

DESCRIPTION

TITLE OF INVENTION

Glass Substrate

5 TECHNICAL FIELD

The present invention relates to a glass substrate.

BACKGROUND ART

10 In recent years, as the storage capacity of a HDD (hard disk drive) is exponentially increasing, it is essential to reduce a recording area for one bit in the medium. Moreover, in order to attain a high density by reducing the recording area, a distance between a head and the disk needs to be more stable during reading and writing in recording.

15 In order to attain this, surface roughness Ra of a glass substrate, which serves as the substrate of the disk, needs to be decreased. However, presently proposed surface roughness Ra is about 3 Å (Japanese Patent Laying-Open No. 2008-097821 (Patent Document 1)). It is required to further decrease surface roughness Ra (arithmetic average roughness).

CITATION LIST

PATENT DOCUMENT

20 PTD 1: Japanese Patent Laying-Open No. 2008-097821

SUMMARY OF INVENTION

TECHNICAL PROBLEM

25 In order to decrease surface roughness Ra of the glass substrate as described above, a high-precision polishing technique is required. However, the cost of abrasive materials used for such a polishing technique, such as cerium oxide, is rising. Hence, it is essential to reduce an amount of usage thereof.

However, in order to obtain a glass substrate having a low surface roughness Ra under conditions that polishing is performed with the reduced amount of usage of the abrasive material such as cerium oxide, the glass substrate is required to have excellent

chemical durability to highly stabilize the surface state and to have an appropriate strength property. However, glass substrates having such properties have not been provided yet.

The present invention has been made in view of such a circumstance, and has an object to provide a glass substrate that has excellent chemical durability to achieve a highly stabilized surface state and that has appropriate strength properties in terms of Vickers hardness, Young's modulus, fracture toughness, and the like, thereby achieving a low surface roughness Ra at a high polishing rate (polishing amount per unit time) while attaining the suitable property values.

SOLUTION TO PROBLEM

A glass substrate of the present invention includes a glass composition having, by mol%, the following content range:

58% to 74% of SiO₂;

0% to 5% of Al₂O₃;

0% to 5% of B₂O₃;

0% to 3% of Li₂O;

0.1% to 6% of Na₂O;

3% to 9% of K₂O;

2% to 10% of MgO;

8% to 18% of CaO;

0% to 5% of ZnO;

0% to 5% of TiO₂; and

1% to 8% of ZrO₂,

the glass composition satisfying the following condition:

$0.01 < \text{ZrO}_2 / (\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{B}_2\text{O}_3) < 0.15$.

Here, the glass substrate is preferably a HDD glass substrate. Further, the glass substrate preferably has a surface roughness Ra of 1.8 Å or less in a region of 1 μm × 1 μm after a reverse rotation type polishing process.

The glass substrate of the present invention preferably includes a glass

composition having, by mol%, the following content range:

61% to 71% of SiO_2 ;

0% to 3% of Al_2O_3 ;

0% to 3% of B_2O_3 ;

5 0% to 2% of Li_2O ;

1% to 5% of Na_2O ;

4% to 8% of K_2O ;

4% to 9% of MgO ;

9% to 16% of CaO ;

10 0% to 3% of ZnO ;

0% to 3% of TiO_2 ; and

2% to 7% of ZrO_2 ,

the glass composition satisfying the following condition:

$0.02 < \text{ZrO}_2 / (\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{B}_2\text{O}_3) < 0.12$.

15 Further, the glass composition preferably contains no BaO . A chemical strengthening step is preferably performed during production of the glass substrate.

ADVANTAGEOUS EFFECTS OF INVENTION

Because the glass substrate of the present invention has the above-described configuration, the glass substrate provides an excellent effect of achieving a low surface roughness R_a at a high polishing rate while attaining suitable property values.

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DESCRIPTION OF EMBODIMENTS

The following describes the present invention more in detail.

