

ALKALI-FREE GLASS FOR MAGNETIC RECORDING MEDIUM AND GLASS SUBSTRATE FOR MAGNETIC RECORDING MEDIUM USING SAME

FIELD OF THE INVENTION

5 [0001]

The present invention relates to an alkali-free glass which is favorable as a substrate glass for a magnetic recording medium, does not substantially contain an alkali metal oxide, and can be formed by a float process.

Further, the present invention relates to a glass substrate for a magnetic
10 recording medium using the above-described alkali-free glass.

BACKGROUND OF THE INVENTION

[0002]

In the related art, in substrate glass for a magnetic recording medium,
15 particularly substrate glass with a metal thin film or an oxide thin film formed on the surface thereof, for example, the following characteristics as disclosed in Patent Document 1 have been demanded.

(1) It is preferable that the amount of alkali metal ions is small because, when an alkali metal oxide is contained, it reacts with water and carbon dioxide in the air, a
20 reaction product thereof is generated on the surface of the substrate, so-called weather resistance is degraded, and a magnetic recording layer is deteriorated.

(2) The substrate glass is required to have a high glass transition point such that deformation of the glass and shrinkage (thermal shrinkage) accompanied by structure stabilization of the glass can be suppressed to a minimum when the glass is exposed to a
25 high temperature in a step of forming a thin film.

Further, in recent years, high recording densification has proceeded at a high pace as a recording capacity of a hard disk drive has increased. However, along with the high recording densification, crosstalk or decrease in an S/N ratio of a reproduction signal has been a problem because thermal stability is damaged by micronization of magnetic particles. Here, heat-assisted magnetic recording technology has been focused upon as a technology of fusion of light and magnetism. Heat-assisted magnetic recording technology is a technology of recording by applying an external magnetic field and reading recorded magnetization using a GMR element or the like in a state that a magnetic recording layer is irradiated with laser light or near-field light and coercivity of the locally heated portion is decreased, and it is possible to micronize magnetic particles while the thermal stability is maintained because a medium having a high coercivity can record. However, in order for a medium having a high coercivity to be formed to have a multilayer film, a substrate needs to be sufficiently heated and to have heat resistance. In a vertical magnetic recording system, a magnetic recording layer which is different from that of the related art to respond to the requirement of high recording densification has been proposed, but there is a tendency for it to be necessary for film formation of the magnetic recording layer to be performed in a state that the substrate is maintained at a high temperature. For these reasons, it is necessary for the glass transition point to be high.

[0003]

(3) In a process of producing a glass substrate for a magnetic recording medium, polishing using slurry which contains cerium oxide abrasives is performed in many cases. In addition, a strong acidic cleaning liquid having a pH of 2 or less or a strong alkaline cleaning liquid having a pH of 12 or more is used for cleaning the substrate to remove the slurry after polishing the substrate, so the substrate is required to have sufficient chemical durability with respect to these chemicals.

[0004]

(4) The surface of the substrate after being polished or cleaned is sufficiently smooth.

(5) A specific elastic modulus of the substrate glass needs to be high in order
5 not to generate warpage or deflection while a hard disk drive is rotated.

(6) The substrate glass needs to have high strength in order not to generate cracks.

(7) There are no defects (bubbles, striae, inclusions, pits, or scratches) in the inside or on the surface of the substrate glass.

10 [0005]

In addition to the above-described requirements, the situation has become as follows in recent years.

(8) The weight of a magnetic disk has been required to be reduced and glass with low density is desirable for reducing power consumption and reducing the load on
15 a motor at the time when a hard disk drive is rotated.

(9) It is desirable that substrate glass has a thin thickness from a requirement for reduction in weight of a magnetic recording medium.

[0006]

(10) Glass having a small linear expansion coefficient is preferable for
20 improving productivity and thermal impact resistance by increasing a rate of temperature increase/decrease at the time of forming a film of a magnetic recording layer.

[0007]

On the other hand, in a case where a substrate for a magnetic recording
25 medium is produced, a main surface of a glass substrate is mirror-polished in order to make the main surface thereof into a smooth surface (see Patent Document 2). In the

above-described mirror polishing, a polishing pad is brought into contact with the main surface of the glass substrate, an acidic (a pH of 1 to 3) polishing liquid containing polishing abrasives is supplied on the main surface of the glass substrate, the glass substrate is relatively moved with respect to the polishing pad, and the main surface of the glass substrate is polished.

[0008]

Patent Document 1: JP-A-2012-106908

Patent Document 2: JP-A-2007-257810

10 SUMMARY OF THE INVENTION

[0009]

As a magnetic recording medium becomes thinner and recording density becomes highly densified, further decrease in warpage or deflection of a hard disk drive during rotation, further improvement in surface smoothness after being polished or cleaned, and improvement in heat resistance corresponding to a high temperature of the film formation temperature of the magnetic recording layer have been demanded. In addition, practical strength of the magnetic recording medium is greatly required, and thus it is effective for fracture toughness of substrate glass to be improved in order to respond to this requirement.

20 Therefore, the substrate glass for a magnetic recording medium is required to have a high specific elastic modulus, a high Young's modulus, high heat resistance, high chemical durability, low density, and high strength.

[0010]

An object of the invention is to provide an alkali-free glass for a magnetic recording medium which has high specific elastic modulus, a high Young's modulus, a high glass transition point, high chemical durability, low density, and high strength, and

in which float forming is easily performed, and to provide a glass substrate for a magnetic recording medium using the same.

Further, another object of the present invention is to provide a method for producing a glass substrate for a magnetic recording medium in which deterioration of the surface roughness of a main surface of the glass substrate at the time when mirror polishing is performed is suppressed.

