

[DESCRIPTION]

[Title of Invention]

METHOD FOR MANUFACTURING GLASS BLANK FOR MAGNETIC DISK, METHOD FOR MANUFACTURING GLASS SUBSTRATE FOR MAGNETIC DISK, GLASS BLANK FOR MAGNETIC DISK, GLASS SUBSTRATE FOR MAGNETIC DISK AND MAGNETIC DISK

[Technical Field]

[0001]

The present invention relates to a method for manufacturing a glass blank for magnetic disk, a method for manufacturing a glass substrate for magnetic disk, a glass blank for magnetic disk, a glass substrate for magnetic disk and a magnetic disk.

[Background Art]

[0002]

Recently, a hard disk device (HDD) is incorporated in a personal computer or a DVD (Digital Versatile Disc) recording apparatus in order to record data. Particularly, in the hard disk device used in an apparatus such as the notebook personal computer based on portability, a magnetic disk in which a magnetic layer is provided on a glass substrate is used, and magnetic recording information is recorded in or read from a magnetic layer using a magnetic head (DFH (Dynamic Flying Height) head) that is slightly floated on a surface of the magnetic disk surface. A glass substrate is suitably used as the substrate for magnetic disk because the glass substrate hardly plastically deformed as compared to a metallic substrate (aluminum substrate) and the like.

[0003]

The magnetic head includes, for example, a magnetic resistance effect element, but such a magnetic head may cause a thermal asperity trouble as its specific trouble. The thermal asperity trouble is a trouble in which when a magnetic head passes over a micro-irregularly-shaped surface of a magnetic disk while floating and flying, a magnetic resistance effect element is heated by adiabatic compression or contact of air, causing a read error. Thus, for avoiding the thermal asperity trouble, the glass substrate for magnetic disk is prepared such that surface properties, such as the surface roughness and flatness, of the principal face of the glass substrate are at a satisfactory level.

[0004]

As a conventional method for manufacturing a sheet glass (glass blank), a vertical direct press method is known. This press method is a method in which a lump of molten glass is fed

onto a lower die, and the lump of molten glass (molten glass lump) is press-formed using an upper die (see PLT 1). Furthermore, there is known a horizontal direct press method for sandwiching a falling molten glass in the horizontal direction to press-form the same (see PLT 2, FIG. 4 etc).

[0005]

As a conventional method for manufacturing a glass substrate for magnetic disk, a method is known in which a glass blank formed by press-forming a molten glass lump is subjected to annealing treatment. The annealing treatment is a treatment for releasing a strain (internal strain) generated within a glass blank by holding the press-formed glass blank for a predetermined time period at a temperature which is no lower than a strain point and no higher than a glass transition point (T_g) (see PLT 3). The strain point is a temperature at which the internal strain of glass disappears in several hours, and at which the viscosity of glass is about $10^{14.5}$ dPa·s.

[Citation List]

[Patent Literature]

[0006]

[PTL 1]

Japanese Patent Laid-open Publication No. 1999-255521

[PTL 2]

Japanese Patent Publication No. 4380379

[PTL 3]

Japanese Patent Laid-open Publication No. 2008-287779

[Summary of Invention]

[Technical Problem]

[0007]

However, the known vertical direct press method has the problem that the surface waviness of a glass blank prepared is bad. The reason for this is as follows.

In the vertical direct press method, when press forming of a molten glass lump is started, an upper die and a lower die come into contact with each other, so that the molten glass lump is cooled to be solidified. At this time, heat of the molten glass lump is easily confined at the central portion of the press forming surface of each of the upper die and the lower die due to the existence of the molten glass around the central portion. On the other hand, heat of the molten glass lump is easily diffused at the circumferential edge portion of the press forming surface of each of the upper die and the lower die for the reason that an area of the press forming surface which comes into

contact with the molten glass is relatively large compared to the central portion thereof, and for the reason that some outer edge portions of dies do not come into contact with the molten glass when the outer shape of the molten glass is not restricted, and therefore a difference in temperature in the press forming surface is increased during press forming. Accordingly, an uneven heat deformation (thermal expansion) is generated in the press forming surface during press forming so that the glass blank prepared has an increase in surface waviness of the principal face as the heat deformation of the press forming surface is shape-transferred. Therefore, the surface waviness of the glass blank is deteriorated. The known horizontal direct press method has also similar problems described above.

[0008]

For performing annealing treatment efficiently, a large-scale annealing treatment apparatus is required. Further, when the annealing treatment is performed, a state in which the temperature of a glass blank is set at around a strain point should be maintained for about 15 minutes. A treatment time of about 3 to 12 hours is required including treatment for elevating the temperature to the strain point and treatment for slow cooling from the strain point. Accordingly, when a glass substrate for magnetic disk is manufactured by performing the annealing treatment, large-scale equipment and much time are required, so that manufacture costs of the glass substrate for magnetic disk are increased. Therefore, it is preferred that the annealing treatment is not performed wherever possible.

When a glass blank with an internal strain generated during press forming is subjected to the annealing treatment, the internal strain of the glass blank is released, but the glass blank is deformed as the internal strain is released, so that the flatness of the glass blank is deteriorated. For example, when a glass blank is press-formed so that the flatness is 4 μm or less is subjected to annealing treatment, the flatness of the glass blank after annealing treatment may be larger than 4 μm if the internal strain remains in the glass blank during press forming. In this case, it is required to perform a grinding process to ensure that the flatness of the glass blank is 4 μm or less.

[0009]

In heat assisted magnetic recording (HAMR) for which studies have been conducted in recent years as a magnetic recording technique for increasing storage density of the magnetic disk, a magnetic layer composed of a ferromagnetic alloy having a L10 ordered structure is formed on the principal face of a glass substrate. Here, for forming the L10 ordered structure, film forming treatment under a high-temperature environment and/or annealing treatment after the film forming

treatment are required. The temperature at this time may be a high temperature close to the strain point of glass. At this time, if the internal strain remains in the glass blank as a base of the glass substrate, the internal strain of the glass substrate is released under a high-temperature environment, but the flatness of the glass substrate is deteriorated as in the case of the annealing treatment described above, so that substrate performance cannot meet requirements in some cases.

Therefore, the glass substrate for magnetic disk, which is used in heat assisted magnetic recording, is preferably one that is manufactured based on a glass blank in which the internal strain is small or does not remain.

[0010]

The first object of the present invention is to provide a method for manufacturing a glass blank for magnetic disk, which is capable of producing a glass blank for magnetic disk having a good surface waviness by press forming, and a method for manufacturing a glass substrate for magnetic disk.

The second object of the present invention is to provide a method for manufacturing a glass blank for magnetic disk and a method for manufacturing a glass substrate for magnetic disk, which are capable of reducing an internal strain without performing annealing treatment, and a glass blank for magnetic disk, a glass substrate for magnetic disk and a magnetic disk.

[Solution to Problem]

[0011]

From the viewpoint described above, the first viewpoint of the present invention is a method for manufacturing a glass blank for magnetic disk, which includes a forming process of press-forming a lump of molten glass using a pair of dies to obtain a sheet glass material, wherein in the forming process, a difference in temperature in a press forming surface of the die is controlled (adjusted) so that the surface waviness of the sheet glass material is equal to 30 nm or less.

[0012]

The second viewpoint of the present invention is a method for manufacturing a glass blank for magnetic disk, which includes a forming process of press-forming a lump of molten glass using a pair of dies to form a sheet glass material, wherein in the forming process, press forming is performed using thermally equalizing means for reducing a difference in temperature in the press forming surface of the die during pressing of the molten glass.

“Difference in temperature in the press forming surface” means a difference in temperature between a central portion and circumferential edge portion of a die, for example.

[0013]

In the method for manufacturing a glass blank for magnetic disk, preferably the thermally equalizing means may reduce a difference in temperature in the press forming surface by heat-exhausting and/or heating the press forming surface.

[0014]

In the method for manufacturing a glass blank for magnetic disk, the thermally equalizing means may be a heat sink.

[0015]

In the method for manufacturing a glass blank for magnetic disk, the heat sink may be provided on at least a part of the surface opposite to the press forming surface.

[0016]

In the method for manufacturing a glass blank for magnetic disk, the heat sink may be provided so that amount of heat exhausted from a central portion of the molten glass is larger than that from the circumferential edge portion of the molten glass during the press forming.

[0017]

In the method for manufacturing a glass blank for magnetic disk, in the forming process, the falling lump of molten glass may be press-formed using the pair of dies from a direction orthogonal to the falling direction.

[0018]

In the method for manufacturing a glass blank for magnetic disk, in the forming process, press forming may be performed so that the temperature of the press forming surface of the pair of dies is substantially the same.

[0019]

In the method for manufacturing a glass blank for magnetic disk, the thermal expansion coefficient at 100°C to 300°C of a glass blank obtained after press forming may be in a range of 30 to $100 \times 10^{-7}(\text{K}^{-1})$.

[0020]

In the method for manufacturing a glass blank for magnetic disk, surface roughness of the press forming surface of the die is substantially uniform throughout the surface.

[0021]

The third viewpoint of the present invention may be a method for manufacturing a glass substrate for magnetic disk, wherein a glass blank for magnetic disk may be subjected to polishing

processing having machining allowance of 50 μm or less to manufacture a glass substrate for magnetic disk, the glass blank being manufactured with the above-described method for manufacturing a glass blank for magnetic disk.

[0022]

The fourth viewpoint of the present invention is a method for manufacturing a glass substrate for magnetic disk, wherein a glass substrate for magnetic disk may be manufactured using a glass blank for magnetic disk, which is obtained by the above-described method for manufacturing a glass blank for magnetic disk.

[0023]

With reference to the second object of the present invention, the present inventors have intensively conducted studies, and resultantly devised a novel press forming method. That is, in a method for manufacturing a glass blank according to this embodiment, a horizontal direct press method is employed in which a falling molten glass lump is press-formed using a pair of dies (press forming dies) arranged so as to face each other in a direction (horizontal direction) orthogonal to the falling direction of the molten glass lump. In the horizontal direct press method, unlike the conventional vertical direct press method, the molten glass lump is not temporarily retained in contact with a member having a temperature lower than that of the molten glass lump in the period during which it is press-formed. Thus, at the time point immediately before press forming is started, the viscosity distribution of the interior of the molten glass lump becomes very wide during press forming in the vertical direct press method. In short, in the conventional vertical direct press method, there is a difference between a period during which an upper die contacts a lump of molten glass and a period during which a lower die contacts a lump of molten glass, since the upper die goes downwardly to press the molten glass lump after the molten glass lump contacts the lower die. As a result, the lower part of the molten glass lump which contacts the lower die in advance is cooled and becomes high in viscosity. On the other hand, at the time of pressing, the upper part of the molten glass lump is not cooled, and therefore the viscosity of the upper part is low. Consequently, it is difficult to uniformly thinly draw the molten glass lump. Furthermore, due to the same reason described above, a difference in temperature occurs between the upper and lower dies when pressing, and the flatness of a glass blank obtained after pressing is then deteriorated. In contrast, in the horizontal direct press method, there is no difference or extremely small difference between time when a right die contacts a lump of molten glass and time when left die contacts the lump of molten glass, and the molten glass lump is pressed with its viscosity being

uniform. Accordingly, in the horizontal direct press method, it is extremely easy to uniformly thinly draw the molten glass lump to be press-formed as compared to the vertical direct press method. Consequently, as compared to the case where a glass blank is prepared using the vertical direct press method, it is extremely easy to drastically suppress deterioration of the flatness when a glass blank is prepared using the horizontal direct press method.

[0024]

In addition, the present inventors have arrived at the following findings.

As described above, the flatness of a glass blank prepared is improved by using a horizontal direct press method using a pair of dies. Here, even when the horizontal direct press method is used, heat of a molten glass lump is easily confined in a central portion of the press forming surface of a die during press forming, so that molten glass present at the central portion is hardly cooled. On the other hand, heat of the molten glass lump is easily diffused at a circumferential edge portion of the press forming surface of the die during press forming, so that the molten glass present at the circumferential edge portion is easily cooled. That is, it is presumed that the molten glass is solidified along a direction from the circumferential edge portion to the central portion of the press forming surface. In this way, an internal strain (in-plane strain) by a residual stress extending in the direction from the circumferential edge portion to the central portion of the press forming surface is generated in the press-formed glass blank. If in-plane strain is generated, the flatness may be deteriorated because the strain is released when a heating treatment is performed until temperature of the glass blank rises to a glass transition point (T_g) or nearly a strain point in the post-process.

The present inventors have found that when cooling rate of the molten glass is controlled so that a difference in temperature on a surface of a molten glass (e.g. between the circumferential edge portion and the central portion of the surface of the molten glass) during press forming is reduced, the area on the surface of the molten glass can be solidified almost at the same time without causing an internal strain.