<Glass Substrate>

A glass substrate of the present invention is characterized in that the glass substrate includes a glass composition having, by mol%, the following content range:

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58% to 74% of SiO_2 ;

0% to 5% of Al_2O_3 ;

0% to 5% of B_2O_3 ;

0% to 3% of Li_2O ;

0.1% to 6% of Na₂O;
3% to 9% of K₂O;
2% to 10% of MgO;
8% to 18% of CaO;
5 0% to 5% of ZnO;
0% to 5% of TiO₂; and
1% to 8% of ZrO₂,

the glass composition satisfying the following condition:

0.01 < ZrO₂/(SiO₂ + Al₂O₃ + B₂O₃) < 0.15. It should be noted that the symbol
10 "%" for the glass composition in the present invention is intended to represent "mol%"
unless otherwise stated. Further, "SiO₂+Al₂O₃+B₂O₃" represents the total amount of
SiO₂, Al₂O₃, and B₂O₃.

Because the glass substrate of the present invention has the above-described
configuration, the glass substrate has excellent chemical durability to attain a highly
15 stabilized surface state and has appropriate strength properties in terms of Vickers
hardness, Young's modulus, fracture toughness, and the like, thereby exhibiting an
excellent effect of achieving a low surface roughness Ra at a high polishing rate while
attaining the suitable property values. Such an excellent effect is attained by
synergistically exhibiting the below-described functions of the components of the glass
20 composition.

It should be noted that the glass composition is preferably composed of only the
above-described components except for an inevitable impurity. Regarding this point,
one of features of the glass composition of the present invention lies in that the glass
composition contains no BaO. This is because the chemical durability is greatly
25 decreased and heat resistance is also decreased if BaO is contained.

The glass substrate having the above-described feature in the present invention
can be used for a glass substrate of, for example, an organic EL (Electro Luminescence),
a TFT (Thin Film Transistor) liquid crystal display, or the like without any particular
limitation, but the glass substrate can be particularly suitably used for a HDD (hard disk

drive) glass substrate. In addition to the above-described properties, the glass substrate of the present invention has a high heat resistance such that a glass transition point T_g is equal to or more than 650°C , and is therefore also suitable for a HDD glass substrate for heat-assisted recording, which is drawing attention as a next-generation high-density recording technique.

It should be noted that the glass substrate of the present invention preferably has a disk-like shape. Accordingly, the glass substrate becomes suitable to be incorporated in a HDD. It should be noted that the size of the disk-like shape is not particularly limited when the glass substrate has the disk-like shape. For example, the disk can have a small diameter such as 3.5 inches, 2.5 inches, or 1.8 inches or less and can have a thin thickness such as 2 mm, 1 mm, 0.8 mm, or 0.635 mm or less.

<Glass Composition>

The following describes each of the components of the glass composition of the present invention.

SiO_2 , which is a component of the glass composition of the present invention, is an important component to form a network structure of glass. The glass composition of the present invention contains 58% to 74% of SiO_2 . (Such a numerical range in the present invention is intended such that the lower limit value and the upper limit value are included in the range. Hence, the phrase "58% to 74%" indicates "not less than 58% and not more than 74%".)

If the content of SiO_2 is less than 58%, it becomes difficult to form glass and presumably result in deterioration of chemical durability. On the other hand, if the content is more than 74%, a melting temperature becomes too high. A more preferable content range of SiO_2 is 61% to 71%.

Al_2O_3 is a component to form the network structure together with SiO_2 , has a function of improving ion exchange performance, and shows a tendency to decrease the polishing rate, so that Al_2O_3 is contained as required. If the content of Al_2O_3 is more than 5%, the polishing rate is greatly decreased, devitrification resistance is deteriorated due to increase of liquid phase temperature, and moldability is decreased due to

increase of the melting temperature. Hence, the content of Al_2O_3 needs to fall within a range of 0% to 5%. In the range, a range of 0% to 3% is preferable.

5 B_2O_3 is a component to form the network structure together with SiO_2 , and has a function of decreasing the melting temperature. Hence, B_2O_3 is contained as required. If the content of B_2O_3 is more than 5%, the Tg (glass transition point), which serves as an index for the heat resistance, is decreased. Hence, the content range of B_2O_3 needs to fall within a range of 0% to 5%. In the range, a range of 0% to 3% is preferable.

10 Li_2O is a component that improves the Young's modulus and that is required for a chemical strengthening treatment employing ion exchange. Hence, Li_2O is contained as required. In the chemical strengthening treatment, Li^+ ion in the glass composition is exchanged with Na^+ ion or K^+ ion in a chemical strengthening treatment liquid, thereby strengthening the glass substrate. When the content of Li_2O is more than 3%, the chemical durability is deteriorated and the Tg is decreased. Hence, the content range of Li_2O needs to fall within a range of 0% to 3%. In the range, a range of 0% to 2% is preferable.