[0011]

The present invention provides an alkali-free glass for a magnetic recording medium, having a Young's modulus of 87 GPa or more, and comprising in terms of mass% on the basis of oxides:

61 to 68.5 of SiO₂;

17 to 23.5 of Al₂O₃;

6.5 to 15 of MgO; and

3 to 13 of CaO,

wherein the contents of MgO and CaO satisfy the following relationship:

$$0.42 < \text{MgO}/(\text{MgO} + \text{CaO}) \leq 0.68.$$

[0012]

Additionally, the present invention provides a glass substrate for a magnetic recording medium, prepared using the alkali-free glass for a magnetic recording medium of the present invention.

[0013]

Furthermore, the present invention provides a method for producing a glass substrate for a magnetic disk, said method comprising a mirror polishing step of performing mirror polishing on a main surface of a glass substrate using a polishing pad and a polishing liquid which contains polishing abrasives and has a pH of less than 7, using the alkali-free glass for a magnetic recording medium of the present invention,

wherein, in the mirror polishing step, the mirror polishing is performed under a condition that an elution rate f ($\mu\text{g}\cdot\text{cm}^{-2}\cdot\text{min}^{-1}$) of a glass component derived from the following formula (1) satisfies the following formula (2):

$$f = f_0 \cdot 10^{\alpha \cdot \text{pH} + \beta} \cdot \exp(-\gamma / T) \quad (1)$$

5 in which f_0 is 7.93×10^6 , α and β are respectively $0.0121 \times w - 1.46$, and $-0.0868 \times w + 4.38$ in a case where a content w of SiO_2 of the alkali-free glass is 60% by mass or more, α and β are respectively $0.0562 \times w - 4.07$, and $-0.381 \times w + 21.8$ in a case where the content w of SiO_2 of the alkali-free glass is less than 60% by mass, the pH is a pH value of the polishing liquid, and γ is 5.81×10^3 ;

10
$$1 \times 10^{-3} \leq f \leq 1 \quad (2).$$

[0014]

The alkali-free glass of the present invention is suitable for a substrate glass for a magnetic recording medium.

15 BRIEF DESCRIPTION OF THE DRAWING

[0015]

Fig. 1 is a graph illustrating a relationship of the content (w) of SiO_2 of an alkali-free glass and an elution rate f of a glass component with regard to the alkali-free glass containing SiO_2 , Al_2O_3 , MgO , and CaO as main components, and the relationship is illustrated using a (pseudo) polishing liquid at three different temperatures of 50°C , 70°C , and 90°C .

Fig. 2 is a graph illustrating a relationship of the content (w) of SiO_2 of an alkali-free glass and an elution rate f of a glass component with regard to the alkali-free glass containing SiO_2 , Al_2O_3 , MgO , and CaO as main components, and the relationship is illustrated using a (pseudo) polishing liquid with three different pH values of 1, 2, and 3.

Fig. 3 is a perspective view schematically illustrating a partial cross section of a double-sided polishing machine used for mirror-polishing a main surface of a glass substrate.

5

DETAILED DESCRIPTION OF THE INVENTION

[0016]

Next, composition ranges of respective components will be described. The content of SiO_2 is set to 68.5% (mass%, the same applies hereinafter unless otherwise noted) or less for maintaining the Young's modulus at a high value. In addition, the content of SiO_2 is set to 61% or more for maintaining T_4-T_L at a high value by increasing devitrification viscosity and maintaining chemical durability. The content thereof is preferably in the range of 61.5% to 68% and more preferably in the range of 62% to 67.5%.

[0017]

The content of Al_2O_3 is set to 17% or more for increasing the glass transition point, suppressing phase-separation of the glass, decreasing the average thermal expansion coefficient, and improving the specific elastic modulus. Further, the content thereof is set to 23.5% or less for preventing the devitrification temperature from being increased, securing the solubility and the chemical durability. The content thereof is preferably in the range of 17% to 23% and more preferably in the range of 19% to 22.5%.

[0018]

It is necessary for 6.5% or more of MgO to be contained for improving the solubility and the Young's modulus. However, the content thereof is set to 15% or less in order to prevent the devitrification temperature from being excessively increased and prevent the chemical durability from being excessively decreased and in view of the

concern that since the amount of SiO_2 is relatively reduced, the devitrification viscosity is decreased so that T_4-T_L becomes extremely small. The content thereof is preferably in the range of 7% to 14.5% and more preferably in the range of 8% to 14%.

[0019]

5 It is necessary for 3% or more of CaO to be contained because the solubility is improved and generation of devitrification can be suppressed by being contained together with MgO. However, when the content thereof is more than 13%, the average thermal expansion coefficient becomes larger. Further, since the amount of SiO_2 is relatively reduced, the devitrification viscosity is decreased so that T_4-T_L becomes
10 extremely small. The content thereof is preferably in the range of 3.5% to 12.5% and more preferably in the range of 4% to 12%.

[0020]

When $\text{MgO}/(\text{CaO} + \text{MgO})$ is larger than 0.68, the devitrification temperature is increased. Further, when $\text{MgO}/(\text{CaO} + \text{MgO})$ is 0.42 or less, the Young's modulus
15 and the specific elastic modulus are decreased. $\text{MgO}/(\text{CaO} + \text{MgO})$ is preferably in the range of 0.44 to 0.66 and preferably in the range of 0.46 to 0.64.

[0021]

Other components, for example, the following components may be contained within the range not impairing the effects of the present invention. The content of
20 other components in this case is preferably less than 5%, more preferably less than 3%, still more preferably less than 1%, even still more preferably less than 0.5%, and the alkali-free glass is particularly preferably substantially free of other components with the exception of inevitable impurities, for preventing the Young's modulus from being decreased. Accordingly, in the present invention, the total content of SiO_2 , Al_2O_3 ,
25 CaO, and MgO is preferably 95% or more, more preferably 96% or more, still more preferably 97% or more, even still more preferably 99% or more, and still further

preferably 99.5% or more. It is particularly preferable that the alkali-free glass substantially, namely with the exception of inevitable impurities, consist of SiO_2 , Al_2O_3 , CaO , and MgO .