[0025]

The fifth viewpoint of the present invention may be a method for manufacturing a glass blank for magnetic disk, which includes a forming process of press-forming a lump of molten glass using a pair of dies to obtain a sheet glass material, wherein in the forming process, press forming is performed while temperature of the molten glass is controlled so that cooling rate of the molten glass is $-10\text{ }^{\circ}\text{C/second}$ or less during the period of time in the molten glass is cooled from a glass

transition point (T_g) to a strain point.

It is noted that when temperature reduction is 10°C per second, for example, it is referred to as “-10 °C/second”. In addition, “cooling rate is -10 °C/second or less” means that temperature reduction is lower than 10 °C per second.

[0026]

The sixth viewpoint of the present invention may be a method for manufacturing a glass blank for magnetic disk, which includes a forming process of press-forming a lump of molten glass using a pair of dies to obtain a sheet glass material, wherein in the forming process, press forming is performed while cooling rate of the molten glass is controlled during the period of time in the molten glass is cooled from a glass transition point to a strain point so as to reduce in-plane strain generated when the molten glass lump is solidified into a sheet glass blank.

[0027]

The seventh viewpoint of the present invention may be a method for manufacturing a glass blank for magnetic disk, which includes a forming process of press-forming a lump of molten glass using a pair of dies to obtain a sheet glass blank, wherein in the forming process, press forming is performed while cooling rate of the molten glass is controlled so that a difference in temperature on a surface of the molten glass during pressing of the molten glass is reduced.

[0028]

In the method for manufacturing a glass blank for magnetic disk, preferably press forming may be performed while the cooling rate of the molten glass is controlled so that a difference in temperature on a surface of the molten glass is reduced during the period of time in which the pair of dies close and separate.

[0029]

In the method for manufacturing a glass blank for magnetic disk, in the forming process, press forming may be performed while the cooling rate of the molten glass is controlled so that a difference in temperature on a surface of the molten glass is reduced during the period of time in which the temperature of the molten glass moves from a glass transition point (T_g) to a strain point during the pressing of the molten glass.

[0030]

In the method for manufacturing a glass blank for magnetic disk, in the forming process, the falling lump of molten glass may be press-formed using the pair of dies from a direction orthogonal to the falling direction.

[0031]

In the method for manufacturing a glass blank for magnetic disk, in the forming process, press forming may be performed while temperature of a press forming surface of the die during pressing of the molten glass is kept substantially uniform.

[0032]

In the method for manufacturing a glass blank for magnetic disk, in the forming process, press forming may be performed so that temperature of a press forming surface of the pair of dies is substantially identical.

[0033]

In the method for manufacturing a glass blank for magnetic disk, the temperature of the pair of dies is kept lower than the glass transition point (T_g) of the molten glass during the period of time in which the glass blank is separated from the die after contacting the die.

[0034]

In the method for manufacturing a glass blank for magnetic disk, the forming process may be performed using a molten glass having a glass transition point (T_g) of 600°C or higher.

[0035]

The eighth viewpoint of the present invention may be a method for manufacturing a glass blank for magnetic disk, which includes a forming process of press-forming a lump of molten glass using a pair of dies to obtain a sheet glass material, wherein in the forming process, press forming is performed while temperature of the molten glass is controlled so that surface waviness of the sheet glass material is 30 nm or less and the cooling rate is -10 °C/second or less during the period of time in which the temperature of the molten glass is cooled from a glass transition point to a strain point

[0036]

The ninth viewpoint of the present invention may be a method for manufacturing a glass substrate for magnetic disk, wherein a glass substrate for magnetic disk may be manufactured without performing annealing treatment using a glass blank for magnetic disk, the glass blank being obtained with the above-described method for manufacturing a glass blank for magnetic disk,.

[0037]

The tenth viewpoint of the present invention may be a glass substrate for magnetic disk, which is obtained with the above-described method for manufacturing a glass substrate for magnetic disk, wherein the glass transition point (T_g) is 600°C or higher.

[0038]

The eleventh viewpoint of the present invention may be a magnetic disk, which is manufactured using the glass substrate for magnetic disk which is obtained with the above-described method for manufacturing a glass substrate for magnetic disk.

[Advantageous Effects of Invention]

[0039]

According to the present invention, a glass blank for magnetic disk and a glass substrate for magnetic disk, which have a good surface waviness, can be manufactured by press forming.

[Brief Description of Drawings]

[0040]

FIG. 1 is a perspective view illustrating an external shape of a glass substrate for magnetic disk of an embodiment.

FIG. 2 is a view illustrating a flow of one embodiment of a method for manufacturing the glass substrate for magnetic disk of the embodiment.

FIG. 3 is a plan view of an apparatus used in press forming of the embodiment.

FIG. 4 is a view illustrating an example of press forming of the embodiment.

FIG. 5 is a view illustrating a modification of press forming of the embodiment using a gob forming die.

FIG. 6 is a view illustrating a modification of press forming of the embodiment in which a cutting unit is not used.

FIG. 7 is a view illustrating a modification of press forming of the embodiment using an optical glass heated by a softening furnace.

FIG. 8 is a view illustrating a modification of thermally equalizing or heat exhausting means used in press forming of the embodiment.

FIG. 9 is a view illustrating a time course of the temperature of a gob in press forming of the embodiment.

[Description of Embodiments]

[0041]

<First Embodiment>

A method for manufacturing a glass blank for magnetic disk and a method for manufacturing a glass substrate for magnetic disk according to this embodiment will be described in detail below.

[0042]

[Glass substrate for magnetic disk]

As illustrated in FIG. 1, a glass substrate for magnetic disk 1 in this embodiment is a donut-shaped thin glass substrate. The size of the glass substrate for magnetic disk is not limited but for example, a glass substrate for magnetic disk having a nominal diameter of 2.5 inches is suitable. In the case of the glass substrate for magnetic disk having a nominal diameter of 2.5 inches, for example, the outer diameter is 65 mm, the diameter of a central hole 2 is 20 mm, and the thickness T is 0.6 to 1.0 mm. The flatness of the principal face of the glass substrate for magnetic disk of the embodiment is, for example, 4 μm or less, and the surface roughness (arithmetic mean roughness Ra) of the principal face is, for example, 0.2 nm or less. It is to be noted that the flatness required for a substrate for magnetic disk as a final product is, for example, 4 μm or less.

[0043]

Aluminosilicate glass, soda-lime glass, borosilicate glass or the like can be used as a material of the glass substrate for magnetic disk in this embodiment. Particularly, the amorphous aluminosilicate glass can be suitably used in that chemically strengthening can be performed, and a glass substrate for magnetic disk excellent in flatness of the principal face and strength of the substrate can be prepared.

[0044]

The composition of the glass substrate for magnetic disk of this embodiment is not limited, but the glass substrate of this embodiment is preferably made of amorphous aluminosilicate glass having a composition including 50 to 75% of SiO_2 , 1 to 15% of Al_2O_3 , 5 to 35% in total of at least one component selected from Li_2O , Na_2O and K_2O , 0 to 20% in total of at least one component selected from MgO , CaO , SrO , BaO and ZnO and 0 to 10% in total of at least one component selected from ZrO_2 , TiO_2 , La_2O_3 , Y_2O_3 , Ta_2O_5 , Nb_2O_5 and HfO_2 in an oxide-based conversion indicated in mol%.

In order to decrease in-plane strain in pressing, a glass transition point (T_g) of glass is preferably 600°C or higher, more preferably 650°C or higher. This is because a period of time changing from molten state to solid state (around the glass transition point T_g) is shorter and the cooling rate tends to be higher as the glass transition point (T_g) becomes higher, and “difference in temperature on a surface of a die” affects the glass largely. Thus, the manufacturing method of the present embodiment is particularly preferred when such the glass is used.

Furthermore, in the glass substrate in the present embodiment, the thermal expansion coefficient of glass is preferably $50 \times 10^{-7}(\text{K}^{-1})$ or more, more preferably $80 \times 10^{-7}(\text{K}^{-1})$ or more.

The glass is easily deformed and warp of the glass tends to occur due to the temperature change as the thermal expansion coefficient is higher. Therefore, the method in the present embodiment that reduces in-plane strain is preferably applied to a glass of high thermal expansion coefficient rather than low thermal expansion coefficient.

In the present embodiment (as well as the first embodiment), press forming can be performed to any glass having a wide range of viscosity since horizontal pressing is applied, and glass having high viscosity is particularly preferable. This is because the glass is pressed in the middle of falling down in vertical direction, and circularity of the glass having relatively high viscosity becomes better. Specifically, the viscosity may be preferably 500 poises or more. Glass having the viscosity of 2000 poises or more is not preferable for the reason that the glass becomes difficult to be thinned.

[0045]

[Method for manufacturing glass substrate for magnetic disk of embodiment]

Next, a flow of a method for manufacturing a glass substrate for magnetic disk will be described with reference to FIG. 2. FIG. 2 is a view illustrating a flow of one embodiment of a method for manufacturing a glass substrate for magnetic disk.

As illustrated in FIG. 2, in the method for manufacturing a glass substrate for magnetic disk in this embodiment, first a disk-shaped glass blank is prepared by press forming (Step S10). Next, the formed glass blank is scribed to prepare a donut-shaped glass substrate (Step S20). Next, the scribed glass substrate is subjected to shape processing (chamfering processing) (Step S30). Next, the glass substrate is subjected to grinding using a fixed abrasive grain (Step S40). Next, edge polishing of the glass substrate is performed (Step S50). Next, the principal face of the glass substrate is subjected to first polishing (Step S60). Next, the glass substrate, after first polishing, is subjected to chemically strengthening (Step S70). Next, the chemically strengthened glass substrate is subjected to second polishing (Step S80). The glass substrate for magnetic disk is obtained through the above processes.

Each process will be described in detail below.

[0046]

(a) Press Forming Process (Step S10)

First, the press forming process will be described with reference to FIG. 3. FIG. 3 is a plan view of an apparatus used in press forming. As illustrated in FIG. 3, an apparatus 101 includes four sets of press units 120, 130, 140 and 150, a cutting unit 160 and a cutting blade 165

(not illustrated in FIG. 2). The cutting unit 160 is provided on a path of a molten glass that flows out from a molten glass outflow port 111. In the apparatus 101, a lump of molten glass (hereinafter, also referred to as a gob) cut by the cutting unit 160 is caused to fall down, and the lump is pressed from both sides of the falling path of the lump while the lump is sandwiched between surfaces of a pair of dies facing each other, thereby forming the glass blank.

Specifically, as illustrated in FIG. 4, in the apparatus 101, the four sets of press units 120, 130, 140, and 150 are provided at intervals of 90 degrees around the molten glass outflow port 111.
[0047]

Each of the press units 120, 130, 140, and 150 is driven by a moving mechanism (not illustrated) so as to be able to proceed and retreat with respect to the molten glass outflow port 111. That is, each of the press units 120, 130, 140, and 150 can be moved between a catch position and a retreat position. The catch position (position in which the press unit 140 is drawn by a solid line in FIG. 3) is located immediately below the molten glass outflow port 111. The retreat position (positions in which the press units 120, 130, and 150 are drawn by solid lines and a position in which the press unit 140 is drawn by a broken line in FIG. 3) is located away from the molten glass outflow port 111.
[0048]

The cutting unit 160 is provided on a path of the molten glass between the catch position (position in which the gob is captured by the press unit) and the molten glass outflow port 111. The cutting unit 160 forms the lump of molten glass by cutting a proper quantity of the molten glass flowing out from the molten glass outflow port 111. The cutting unit 160 includes a pair of cutting blades 161 and 162. The cutting blades 161 and 162 are driven so as to intersect each other on the path of the molten glass at constant timing. When the cutting blades 161 and 162 intersect each other, the molten glass is cut to obtain the gob. The obtained gob falls down toward the catch position.
[0049]

The press unit 120 includes a first die 121, a second die 122, a first driving unit 123, a second driving unit 124 and a thermally equalizing unit 125. Each of the first die 121 and the second die 122 is a plate-shaped member including a surface (press forming surface) used to perform the press forming for the gob. The press forming surface may be a disk shape, for example. The first die 121 and the second die 122 are disposed such that normal directions of the surfaces become substantially horizontal, and such that the surfaces become parallel to each other.

The first die 121 and the second die 122 are only required to have a press forming surface, and the shapes of the first and second dies 121, 122 are not limited to the plate shape. The first driving unit 123 causes the first die 121 to proceed and retreat with respect to the second die 122. On the other hand, the second driving unit 124 causes the second die 122 to proceed and retreat with respect to the first die 121. Each of the first driving unit 123 and the second driving unit 124 includes a mechanism for causing the surface of the first driving unit 123 and the surface of the second driving unit 124 to be rapidly brought close to each other, for example, a mechanism in which an air cylinder or a solenoid and a coil spring are combined.