20 Na_2O is a component required for the chemical strengthening treatment employing ion exchange. In the chemical strengthening treatment, the glass substrate is strengthened by ion exchange between the Na^+ ion in the glass composition and the K^+ ion in the chemical strengthening treatment liquid. If the content of Na_2O is less than 0.1%, the ion exchange performance is decreased and meltability and devitrification resistance are deteriorated. On the other hand, if the content is more than 6%, the chemical durability is decreased. Hence, the content range of Na_2O needs to fall within a range of 0.1% to 6%. In the range, a range of 1% to 5% is preferable.

25 K_2O has an effect of improving the meltability without decreasing glass transition point Tg. If the content of K_2O is less than 3%, the effect of improving the meltability cannot be obtained. On the other hand, if the content is more than 9%, the Tg is inevitably decreased. Hence, the content range of K_2O falls within a range of

3% to 9%. In the range, a range of 4% to 8% is preferable.

MgO has effects of increasing the Young's modulus and improving the meltability. If the content of MgO is less than 2%, the effect of increasing the Young's modulus and the effect of improving the meltability cannot be obtained. On the other hand, if the content is more than 10%, the glass structure becomes unstable to result in deterioration of the devitrification resistance. For this reason, the content range of MgO falls within a range of 2% to 10%. In the range, a range of 4% to 9% is preferable.

CaO has effects of increasing a linear thermal expansion coefficient and the Young's modulus and improving the meltability. If the content of CaO is less than 8%, the effect of increasing the linear thermal expansion coefficient and the Young's modulus cannot be obtained sufficiently. On the other hand, if the content is more than 18%, the glass structure becomes unstable to result in deterioration of the devitrification resistance. Therefore, the content range of CaO falls within a range of 8% to 18%. In the range, a range of 9% to 16% is preferable.

Because ZnO has effects of increasing the Young's modulus and improving the meltability, ZnO is contained as required. If the content of ZnO is more than 5%, the glass structure becomes unstable to result in deterioration of the devitrification resistance. Therefore, the content range of ZnO falls within a range of 0% to 5%. In the range, a range of 0% to 3% is preferable.

Because TiO₂ has effects of softening a high temperature viscosity and increasing rigidity, TiO₂ is contained as required. However, if the content of TiO₂ is more than 5%, the devitrification resistance is deteriorated. Therefore, the content range of TiO₂ falls within a range of 0% to 5%. In the range, a range of 0% to 3% is preferable.

ZrO₂ has an effect of greatly improving the chemical durability to provide a stable polishing rate, thereby improving surface smoothness. If the content of ZrO₂ is less than 1%, the effect of improving the chemical durability cannot be obtained sufficiently. On the other hand, if the content is more than 8%, the devitrification

resistance is deteriorated to result in deterioration of the moldability. Therefore, the content range of ZrO_2 falls within a range of 1% to 8%. In the range, a range of 2% to 7% is preferable.

5 In the present invention, it is important that a ratio of ZrO_2 to the total amount of SiO_2 , Al_2O_3 , and B_2O_3 ($\text{ZrO}_2/(\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{B}_2\text{O}_3)$) is set to fall within a range of more than 0.01 and less than 0.15 ($0.01 < \text{ZrO}_2/(\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{B}_2\text{O}_3) < 0.15$). This ratio represents a ratio of the component for improving the chemical durability and heat resistance of the glass to the skeleton components of the glass. If the ratio is equal to or less than 0.01, sufficient chemical durability and heat resistance cannot be obtained.
10 On the other hand, if the ratio is equal to or more than 0.15, the glass structure becomes unstable to result in decrease of the chemical durability or the fracture toughness. This ratio more preferably falls within a range of more than 0.02 and less than 0.12 ($0.02 < \text{ZrO}_2/(\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{B}_2\text{O}_3) < 0.12$).