[0022]

5 Less than 5% of B_2O_3 can be contained for improving melting reactivity of the glass and for reducing the devitrification temperature. However, when B_2O_3 is contained in an excessive amount, the Young's modulus is decreased. Accordingly, the content thereof is preferably less than 3%, more preferably less than 1%, even more preferably less than 0.5%, and the alkali-free glass is particularly preferably
10 substantially free of B_2O_3 .

[0023]

 Less than 1.5% of SrO can be contained for improving the solubility without increasing the devitrification temperature of the glass. However, when SrO is contained in an excessive amount, the average thermal expansion coefficient is
15 increased. Accordingly, the content thereof is preferably less than 1%, more preferably less than 0.5%, and the alkali-free glass is particularly preferably substantially free of SrO .

[0024]

 Less than 5% of BaO can be contained for improving the solubility of the
20 glass. However, when BaO is contained in an excessive amount, the average thermal expansion coefficient is increased. Accordingly, the content thereof is preferably less than 3%, more preferably less than 1%, still more preferably less than 0.5%, and the alkali-free glass is particularly preferably substantially free of BaO .

[0025]

25 Less than 3% of ZrO_2 can be contained for improving the Young's modulus of the glass. However, when ZrO_2 is contained in an excessive amount, the

devitrification temperature is increased. Accordingly, the content thereof is preferably less than 2%, more preferably less than 1%, even more preferably less than 0.5%, and the alkali-free glass is particularly preferably substantially free of ZrO_2 .

[0026]

5 In addition, it is preferable that the glass of the present invention contain alkali metal oxides in an amount not exceeding an impurity level (that is, substantially not being contained), in order not to deteriorate characteristics of a metal thin film or an oxide thin film provided on the surface of the glass at the time of producing a magnetic recording medium. Further, for easy recycling of the glass, it is preferable that PbO ,
10 As_2O_3 , and Sb_2O_3 are substantially not contained.

Additionally, in the present invention, in order to improve solubility, refinement ability and formability of the glass, ZnO , SO_3 , Fe_2O_3 , F, Cl and SnO_2 may be contained in the glass raw material in a total amount of less than 1%, preferably less than 0.5%, more preferably less than 0.3%, further preferably less than 0.1%.

15 [0027]

The alkali-free glass of the present invention is suitable for a substrate glass for a magnetic recording medium which is required to have a thin thickness because the Young's modulus is 87 GPa or more and the fracture toughness is improved. The Young's modulus is preferably 88 GPa or more and more preferably 89 GPa or more.

20 [0028]

In the alkali-free glass of the present invention, since the glass transition point is preferably 760°C or more, thermal deformation at the time of producing a magnetic recording medium can be suppressed.

Since the glass transition point is preferably 760°C or more, the alkali-free
25 glass of the present invention is suitable for use in which the fictive temperature of the glass is easily increased in the production process (for example, a glass substrate for a

magnetic recording medium having a thickness of 0.7 mm or less, preferably 0.5 mm or less, more preferably 0.3 mm or less, and still more preferably 0.1 mm or less).

In forming a sheet glass having a thickness of 0.7 mm or less, preferably 0.5 mm or less, more preferably 0.3 mm or less, and still more preferably 0.1 mm or less, since there is a tendency that a drawing speed at the time of formation is increased, the fictive temperature of the glass is increased and the thermal deformation of the glass is also easily increased. In this case, when the glass has a high glass transition point, the thermal deformation can be suppressed.

[0029]

Moreover, when the average thermal expansion coefficient of the alkali-free glass of the present invention at a temperature range of 50° to 350°C is preferably $48 \times 10^{-7}/^{\circ}\text{C}$ or less, the thermal impact resistance is increased and the productivity at the time of film formation of the magnetic recording layer can be improved. The average thermal expansion coefficient is more preferably $46 \times 10^{-7}/^{\circ}\text{C}$ or less and still more preferably $44 \times 10^{-7}/^{\circ}\text{C}$ or less.

[0030]

Further, the alkali-free glass of the present invention preferably has a temperature T_2 , at which a viscosity η is 10^2 poise (dPa·s) of 1720°C or less, more preferably 1700°C or less, and still more preferably 1680°C or less, and therefore is comparatively easily melted.

[0031]

Furthermore, the alkali-free glass of the present invention preferably has a temperature T_4 , at which a viscosity η is 10^4 poise (dPa·s) of 1320°C or less, more preferably 1300°C or less, and still more preferably 1280°C or less, and therefore can be formed by a float process.

[0032]

Further, since the difference ($T_4 - T_L$) of the alkali-free glass of the present invention between the temperature T_4 at which a glass viscosity η is 10^4 poise and the devitrification temperature T_L is preferably -100°C or more, the alkali-free glass of the present invention can be formed by the float process. The difference ($T_4 - T_L$) is
5 preferably -70°C or more and more preferably -50°C or more.

The devitrification temperature described in the present specification is an average value between a maximum temperature at which crystals are deposited on the surface and in the inside of the glass and the minimum temperature at which crystals are not deposited, which are observed by optical microscopy after a heat treatment
10 performed on pulverized glass particles for 17 hours, which are put into a platinum plate in an electric furnace whose temperature is controlled to a constant temperature.

[0033]

Furthermore, since the specific elastic modulus (Young's modulus/density) of the alkali-free glass of the present invention is preferably $34.5 \text{ GPa}\cdot\text{cm}^3/\text{g}$ or more, the
15 warpage or the deflection while a hard disk drive is rotated is decreased. Therefore, the alkali-free glass of the present invention can respond to high densification of the magnetic recording medium. The specific elastic modulus thereof is more preferably $34.7 \text{ GPa}\cdot\text{cm}^3/\text{g}$ or more and still more preferably $34.9 \text{ GPa}\cdot\text{cm}^3/\text{g}$ or more.