The thermally equalizing unit 125 reduces a difference in temperature within the press forming surface by making heat transfer easy in the press forming surface of each of first and second dies 121 and 122 during press forming of the gob. The thermally equalizing unit 125 is a heat sink, for example, which is one example of thermally equalizing means. The thermally equalizing unit 125 is provided so as to contact entire surfaces opposite to the press forming surfaces of first and second dies 121 and 122. Preferably the thermally equalizing unit 125 is formed with material having heat conductivity higher than that of each of first and second dies 121 and 122. For example, when first and second dies 121 and 122 are formed of an ultrahard alloy (e.g. VM40), the thermally equalizing unit 125 may be formed of copper, a copper alloy, aluminum, an aluminum alloy or the like. Since the thermally equalizing unit 125 has a heat conductivity higher than that of each of first and second dies 121 and 122, heat from first and second dies 121 and 122 can be efficiently discharged to outside. The heat conductivity of the ultrahard alloy (VM40) is 71 (W/m·K), and the heat conductivity of copper is 400 (W/m·K). The member that forms the temperature controlling unit 125 may be appropriately selected according to the heat conductivity, hardness, thickness and dimension, etc. of the metal forming first and second dies 121 and 122. First and second dies 121 and 122 are required to have strength capable of sustaining press, and therefore preferably they are not integrated with the thermally equalizing unit 125.

A heat exhausting mechanism including, for example, a path of a liquid, a gas or the like having a cooling effect, or a heating mechanism such as a heater may be configured as thermally equalizing means for reducing a difference in temperature of the inner circumferential surface of the die (the inner circumferential surface of the cylindrical die).

Because the structures of the press units 130, 140, and 150 are similar to that of the press unit 120, the descriptions of the press units 130, 140, and 150 are omitted.

[0050]

After each press unit moves to the catch position, the falling gob is sandwiched between the first die and the second die by driving the first driving unit and the second driving unit, and the gob is formed into a predetermined thickness while rapidly cooled, thereby preparing a circular glass blank G. The load (pressing pressure) is preferably set 2000 - 3000 kgf. With the load in the range above, short time pressing becomes possible with sufficient acceleration, and therefore glass having suitable thickness for a glass blank for a magnetic disk can be formed regardless of the composition of glass material. Next, after the press unit moves to the retreat position, the first die and the second die are separated to cause the formed glass blank G to fall down. A first conveyer 171, a second conveyer 172, a third conveyer 173, and a fourth conveyer 174 are provided below the retreat positions of the press units 120, 130, 140, and 150, respectively. Each of the first to fourth conveyers 171 to 174 receive the glass blank G falling down from the corresponding press unit, and the conveyer conveys the glass blank G to an apparatus (not illustrated) of the next process.

[0051]

The apparatus 101 is configured such that the press units 120, 130, 140, and 150 sequentially move to the catch position and move to the retreat position while the gob is sandwiched, so that the glass blank G can continuously be formed without waiting for the cooling of the glass blank G in each press unit.

[0052]

FIG. 4 (a) to (c) more specifically illustrates press forming performed by the apparatus 101. FIG. 4 (a) is a view illustrating the state before the gob is made, FIG. 4 (b) is a view illustrating the state in which the gob is made by the cutting unit 160, and FIG. 4 (c) is a view illustrating the state in which the glass blank G is formed by pressing the gob.

[0053]

As illustrated in FIG. 4 (a), a molten glass material L_G continuously flows out from the molten glass outflow port 111. At this point, the cutting unit 160 is driven at predetermined timing to cut the molten glass material L_G using the cutting blades 161 and 162 (FIG. 4 (b)). Therefore, the cut molten glass becomes a substantially spherical gob G_G due to a surface tension thereof. Adjustment of the outflow quantity per time of the molten glass material L_G and the driving interval of the cutting unit 160 may be appropriately performed according to a volume determined by the target size and thickness of the glass blank G.

[0054]

The made gob G_G falls down toward a gap between the first die 121 and second die 122 of the press unit 120. At this point, the first driving unit 123 and the second driving unit 124 (see FIG. 4) are driven such that the first die 121 and the second die 122 come close to each other at the timing the gob G_G enters the gap between the first die 121 and the second die 122. Therefore, as illustrated in FIG. 4 (c), the gob G_G is captured (caught) between the first die 121 and the second die 122. An inner circumferential surface 121a (press forming surface) of the first die 121 and an inner circumferential surface 122a (press forming surface) of the second die 122 come close to each other with a micro gap, and the gob G_G sandwiched between the inner circumferential surface 121a of the first die 121 and the inner circumferential surface 122a of the second die 122 is formed into a thin-plate shape. A projection 121b and a projection 122b are provided in the first inner circumferential surface 121a of the first die 121 and the second inner circumferential surface 122a of the second die 122, respectively, in order to keep the gap between the inner circumferential surface 121a of the first die 121 and the inner circumferential surface 122a of the second die 122 constant. That is, the projection 121b and the projection 122b abut against each other, whereby the gap between the inner circumferential surface 121a of the first die 121 and the inner circumferential surface 122a of the second die 122 is kept constant, so that a plate-shaped space is generated. Here, as illustrated in FIG. 4 (c), heat transferred to central portions of inner circumferential surfaces 121a and 122a from the gob G_G is discharged to outside through the thermally equalizing unit 125 in accordance with a flow of heat illustrated by the arrow in the figure. Press forming is performed using a pair of dies 121 and 122 in the press forming process in press forming in this embodiment, and the outer shape of the glass blank is not restricted by the shape of the die. That is, as illustrated in FIG. 4 (c), the gob stretched by closed dies does not reach projections 121b and 122b.

[0055]

A temperature control mechanism (not illustrated) is provided in each of the first die 121 and second die 122, and temperatures at the first die 121 and second die 122 is retained sufficiently lower than the glass transition point T_g of the molten glass L_G . The temperature control mechanism may be configured as thermally equalizing means.

It is not necessary to attach a mold release material to the first die 121 and the second die 122 in the press forming process.

[0056]

The surface waviness of the glass blank obtained after press forming becomes better as a

difference in temperature between the central portion and the circumferential edge portion of each of the inner circumferential surface 121a of the first die 121 and the inner circumferential surface 122a of the second die 122 (difference in temperature in the press forming surface) at the time of press-forming the gob G_G decreases. Particularly, it is preferable to decrease the difference in temperature by efficiently discharging heat from the gob G_G , which is easily confined in the central portion of each of inner circumferential surfaces 121a and 122a, to outside. This is because when a difference in temperature of each of the interior of the inner circumferential surface 121a of the first die 121 and the interior of the inner circumferential surface 122a of the second die 122 at the time of press forming is decreased, there is no difference in deformation degree of inner circumferential surfaces 121a and 122a between the central portion and the circumferential edge portion in inner circumferential surfaces 121a and 122a, and therefore generation of an uneven heat deformation in inner circumferential surfaces 121a and 122a can be prevented, so that a glass blank having a good surface waviness can be prepared.

Thus, by reducing a difference in temperature within each of inner circumferential surfaces 121a and 122a during pressing of the glass blank using the thermally equalizing unit 125, a surface waviness required for the glass substrate for magnetic disk can be achieved. For example, when the surface waviness required for the glass substrate for magnetic disk is 10 nm, it is preferable to perform press forming while a difference in temperature between the central portion and the circumferential edge portion of each of inner circumferential surfaces 121a and 122a is kept at 1°C or less. The glass blank prepared has the best surface waviness when a difference in temperature between the central portion and the circumferential edge portion is 0°C, but the difference in temperature may be appropriately determined according to the surface waviness required for the glass substrate for magnetic disk.

The difference in temperature of the interior of the inner circumferential surface is a difference in temperature which is the largest of differences in temperature between the central portion and each circumferential edge portion as measured using a thermocouple at a point which is located 1 mm from the front face of inner circumferential surface of the die to the inside of the die and corresponds to each of the central portion and a plurality of circumferential edge portions of the inner circumferential surface (e.g. a point corresponding to the central position of a glass blank having a diameter of 75 mm and upper and lower and left and right four positions on the circumference of a circle centered on the aforementioned point and having a radius of about 30 mm). The temperature is measured at the timing of releasing of the first die 121 and the second die 122

after press forming.

[0057]

A difference in temperature between a pair of dies can be determined from the following viewpoint according to a flatness required for the glass substrate for magnetic disk.

Since glass substrate for magnetic disk of this embodiment is incorporated while being pivotally supported by a metallic spindle having a high thermal expansion coefficient within a hard disk as a magnetic disk that is a final product, the thermal expansion coefficient of the glass substrate for magnetic disk is preferably as high as that of the spindle. Therefore, the composition of the glass substrate for magnetic disk is defined so that the glass substrate for magnetic disk has a high thermal coefficient. The thermal expansion coefficient of the glass substrate for magnetic disk is, for example, in a range of 30 to $100 \times 10^{-7}(\text{K}^{-1})$, preferably in a range of 50 to $100 \times 10^{-7}(\text{K}^{-1})$. The thermal expansion coefficient is a value calculated using the linear expansion coefficients of the glass substrate for magnetic disk at temperatures of 100°C and 300°C . A thermal expansion coefficient of, for example, less than $30 \times 10^{-7}(\text{K}^{-1})$ or more than 100×10^{-7} is not preferable because a difference in thermal expansion coefficient between the glass substrate and the spindle is increased. From the point of view, temperature conditions at the circumference of the principal face of the glass blank are made uniform in the press forming process when a glass substrate for magnetic disk having a high thermal expansion coefficient is prepared. As one example, it is preferable to perform temperature control so that the temperatures of the inner circumferential surface 121a of the first die 121 and the inner circumferential surface 122a of the second die 122 become substantially identical. When temperature control is performed so that the temperatures become identical, for example, a difference in temperature is preferably 5°C or less. The difference in temperature is more preferably 3°C or less, especially preferably 1°C or less.

The difference in temperature between dies is a difference in temperature as measured using a thermocouple at a point which is located 1 mm from each of the front faces of the inner circumferential surface 121a of the first die 121 and the inner circumferential surface 122a of the second die 122 to the inside of the die and at which the inner circumferential surface 121a and the inner circumferential surface 122a face each other (e.g. a point corresponding to the central position of the glass blank and central points of the inner circumferential surface 121a and the inner circumferential surface 122a).

[0058]

A time until the gob G_G is completely confined between the first die 121 and the second die

122 after the gob G_G comes into contact with the inner circumferential surface 121a of the first die 121 or the inner circumferential surface 122a of the second die 122, is as extremely short as 0.1 second or less (about 0.06 second) in the apparatus 101. Therefore, the gob G_G is formed into the substantially disk shape by spreading along the inner circumferential surface 121a of the first die 121 and the inner circumferential surface 122a of the second die 122 within an extremely short time, and the gob G_G is rapidly cooled and solidified in the form of amorphous glass. In this way, the glass blank G is prepared. The size of the glass blank G formed in this embodiment is, depending on the size of a desired glass substrate for magnetic disk, for example about 20 to 200 mm in diameter.

[0059]

In the press forming method of this embodiment, the glass blank G is formed in a manner such that the inner circumferential surface 121a of the first die 121 and the inner circumferential surface 122a of the second die 122 are shape-transferred, and therefore preferably the flatness and the smoothness of each of the inner circumferential surfaces of a pair of dies are made comparable to those of a desired glass substrate for magnetic disk. In this case, necessity to subject the glass blank G to a surface processing process, i.e. a grinding and polishing process after press forming may be eliminated. That is, the glass blank G formed in the press forming method of this embodiment may have a thickness identical to the target thickness of the glass substrate for magnetic disk that is finally obtained. For example, the glass blank G is a disk-shaped sheet having a thickness of 0.2 to 1.1 mm. The surface roughness of each of the inner circumferential surface 121a and the inner circumferential surface 122a is substantially uniform throughout the surface, and preferably adjusted to 0.0005 to 0.05 μm so that the arithmetic mean roughness R_a of the glass blank G is 0.001 to 0.1 μm . The surface roughness of the glass blank G is uniform throughout the surface because surface properties of the inner circumferential surface 121a and the inner circumferential surface 122a are shape-transferred to the glass blank G.

If the surface roughness differs throughout the surface of the die, a place of changing the roughness may prevent glass from uniformly drawing in pressing, which causes a defect such as a linear scar.

[0060]

After the first die 121 and the second die 122 are closed, the press unit 120 quickly moves to the retreat position, instead the press unit 130 moves to the catch position, and the press unit 130 performs the pressing to the gob G_G .

[0061]

After the press unit 120 moves to the retreat position, the first die 121 and the second die 122 are kept closed until the glass blank G is sufficiently cooled (at least until the glass blank G has a temperature below a yield point). Then, the first driving unit 123 and the second driving unit 124 are driven to separate the first die 121 and the second die 122, the glass blank G falls down from the press unit 120, and the conveyer 171 located below the press unit 120 receives the glass blank G (see FIG. 3).

[0062]

In the example illustrated in FIG. 4, the substantially spherical gob G_G is formed by cutting the flowing-out molten glass L_G using the cutting blades 161 and 162. However, when viscosity of the molten glass material L_G is small with respect to a volume of the gob G_G to be cut, the glass does not become the substantially spherical shape only by cutting the molten glass L_G , and the gob is not formed. In such cases, a gob forming die is used to form the gob.