15 As apparent from the explanation for each of the above-described components, in the glass composition of the present invention, the content range of each of the components is set to be the specific range and the content ratio of the specific ones of the components falls within the specific range. Accordingly, there can be provided a glass substrate that has excellent chemical durability to achieve a highly stabilized surface state and that has an appropriate strength, thereby achieving a low surface
20 roughness R_a at a high polishing rate while attaining suitable property values.

<Suitable Composition>

As described above, the glass substrate of the present invention preferably includes a glass composition having, by mol%, the following content range:

- 25 61% to 71% of SiO_2 ;
0% to 3% of Al_2O_3 ;
0% to 3% of B_2O_3 ;
0% to 2% of Li_2O ;
1% to 5% of Na_2O ;
4% to 8% of K_2O ;

4% to 9% of MgO;
9% to 16% of CaO;
0% to 3% of ZnO;
0% to 3% of TiO₂; and
5 2% to 7% of ZrO₂,
the glass composition satisfying the following condition:
 $0.02 < \text{ZrO}_2 / (\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{B}_2\text{O}_3) < 0.12$. This can be a suitable embodiment
of the present invention.

<Property Values>

10 Because the glass substrate of the present invention has the above-described
configuration, the glass substrate has excellent chemical durability to attain a highly
stabilized surface state and has appropriate strength properties in terms of Vickers
hardness, Young's modulus, fracture toughness, and the like, thereby exhibiting an
excellent effect of achieving a low surface roughness Ra at a high polishing rate while
15 attaining the suitable property values.

Here, the glass substrate of the present invention preferably has a Vickers
hardness of 550 kg/mm² to 650 kg/mm². If the Vickers hardness is less than 550
kg/mm², defects are increased during the production process, and more scratches are
generated due to contact with a head when the glass substrate is incorporated in a HDD.
20 On the other hand, if the Vickers hardness is more than 650 kg/mm², the polishing rate
is decreased to result in increase of processing cost.

Meanwhile, the Young's modulus is preferably 75 GPa to 90 GPa. If the
Young's modulus is less than 75 GPa, a fluttering characteristic is deteriorated when the
disk is rotated using a spindle motor, which results in increase of reading/writing errors.
25 On the other hand, if the Young's modulus is more than 90 GPa, the polishing rate is
decreased to result in increase of the processing cost.

Meanwhile, the fracture toughness is preferably 0.55 MPa·m^{1/2} to 0.95
MPa·m^{1/2}. If the fracture toughness is less than 0.55 MPa·m^{1/2}, more cracks are
generated in the glass substrate. If the fracture toughness is more than 0.95 MPa·m^{1/2},

cracks are not developed to result in decrease of the polishing rate. This leads to increase of the processing cost.

In addition to these property values, an amount of elution of Si is preferably equal to or less than 120 ppb, for example. If the amount is more than 120 ppb, it becomes difficult to stably obtain a substrate having a high surface smoothness. Meanwhile, the glass transition point is preferably equal to or more than 650°C. This is because if the glass transition point is equal to or less than 650°C, the glass substrate may be deformed during formation of a film of magnetic material having high magnetic anisotropy energy necessary for a heat-assisted recording medium.

Moreover, the glass substrate of the present invention preferably has a surface roughness Ra of 1.8 Å or less in a region of 1 μm × 1 μm after a below-described reverse rotation type polishing process, thereby exhibiting an excellent effect of allowing for reading and writing in recording without any problem with a distance between the head and the disk being stable when the glass substrate is incorporated in a HDD. Further, such an excellent surface roughness Ra can be achieved at a high polishing rate even under conditions that the amount of usage of the abrasive material is reduced, thereby providing the greatest feature of the present invention.

<Production Method>

A method of producing the glass substrate of the present invention is not particularly limited and a conventionally known production method can be employed. For example, as a raw material for each of the components of the glass composition of the glass substrate, a relevant oxide, a relevant carbonate, a relevant nitrate, a relevant hydroxide, or the like is employed. They are measured in a desired ratio, and are mixed sufficiently in the form of powders, thereby obtaining a prepared raw material.

Then, the prepared raw material is introduced into a platinum crucible or the like in an electric furnace heated to, for example, 1300°C to 1550°C, is melted and becomes clear, thereafter is stirred and becomes uniform, is poured into a mold heated in advance, and then is gradually cooled, thereby obtaining a glass block. Next, the glass block is held for 1 hour to 3 hours at a temperature around the glass transition

point, and is then gradually cooled to remove strain.