[0034]

20 The alkali-free glass of the present invention can be produced using, for example, the following method. Raw materials of respective components being generally used are mixed to become a target component, and the mixture obtained is continuously put into a melting furnace and is heated at a temperature range of 1550°C to 1650°C to be made molten. The sheet glass can be obtained by forming the molten
25 glass having a predetermined thickness using a float process, gradually cooling and then cutting the molten glass.

[0035]

In a case where a glass substrate for a magnetic disk is produced using the alkali-free glass of the present invention, mirror polishing is performed on a main surface of the glass substrate using a polishing pad and a polishing liquid which contains polishing abrasive and has a pH of less than 7 after the sheet glass obtained by the above-described procedures is processed to a glass substrate having a predetermined shape.

In the present invention, the mirror polishing is performed under a condition that an elution rate f ($\mu\text{g}\cdot\text{cm}^{-2}\cdot\text{min}^{-1}$) of a glass component derived from the following formula (1) satisfies the following formula (2):

$$f = f_0 \cdot 10^{\alpha \cdot \text{pH} + \beta} \cdot \exp(-\gamma/T) \quad (1)$$

(in the formula (1), f_0 is 7.93×10^6 , α and β are respectively $0.0121 \times w - 1.46$, and $-0.0868 \times w + 4.38$ in a case where a content w of SiO_2 of the alkali-free glass is 60% by mass or more, α and β are respectively $0.0562 \times w - 4.07$, and $-0.381 \times w + 21.8$ in a case where the content w of SiO_2 of the alkali-free glass is less than 60% by mass, the pH is a pH value of the polishing liquid, and γ is 5.81×10^3);

$$1 \times 10^{-3} \leq f \leq 1 \quad (2).$$

[0036]

With regard to the alkali-free glass of the present invention, that is, the alkali-free glass containing SiO_2 , Al_2O_3 , MgO , and CaO as main components, three factors of a content (w) of SiO_2 of the alkali-free glass, a temperature (T) of the polishing liquid, and a pH value (pH) of the polishing liquid are specified as factors affecting the elution rate f of the glass component with respect to the polishing liquid having a pH of less than 7 in the above formula (1), the influence of the specified factors on the elution rate f of the glass components are quantitatively determined and also formulated.

It is possible to suppress deterioration of the surface roughness of the main surface of the glass substrate by performing mirror polishing under the condition that the elution rate f of the glass components derived from the above formula (1) satisfies the above formula (2). In addition, the fluctuation in pH value of the polishing liquid due to the elution of the glass component is suppressed and a stabilized polishing process rate is secured.

When the elution rate f is greater than $1 \mu\text{g}\cdot\text{cm}^{-2}\cdot\text{min}^{-1}$, the surface roughness of the main surface of the glass substrate is deteriorated. Further, the fluctuation in pH value of the polishing liquid is generated by the elution of the glass component so that the stabilized polishing process rate cannot be secured.

In contrast, when the elution rate f is smaller than $1 \times 10^{-3} \mu\text{g}\cdot\text{cm}^{-2}\cdot\text{min}^{-1}$, the productivity is decreased because the polishing process rate is considerably decreased.

In the present invention, it is possible to produce a glass substrate for a magnetic disk having extremely high flatness using an alkali-free glass having any composition that belongs to the present invention by performing the mirror polishing under a condition that an elution rate f ($\mu\text{g}\cdot\text{cm}^{-2}\cdot\text{min}^{-1}$) of a glass component derived from the following formula (1) satisfies the following formula (2).

[0037]

When the mirror polishing is performed under the condition satisfying the above formula (2), the temperature (T) of the polishing liquid and/or the pH value (pH) of the polishing liquid may be appropriately adjusted according to the content (w) of SiO_2 of the alkali-free glass used to produce the glass substrate for a magnetic disk.

Fig. 1 is a graph illustrating a relationship of the content (w) of SiO_2 of an alkali-free glass and the elution rate f of the glass component with regard to the alkali-free glass containing SiO_2 , Al_2O_3 , MgO , and CaO as main components. The plots

(points) in Fig. 1 are measured values of the elution rate acquired by the following procedures.

The elution rate f of the glass component is calculated by preparing a glass substrate whose both surfaces with dimensions of a length of 40 mm, a width of 40 mm, and a thickness of 1 mm are mirror-polished, immersing the glass substrate in hydrochloric acid from 5 hours to 45 hours, and measuring a difference between the masses before and after the immersion.

Moreover, hydrochloric acid having a pH of 1 is used as a (pseudo) polishing liquid. Measurement is performed using a (pseudo) polishing liquid at three different temperatures (T) of 50°C, 70°C, and 90°C.

Fig. 2 is a graph illustrating a relationship of the content (w) of SiO_2 of an alkali-free glass and the elution rate f of a glass component, as in Fig. 1. Provided that, the temperature (T) of the (pseudo) polishing liquid is set to only 90°C, and measurement is performed using the (pseudo) polishing liquid with three different pH values of 1, 2, and 3. The plots (points) in Fig. 2 are measured values of the elution rate acquired by the above procedures.

[0038]

The predetermined shape of the above-described glass substrate is not particularly limited, but a disk shape having a circular hole at the center portion thereof can be exemplified.

After the glass substrate having the predetermined shape is processed, both upper and lower main surfaces of the glass substrate are generally subjected to a grinding (wrapping) process using a loose abrasive tool or a fixed abrasive tool before the main surface of the glass substrate is mirror-polished. Further, when the shape of the glass substrate is a disk shape having a circular hole at the center portion thereof, the

inner peripheral edge surface and the outer peripheral edge surface of the glass substrate are polished.