[0063]

FIG. 5 (a) to (c) are views illustrating a modification of the embodiment of FIG. 4. The gob forming die is used in the modification. FIG. 5 (a) is a view illustrating the state before the gob is made, FIG. 5 (b) is a view illustrating the state in which the gob G_G is made by the cutting unit 160 and a gob forming die 180, and FIG. 5 (c) is a view illustrating the state in which the press forming is performed to the gob G_G to make the glass blank G.

As illustrated in FIG. 5 (a), the path of the molten glass L_G to the press unit 120 is closed by closing the blocks 181 and 182, and the lump of the molten glass L_G cut with the cutting unit 160 is received by a recess 180C formed by the block 181 and 182. Then, as illustrated in FIG. 5 (b), the molten glass L_G that becomes the spherical shape in the recess 180C falls down toward the press unit 120 at one time by opening the blocks 181 and 182. When falling down toward the press unit 120, the gob G_G becomes the spherical shape by the surface tension of the molten glass L_G . As illustrated in FIG. 5 (c), during the fall of the gob G_G , the spherical gob G_G is sandwiched between the first die 121 and the second die 122 to perform the press forming, thereby preparing the disk-shaped glass blank G.

[0064]

Alternatively, as illustrated in FIG. 6 (a) to (d), in the apparatus 101, instead of using the cutting unit 160 illustrated in FIG. 5 (a) to (c), a moving mechanism that moves the gob forming die 180 in an upstream direction or a downstream direction along the path of the molten glass L_G may

be used. FIG. 6 (a) to (d) are views illustrating a modification in which the gob forming die 180 is used. FIG. 6 (a) and (b) are views illustrating the state before the gob G_G is made, FIG. 6 (c) is a view illustrating the state in which the gob G_G is made by the gob forming die 180, and FIG. 6 (d) is a view illustrating the state in which the gob G_G is subjected to press forming to make the glass blank G.

As illustrated in FIG. 6 (a), the recess 180C formed by the block 181 and 182 receives the molten glass L_G flowing out from the molten glass outflow port 111. As illustrated in FIG. 6 (b), the blocks 181 and 182 are quickly moved onto the downstream side of the flow of the molten glass L_G at predetermined timing. In this way, the molten glass L_G is cut. Then, as illustrated in FIG. 6 (c), the blocks 181 and 182 are separated at predetermined timing. Therefore, the molten glass L_G retained by the blocks 181 and 182 falls down at one time, and the gob G_G becomes the spherical shape by the surface tension of the molten glass L_G . As illustrated in FIG. 6 (d), during the fall of the gob G_G , the spherical gob G_G is sandwiched between the first die 121 and the second die 122 to perform the press forming, thereby preparing the disk-shaped glass blank G.

[0065]

FIG. 7 (a) to (c) are views illustrating another modification in which, instead of the gob G_G , a lump C_P of the optical glass heated by a softening furnace (not illustrated) is caused to fall down and the press forming is performed to the lump C_P while the lump C_P is sandwiched from both sides between dies 221 and 222 during the fall of the lump C_P . FIG. 7 (a) is a view illustrating the state before the lump of the heated optical glass is formed, FIG. 7 (b) is a view illustrating the state in which the lump of the optical glass falls down, and FIG. 7 (c) is a view illustrating the state in which the press forming is performed to the lump of the optical glass to make the glass blank G.

As illustrated in FIG. 7 (a), in an apparatus 201, a glass material grasping mechanism 212 conveys the lump C_P of the optical glass to a position above a press unit 220. As illustrated in FIG. 7 (b), the glass material grasping mechanism 212 releases the lump C_P of the optical glass to cause the lump C_P of the optical glass to fall down. As illustrated in FIG. 7 (c), during the fall of the lump C_P of the optical glass, the lump C_P is sandwiched between the first die 221 and the second die 222 to perform the press forming, thereby preparing the disk-shaped glass blank G. Because the first die 221 and the second die 222 have the same configuration and action as those of the first die 121 and second die 122 illustrated in FIG. 5, the descriptions are omitted.

[0066]

FIG. 8 (a) to (c) are views illustrating a modification of the embodiment of FIG. 4. In this

modification, various forms of thermally equalizing units 125 are used. FIG. 8 (a) is a view illustrating a state in which a second thermally equalizing unit 126 each having a thermal expansion coefficient higher than that of the thermally equalizing unit 125 is provided between thermally equalizing units 125 provided at the circumferential edge portions of surfaces opposite to the inner circumferential surface 121a of the first die 121 and the inner circumferential surface 122a of the second die 122, respectively. FIG. 8 (b) is a view illustrating a state in which thermally equalizing units 125 are provided only at the central portions of the surfaces opposite to the inner circumferential surface 121a of the first die 121 and the inner circumferential surface 122a of the second die 122. FIG. 8 (c) is a view illustrating a state in which recessed portions extending toward the central portions of the surfaces opposite to the inner circumferential surface 121a of the first die 121 and the inner circumferential surface 122a of the second die 122 are provided in thermally equalizing units 125.

Examples are illustrated in FIG. 8 (a) to (c) in which molten glass is pressed in the substantially center of each of the inner circumferential surface 121a and the inner circumferential surface 122a. In the case where the position of the molten glass in the middle of pressing is shifted from the central portion of each inner circumferential surface, set positions of the thermally equalizing portion 125 in FIG. 8 (b) and the recessed portion in FIG. 8 (c) may be adjusted depending on the shift level.

As illustrated in FIG. 8 (a), the second thermally equalizing unit 126 is provided at the central portion of each of the surfaces opposite to the circumferential surface 121a of the first die 121 and the inner circumferential surface 122a of the second die 122. For example, when the thermally equalizing unit 125 is made of aluminum or an aluminum alloy, copper, a copper alloy or the like is used as a material of the second thermally equalizing unit 126. By using the second thermally equalizing unit 126, heat confined in the central portions of inner circumferential surfaces 121a and 122a during press forming is discharged to outside through the second thermally equalizing unit 126 having heat conduction efficiency higher than that of the thermally equalizing unit 125. Heat transferred to the circumferential edge portions of inner circumferential surfaces 121a and 122a from the gob G_G is discharged to outside through the thermally equalizing unit 125. In this way, a difference in temperature of the interior the inner circumferential surface during press forming can be reduced.

When temperature thermally equalizing units 125 are provided only at the central portions of the surfaces opposite to inner circumferential surfaces 121a and 122a as illustrated in FIG. 8 (b),

heat confined in the central portions of inner circumferential surfaces 121a and 122a during press forming is discharged to outside through the thermally equalizing unit 125. In this way, a difference in temperature of the interior of each of inner circumferential surfaces 121a and 122a during press forming can be reduced. The second thermally equalizing unit 126 may be provided in place of the thermally equalizing unit 125.

Further, when a recessed portion extending toward the central portion of the surface opposite to each of inner circumferential surfaces 121a and 122a is provided in the thermally equalizing unit 125 as illustrated in FIG. 8 (c), the recessed portion may be cooled using, for example, a liquid, a gas and/or the like having a cooling effect. In this case, the central portions of inner circumferential surfaces 121a and 122a are rapidly cooled, whereby a difference in temperature of the interior of the inner circumferential surface during press forming can be reduced. The thermally equalizing unit 125 may be formed so that the central portion of the surface opposite to each of inner circumferential surfaces 121a and 122a can be directly cooled using, for example, a liquid, a gas or the like having a cooling effect.

As illustrated in FIG. 8 (d), a plurality of thermally equalizing units 125 may be provided on the rear surface of each of first and second dies 121 and 122. The plurality of thermally equalizing units 125 may be heat sinks. In this case, as compared to the case where one thermally equalizing unit 125 is provided, the contact area of the thermally equalizing unit to outside can be increased, and therefore heat transferred to inner circumferential surfaces 121a and 122a from the gob G_G can be efficiently discharged to outside.

[0067]

(b) Scribing Process (Step S20)

Next, the scribing process will be described. After the press forming process, the formed glass blank G is subjected to scribing in the scribing process.

As used herein, the scribing means that two concentric (inside concentric and outside concentric) cutting lines (linear scratches) are provided in the surface of the glass blank G with a scriber made of a super alloy or diamond particles in order to obtain the donut-shape (ring-shape) of the formed glass blank G having a predetermined size. The glass blank G scribed into two-concentric-circle shape is partially heated, and a portion outside the outside concentric circle and a portion inside the inside concentric circle are removed by a difference in thermal expansion of the glass blank G. In this way, a donut-shaped glass substrate is obtained.

A donut-shaped glass substrate can also be obtained by forming a circular hole in the glass

blank using a core drill or the like.

[0068]

(c) Shape Processing Process (Step S30)

Next, the shape processing process will be described. The shape processing process includes chamfering processing of the end portion of the glass substrate (chamfering of outer circumferential end portion and inner circumferential end portion) after the scribing process. Chamfering processing is shape processing in which the outer circumferential end portion and inner circumferential end portion of the glass substrate after the scribing process is chamfered between a principal face and a side wall portion perpendicular to the principal face using a diamond abrasive grain. The chamfering angle is, for example, 40 to 50 degrees with respect to the principal face.

[0069]

(d) Grinding Process using Fixed Abrasive Grain (Step S40)

In the grinding process using a fixed abrasive grain, the principal face of the glass substrate after the shape processing process is subjected to grinding processing (machining) using a double faces grinding apparatus including a planet gear mechanism. For example, the grinding has the machining allowance of several micrometers to about 100 micrometers (Total machining allowance of both principal faces; the same applies hereinafter.) The double faces grinding apparatus includes a pair of upper and lower surface plates (upper surface plate and lower surface plate), and a glass substrate is held between the upper surface plate and the lower surface plate. By moving one or both of the upper surface plate and the lower surface plate, the glass substrate and each surface plate are relatively moved, whereby both principal faces of the glass substrate can be ground.

In the press forming process of this embodiment, a glass blank having an extremely high flatness can be prepared, and therefore the grinding process may be omitted. Before the grinding process, a lapping process may be performed using a double faces grinding apparatus similar to the apparatus used in the grinding process and an alumina loose abrasive grain.

[0070]

(e) Edge Polishing Process (Step S50)

Next, edge polishing of the glass substrate after the grinding process is performed.

In edge polishing, the inner circumferential end face and outer circumferential end face of the glass substrate are subjected to mirror surface finishing by brush polishing. At this point, slurry that includes fine particles such as cerium oxide as the loose abrasive grain is used. By performing edge polishing, an impairment such as contamination by deposition of dust or the like,

damage or a flaw is eliminated, whereby occurrence of a thermal asperity and deposition of ions of sodium, potassium and the like which may cause corrosion can be prevented.

[0071]

(f) First Polishing Process (Step S60)

Next, the principal face of the glass substrate after the edge polishing process is subjected to first polishing. For example, first polishing has the machining allowance of several micrometers to about 50 micrometers. First polishing is intended to remove the flaw left on the principal face after the grinding using the fixed abrasive grain, the deformation and the micro-surface irregularity (micro-waviness and roughness). In the first polishing process, polishing is performed while a polishing solution is fed using a double polishing apparatus having a structure similar to that of the apparatus used in the grinding process. A polishing agent contained in the polishing solution is, for example, a cerium oxide abrasive grain or a zirconia abrasive grain.

[0072]

In the first polishing process, polishing is performed so as to have a surface roughness (Ra) of 0.5 nm or less and a micro-waviness (MV-Rq) of 0.5 nm or less for the principal face of the glass substrate. The micro-waviness may be represented by a RMS (Rq) value calculated as a roughness at a wavelength bandwidth of 100 to 500 μm in a region of 14.0 to 31.5 mm radius in the whole of the principal face, and can be measured using, for example, Model-4224 manufactured by Polytec Inc.

The surface roughness is represented by an arithmetic mean roughness Ra defined in JIS B0601:2001 and, for example, can be measured with a roughness measuring machine SV-3100 manufactured by Mitutoyo Corporation and calculated by a method defined in JIS B0633:2001 when the roughness is no less than 0.006 μm and no more than 200 μm . When as a result, the roughness is 0.03 μm or less, for example, the roughness can be measured with a scanning probe microscope (atomic force microscope) nanoscope manufactured by Veeco Instruments Inc. and can be calculated by a method defined in JIS R1683:2007. In the present application, an arithmetic mean roughness Ra as measured in a resolution of 512×512 pixels in a measurement area of $1 \mu\text{m} \times 1 \mu\text{m}$ square can be used.

[0073]

(g) Chemically Strengthening Process (Step S70)

Next, the glass substrate after the first polishing process is chemically strengthened.

For example, a mixed solution of potassium nitride (60% by weight) and sodium sulfate

(40% by weight) can be used as a chemically strengthening solution. In the chemically strengthening process, a chemically strengthening solution is heated to, for example, 300°C to 400°C, a washed glass substrate is preheated to, for example, 200°C to 300°C, and the glass substrate is then dipped in the chemically strengthening solution for, for example, 3 to 4 hours.