Next, the glass block thus obtained is sliced into a disk shape, and is cut using a core drill such that the inner circumference and outer circumference thereof become concentric circles. Alternatively, the molten glass is pressed into a disk-like shape.

5 The disk-like glass substrate thus obtained is then subjected to rough polishing and precision polishing for both sides thereof, and then is cleaned using at least one liquid of water, acid, and alkali. In this way, a final glass substrate is obtained.

It should be noted that in course of the above-described processes, after the rough polishing and precision polishing for the both sides, the glass substrate can be
10 immersed in a mixed solution of potassium nitrate (50 wt%) and sodium nitrate (50 wt%) to chemically strengthen a surface of the glass substrate. Alternatively, the chemical strengthening may be performed before the rough polishing or the precision polishing and then the ion exchange layer may be removed in either of the polishing processes (in this case, however, the ion exchange layer still remains at the end surface
15 thereof).

Such an operation of immersing the glass substrate (precursor) in the solution including alkali is generally called a "chemical strengthening process", and is an ion exchange process in which alkali metal ions such as lithium ion or sodium ion in the glass substrate precursor are replaced with alkali metal ions each having a larger ionic
20 radius such as potassium ion. Strain resulting from the difference in ionic radius provides compressive stress generated centrally at the region having been through the ion exchange, thereby strengthening the surface of the glass substrate precursor in the region. An example of such a chemical strengthening treatment liquid is the above-described solution containing nitrate.

25 Such a chemical strengthening process is preferably performed during the production of the glass substrate of the present invention. It should be noted that the chemical strengthening process is performed before or after the rough polishing and precision polishing processes in the above description, but there is no particular limitation as to in what stage the chemical strengthening process is to be performed

during the production process. Further, the ion exchange layer formed by the chemical strengthening process as described above may remain in the final glass substrate or may be removed. In the case where the ion exchange layer remains, the composition of the layer may differ from the glass composition of the present invention, but the glass composition of the present invention assumes portions other than the ion exchange layer.

Meanwhile, in the method of producing the glass substrate of the present invention, the reverse rotation type polishing method is preferably employed in the polishing process (in the rough polishing process in the case where the polishing process is divided into the rough polishing and the precision polishing as in the above-described example). Here, the reverse rotation type polishing method refers to a method of polishing a glass substrate as follows: a both-side polishing apparatus is employed, rigid urethane is employed as a polishing pad, cerium oxide is employed as an abrasive material, and the direction of rotation of the polishing pad is changed in the opposite direction whenever a predetermined time (for example, 1 minute) passes during the polishing of both the surfaces of the glass substrate. In addition, the polishing process employing such a reverse rotation type polishing method will be referred to as a "reverse rotation type polishing process" in the present invention.

Such a reverse rotation type polishing process is preferably performed during production of the glass substrate of the present invention, thereby decreasing surface roughness Ra and improving the polishing rate. Although detailed mechanism of this phenomenon is still unknown, it is considered that this is due to the following reason: by the reverse rotation of the polishing pad, a nap (pleated fine irregularities in the surface of the polishing pad) of the polishing pad is raised from a collapsed, closed state into which the nap has been brought before the reverse rotation. Accordingly, the abrasive material stored in the nap flows out to exhibit a polishing function, thereby improving the polishing rate. It should be noted that in such a reverse rotation type polishing process, the polishing rate itself is improved due to increased contact between the abrasive material and the glass substrate but the polishing rate is expected to

become unstable. However, the glass substrate of the present invention has high chemical durability, so that the polishing rate does not become unstable.

Accordingly, the glass substrate of the present invention can achieve a very low surface roughness Ra, specifically, a surface roughness Ra of 1.8 Å or less in a region of 1 μm × 1 μm, after the reverse rotation type polishing process without an unstable polishing rate.

It should be noted that in the case where the glass substrate of the present invention is used for a HDD glass substrate, a magnetic layer (magnetic film) serving as a recording layer is formed after the glass substrate is produced using the above-described production method, thereby obtaining an information recording medium (magnetic recording medium). This information recording medium can be incorporated in a HDD and can be used.

[Examples]

In the following, the present invention will be described in more detail in connection with Examples. The present invention, however, is not limited to them.