[0039]

For example, the double-sided polishing machine illustrated in Fig. 3 can be
5 used for mirror-polishing the main surface of the glass substrate. A double-sided
polishing machine 20 includes an upper platen 201 and a lower platen 202 which are
arranged so as to face each other in the vertical direction, and a carrier 30 disposed
between the upper platen 201 and the lower platen 202. The carrier 30 holds a
plurality of glass substrates 10 in a holding unit thereof. Polishing pads 40 and 50
10 respectively made of a resin are mounted on the surfaces of the upper platen 201 and the
lower platen 202, which face the glass substrate 10.

[0040]

The mirror polishing of the main surface of the glass substrate using the
double-sided polishing machine 20 illustrated in Fig. 3 is performed by the following
15 procedures.

The glass substrate 10 is sandwiched between the polishing surface of the
polishing pad 40 on the upper side and the polishing surface of the polishing pad 50 on
the lower side in a state of the glass substrate 10 being held by the holding unit of the
carrier 30. The polishing surfaces of the polishing pads 40 and 50 indicate surfaces in
20 contact with the glass substrate 10 which is a subject to be polished.

The both main surfaces of the glass substrate 10 are simultaneously mirror-
polished by supplying polishing liquid containing polishing abrasive and having a pH of
less than 7 to the both main surfaces of the glass substrate 10, allowing the carrier 30 to
spin and revolve around a sun gear 203, and allowing the upper platen 201 and the
25 lower platen 202 to rotate at a predetermined rotation speed, in a state where the

polishing surfaces of the polishing pads 40 and 50 on the upper and lower sides are respectively pressed against the both main surfaces of the glass substrate 10.

[0041]

It is preferable that the polishing pad is made of a soft or hard foam resin and particularly preferable that the polishing pad is made of a soft foam urethane resin.

[0042]

It is preferable that the polishing liquid contains silica particles having an average primary particle size of 1 nm to 80 nm as polishing abrasive. In order to maintain the polishing rate, the average primary particle size of the silica particles is preferably 1 nm or more. In order to obtain a small and appropriate value of the surface roughness of the main surface obtained by the polishing, the average primary particle size of the silica particles is preferably 80 nm or less. The average primary particle size of the silica particles is preferably in the range of 1 nm to 60 nm, more preferably in the range of 1 nm to 50 nm, and particularly preferably in the range of 1 nm to 40 nm. Further, the average primary particle size can be measured using a laser diffraction/scattering particle size distribution analyzer, a dynamic light scattering particle size distribution analyzer, or an electron microscope.

[0043]

A part of the silica particles contained in the polishing liquid may be present in a form of aggregated particles (secondary or tertiary particles). The average particle size of the silica particles in the polishing liquid can be measured using a dynamic light scattering particle size distribution analyzer (for example, trade name: UPA-EX150 manufactured by NIKKISO CO., LTD.), but an average particle size (D_{50}) of the silica particles measured in this manner is one obtained by measuring the primary particle size and the particle size of the secondary or more particles. The average particle size (D_{50}) of the silica particles in the polishing liquid measured in this manner is preferably in the

range of 10 nm to 40 nm. Incidentally, the average particle size D_{50} is 50% cumulative particle size in a volume basis. That is, the average particle size D_{50} is a particle size in which the particle size distribution is acquired on a volume basis and a cumulative value becomes 50% in a cumulative curve with the total volume of 100%.

5 [0044]

Water is contained in the polishing liquid as a dispersion medium of the polishing abrasive. The kind of water is not particularly limited, but it is preferable to use pure water, ultrapure water, ion exchange water, or the like in view of reducing influence on other components described below, mixture of impurities, and influence on
10 the pH or the like. In a case of using silica particles as the polishing abrasive, the content ratio (concentration) of the silica particles in the polishing liquid is preferably 3% by mass to 30% by mass. In a case where the content ratio of the silica particles is less than 3% by mass, it is difficult to obtain sufficient polishing rate. In a case where the content ratio thereof is more than 30% by mass, the silica particles are likely to be
15 aggregated when the pH value of the polishing liquid is adjusted to less than 7 by the following procedures. The content ratio of the silica particles is preferably in the ratio of 5% by mass to 25% by mass, more preferably in the range of 7% by mass to 20% by mass, and particularly preferably in the range of 10% by mass to 18% by mass.

[0045]

20 In the present invention, the reason why the polishing liquid having a pH value of less than 7 is used is that the polishing rate becomes lower and the productivity cannot be sufficiently improved when the polishing liquid having a pH value of 7 or more is used. The pH value of the polishing liquid is appropriately adjusted in order to perform mirror polishing under the condition satisfying the above formula (2) as
25 described above, but the pH value thereof is preferably in the range of 0.5 to 6, more preferably in the range of 0.5 to 5, and particularly preferably in the range of 1 to 4.5.

[0046]

Water as a dispersion medium of the polishing abrasive contains an inorganic acid or an organic acid for adjusting the pH value of the polishing liquid to less than 7.

Examples of the inorganic acid include hydrochloric acid, nitric acid, phosphoric acid, and hydrofluoric acid. Among these, sulfuric acid or hydrochloric acid is readily available and has little effect on users and the environment, which is preferable.

Examples of the organic acid include ascorbic acid, citric acid, succinic acid, malic acid, tartaric acid, fumaric acid, maleic acid, and phthalic acid. In addition, a carboxylic acid having a carboxylic acid group can be preferably used as the organic acid. A polycarboxylic acid which includes two or more carboxylic acid groups and has a valence of two or more is more preferable. The polycarboxylic acid having a valence of two or more improves the polishing rate by an action of forming a complex and prevents generation of polishing scratches by suppressing aggregation of the abrasive. That is, the polycarboxylic acid having a valence of two or more contributes to an improvement of the polishing rate and suppresses aggregation of the silica particles by capturing metal ions generated at the time of mirror polishing of the glass substrate and forming a complex (chelate).