When the glass substrate is dipped in the chemically strengthening solution, the lithium ion and the sodium ion in the surface layer of the glass substrate are replaced, respectively, with the sodium ion and the potassium ion which have relatively large ion radiuses in the chemically strengthening solution, so that a compressive stress layer is formed on the surface layer portion, thereby strengthening the glass substrate. The glass substrate subjected to the chemically strengthening treatment is washed. For example, the glass substrate is washed with sulfuric acid, and then washed with pure water or the like.

[0074]

(h) Second Polishing Process (Step S80)

Next, the glass substrate after chemically strengthening process is subjected to second polishing. Second polishing has the machining allowance of about 1 μm . Specifically, the machining allowance in the range of 0.5 - 2 μm is preferred. If the machining allowance is lower than the range, the surface roughness may not be decreased sufficiently. On the other hand, if the machining allowance is higher than the range, the deterioration (such as roll-off) of the edge shape may be caused. Second polishing is intended at the mirror surface polishing of the principal face. In second polishing, for example, the polishing apparatus used in first polishing is used. At this point, the second polishing differs from the first polishing in the following points: the kind and particle size of the loose abrasive grain, and hardness of the resin polisher.

For example, the slurry of the turbid fine particles such as colloidal silica (particle size: diameter of about 10 to 50 nm) is used as the loose abrasive grain used in the second polishing.

The polished glass substrate is washed with a neutral detergent, pore water, IPA or the like to obtain a glass substrate for magnetic disk.

It is not necessarily essential to perform the second polishing process, but it is preferable to perform the second polishing process because the level of the surface irregularity of the principal face of the glass substrate can be further improved. By performing the second polishing process, the principal face can be made to have a roughness (Ra) of 0.2 nm or less, more preferably 0.1 nm or less and a micro-waviness (MW-Rq) of 0.3 nm or less, more preferably 0.1 nm or less.

[0075]

As described above, the method for manufacturing a glass blank for magnetic disk in this embodiment includes a press forming process of press-forming a lump of molten glass using a pair of dies. Therefore, when the surface roughness of the inner circumferential surfaces of a pair of dies is set at a good level (e.g. surface roughness required for the glass substrate for magnetic disk), the surface roughness of the glass blank can be kept at a good level because the surface roughness of the inner circumferential surface of the die is shape-transferred as the surface roughness of the glass blank. In the press forming step, press forming may be performed using thermally equalizing means for reducing a difference in temperature in the press forming surface of the die during pressing of the molten glass. Therefore, the glass blank obtained in the press forming process of this embodiment does not require a process of machining the principal face because the flatness and surface waviness of the principal face of the glass blank can be kept at a level required for the glass substrate for magnetic disk. The glass substrate shape-processed into a predetermined shape based on the glass blank is subjected to chemically strengthening, but the flatness of the glass substrate is not deteriorated by chemically strengthening in this embodiment. Therefore, the glass substrate for magnetic disk which is finally obtained is thin, and has a high mechanical strength, and a flatness and surface waviness better than was previously possible.

[0076]

[Magnetic disk]

The glass substrate for magnetic disk is prepared through the processes described above. A magnetic disk is obtained in the following manner using the above-described glass substrate for magnetic disk.

The magnetic disk has, for example, a configuration in which on the principal face of the glass substrate, at least an adhesive layer, an underlying layer, a magnetic layer (magnetic recording layer), a protective layer and a lubricant layer are stacked in this order from the side closest to the principal face.

For example, the substrate is introduced into an evacuated deposition apparatus, and the adhesive layer, the underlying layer and the magnetic layer are sequentially deposited in an Ar atmosphere by a DC magnetron sputtering method. For example CrTi may be used as the adhesive layer, and for example CrRu may be used as the underlying layer. For example a CoPt-based alloy may be used as the magnetic layer. Also, a CoPt-based alloy or FePt-based alloy having a L_{10} ordered structure may be deposited to form a magnetic layer for heat assisted magnetic recording. After the deposition described above, the protective layer is deposited using C_2H_4 by, for example, a

CVD method, and subsequently nitriding treatment is performed to introduce nitrogen to the surface, whereby a magnetic recording medium can be formed. Thereafter, the lubricant layer can be formed by applying, for example, PFPE (perfluoropolyether) onto the protective layer by a dip coating method.

[0077]

<Second Embodiment>

A method for manufacturing a glass blank for magnetic disk and a method for manufacturing a glass substrate for magnetic disk according to this embodiment will be described in detail below. The glass substrate for magnetic disk in this embodiment is the same as the glass substrate for magnetic disk in the first embodiment. In the below description, only different parts from the method for manufacturing a glass blank for magnetic disk and the method for manufacturing a glass substrate for magnetic disk in the first embodiment are explained, and the other repeated explanation may be omitted. In this embodiment, a member 125 indicated as “a thermally equalizing unit” in the first embodiment is indicated as “a temperature controlling unit” for the sake of convenience.

[0078]

In the glass substrate of this embodiment, amorphous aluminosilicate glass can be also preferably used as described in the first embodiment.

[0079]

In this embodiment, molten glass is press-formed with a press unit 120 provided with a temperature controlling unit 125 having the same configuration as the thermally equalizing unit 125 in the first embodiment. The press unit 120 has the same configuration as in the first embodiment except for indicating a thermally equalizing unit 125 in the first embodiment as a temperature controlling unit 125. In this embodiment, the temperature controlling unit 125 is one example of temperature controlling means for reducing a difference in temperature within the press forming surface of the die. Like the thermally equalizing unit 125, the temperature controlling unit 125 may be formed of copper, a copper alloy, aluminum, an aluminum alloy or the like, and may be formed of silver, extra super duralumin or the like.

[0080]

Press forming in this embodiment will be described below with reference again to FIG. 4 (a) to (c) which are described above.

[0081]

As illustrated in FIG. 4 (a), a molten glass material L_G continuously flows out from the molten glass outflow port 111. At this point, the cutting unit 160 is driven at predetermined timing to cut the molten glass material L_G using the cutting blades 161 and 162 (FIG. 4 (b)). Therefore, the cut molten glass becomes a substantially spherical gob G_G due to a surface tension thereof. Adjustment of the outflow quantity per time of the molten glass material L_G and the driving interval of the cutting unit 160 may be appropriately performed according to a volume determined by the target size and thickness of the glass blank G.

[0082]

The made gob G_G falls down toward a gap between the first die 121 and second die 122 of the press unit 120. At this point, the first driving unit 123 and the second driving unit 124 (see FIG. 4) are driven such that the first die 121 and the second die 122 come close to each other at the timing the gob G_G enters the gap between the first die 121 and the second die 122. Therefore, as illustrated in FIG. 4 (c), the gob G_G is captured (caught) between the first die 121 and the second die 122. An inner circumferential surface 121a (press forming surface) of the first die 121 and an inner circumferential surface 122a (press forming surface) of the second die 122 come close to each other with a micro gap, and the gob G_G sandwiched between the inner circumferential surface 121a of the first die 121 and the inner circumferential surface 122a of the second die 122 is formed into a thin-plate shape. A projection 121b and a projection 122b are provided in the first inner circumferential surface 121a of the first die 121 and the second inner circumferential surface 122a of the second die 122, respectively, in order to keep the gap between the inner circumferential surface 121a of the first die 121 and the inner circumferential surface 122a of the second die 122 constant. That is, the projection 121b and the projection 122b abut against each other, whereby the gap between the inner circumferential surface 121a of the first die 121 and the inner circumferential surface 122a of the second die 122 is kept constant, so that a plate-shaped space is generated.

Press forming is performed using a pair of dies 121 and 122 in the press forming process in press forming in this embodiment, and the outer shape of the glass blank is not restricted by the shape of the die. That is, as illustrated in FIG. 4 (c), the gob stretched by closed dies does not reach projections 121b and 122b.

As illustrated in FIG. 4 (c), heat transferred to central portions of inner circumferential surfaces 121a and 122a from the gob G_G is discharged to outside through the temperature controlling unit 125 in accordance with a flow of heat illustrated by the arrow in the figure.

[0083]

A temperature control mechanism (not illustrated) is provided in each of the first die 121 and second die 122, and temperatures at the first die 121 and second die 122 is retained lower than the glass transition point T_G of the molten glass L_G . The temperature control mechanism controls the cooling rate of the gob G_G sandwiched between the inner circumferential surface 121a of the first die 121 and the inner circumferential surface 122a of the second die 122 so that a difference in temperature on a surface of the gob G_G (e.g. between the circumferential edge portion and the central portion of the surface of the gob G_G) is reduced. In the control, the cooling rate of the gob G_G is increased or reduced. Therefore, the temperature control mechanism may have a cooling mechanism including, for example, a path of a liquid, a gas or the like having a cooling effect, or a heating mechanism such as a heater. The temperature controlling unit 125 may be configured as the temperature control mechanism. Since the cooling rate of the gob G_G is controlled, necessity of the annealing treatment of the glass blank can be eliminated. For example, generation of the in-plane strain can be prevented by lowering the cooling rate. The reasons for this are as follows. In short, heat conductivity of glass is generally lower than that of metal, so that the heat is difficult to transfer internally in glass. When transfer speed of heat of glass to the dies is lowered, time for transferring the heat uniformly internally in the glass can be spared, and thus difference in temperature in the interior of the glass becomes small, so that the deformation cannot occur easily. One example of control of the cooling rate of the gob G_G will be described later.

Further, it is not necessary to attach a mold release material to the first die 121 and the second die 122 in the press forming process, since the press forming can be finished in an extremely short time, and the wide surface of the dies can cool the glass quickly such that the die is not over heated, and therefore the glass and the die are not fused to each other..

[0084]

It is preferable that the temperature of the inner circumferential surface of the die at the time of press-forming the gob G_G is substantially uniform because the glass blank obtained after press forming has a good flatness. Particularly, it is preferable to decrease a difference in temperature of the inner circumferential surface (press forming surface) by efficiently discharging heat from the gob G_G , which is easily confined in the central portion of each of inner circumferential surfaces 121a and 122a, to outside. This is because when a difference in temperature of the inner circumferential surface of the die during press forming is decreased, the temperature of the central portion and the temperature of the circumferential edge portion of the inner circumferential surface are almost identical, so that the central portion and the circumferential

edge portion of the gob G_G can be solidified almost at the same time.

Since the temperature of the central portion and the temperature of the circumferential edge portion of the inner circumferential surface are almost identical, an internal strain (in-plane strain) by a compressive stress directing from the circumferential edge portion to the central portion of the press forming surface can be prevented from being generated in the press-formed glass blank.

Thus, by reducing a difference in temperature of the inner circumferential surface of the die during pressing of the glass blank using the temperature controlling unit 125, flatness required for the glass substrate for magnetic disk can be achieved, and the central portion and the circumferential edge portion of the gob G_G can be solidified at the same time, thereby preventing in-plane strain. For example, if the flatness required for the glass substrate for magnetic disk is 4 μm , press forming is performed while the temperature of the inner circumferential surface is kept substantially uniform, e.g. a difference in temperature between the central portion and the circumferential edge portion is kept at 10°C or less. Generation of the in-plane strain of the glass blank is best prevented when a difference in temperature between the central portion and the circumferential edge portion is 0°C, but the difference in temperature may be appropriately determined according to the size of the glass blank G formed, the composition of the glass, and so on.

The difference in temperature of the inner circumferential surface is a difference in temperature which is the largest of differences in temperature between the central portion and each circumferential edge portion as measured using a thermocouple at a point which is located 1 mm from the front face of inner circumferential surface of the die to the inside of the die and corresponds to each of the central portion and a plurality of circumferential edge portions of the inner circumferential surface (e.g. a point corresponding to the central position of a glass blank having a diameter of 75 mm and upper and lower and left and right four positions on the circumference of a circle centered on the aforementioned point and having a radius of about 30 mm).

In this embodiment, the central portion and the circumferential edge portion of the surface of the gob G_G can be solidified almost at the same time because press forming is performed while the cooling rate of the molten glass is controlled so that a difference in temperature on the surface of the gob G_G is reduced. Therefore, it is not necessary to provide the temperature controlling unit 125.

[0085]

The same configurations as illustrated in FIG. 5 to FIG. 8 may be also applied to the present embodiment.

