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Title of the Invention

A GLASS SUBSTRATE OF DISK FOR RECORDING INFORMATION , A DISK FOR RECORDING INFORMATION, AND A DISK DEVICE FOR RECORDING INFORMATION

Background of the Invention

The present invention relates to a glass substrate of disk for recording information, particularly, to a glass substrate of disk used in a fixed type magnetic disk recorder, and in a photomagnetic disk apparatus, which is superior in chemical stability and thermal stability at a high temperature, and flatness, and a disk for recording information and a disk apparatus for recording information using the glass substrate.

Magnetic disks, and photomagnetic disks are used at the present as media for recording information in large scale computers and personal computers. Currently, increasing the recording density, and decreasing the size and weight of the media for recording information have been progressed rapidly. In the field of the magnetic disk apparatus, small size magnetic disk substrates such as the disk in diameters of 2.5 inches, 1.8 inches, and 1.3 inches have been developed. Not only the diameter, thickness of the disk substrate has been decreased. Accordingly, a substrate having a larger mechanical strength than ever is required. Furthermore, a levitating amount of the disk on the head has been decreased, and

the flatness of the disk which is capable of controlling the levitating amount is required.

Conventionally, an aluminum alloy has been used as the material of the substrate for the magnetic disk. However, the aluminum alloy had such problems as deforming readily, and having undesirable flatness of the disk surface after polishing on account of insufficient hardness. Furthermore, the aluminum alloy had another problem such that the layer of the magnetic recording medium was readily peeled off when the magnetic disk was contacted mechanically with the head. Therefore, the glass substrate having smaller deformation, more preferable flatness, and a larger mechanical strength than the aluminum substrate has been developed. The glass substrate can be used further as the substrate for photomagnetic disk, wherein the substrate itself is required to be transparent.

In order to use as the glass substrate for media which record information, chemically strengthened glass, of which mechanical strength is increased by replacing alkali elements at surface of the substrate with other alkali elements, and crystallized glass, wherein fine crystallized particles are deposited in amorphous glass matrix, have been developed. However, the chemically strengthened glass had such a problem that the alkali ions corroded the magnetic film and deteriorated the adhesive strength of the film during a heating step and a cleaning step in the magnetic film forming process,

because of presence of the alkali substituted layer at the surface of the film. Accordingly, JP-A-7-223845 (1995) proposed chemically strengthened glass, which was superior in chemical resistance, prepared by a further chemical treatment after the chemical strengthening.

On the other hand, the crystallized glass had such a problem that irregularity of the surface of the glass substrate after polishing was so large, because of difference in abrasion resistance between the generated crystalline fine particles and the amorphous glass, that a desirable flatness of the surface could not be obtained. Therefore, decreasing the levitating amount of the head was difficult for responding. In accordance with JP-A-7-300340 (1995), the flatness was improved by decreasing the particle size of the crystallized fine particles to the range of 5 ~ 100 nm.

However, the chemical strengthening method disclosed in JP-A-7-223845 (1995) has such a problem that making the substrate homogeneous in characteristics after the chemical strengthening process and the polishing process in the chemical strengthening treatment is still difficult. Furthermore, providing an intermediate film to prevent a diffusion of alkaline ions between the magnetic film and the glass substrate is necessary, because a problem that the magnetic film is corroded by the alkaline ions is not solved completely yet. In accordance with the crystallizing method disclosed in JP-A-7-300340 (1995), the obtained glass substrate has

a low transmittance because the glass is colored in milky color, and accordingly, the glass substrate is difficult to use as a substrate for optical information recording media. Furthermore, the crystallizing method has another problem that making the substrate homogeneous in characteristics is difficult, because a fine precise crystallizing process is required.

In either cases using the above methods, decreasing the production cost is difficult, because a post-treating process such as the chemical strengthening process or the crystallizing process is required.

Summary of the Invention

One of the objects of the present invention is to provide a glass substrate of disk for recording information having a preferable mechanical strength, a desirable chemical stability, and a sufficient optical transmittance for optical information recording, which can be manufactured by a short process.

Another object of the present invention is to provide a disk for recording information, which can achieve a high recording density and decreasing the size and weight of the disk by using the thin disk for recording information having no intermediate film, and a disk apparatus for recording information using the same.

In order to achieve the above objects, the first invention of the present invention provides an

information recording disk comprising a film of a medium for recording information formed on at least one surface of the substrate in a shape of disk, wherein the substrate is composed of a glass containing at least a rare earth element. The film of the medium for recording information can be formed directly on the surface of the substrate, or can be formed indirectly on the surface of the substrate via an intermediate film (pre-coated film).

