, wherein

a temperature of the liquid to be supplied during the edge surface polishing processing is less than or equal to room temperature.

4. The method for manufacturing a nonmagnetic substrate according to any one of claims 1 to 3, wherein

the polishing abrasive particles are supplied to a position at which the edge surface of the substrate comes into contact with the magnetic functional fluid along a movement direction of the edge surface of the substrate that comes into contact with the magnetic functional fluid.

5

5. A method for manufacturing a nonmagnetic substrate, comprising edge surface polishing processing for polishing an edge surface of a plate-like nonmagnetic substrate having a side wall surface and a chamfered surface formed between a main surface and the side wall surface, wherein

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the edge surface polishing processing is for polishing the edge surface of the substrate by forming a magnetic field such that magnetic field lines advance in a thickness direction of the substrate using a magnetic field generation means in a state in which magnetic functional fluid containing polishing abrasive particles and the substrate are immersed in a liquid containing the polishing abrasive particles, bringing the edge surface of the substrate and the magnetic functional fluid into contact with each other in a state in which the magnetic functional fluid containing the polishing abrasive particles is held by the magnetic field, and moving the substrate and the magnetic functional fluid relative to each other.

20

6. The method for manufacturing a nonmagnetic substrate according to any one of claims 1 to 5, wherein

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the magnetic field generation means includes a pair of magnets disposed in a state in which an N-pole surface and an S-pole surface are disposed apart from each other and facing each other in the thickness direction of the substrate.

7. The method for manufacturing a nonmagnetic substrate according to claim 6, wherein

30

a spacer made of a nonmagnetic material is provided between the

N-pole surface and the S-pole surface of the pair of magnets.

8. The method for manufacturing a nonmagnetic substrate according to any one of claims 1 to 7, wherein

- 5 the substrate has a disk shape having a circular inner hole,
the magnetic field generation means includes an inner circumferential side means that is provided in the inner hole of the substrate and that forms a magnetic field around an inner circumferential edge surface, which is the side wall surface of the inner hole, such that inner circumferential side magnetic
10 field lines advance in the thickness direction of the substrate, and/or an outer circumferential side means that is provided on an outer circumferential side of the substrate and that forms a magnetic field around an outer circumferential edge surface of the substrate such that outer circumferential side magnetic field lines advance in the thickness direction of the substrate, and
15 the inner circumferential edge surface and/or the outer circumferential edge surface of the substrate are polished in a state in which the magnetic functional fluid is held by the magnetic fields respectively formed by the inner circumferential side means and/or the outer circumferential side means.

- 20 9. A method for manufacturing a nonmagnetic substrate, comprising edge surface polishing processing for polishing a nonmagnetic edge surface of a plate-like substrate having a side wall surface and a chamfered surface formed between a main surface and the side wall surface, wherein

- the edge surface polishing processing is processing for polishing the
25 edge surface of the substrate by forming a magnetic field such that magnetic field lines advance in a thickness direction of the substrate using a magnetic field generation means, forming a mass of magnetic functional fluid by causing the magnetic field to hold the magnetic functional fluid containing polishing abrasive particles, bringing the edge surface of the substrate and the mass of
30 the magnetic functional fluid into contact with each other, and moving the

substrate and the mass of the magnetic functional fluid relative to each other,
and

5 a shape of the mass of the magnetic functional fluid deformed due to
contact with the substrate is modified such that a pressing force against the
substrate is kept constant.

10. The method for manufacturing a nonmagnetic substrate according to
claim 9, wherein

10 the shape of the mass of the magnetic functional fluid is modified by
bringing a jig into contact with the deformed mass of the magnetic functional
fluid.

11. A method for manufacturing a nonmagnetic substrate, comprising edge
surface polishing processing for polishing an edge surface of a plate-like
15 nonmagnetic substrate having a side wall surface and a chamfered surface
formed between a main surface and the side wall surface, wherein

the edge surface polishing processing is processing for polishing the
edge surface of the substrate by forming a magnetic field such that magnetic
field lines advance in a thickness direction of the substrate using a magnetic
20 field generation means, forming a mass of magnetic functional fluid by causing
the magnetic field to hold the magnetic functional fluid containing polishing
abrasive particles, bringing the edge surface of the substrate and the mass of
the magnetic functional fluid into contact with each other, and moving the
substrate and the mass of the magnetic functional fluid relative to each other,
25 and

a shape of the mass of the magnetic functional fluid deformed due to
contact with the substrate is modified so as to return to an original shape.

12. A method for manufacturing a nonmagnetic substrate, comprising edge
30 surface polishing processing for polishing an edge surface of a plate-like

nonmagnetic substrate having a side wall surface and a chamfered surface formed between a main surface and the side wall surface, wherein

the edge surface polishing processing is processing for polishing the edge surface of the substrate by forming a magnetic field such that magnetic field lines advance in a thickness direction of the substrate using a magnetic field generation means, forming a mass of magnetic functional fluid by causing the magnetic field to hold the magnetic functional fluid containing polishing abrasive particles, bringing the edge surface of the substrate and the mass of the magnetic functional fluid into contact with each other, and moving the substrate and the mass of the magnetic functional fluid relative to each other, and

a shape of the mass of the magnetic functional fluid is changed by bringing a jig into contact with the mass of the magnetic functional fluid.

13. The method for manufacturing a substrate according to claim 10 or 12, wherein

the jig is brought into contact with the mass of the magnetic functional fluid by inserting a tip of the jig into the mass of the magnetic functional fluid.

14. The method for manufacturing a nonmagnetic substrate according to claim 9 or 11, wherein

the shape of the magnetic functional fluid is modified by supplying an additional mass of the magnetic functional fluid.

15. The method for manufacturing a nonmagnetic substrate according to any one of claims 9 to 14, wherein

the magnetic field generation means includes a pair of magnets disposed in a state in which an N-pole surface and an S-pole surface are disposed apart from each other and facing each other in the thickness direction of the substrate.

16. The method for manufacturing a nonmagnetic substrate according to claim 15, wherein

5 a spacer made of a nonmagnetic material is provided between the N-pole surface and the S-pole surface of the pair of magnets.

17. The method for manufacturing a nonmagnetic substrate according to any one of claims 9 to 16, wherein

the substrate has a disk shape having a circular inner hole,

10 the magnetic field generation means includes an inner circumferential side means that is provided in the inner hole of the substrate and that forms a magnetic field around an inner circumferential edge surface, which is the side wall surface of the inner hole, such that inner circumferential side magnetic field lines advance in the thickness direction of the substrate, and/or an outer
15 circumferential side means that is provided on an outer circumferential side of the substrate and that forms a magnetic field around an outer circumferential edge surface of the substrate such that outer circumferential side magnetic field lines advance in the thickness direction of the substrate, and

the inner circumferential edge surface and/or the outer circumferential
20 edge surface of the substrate are polished in a state in which the mass of the magnetic functional fluid is held by the magnetic fields respectively formed by the inner circumferential side means and/or the outer circumferential side means.

25 18. The method for manufacturing a nonmagnetic substrate according to any one of claims 9 to 17, wherein

the polishing abrasive particles are supplied to the mass of the magnetic functional fluid during the processing for polishing the edge surface of the substrate.