Specific examples of the polycarboxylic acid having a valence of two or more include citric acid, succinic acid, malic acid, tartaric acid, fumaric acid, maleic acid, and phthalic acid. Particularly citric acid is preferable.

[0047]

The mirror polishing is terminated at the time when the surface roughness of the main surface of the glass substrate reaches the predetermined value.

With regard to the surface roughness to be aimed, for example, an arithmetic average roughness (Ra) is 0.4 nm or less and a maximum peak height (Rp) is 2 nm or

less. The arithmetic average roughness (Ra) is preferably less than 0.2 nm. The maximum peak height (Rp) is preferably 1.5 nm or less.

[0048]

The glass substrate for a magnetic disk is obtained by performing cleaning (for example, precision cleaning) on the glass substrate after the mirror polishing. In
5 cleaning the glass substrate after the mirror polishing, for example, scrub cleaning using a detergent, ultrasonic cleaning in a state of immersing the glass substrate in a cleaning solution, and ultrasonic cleaning in a state of immersing the glass substrate in pure water are sequentially performed. Drying after the cleaning is performed by vapor
10 drying using isopropyl alcohol vapor. A thin film such as a magnetic film is formed on the main surface of the glass substrate for a magnetic disk obtained in this manner, thereby producing a magnetic disk.

EXAMPLES

15 [0049]

Examples 1 to 22 below are Working Examples and Examples 23 to 25 are Comparative Examples. Raw materials of respective components were mixed to have a target composition and the mixture was melted at a temperature range of 1550°C to 1650°C using a platinum crucible. At the time when the glass was being melted, the
20 glass was homogenized by stirring using a platinum stirrer. Next, the melted glass was poured, formed to have a sheet shape, and then was gradually cooled.

[0050]

In Tables 1 to 3, glass compositions (unit: mass%), densities ρ (g/cm³), Young's moduli E (GPa) (measured by an ultrasonic method), specific elastic moduli
25 E/ρ (GPa·cm³/g), glass transition points T_g (unit: °C), average thermal expansion coefficients α at a temperature range of 50°C to 350°C (unit: $\times 10^{-7}/^{\circ}\text{C}$), temperatures T₂

at which glass viscosities η become 10^2 poise (unit: °C), temperatures T_4 at which glass viscosities η become 10^4 poise (unit: °C), the devitrification temperatures T_L (unit: °C), and $T_4 - T_L$ are listed.

In addition, values in parentheses are calculated values in Tables 1 to 3.

[0051]

Table 1

Mass%	Example 1	Example 2	Example 3	Example 4	Example 5	Example 6	Example 7	Example 8	Example 9
SiO ₂	64	62	65	62	65	63	63	64	64
Al ₂ O ₃	20	20	20	20	19	21	19	21	22
MgO	8.5	8.5	8.5	11	8.5	8.5	8.5	8	7.5
CaO	7.5	9.5	6.5	7	7.5	7.5	9.5	7	6.5
B ₂ O ₃	0	0	0	0	0	0	0	0	0
BaO	0	0	0	0	0	0	0	0	0
SrO	0	0	0	0	0	0	0	0	0
ZrO ₂	0	0	0	0	0	0	0	0	0
MgO/(CaO+MgO)	0.53	0.47	0.57	0.61	0.53	0.53	0.47	0.53	0.54
Density ρ (g/cm ³)	2.54	2.56	2.52	2.57	2.53	2.54	2.56	2.52	2.53
Young's modulus E (GPa)	94.1	92.7	91.2	94.2	91.4	92.5	92.1	91.9	92.1
Specific elastic modulus E/ ρ (GPa·cm ³ /g)	37.0	36.2	36.2	36.7	36.2	36.4	36.0	36.4	36.4
Glass transition point T _g (°C)	793	(788)	788	776	783	787	782	795	802
Average thermal expansion coefficient α ($\times 10^{-7}/^{\circ}\text{C}$)	40	(42)	38	41	39	39	42	38	37
T ₂ (°C)	1622	1575	(1621)	(1552)	(1612)	(1598)	(1580)	(1618)	(1632)
T ₄ (°C)	1273	1250	(1274)	(1227)	(1265)	(1263)	(1246)	(1277)	(1289)
Devitrification temperature T _L (°C)	1285	1235	1345	1295	1345	1305	1285	1315	1350
T ₄ -T _L	-12	15	(-71)	(-68)	(-80)	(-42)	(-39)	(-38)	(-61)

[0052]

Table 2

Mass%	Example 10	Example 11	Example 12	Example 13	Example 14	Example 15	Example 16	Example 17	Example 18
SiO ₂	64	61	61	61	67	63.6	64	63	63.4
Al ₂ O ₃	21	17	23	23	23	20	20	20	19.8
MgO	8.5	9.4	7	10.5	6.5	7	8.5	8.5	8.4
CaO	6.5	12.6	9	5.5	3.5	9.4	7.2	7.5	7.4
B ₂ O ₃	0	0	0	0	0	0	0	0	0
BaO	0	0	0	0	0	0	0	0	1
SrO	0	0	0	0	0	0	0.3	0	0
ZrO ₂	0	0	0	0	0	0	0	1	0
MgO/(CaO+MgO)	0.57	0.43	0.44	0.66	0.65	0.43	0.54	0.53	0.53
Density ρ (g/cm ³)	2.53	2.60	2.56	2.57	2.47	2.55	2.54	2.56	2.55
Young's modulus E (GPa)	92.2	92.7	92.3	95.7	91.0	90.9	92.0	92.9	91.7
Specific elastic modulus E/ ρ (GPa·cm ³ /g)	36.4	35.6	36.1	37.3	36.8	35.7	36.3	36.3	35.9
Glass transition point T _g (°C)	794	764	795	793	814	792	784	788	784
Average thermal expansion coefficient α ($\times 10^{-7}/^{\circ}\text{C}$)	37	47	38	39	30	40	38	39	40
T ₂ (°C)	(1614)	(1523)	(1596)	(1567)	(1701)	1622	-	-	-
T ₄ (°C)	(1273)	(1205)	(1273)	(1247)	(1335)	1281	-	-	-
Devitrification temperature T _L (°C)	1315	1210	1270	1343	1410	1255	1310	1285	1285
T ₄ -T _L	(-42)	(-5)	(3)	(-96)	(-75)	26	-	-	-