[0086]

Next, control of the cooling rate of the gob G_G will be described with reference to FIG. 9. FIG. 9 is a view illustrating a time course of the temperature of a gob in press forming of the embodiment. If the cooling rate of the gob G_G sandwiched between the inner circumferential surface 121a of the first die 121 and the inner circumferential surface 122a of the second die 122 is too high, a difference in temperature is generated on the surface of the gob G_G . This is because the following reasons. In short, heat conductivity of glass is generally lower than that of metal, and thus heat is difficult to transfer internally in glass. Further, when transfer speed of heat of glass to the dies is made too high, time for transferring the heat uniformly internally in the glass cannot be spared. At this time, shrinkage associated with cooling precedes at the circumferential edge portion of the surface of the gob G_G , and therefore an internal strain (in-plane strain) by a residual stress extending from the circumferential edge portion toward the central portion of the surface of the gob G_G is generated in the glass blank formed by press forming of the gob G_G . Thus, in this embodiment, the cooling rate is controlled by the temperature control mechanism in the period during which the temperature of the gob G_G during press forming falls from a glass transition point (T_g) to a strain point. In the example illustrated in FIG. 9, when a glass blank having a diameter of 75 mm and a thickness of 0.9 mm is manufactured, the cooling rate of the gob G_G is controlled to a moderate cooling rate of about -8 to -2°C in the period during which the temperature of the gob G_G falls from the glass transition point (T_g) to the strain point. In this case, a difference in temperature on the surface of the gob G_G is reduced, so that the size of the strain generated in the glass blank can be decreased.

The temperature of the gob G_G may be measured using a thermocouple at a point which is located 1 mm from each of the front faces of the inner circumferential surface 121a of the first die 121 and the inner circumferential surface 122a of the second die 122 to the inside of the die and at which the inner circumferential surface 121a and the inner circumferential surface 122a face each other (e.g. a point corresponding to the central position of the glass blank and central points of the inner circumferential surface 121a and the inner circumferential surface 122a).

The time course of the temperature of the gob illustrated in FIG. 9 is intended for explaining one example of control of the cooling rate of the gob G_G , and the cooling rate of the gob G_G may be appropriately controlled according to the composition of the glass and the size of the

glass blank formed.

[0087]

In this way, press forming is performed while the cooling rate of the molten glass is controlled so that a difference in temperature on the surface of the gob G_G during pressing of the molten glass is reduced. Then, the molten glass can be solidified without generating an in-plane strain. Therefore, the annealing treatment for releasing the internal strain generated in the glass blank can be omitted.

Processes after the scribing process may be the same as in the first embodiment.

[0088]

As described above, the method for manufacturing a glass blank for magnetic disk and a glass substrate for magnetic disk in this embodiment includes a press forming process of press-forming a lump of molten glass using a pair of dies. Therefore, when the surface roughness of the inner circumferential surfaces of a pair of dies is set at a good level (e.g. surface roughness required for the glass substrate for magnetic disk), the surface roughness of the glass blank can be kept at a good level because the surface roughness of the inner circumferential surface of the die is shape-transferred as the surface roughness of the glass blank. In the press forming process, press forming may be performed while the cooling rate of the molten glass is controlled. Here, it is even better to control such that difference in temperature on the surface of the molten glass is reduced. Therefore, the glass blank obtained in the press forming process of this embodiment can be manufactured without necessity of a process of machining the principal face because the surface roughness and flatness of the principal face of the glass blank can be kept at a level required for the glass substrate for magnetic disk. The glass substrate shape-processed into a predetermined shape based on the glass blank is subjected to chemically strengthening, but the flatness of the glass substrate is not deteriorated by chemically strengthening in this embodiment. Therefore, the glass substrate for magnetic disk which is finally obtained is thin, and has a high mechanical strength, and flatness higher than was previously possible.

In this embodiment, the molten glass can be solidified without causing an in-plane strain by controlling the cooling rate of the molten glass so that a difference in temperature on the surface of the molten glass. Accordingly, in this embodiment, a glass blank for magnetic disk and a glass substrate for magnetic disk, the internal strain of which is reduced, can be manufactured without performing annealing treatment.

[Examples]

[0089]

The present invention will be further described below by way of Examples. However, the present invention is not limited to aspects described in Examples.

[0090]

<First Example>

- Preparation of Molten Glass

Raw materials were weighed so as to obtain a glass having the following composition, and mixed to obtain a mixed raw material. This raw material was put in a melting vessel, heated, melted, clarified and stirred to prepare a homogeneous molten glass free from foam and an unmelted substance. Foam and an unmelted substance, deposition of crystals, and contaminants such as a refractory material and platinum forming the melting vessel were not observed in the glass obtained.

[Composition of glass]

Amorphous aluminosilicate glass having a composition including 50 to 75% of SiO_2 , 1 to 15% of Al_2O_3 , 5 to 35% in total of at least one component selected from Li_2O , Na_2O and K_2O , 0 to 20% in total of at least one component selected from MgO , CaO , SrO , BaO and ZnO and 0 to 10% in total of at least one component selected from ZrO_2 , TiO_2 , La_2O_3 , Y_2O_3 , Ta_2O_5 , Nb_2O_5 and HfO_2 in an oxide-based conversion indicated in mol%.

[0091]

The above-described molten glass was provided, and a glass blank having a diameter of 75 mm and a thickness of 0.9 mm was prepared using a press forming method of the present invention (method using the apparatus in FIGS. 3 and 4). The temperature of a molten glass material L_G discharged from a molten glass outflow port 111 is 1300°C , and the viscosity of the molten glass material L_G at this time is 700 poises. The surface roughness (arithmetic mean roughness R_a) of the inner circumferential surfaces of a first die and a second die throughout the surface was $0.01\text{ }\mu\text{m}$ to $1\text{ }\mu\text{m}$, specifically $0.1\text{ }\mu\text{m}$. Further, the first die and the second die are formed of an ultrahard alloy (e.g. VM40). Copper was used as a thermally equalizing unit.

The molten glass material L_G discharged from a molten glass outflow port 111 is cut by a cutting unit 160, so that a gob G_G having a thickness of about 20 mm is formed. The gob G_G was pressed under a load of 3000 kgf by a press unit until the gob G_G had a temperature equal to or lower than the glass transition point (T_g) of the molten glass material (about 3 seconds), so that a glass blank having a diameter of 75 mm was formed.

The difference in temperature in the inner circumferential surface of the die during pressing is a difference in temperature which is the largest of differences in temperature between the central portion and each circumferential edge portion as measured using a thermocouple at a point which is located 1 mm from the front face of inner circumferential surface of the die to the inside of the die and corresponds to each of the central portion and a plurality of circumferential edge portions of the inner circumferential surface (specifically, a point corresponding to the central position of a glass blank having a diameter of 75 mm and upper and lower and left and right four positions on the circumference of a circle centered on the aforementioned point and having a radius of about 30 mm). In Example, the difference in temperature which was the largest of differences in temperature between the central portion and circumferential edge portions was determined as a difference in temperature between the central portion and the circumferential edge portion in the inner circumferential surface of the die.

In this Example, when a flatness required for the glass substrate for magnetic disk was 4 μm , a difference in temperature between the first die and the second die was set at 10°C in each press unit for achieving this flatness. Specifically, the temperature of the first die was set at 420°C, and the temperature of the second die was set at 411 to 429°C.

[0092]

[Evaluation of glass blank prepared in Example]

For the plate-shaped glass blank having a diameter of about 75 mm, which had been prepared in Example, the flatness and the surface roughness (arithmetic mean roughness Ra) were measured.

Here, the surface waviness was defined as a PV value (Peak - Valley value: maximum elevation difference) when the principal surface (entire surface) of the glass blank was measured in a component having wavelength of 5 mm or less in surface property. The surface waviness can be measured using, for example, OPTIFLAT manufactured by Phase Shift Technology, Inc., which is a white light interference microscope-type surface shape measuring apparatus. It should be noted that data of the surface waviness which cannot be correctly measured due to low reflection rate of light such as a part vicinity of the edge portion needs to be eliminated. In such a case, the measurement area may be a circle of 65 mm in diameter, for example. The surface waviness may also be calculated by cutting a waviness having a wavelength longer than 5 mm with the cutoff value set at 5 mm using a different measuring apparatus. Evaluation criteria for the surface waviness illustrated in Table 1 are as follows.

If the surface waviness of the glass blank is more than 30 nm in the following criteria, it is necessary to reduce the surface waviness to 30 nm or less by performing a grinding process. A glass blank having a surface waviness of more than 10 nm and no more than 30 nm is preferable because the grinding process can be omitted, but the glass blank is inferior in productivity to a glass blank having a surface waviness of 10 nm or less because the machining allowance in a polishing process should be increased for stabilization of quality. A glass blank having a surface waviness of 10 nm or less is most preferable because the grinding process can be omitted, and also the machining allowance in the polishing process can be decreased.

Very good: Surface waviness is no more than 10 nm.

Good: Surface waviness is more than 10 nm and no more than 30 nm.

Poor: Surface waviness is more than 30 nm.

[0093]

The surface roughness is represented by an arithmetic mean roughness Ra defined in JIS B0601:2001 and, for example, can be measured with a roughness measuring machine SV-3100 manufactured by Mitutoyo Corporation and calculated by a method defined in JIS B0633:2001 when the roughness is no less than 0.006 μm and no more than 200 μm . When as a result, the roughness is 0.03 μm or less, for example, the roughness can be measured with a scanning probe microscope (atomic force microscope) nanoscope manufactured by Veeco Instruments Inc. and can be calculated by a method defined in JIS R1683:2007. In the present application, an arithmetic mean roughness Ra as measured in a resolution of 256×256 pixels in a measurement area of $10 \mu\text{m} \times 10 \mu\text{m}$ square was used. As a result, the surface roughness of the glass blank was 0.5 μm or less in all examples. This is because regardless of the temperature of the die, the inner circumferential surfaces of the first die and the second die are shape-transferred to the glass blank, so that the surface roughness of the glass blank is comparable to the surface roughness of the inner circumferential surfaces of the first die and the second die. When the arithmetical mean roughness Ra is 0.1 μm or less, target surface properties of the glass substrate for magnetic disk can be obtained by omitting the grinding process to the principal face and performing the polishing process directly.

[0094]

[Table 1]

	Thickness dimensions of die and thermally equalizing unit	Difference in temperature between central portion and circumferential edge portion of	Surface waviness	Evaluation of surface waviness
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		inner circumferential surface of die		
Comparative Example	Die: 8 mm Thermally equalizing unit: None	20 °C	38 nm	Poor
Example 1	Die: 8 mm Thermally equalizing unit: 8 mm	9 °C	21 nm	Good
Example 2	Die: 8 mm Thermally equalizing unit: 26 mm	1 °C or less	9 nm	Very good

[0095]

It is apparent from Table 1 that a glass blank having a good surface waviness is prepared by reducing a difference in temperature between the central portion and the circumferential edge portion of the inner circumferential surface of a pair of dies. Particularly, when the thickness dimension of the thermally equalizing unit was increased relative to the thickness dimension of the die, a glass blank having the best surface waviness was obtained. The inner circumferential surfaces of the first die and the second die were shape-transferred to the glass blank, and therefore the surface roughness of the glass blank in each example was almost identical to the surface roughness of the inner circumferential surfaces of the first die and the second die.

[0096]

[Preparation of glass substrate for magnetic disk in Example]

Using the glass blanks of Comparative Example and Examples 1 and 2 described above, processes of Steps S20 (scribing), S30 (shape processing), S50 (edge polishing), S60 (first polishing), S70 (chemically strengthening) and S80 (second polishing) illustrated in FIG. 2 were sequentially performed to prepare glass substrates for magnetic disk, respectively. That is, the glass substrate for magnetic disk was prepared without performing the process of grinding the principal face for improving the flatness.

In preparation of the glass substrate for magnetic disk, the processes of first polishing and second polishing were performed under the following conditions.

- First polishing process: polishing was performed using cerium oxide (average particle size: 1 to 2 μm in diameter) and a hard urethane pad. Machining allowance was 10 μm .
- Second polishing process: polishing was performed using colloidal silica (average particle size: 0.1 μm in diameter) and a soft urethane pad. Machining allowance was 1 μm .

[0097]

Next, recording layers were deposited on the glass substrates for magnetic disk, which had been prepared based on the glass blanks of Comparative Example and Examples 1 and 2, to prepare magnetic disks (Comparative Example A, Example 1A and Example 2A, respectively). The prepared magnetic disk had a nominal 2.5 inch size (an inner diameter of 20 mm, an outer diameter of 65 mm and a thickness of 0.8 mm).

Deposition of recording layer on the glass substrate for magnetic disk was performed in the following manner. First, an adhesive layer, a soft magnetic layer, a pre-underlying layer, an underlying layer, a principal recording layer, and an auxiliary recording layer, a protective layer and a lubricant layer were sequentially deposited in an Ar atmosphere by a DC magnetron sputtering method using an evacuated deposition apparatus. The Ar gas pressure at the time of deposition was 0.6 Pa unless otherwise specified. As the adhesive layer, Cr-50Ti was deposited in a thickness of 10 nm. As the soft magnetic layer, layers of 92Co-3Ta-5Zr were each deposited in a thickness of 20 nm with a Ru layer of 0.7 nm interposed therebetween. As the pre-underlying layer, Ni-5W was deposited in a thickness of 8 nm. As the underlying layer, Ru was deposited in a thickness of 10 nm at 0.6 Pa, and Ru was deposited thereon in a thickness of 10 nm at 5 Pa. As the principal recording layer, 90(72Co-10Cr-18Pt)-5(SiO₂)-5(TiO₂) was deposited in a thickness of 15 nm at 3 Pa. As the auxiliary recording layer, 62Co-18Cr-15Pt-5B was deposited in a thickness of 6 nm. As the protective layer, a layer was deposited in a thickness of 4 nm using C₂H₄ by a CVD method, and the surface layer was subjected to nitriding treatment. As the lubricant layer, a layer was formed in a thickness of 1 nm using PFPE by a dip coating method.