<Examples 1 to 10 and Comparative Examples 1 to 5>

In order to obtain each of glass compositions illustrated in Table 1 and Table 2 below, predetermined amounts of raw material powders were measured, were introduced into a platinum crucible, were mixed, and were then melted in an electric furnace at 1550°C. After the raw materials were sufficiently melted, a stirring blade made of platinum was inserted into the glass melt to stir it for 1 hour.

Thereafter, the stirring blade was removed and then the glass melt was left for 30 minutes. Then, the glass melt was flown into a jig, thereby obtaining a glass block. Thereafter, the glass block was held for 2 hours at a temperature around the glass transition point (T_g) for each glass, and thereafter was gradually cooled to remove strain.

Next, the glass block thus obtained was sliced into a 2.5-inch disk shape having a thickness of about 1.5 mm, and was cut using a cutter such that the inner circumference and outer circumference thereof became concentric circles. Then, a

both-side polishing apparatus was employed to polish the both sides thereof in accordance with a reverse rotation type polishing method (the direction of rotation was changed at an interval of 1 minute) using cerium oxide as the abrasive material and rigid urethane as a polishing pad. Thereafter, cleaning was performed to fabricate a glass substrate of each of the examples and the comparative examples. It should be noted that the glass substrate of each of the comparative examples does not have the glass composition of the present invention.

Evaluation was made in a below-described manner on physical properties of the glass substrate thus fabricated. Results of these are shown in Table 1 and Table 2 below.

<Elution Test>

The surface of the glass substrate of each of the examples and the comparative examples was cleaned and was immersed in 50 ml of reverse osmotic membrane water at 80°C for 24 hours, and an amount of elution of Si was then calculated by analyzing the eluate using an ICP emission spectrophotometric analyzer (trademark: "SPS7800" provided by Seiko Instruments Inc.,).

The amount of elution of Si is preferably 120 ppb or less. If the amount is more than 120 ppb, it becomes difficult to stably obtain a glass substrate having a high surface smoothness.

<Vickers Hardness>

A Vickers hardness tester (trademark: "HM-112" provided by Mitutoyo Corporation) was used to measure a Vickers hardness Hv at a load of 100 g for a loading time of 15 sec.

Vickers hardness Hv is preferably 550 kg/mm² to 650 kg/mm². If Vickers hardness Hv is less than 550 kg/mm², defects are increased during the production process, and more scratches are generated due to contact with a head when the glass substrate is incorporated in a HDD. If Vickers hardness Hv is more than 650 kg/mm², the polishing rate is decreased to result in increase of the processing cost.

<Young's Modulus>

Young's modulus E was measured in accordance with a dynamic elastic modulus testing method of testing methods for elastic modulus of fine ceramics in JIS R 1602.

5 Young's modulus E is preferably 75 GPa to 90 GPa. If Young's modulus E is less than 75 GPa, a fluttering characteristic is deteriorated when rotating the disk using a spindle motor, which results in increase of reading/writing errors. If Young's modulus E is more than 90 GPa, the polishing rate is decreased to result in increase of the processing cost.

<Fracture Toughness>

10 The Vickers hardness and crack length from indentation were measured using a testing method for fracture toughness of fine ceramics in JIS R 1607, thereby measuring a fracture toughness value K_{IC}.

15 The fracture toughness is preferably 0.55 MPa·m^{1/2} to 0.95 MPa·m^{1/2}. If the fracture toughness is less than 0.55 MPa·m^{1/2}, more cracks are generated in the glass substrate. If the fracture toughness is more than 0.95 MPa·m^{1/2}, cracks are not developed to result in decrease of the polishing rate and increase of the processing cost.

<Glass Transition Point>

20 A differential thermal measurement device (trademark: "EXSTAR6000" provided by Seiko Instruments Inc.,) was used to heat the glass sample, which had been prepared in the form of powders, at a temperature increasing rate of 10°C/min within a temperature range from a room temperature to 900°C and perform measurement, thereby measuring the glass transition point (T_g).

25 The glass transition point is preferably equal to or more than 650°C. If the glass transition point is equal to or less than 650°C, the glass substrate may be deformed during formation of a film of magnetic material having high magnetic anisotropy energy necessary for a heat-assisted recording medium.