[0053]

Table 3

Mass%	Example 19	Example 20	Example 21	Example 22	Example 23	Example 24	Example 25
SiO ₂	63	64	62.5	63	59.6	62.9	58
Al ₂ O ₃	20	20	20	20	17.2	20.6	20
MgO	7	7.5	7	6.5	3.1	5.1	14
CaO	7	7.5	7.5	7	3.8	7.6	8
B ₂ O ₃	0	1	3	0	8.1	0	0
BaO	0	0	0	1.5	0	0	0
SrO	0	0	0	3	8.2	3.8	0
ZrO ₂	3	0	0	0	0	0	0
MgO/(CaO+MgO)	0.50	0.50	0.48	0.48	0.45	0.40	0.64
Density ρ (g/cm ³)	2.57	2.52	2.50	2.59	2.51	2.57	2.64
Young's modulus E (GPa)	91.6	90.4	89.3	89.7	76.0	86.7	97.6
Specific elastic modulus E/ ρ (GPa·cm ³ /g)	35.7	35.8	35.7	34.7	30.3	33.7	37.0
Glass transition point T _g (°C)	-	-	-	-	720	797	762
Average thermal expansion coefficient α ($\times 10^{-7}/^{\circ}\text{C}$)	-	-	-	-	38	40	48
T ₂ (°C)	1627	-	-	-	1669	1670	1458
T ₄ (°C)	1292	-	-	-	1284	1309	1168
Devitrification temperature T _L (°C)	1360	1270	1350	1250	1270	1287	1295
T ₄ -T _L	(-68)	-	-	-	14	22	-127

[0054]

As is obvious from the tables, in the glass of Working Examples, the Young's modulus is 87 GPa or more, which is high, the glass transition point T_g is 760°C or more, and the specific elastic modulus is 34.5 GPa·cm³/g or more. Further, the average thermal expansion coefficient at a temperature range of 50°C to 350°C is $48 \times 10^{-7}/^\circ\text{C}$ or less, the temperature T_2 is 1720°C or less, and $T_4 - T_L$ is -100°C or more.

[0055]

With regard to Examples 11 and 15, the elution rate of the glass component was measured by the procedures described above. Incidentally, a pH value of (pseudo) polishing liquid, a temperature (T) of the (pseudo) polishing liquid and a measured value of an elution rate of a glass component are as follows. Additionally, an elution rate f of the glass component derived from the formula (1) by applying the content (w) of SiO₂ of the alkali-free glass, the temperature (T) of the polishing liquid, and the pH value (pH) of the polishing liquid in this case is also shown below.

15 Example 11-1

pH value of (pseudo) polishing liquid:	1
Temperature of polishing liquid:	90°C
Elution rate of glass component:	$1.3 \times 10^{-2} \mu\text{g}\cdot\text{cm}^{-2}\cdot\text{min}^{-1}$
f :	$2.1 \times 10^{-2} \mu\text{g}\cdot\text{cm}^{-2}\cdot\text{min}^{-1}$

20 Example 11-2

pH value of (pseudo) polishing liquid:	2
Temperature of polishing liquid:	90°C
Elution rate of glass component:	$8.7 \times 10^{-3} \mu\text{g}\cdot\text{cm}^{-2}\cdot\text{min}^{-1}$
f :	$3.9 \times 10^{-3} \mu\text{g}\cdot\text{cm}^{-2}\cdot\text{min}^{-1}$

25 Example 15-1

pH value of (pseudo) polishing liquid:	1
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Temperature of polishing liquid:	90°C
Elution rate of glass component:	$1.4 \times 10^{-2} \mu\text{g}\cdot\text{cm}^{-2}\cdot\text{min}^{-1}$
f:	$1.3 \times 10^{-3} \mu\text{g}\cdot\text{cm}^{-2}\cdot\text{min}^{-1}$

Example 15-2

5	pH value of (pseudo) polishing liquid:	1
	Temperature of polishing liquid:	70°C
	Elution rate of glass component:	$2.5 \times 10^{-3} \mu\text{g}\cdot\text{cm}^{-2}\cdot\text{min}^{-1}$
	f:	$4.8 \times 10^{-3} \mu\text{g}\cdot\text{cm}^{-2}\cdot\text{min}^{-1}$

Example 15-3

10	pH value of (pseudo) polishing liquid:	1
	Temperature of polishing liquid:	50°C
	Elution rate of glass component:	$7.0 \times 10^{-4} \mu\text{g}\cdot\text{cm}^{-2}\cdot\text{min}^{-1}$
	f:	$1.8 \times 10^{-3} \mu\text{g}\cdot\text{cm}^{-2}\cdot\text{min}^{-1}$

[0056]

15 With regard to the glass substrate to be produced using the glass of Example 11, the mirror polishing is performed on both the main surfaces of the glass substrate using the double-sided polishing machine 20 illustrated in Fig. 3. Silica particles having an average primary particle size of 30 nm are used as polishing abrasives and hydrochloric acid having a pH value of 1 is used as a dispersion medium. The content
20 ratio (concentration) of the silica particles in the polishing liquid is 10% by mass and the temperature (T) of the polishing liquid is 90°C. A polishing pad formed of a soft foam urethane resin is used and the mirror polishing is performed until the arithmetic average roughness (Ra) of both the main surfaces of the glass substrate becomes 0.4 nm or less and the maximum peak height (Rp) thereof becomes 2 nm or less.