[0098]

[Evaluation of magnetic disk of Examples]

For the magnetic disks of Comparative Example and Examples 1 and 2, a touch-down test (DFH touch-down test) of a DFH (Dynamic Fly height) head element portion was conducted using an HDF tester (Head/Disk Flyability Tester) manufactured by Kubota Comps Corporation. In this test, the element portion is gradually protruded by a DFH mechanism, and contact thereof with the surface of magnetic disk is detected with an AE (Acoustic Emission) sensor to thereby evaluate a protrusion amount when the head element portion comes into contact with the surface of the magnetic disk. As the head, a DFH head for 320 GB/P magnetic disks (2.5 inch size) was used. A flying height when the element portion is not protruded is 10 nm. That is, for example, the head flying height is 2 nm when the protrusion amount is 8 nm. Other conditions were set as described below.

- Evaluation radius: 22 mm
- Rotation number of magnetic disk: 5400 rpm
- Temperature: 25°C
- Humidity: 60%

[0099]

Results of the DFH touch-down test are illustrated in Table 2. In Table 2, evaluations were made as described below according to the protrusion amount of the head element portion. It is preferable to have a protrusion amount of 8 nm or more for achieving a recording density of 320 GB/P.

Good: Protrusion amount ≥ 8 nm

Poor: Protrusion amount < 8 nm

[0100]

[Table 2]

	Evaluation of protrusion amount
Comparative Example	Poor
Example 1A	Good
Example 2A	Good

[0101]

As evident from Table 2, the protrusion amount of the DFH head could be sufficiently increased even though the grinding process was omitted for Examples 1A and 2A. That is, for Examples 1A and 2A, setting the difference in temperature within the surface of the die being set to 10°C or less, it could be confirmed that a glass substrate for magnetic disk, which has a good flatness and surface roughness and allows a good DFH touch test result to be obtained when the glass substrate is formed into a medium can be manufactured even though the grinding process is omitted.

Upon comparing Examples 1A and 2A in more detail, the protrusion amount of Example 2A only can be 8.5 nm or more. This is estimated that the surface waviness of the glass blank is much smaller, so that the glass substrate for magnetic disk has small surface waviness.

[0102]

<Second Example>

- Preparation of Molten Glass

Raw materials were weighed so as to obtain a glass having the following composition, and

mixed to obtain a mixed raw material. This raw material was put in a melting vessel, heated, melted, clarified and stirred to prepare a homogeneous molten glass free from foam and an unmelted substance. Foam and an unmelted substance, deposition of crystals, and contaminants such as a refractory material and platinum forming the melting vessel were not observed in the glass obtained.

[Composition of glass]

- First Glass

Amorphous aluminosilicate glass having a composition including 50 to 75% of SiO_2 , 1 to 15% of Al_2O_3 , 5 to 35% in total of at least one component selected from Li_2O , Na_2O and K_2O , 0 to 20% in total of at least one component selected from MgO , CaO , SrO , BaO and ZnO and 0 to 10% in total of at least one component selected from ZrO_2 , TiO_2 , La_2O_3 , Y_2O_3 , Ta_2O_5 , Nb_2O_5 and HfO_2 in an oxide-based conversion indicated in mol% (hereinafter, referred to as a first glass composition). The second glass as a glass for preparing a glass blank, glass substrate and magnetic disk for a heat assisted magnetic recording system had the following composition.

- Second Glass

Amorphous aluminosilicate glass having a composition including 50 to 75% of SiO_2 , 0 to 5% of Al_2O_3 , 0 to 3% of Li_2O , 0 to 5% of ZnO , 3 to 15% in total of Na_2O and K_2O , 14 to 35% in total of MgO , CaO , SrO , and BaO and 2 to 9% in total of ZrO_2 , TiO_2 , La_2O_3 , Y_2O_3 , Yb_2O_3 , Ta_2O_5 , Nb_2O_5 and HfO_2 in an oxide-based conversion indicated in mol% (hereinafter, referred to as a second glass composition)

Further, the first glass composition was configured so that the thermal expansion coefficient of the glass substrate for magnetic disk at a temperature of 100 to 300°C was $98 \times 10^{-7}(\text{K}^{-1})$. The second glass composition was configured so that the thermal expansion coefficient of the glass substrate for magnetic disk at a temperature of 100 to 300°C was $80 \times 10^{-7}(\text{K}^{-1})$. When the thermal expansion coefficient is $50 \times 10^{-7}(\text{K}^{-1})$ or less, the internal strain generated in the glass blank after press forming tends to be small, and therefore the degree of deterioration of the flatness is low after a rapid heating treatment described later is performed. When the thermal expansion coefficient is less than $30 \times 10^{-7}(\text{K}^{-1})$, the thermal expansion coefficient of the glass is smaller than that of a spindle in a hard disk device. This is not preferable because during operations of the hard disk device, the magnetic disk and the spindle may strongly fit together to break the magnetic disk.

When the glass blank, glass substrate and magnetic disk for a heat assisted magnetic

recording system are prepared, it is preferable to compose the glass so as to have a glass transition point (T_g) of 600°C or higher. This is because a period of time changing from molten state to solid state (around the glass transition point T_g) is shorter and the cooling rate tends to be higher as the glass transition point (T_g) becomes higher. Therefore, with such glass composition, it is generally difficult to control internal strain of the glass. When using such glass, the manufacturing method of the present embodiment is particularly preferred. In view of the above, the glass transition point (T_g) in Examples 4B to 6B was 670°C.

Further, the thermal expansion coefficient in each Example was in the range of 50 to $100 \times 10^{-7}(\text{K}^{-1})$.

[0103]

The above-described molten glass was provided, and a glass blank having a diameter of 75 mm and a thickness of 0.9 mm was prepared using a press forming method of the present invention (method using the apparatus in FIGS. 3 and 4). The temperature of a molten glass material L_G discharged from a molten glass outflow port 111 is 1300°C, and the viscosity of the molten glass material L_G at this time is 700 poises. The surface roughness (arithmetic mean roughness R_a) of the inner circumferential surfaces of a first die and a second die was 0.1 μm to 1 μm . Further, the first die and the second die are formed of an ultrahard alloy (e.g. VM40) in a thickness of 10 mm.

Copper in a thickness of 20 mm was used as a temperature controlling unit. In this case, a difference in temperature of the inner circumferential surface of the die is 10°C or less. The difference in temperature of the inner circumferential surface is a difference in temperature which is the largest of differences in temperature between the central portion and each circumferential edge portion as measured using a thermocouple at a point which is located 1 mm from the front face of inner circumferential surface of the die to the inside of the die and corresponds to each of the central portion and a plurality of circumferential edge portions of the inner circumferential surface (e.g. a point corresponding to the central position of a glass blank having a diameter of 75 mm and upper and lower and left and right four positions on the circumference of a circle centered on the aforementioned point and having a radius of about 30 mm).

The molten glass material L_G discharged from a molten glass outflow port 111 is cut by a cutting unit 160, so that a gob G_G having a thickness of about 20 mm is formed. The gob G_G was pressed by a press unit under a load of 3000 kgf until the gob had a temperature equal to or lower than the strain point of the molten glass material (about 5 seconds), so that a glass blank having a diameter of 75 mm was formed.

In this Example, the temperature of the first die was set to the strain point - 20°C, and the temperature of the second die was set to the temperature of the first die $\pm 10^\circ\text{C}$ (strain point -10 to -30°C). The reason why the minimum temperature of the die was set to the strain point -30°C is that when pressing is performed at a too low temperature, the glass may be broken during pressing.

In this Example, it is preferable that the cooling rate of the molten glass material during press forming is arbitrarily controlled in a range of -8 to -2°C/second in the period during which the temperature of the molten glass moves from the glass transition point (T_g) to the strain point. This cooling rate is determined by measuring a temperature for 60 seconds including time before starting pressing and after the die is released at a point which is located 1 mm from the front face of the inner circumferential surface of the die to the inside of the die, and by calculating ratio of a temperature change to the measurement time, specifically, a temperature change within a time period from the detected temperature of the glass transition point (T_g) to the detected temperature of the strain point. In the present invention, the detected temperature described above and the temperature of the glass blank is the same.

[0104]

[Examples and Comparative Examples]

- Comparative Example 1B

In Comparative Example 1B illustrated in Table 3, a glass blank was prepared using a molten glass having a first glass composition. The molten glass had a glass transition point (T_g) of 510°C and a strain point of 490°C. The cooling rate of a molten glass material was controlled to -12°C/second.

- Comparative Example 2B

In Comparative Example 2B illustrated in Table 3, a glass blank was prepared using a molten glass having a first glass composition. The cooling rate of a molten glass material was controlled to -16°C/second.

- Example 1B

In Example 1B illustrated in Table 3, a glass blank was prepared using a molten glass having a first glass composition. The cooling rate of a molten glass material was controlled to -2°C/second.

- Example 2B

In Example 2B illustrated in Table 3, a glass blank was prepared using a molten glass having a first glass composition. The cooling rate of a molten glass material was controlled to

-4°C/second.

- Example 3B

In Example 3B illustrated in Table 3, a glass blank was prepared using a molten glass having a first glass composition. The cooling rate of a molten glass material was controlled to -8°C/second.

- Example 4B

In Example 4B illustrated in Table 3, a glass blank was prepared using a molten glass having a second glass composition. The cooling rate of a molten glass material was controlled to -2°C/second.

- Example 5B

In Example 5B illustrated in Table 3, a glass blank was prepared using a molten glass having a second glass composition. The cooling rate of a molten glass material was controlled to -4°C/second.

- Example 6B

In Example 6B illustrated in Table 3, a glass blank was prepared using a molten glass having a second glass composition. The cooling rate of a molten glass material was controlled to -8°C/second.

[0105]

The cooling rate from the temperature of the glass transition point (T_g) to the temperature of the strain point was controlled by covering the press unit with a thermal insulator and adjusting the thickness or material of the thermal insulator.

[0106]

[Evaluation of glass blank prepared in Example]

First, the flatness of the glass blank having a diameter of 75 mm, which had been prepared in Example, was measured. Next, the glass blank was subjected to a rapid heating treatment to elevate the temperature from room temperature to T_g for 20 seconds, retained for 10 seconds, and then gradually cooled for 10 minutes until the glass blank reached room temperature. Thereafter, the flatness and surface roughness (arithmetic mean roughness Ra) were measured, and an amount of change in flatness before and after the rapid heating treatment was determined. This rapid heating treatment is intended for a deposition treatment in the heat assisted magnetic recording system.

The flatness can be defined as a difference on the normal axis between the lowest position

(trough) and the highest position (crest) on the principal plane of the glass blank when viewed from a fixed height on the normal axis from the horizontal plane with the glass blank placed on the horizontal plane. The flatness was measured using, for example, Flatness Tester FT-900 manufactured by NIDEK CO., LTD. Evaluation criteria for the flatness illustrated in Table 3 are as follows. It is preferred that the flatness of the glass blank is 8.0 μm or less in the following criteria because the flatness can be improved to a level of 4 μm or less, which is a target flatness of the glass substrate for magnetic disk. It is preferred that the flatness of the glass blank is 4.0 μm or less because the target flatness of the glass substrate for magnetic disk can be achieved even if the grinding process is omitted.

[0107]

The surface roughness is represented by an arithmetic mean roughness Ra defined in JIS B0601:2001 and, for example, can be measured with a roughness measuring machine SV-3100 manufactured by Mitutoyo Corporation and calculated by a method defined in JIS B0633:2001 when the roughness is no less than 0.006 μm and no more than 200 μm . When as a result, the roughness is 0.03 μm or less, for example, the roughness can be measured with a scanning probe microscope (atomic force microscope; AFM) nanoscope manufactured by Veeco Japan Inc. and can be calculated by a method defined in JIS R1683:2007. In the present application, an arithmetic mean roughness Ra as measured in a resolution of 256×256 pixels in a measurement area of $10 \mu\text{m} \times 10 \mu\text{m}$ square was used. As a result, the surface roughness of the glass blank was 0.5 μm or less in all examples. This is because regardless of the temperature of the die, the inner circumferential surfaces of the first die and the second die are shape-transferred to the glass blank, so that the surface roughness of the glass blank is comparable to the surface roughness of the inner circumferential surfaces of the first die and the second die. When the arithmetical mean roughness Ra is 0.1 μm or less, target surface properties of the glass substrate for magnetic disk can be obtained by omitting the grinding process to the principal face and performing the polishing process directly.