<Surface Roughness Ra>

After performing the polishing in accordance with the reverse rotation type polishing method as described above (the amount of polishing corresponds to a

thickness of 100 μm from the surface), each of the glass substrates, still in a wet state, was cleaned ultrasonically using pure water. Then, the surface of each glass substrate was observed using an AFM (atomic force microscope) (trademark: "D3100 system" provided by Digital Instrument Inc.,) and surface roughness Ra after the polishing was measured. A region of measurement corresponds to a field of view of $1\ \mu\text{m} \times 1\ \mu\text{m}$. The measurement was performed at five points for each sample. The average value thereof was calculated.

Then, evaluation was made in the following manner: a surface roughness Ra of 1.8 $\text{\AA}$ or less was regarded as "A"; a surface roughness Ra of more than 1.8 $\text{\AA}$ and less than 2.5 $\text{\AA}$ was regarded as "B"; and a surface roughness Ra of 2.5 $\text{\AA}$ or more was regarded as "C". A surface roughness Ra smaller in numerical value represents a higher degree of smoothness.

<Polishing Rate>

The polishing rate was calculated by dividing the amount (100 μm , which was the polishing amount set in the above-described both-side polishing apparatus) of polishing performed in accordance with the above-described reverse rotation type polishing method by time (polishing time) required for the polishing. It should be noted that the polishing rate was calculated by measuring the plate thickness of the glass substrate at five points and dividing the average value thereof by the polishing time. It should be also noted that the plate thickness of the glass substrate before and after the polishing was checked through measurement using a micrometer (trademark: "MDC-25MJ" provided by Mitutoyo Corporation).

Then, evaluation was made in the following manner: a polishing rate of 2.0 $\mu\text{m}/\text{min}$ or more was regarded as "A"; a polishing rate of more than 1.5 $\mu\text{m}/\text{min}$ and less than 2.0 $\mu\text{m}/\text{min}$ was regarded "B"; and a polishing rate of 1.5 $\mu\text{m}/\text{min}$ or less was regarded as "C". A polishing rate larger in numerical value represents a more excellent polishing rate.

[Table 1]

	Unit	Example 1	Example 2	Example 3	Example 4	Example 5	Example 6	Example 7	Example 8	Example 9	Example 10
SiO ₂	mol%	67.0	65.0	59.0	72.0	67.0	67.0	67.0	67.0	65.0	65.0
Al ₂ O ₃	mol%	0.0	2.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B ₂ O ₃	mol%	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Li ₂ O	mol%	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0
Na ₂ O	mol%	2.4	2.4	2.4	2.4	0.4	2.4	2.4	2.4	2.4	2.4
K ₂ O	mol%	5.1	5.1	5.1	5.1	7.1	5.1	5.1	5.1	5.1	5.1
MgO	mol%	7.0	7.0	8.0	4.0	7.0	9.0	5.0	7.0	7.0	7.0
CaO	mol%	13.9	13.9	13.9	12.9	13.9	11.9	15.9	11.9	13.9	13.9
ZnO	mol%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0
TiO ₂	mol%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0
ZrO ₂	mol%	4.6	4.6	4.6	1.6	4.6	4.6	4.6	4.6	4.6	6.6
ZrO ₂ /(SiO ₂ +Al ₂ O ₃ +B ₂ O ₃)	-	0.07	0.07	0.07	0.02	0.07	0.07	0.07	0.07	0.07	0.10
Total	mol%	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Elution Test (Si)	ppb	82	75	93	86	69	83	108	80	71	48
Vickers Hardness	kg/mm ²	597	603	589	576	582	627	613	610	605	631
Young's Modulus	GPa	81.3	83.7	80.3	79.0	78.7	86.4	86.6	85.2	84.1	87.5
Fracture Toughness	MPa·m ^{1/2}	0.65	0.82	0.74	0.82	0.65	0.67	0.61	0.72	0.75	0.72
Glass Transition Point	°C	668	683	651	664	661	672	666	659	669	691
Surface Roughness Ra	Å	A	A	A	A	A	A	A	A	A	A
Polishing Rate	µm/min	A	A	A	A	A	A	A	A	A	A

[Table 2]