25 With regard to the glass substrate to be produced using the glass in Example 11, mirror polishing is performed on both the main surfaces of the glass substrate by the

same procedures as the above procedures. Provided that, with regard to the pH value and the temperature (T) of the polishing liquid, condition of Examples 11-2 is used. With regard to both the main surfaces of the glass substrate after the mirror polishing, the arithmetic average roughness (Ra) is 0.4 nm or less and the maximum peak height (Rp) is 2 nm or less.

With regard to the glass substrate to be produced using the glass in Example 11, mirror polishing is performed on both the main surfaces of the glass substrate by the same procedures as the above procedures. Provided that, hydrochloric acid having a pH value of 1 is used as a dispersion medium of the silica particles, and the temperature (T) of the polishing liquid is set to 40°C. When the content (w) of SiO₂ of the alkali-free glass, the temperature (T) of the polishing liquid, and the pH value (pH) of the polishing liquid in this case are applied to the formula (1), the elution rate of the glass component derived becomes $1.6 \times 10^{-3} (\mu\text{g}\cdot\text{cm}^{-2}\cdot\text{min}^{-1})$.

Mirror polishing is performed on both the main surfaces of the glass substrate by the same procedures as the above procedures, provided that hydrochloric acid having a pH value of 3 is used as a dispersion medium of the silica particles and the temperature (T) of the polishing liquid is set to 50°C. In this case, the polishing rate is remarkably decreased.

With regard to the glass substrate to be produced using the glass in Example 15, mirror polishing is performed on both the main surfaces of the glass substrate by the same procedures as the above procedures, until the arithmetic average roughness (Ra) of both the main surfaces becomes 0.4 nm or less and the maximum peak height (Rp) thereof becomes 2 nm or less. Incidentally, with regard to the pH value and the temperature (T) of the polishing liquid, condition of Example 15-1 is used.

With regard to the glass substrate to be produced using the glass in Example 15, mirror polishing is performed on both the main surfaces of the glass substrate by the

same procedures as the above procedures. Provided that, with regard to the pH value and the temperature (T) of the polishing liquid, conditions of Examples 15-2 and 15-3 are used. In the case of using the condition of Example 15-2, with regard to both the main surfaces of the glass substrate after the mirror polishing, the arithmetic average roughness (Ra) is 0.4 nm or less and the maximum peak height (Rp) is 2 nm or less. In the case of using the condition of Example 15-3, the polishing rate is remarkably decreased.

[0057]

The present application is based on Japanese Patent Applications No. 2013-134880 filed on June 27, 2013 and No. 2014-126447 filed on June 19, 2014, and the contents are incorporated herein by reference.

[0058]

The alkali-free glass of the present invention is suitable for a substrate glass for a magnetic recording medium.

15

Description of Reference Numerals and Signs

[0059]

10: Glass substrate

20: Double-sided polishing machine

20 30: Carrier

40: Polishing pad on upper side

50: Polishing pad on lower side

201: Upper platen

202: Lower platen

25 203: Sun gear

WHAT IS CLAIMED IS:

1. An alkali-free glass for a magnetic recording medium, having a Young's modulus of 87 GPa or more, and comprising in terms of mass% on the basis of oxides:

61 to 68.5 of SiO₂;

17 to 23.5 of Al₂O₃;

6.5 to 15 of MgO; and

3 to 13 of CaO,

wherein the contents of MgO and CaO satisfy the following relationship:

$$0.42 < \text{MgO}/(\text{MgO} + \text{CaO}) \leq 0.68.$$

2. The alkali-free glass for a magnetic recording medium according to claim 1, having a specific elastic modulus of 34.5 GPa·cm³/g or more.

3. The alkali-free glass for a magnetic recording medium according to claim 1 or 2, having a glass transition point of 760°C or more.

4. The alkali-free glass for a magnetic recording medium according to any one of claims 1 to 3, having an average thermal expansion coefficient at a temperature range of 50°C to 350°C of $48 \times 10^{-7}/^{\circ}\text{C}$ or less.

5. The alkali-free glass for a magnetic recording medium according to any one of claims 1 to 4, wherein a difference $T_4 - T_L$ between a temperature T_4 at which a viscosity η becomes 10⁴ poise and a devitrification temperature T_L is -100°C or more.

6. A glass substrate for a magnetic recording medium, prepared using the alkali-free glass according to any one of claims 1 to 5.

7. A method for producing a glass substrate for a magnetic disk, said method comprising a mirror polishing step of performing mirror polishing on a main surface of a glass substrate using a polishing pad and a polishing liquid which contains polishing abrasive and has a pH of less than 7, using the alkali-free glass for a magnetic recording medium according to any one of claims 1 to 5,

wherein, in the mirror polishing step, the mirror polishing is performed under a condition that an elution rate f ($\mu\text{g}\cdot\text{cm}^{-2}\cdot\text{min}^{-1}$) of a glass component derived from the following formula (1) satisfies the following formula (2):

$$f = f_0 \cdot 10^{\alpha \cdot \text{pH} + \beta} \cdot \exp(-\gamma / T) \quad (1)$$

in which f_0 is 7.93×10^6 , α and β are respectively $0.0121 \times w - 1.46$, and $-0.0868 \times w + 4.38$ in a case where a content w of SiO_2 of the alkali-free glass is 60% by mass or more, α and β are respectively $0.0562 \times w - 4.07$, and $-0.381 \times w + 21.8$ in a case where the content w of SiO_2 of the alkali-free glass is less than 60% by mass, the pH is a pH value of the polishing liquid, and γ is 5.81×10^3 ;

$$1 \times 10^{-3} \leq f \leq 1 \quad (2).$$