[0108]

[Table 3]

	Glass transition point (Tg)	Strain point	Cooling rate	Flatness before heating	Flatness after heating	Amount of change in flatness before and after heating
Comparative example 1	510°C	490°C	-12°C/ second	3.8 μm	8.8 μm	5.0 μm

Comparative example 2	510°C	490°C	-16°C/ second	4.0 μm	14.1 μm	10.1 μm
Example 1	510°C	490°C	-2°C/second	3.8 μm	3.9 μm	0.1 μm
Example 2	510°C	490°C	-4°C/second	2.8 μm	3.2 μm	0.4 μm
Example 3	510°C	490°C	-8°C/second	3.1 μm	3.9 μm	0.8 μm
Example 4	670°C	660°C	-2°C/second	3.5 μm	3.6 μm	0.1 μm
Example 5	670°C	660°C	-4°C/second	3.1 μm	3.4 μm	0.3 μm
Example 6	670°C	660°C	-8°C/second	2.9 μm	3.5 μm	0.6 μm

[0109]

It was found from Table 3 that a glass blank having a good flatness is obtained by controlling the cooling rate of the molten glass when the glass blank is press-formed. This indicates that a glass blank, the internal strain of which was reduced, was prepared by press forming. Particularly, when the rate of cooling of the molten glass from the glass transition point to the strain point was controlled to -8 to -2°C/second, a glass blank having a good flatness before and after heating was obtained. That is, when the decrease of the temperature was 10°C/second or less, the amount of change in flatness was controlled to 1 μm or less. Further, when the cooling rate was controlled to -2°C/second, a glass blank having the best amount of change in flatness before and after heating was obtained.

Furthermore, as is apparent from comparing Examples 2B, 3B and Example 5B, and 6B, when the cooling rate was the same, the amount of change in flatness before and after heating was smaller when the glass transition point (T_g) was 670°C. The reason for this is not clear; however, it is presumed that the thermal expansion coefficient of the second glass was lower. As described above, by using the glass blank described above, a glass substrate for magnetic disk and a magnetic disk, the internal strain of which is reduced, can be obtained without performing the annealing treatment.

As a result that the evaluation was carried out under the same condition as in Example 3B except for using glass having glass transition point (T_g) of 600°C (Strain point: 590°C, thermal expansion coefficient: $85 \times 10^{-7}(\text{K}^{-1})$) and glass having glass transition point (T_g) of 650°C (Strain point: 640°C, thermal expansion coefficient: $81 \times 10^{-7}(\text{K}^{-1})$), the amount of change in flatness before and after heating was 0.7 μm and 0.6 μm, respectively. Consequently, when the amount of change before and after heating was compared, the amount of change was smaller and better in order of (1) 670°C, 650°C, (2) 600°C, (3) 510°C of glass transition point (T_g).

[0110]

<Third Example>

Because the above described the first example and the second example can control the temperature within the press forming surface at the time of press forming by use of same members (thermally equalizing unit 125, temperature controlling unit 125), a glass blank can be prepared in such a manner that the first example and the second example are combined. Specifically, with reference to Examples 1B to 6B, when a difference in temperature between the central portion and the circumferential edge portion of the press forming surface at the time of releasing the glass blank from the die was measured, the difference was within the range of 4 - 6°C, which meant that the difference was 10°C or less in each case. Furthermore, the surface waviness was 15 - 19 nm. The amount of change in flatness before and after heating was not changed. That is, a glass blank could be prepared which is good in surface waviness and amount of change in flatness before and after heating. This is because the cooling rate was controlled to eliminate the strain in the plane at the central portion and the circumferential edge portion of the molten glass over the time from starting of contact to releasing from the die, and was controlled to have less difference in temperature in the both portions at the time of releasing from the die, in spite that a difference in temperature in the central portion and the circumferential edge portion of the molten glass was generated immediately after the molten glass came into contact with the press forming surface.

[0111]

The embodiments of the present invention have been described in detail, but the method for manufacturing a glass blank for magnetic disk, the method for manufacturing a glass substrate for magnetic disk, the glass blank for magnetic disk, the glass substrate for magnetic disk and the magnetic disk according to the present invention are not limited to the aforementioned embodiments, and it is needless to say that various modifications and changes may be made without departing from the spirit of the present invention.

[Reference Signs List]

[0112]

1...Glass substrate for magnetic disk

125...Thermally equalizing unit, Temperature controlling unit

126...Second thermally equalizing unit, Second temperature controlling unit

What is claimed is:

1. A method for manufacturing a glass blank for a magnetic disk, the method comprising:

cutting a lump of molten glass from flowing molten glass to cause the lump of molten glass to fall; and

a forming process of press-forming the lump of molten glass using first and second dies each having a plate shape, such that during the forming process, the falling lump of molten glass is press-formed using the first and second dies from a direction orthogonal to a falling direction of the lump of molten glass so that respective press forming inner circumferential surfaces of the first and second dies contact the lump of molten glass at substantially the same time to spread the lump of molten glass along the inner circumferential surfaces of the first and second dies to produce the glass blank having a plate shape, a time from when the lump of molten glass comes into contact with the press forming inner circumferential surface of the first die or the press forming inner circumferential surface of the second die to a time when the lump of molten glass is completely confined between the first and second dies is 0.1 second or less, and a temperature difference along each of the press forming surfaces of the pair of dies is maintained at 10°C or less so that a surface waviness of the glass blank is equal to 30 nm or less and is measured as a maximum elevation difference in wavelength component of 5 mm or less with respect to a principal surface of the glass blank.

2. The method for manufacturing a glass blank for a magnetic disk according to claim 1, further comprising a thermal equalizer configured to reduce the temperature difference along each of the press forming surfaces heat-exhausting from the press forming surfaces and/or heating the press forming surfaces.

3. The method for manufacturing a glass blank for a magnetic disk according to claim 1 or 2, wherein the thermal equalizer comprises a heat sink.

4. The method for manufacturing a glass blank for a magnetic disk according to claim 3, wherein the heat sink is provided on at least a part of a respective surface opposite to a respective one of press forming surfaces.

5. The method for manufacturing a glass blank for a magnetic disk according to any one of claims 1 to 4, wherein the heat sink is provided so that amount of heat exhausted from a central portion of the molten glass is larger than that from a

circumferential edge portion of the molten glass during the press forming.

6. The method for manufacturing a glass blank for a magnetic disk according to any one of claims 1 to 5, wherein in the forming process, press forming is performed so that the temperature of the press forming surface of the pair of dies is substantially the same.

7. The method for manufacturing a glass blank for a magnetic disk according to any one of claims 1 to 6, wherein a thermal expansion coefficient at 100°C to 300°C of a glass blank obtained after press forming is in a range of 30 to $100 \times 10^{-7}(\text{K}^{-1})$.

8. The method for manufacturing a glass blank for a magnetic disk according to any one of claims 1 to 7, surface roughness of the press forming surface of the die is substantially uniform throughout the surface.

9. A method for manufacturing a glass substrate for a magnetic disk, wherein a glass blank for magnetic disk is subjected to polishing processing having machining allowance of $50 \mu\text{m}$ or less to manufacture a glass substrate for magnetic disk, the glass blank being manufactured with the method for manufacturing a glass blank for magnetic disk according to any one of claims 1 to 8.

10. A method for manufacturing a glass blank for a magnetic disk, the method comprising:

cutting a lump of molten glass from flowing molten glass to cause the lump of molten glass to fall; and

a forming process of press-forming the lump of molten glass using first and second dies each having a plate shape, such that during the forming process, the falling lump of molten glass is press-formed using the first and second dies from a direction orthogonal to a falling direction of the lump of molten glass so that respective press forming inner circumferential surfaces of the first and second dies contact the lump of molten glass at substantially the same time to spread the lump of molten glass along the inner circumferential surfaces of the first and second dies to produce the glass blank having a plate shape while a temperature difference between the press forming surfaces of the pair of dies is maintained at 5°C or less and a temperature of the molten glass is controlled so that a cooling rate of the molten glass is $-10^\circ\text{C}/\text{second}$ or less in a period

during a period of time in which the molten glass is cooled from a glass transition point (T_g) to a strain point, and a time from when the lump of molten glass comes into contact with the press forming inner circumferential surface of the first die or the press forming inner circumferential surface of the second die to a time when the lump of molten glass is completely confined between the first and second dies is 0.1 second or less.

11. A method for manufacturing a glass blank for a magnetic disk, the method comprising:

cutting a lump of molten glass from flowing molten glass to cause the lump of molten glass to fall; and

a forming process of press-forming a lump of molten glass using first and second dies each having a plate shape, such that during the forming process, the falling lump of molten glass is press-formed using the first and second dies from a direction orthogonal to a falling direction of the lump of molten glass so that respective press forming inner circumferential surfaces of the first and second dies contact the lump of molten glass at substantially the same time to spread the lump of molten glass along the inner circumferential surfaces of the first and second dies to produce the glass blank having a plate shape while a temperature difference between the press forming surfaces of the pair of dies is maintained at 5°C or less and a cooling rate of the molten glass is controlled during a period of time in which the molten glass is cooled from a glass transition point to a strain point so as to reduce in-plane strain generated when the molten glass lump is solidified into the glass blank, and a time from when the lump of molten glass comes into contact with the press forming inner circumferential surface of the first die or the press forming inner circumferential surface of the second die to a time when the lump of molten glass is completely confined between the first and second dies is 0.1 second or less.

12. A method for manufacturing a glass blank for a magnetic disk, the method comprising:

cutting a lump of molten glass from flowing molten glass to cause the lump of molten glass to fall; and

a forming process of press-forming the lump of molten glass using first and second dies, such that during the forming process, press forming is performed using the first and second dies from a direction orthogonal to a falling direction of the lump of

molten glass so that respective press forming inner circumferential surfaces of the first and second dies contact the lump of molten glass at substantially the same time to spread the lump of molten glass along the inner circumferential surfaces of the first and second dies to produce the glass blank having a plate shape while a temperature difference between the press forming surfaces of the pair of dies is maintained at 5°C or less and a cooling rate of the molten glass is controlled so that a difference in temperature on a surface of the molten glass during pressing of the molten glass is reduced, and a time from when the lump of molten glass comes into contact with the press forming inner circumferential surface of the first die or the press forming inner circumferential surface of the second die to a time when the lump of molten glass is completely confined between the first and second dies is 0.1 second or less.

13. The method for manufacturing a glass blank for a magnetic disk according to any one of claims 10 to 12, wherein press forming is performed while the cooling rate of the molten glass is controlled so that a difference in temperature on a surface of the molten glass is reduced during the period of time in which the pair of dies close and separate .

14. The method for manufacturing a glass blank for a magnetic disk according to any one of claims 10 to 13, wherein in the forming process, press forming is performed while the cooling rate of the molten glass is controlled so that a difference in temperature on a surface of the molten glass is reduced during the period of time in which the temperature of the molten glass moves from a glass transition point (T_g) to the strain point during pressing of the molten glass.

15. The method for manufacturing a glass blank for a magnetic disk according to any one of claims 10 to 14, wherein in the forming process, press forming is performed while temperature of a press forming surface of the die during pressing of the molten glass is kept substantially uniform.

16. The method for manufacturing a glass blank for a magnetic disk according to any one of claims 10 to 15, wherein in the forming process, press forming is performed so that temperature of a press forming surface of the die is substantially identical between the pair of dies.

17. The method for manufacturing a glass blank for a magnetic disk according to

any one of claims 10 to 16, wherein the temperature of the pair of dies is kept lower than the glass transition point (T_g) of the molten glass during a period of time beginning when the glass blank starts to contact at least one of the press forming surfaces and ending when the glass blank and is separated from the at least one of the press forming surfaces.

18. The method for manufacturing a glass blank for a magnetic disk according to any one of claims 10 to 17, wherein the forming process is performed using a molten glass having a glass transition point (T_g) of 600°C or higher.

19. A method for manufacturing a glass substrate for a magnetic disk, wherein a glass substrate for magnetic disk is manufactured without performing annealing treatment using a glass blank for magnetic disk, the glass blank being obtained with the method for manufacturing a glass blank for magnetic disk according to any one of claims 10 to 18.

20. A method for manufacturing a glass substrate for a magnetic disk according to claim 19, wherein the glass transition point (T_g) is 600°C or higher.

21. A method for manufacturing a magnetic disk, the method comprising depositing at least a magnetic layer on a principle surface of the glass substrate for a magnetic disk obtained with the method for manufacturing a glass substrate for a magnetic disk according to claim 9.

22. A method for manufacturing a glass blank for magnetic disk according to claim 1, wherein during the forming process, the difference in temperature along the press forming surface of the die is controlled based on a relation between differences in temperature in the press forming surface of the die during the forming process and corresponding sets of surface waviness of the glass blank.