	Unit	Comparative Example 1	Comparative Example 2	Comparative Example 3	Comparative Example 4	Comparative Example 5
SiO ₂	mol%	63.5	67.0	62.0	67.0	67.0
Al ₂ O ₃	mol%	0.0	4.6	6.0	3.0	0.0
B ₂ O ₃	mol%	0.0	0.0	0.0	0.0	0.0
Li ₂ O	mol%	3.5	0.0	0.0	0.0	2.4
Na ₂ O	mol%	2.4	2.4	2.4	2.4	0.0
K ₂ O	mol%	5.1	5.1	5.1	2.1	5.1
MgO	mol%	7.0	7.0	7.0	12.0	7.0
CaO	mol%	13.9	13.9	13.9	8.9	12.9
ZnO	mol%	0.0	0.0	0.0	0.0	1.0
TiO ₂	mol%	0.0	0.0	0.0	0.0	4.6
ZrO ₂	mol%	4.6	0.0	4.6	4.6	0.0
ZrO ₂ / (SiO ₂ +Al ₂ O ₃ +B ₂ O ₃)	-	0.07	0.00	0.07	0.07	0.00
Total	mol%	100.0	100.0	101.0	100.0	100.0
Elution Test (Si)	ppb	123	291	92	72	384
Vickers Hardness	kg/mm ²	622	563	627	673	630
Young's Modulus	GPa	87.2	76.9	86.4	95.7	85.4
Fracture Toughness	MPa·m ^{1/2}	0.66	0.90	0.96	1.21	1.15
Glass Transition Point	°C	643	662	685	711	649
Surface Roughness Ra	Å	B	C	A	A	C
Polishing Rate	µm/min	A	A	B	C	C

As apparent from Table 1 and Table 2, it was confirmed that as compared with the glass substrate of each of the comparative examples, the glass substrate of each of the examples had appropriate strength properties in terms of the Vickers hardness, the Young's modulus, the fracture toughness, and the like, thereby achieving a low surface roughness Ra at a high polishing rate while attaining the suitable property values.

Heretofore, the embodiments and examples of the present invention have been illustrated, but it has been initially expected to appropriately combine the configurations of the embodiments and examples.

The embodiments and examples disclosed herein are illustrative and non-restrictive in any respect. The scope of the present invention is defined by the terms of the claims, rather than the embodiments described above, and is intended to include

any modifications within the scope and meaning equivalent to the terms of the claims.

CLAIMS

1. A glass substrate comprising a glass composition having, by mol%, the following content range:

- 5 58% to 74% of SiO₂;
 0% to 5% of Al₂O₃;
 0% to 5% of B₂O₃;
 0% to 3% of Li₂O;
 0.1% to 6% of Na₂O;
10 3% to 9% of K₂O;
 2% to 10% of MgO;
 8% to 18% of CaO;
 0% to 5% of ZnO;
 0% to 5% of TiO₂; and
15 1% to 8% of ZrO₂,
 said glass composition satisfying the following condition:
 $0.01 < \text{ZrO}_2 / (\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{B}_2\text{O}_3) < 0.15$.

20 2. The glass substrate according to claim 1, wherein said glass substrate is a HDD glass substrate.

 3. The glass substrate according to claim 1 or 2, wherein said glass substrate has a surface roughness Ra of 1.8 Å or less in a region of 1 μm × 1 μm after a reverse rotation type polishing process.

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 4. The glass substrate according to any one of claims 1 to 3 comprising a glass composition having, by mol%, the following content range:

- 61% to 71% of SiO₂;
 0% to 3% of Al₂O₃;

0% to 3% of B_2O_3 ;
0% to 2% of Li_2O ;
1% to 5% of Na_2O ;
4% to 8% of K_2O ;
5 4% to 9% of MgO ;
9% to 16% of CaO ;
0% to 3% of ZnO ;
0% to 3% of TiO_2 ; and
2% to 7% of ZrO_2 ,
10 said glass composition satisfying the following condition:
 $0.02 < ZrO_2 / (SiO_2 + Al_2O_3 + B_2O_3) < 0.12$.

5. The glass substrate according to any one of claims 1 to 4, wherein said
glass composition contains no BaO .
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6. The glass substrate according to any one of claims 1 to 5, wherein a
chemical strengthening step is performed during production of said glass substrate.