In accordance with the above structure, a disk for recording information having a sufficient mechanical strength for thinning, and a desirable chemical stability and preferable homogeneity for making no intermediate film be necessary can be provided.

In accordance with the first invention, the thermal expansion coefficient of the glass is desirably in the range of 70 ~ 130 X 10^{-7}. The magnetic film is formed on the surface of the disk for recording information such as the magnetic disk, the photomagnetic disk, and the like. The thermal expansion coefficient of the magnetic film is approximately 100 X 10^{-7}. Therefore, if the thermal expansion coefficient of the glass is not in the range of 70 ~ 130 X 10^{-7}, a stress is applied to the magnetic film in the magnetic film manufacturing process accompanying a heat treatment, and the magnetic characteristics can be deteriorated, the magnetic film can be peeled off, or the substrate itself can generate cracks. Therefore, the thermal expansion coefficient is desirably in the above indicated range.

In accordance with the first invention, fine particles are dispersed in the glass, and the rare earth element is desirably contained in the fine particles. Strength of the glass can be increased by the presence of the fine particles being dispersed in the glass.

An amount of the rare earth element, which can be dissolved into a glass composition having a net structure, has an upper limit (a limit of solid solution). If the rare earth element is added to the glass exceeding the upper limit, the rare earth element is deposited in the glass matrix as a crystalline phase or an amorphous phase. The particles composed of the above crystalline phase or the amorphous phase are called the fine particles. If the deposition of the rare earth element is not homogeneous, the fine particles can be deposited partially by exceeding the upper limit of the solid solution. Therefore, the content of the rare earth element is not necessarily exceeds the upper limit of the solid solution in the glass matrix. The rare earth element is desirably contained in both the glass matrix and the fine particles. The fine particles are desirably crystalline. Whether the fine particles are crystalline or amorphous can be readily determined by observing a lattice fringe image taken by a transmission electron microscope., because lattice stripes can be observed at the crystalline portion, but not be observed at the amorphous portion.

The strength of the glass is improved by dispersing the fine particles in the glass matrix, because the fine

particles have an effect to suppress deformation and breakage of the glass matrix when a stress is applied to the glass matrix. The higher strength improving effect of the dispersed fine particles can be obtained by the fine particles having a smaller particle size and are dispersed more uniformly.

In accordance with the first invention, the glass preferably contains the rare earth element in the range of 0.5 ~ 15 % by weight to the total weight of the glass based on the amount converted to the oxide of Ln_2O_3 (Ln is a rare earth element).

When the content of the rare earth element is less than 0.5 % by weight, the effect for improving the mechanical effect is not significant. When the content of the rare earth element exceeds 15 % by weight, the size of the fine particles is increased, and the transmittance for white light is decreased. Therefore, an information recording disk having a preferable mechanical strength balanced with a desirable transmittance for white light can be provided by the composition described above. However, in a case when the information recording disk is used as a fixed type magnetic disk (hard disk), decrease in the transmittance for white light does not make any problem. Therefore, the content of the rare earth element exceeding 15 % by weight can be used without causing any problem.

In accordance with the first invention, the rare earth element is preferably at least any one selected from

a group consisted of Gd, Tb, Dy, Ho, Er, Tm, Yb, and Lu. Any one of the above elements readily forms crystalline fine particles in the glass, and has the significant effect for improving the strength.

Average particle size of the fine particles is desirably in the range of 1 ~ 50 nm. If the average particle size exceeds 50 nm, the volume fraction of the fine particles is increased, and the transmittance for white light is decreased. if the average particle size is less than 1 nm, the effect for improving the strength is not significant.

The volume fraction of the fine particles in the glass is desirably utmost 20 %. If the volume fraction of the deposited particles exceeds 20 %, the transmittance for white light is undesirably decreased.

In accordance with the first invention, the glass desirably contains the rare earth element in the range of 0.5 ~ 15 % by weight to the total weight of the glass based on the amount converted to the oxide of Ln_2O_3, and additionally other components such as SiO_2 : 40 ~ 80 % by weight, B_2O_3 : 0 ~ 20 % by weight, R_2O (R is an alkali metal) : 5 ~ 20 % by weight, RO (R is an alkali earth metal) : 5 ~ 20 % by weight, and Al_2O_3 : 0 ~ 10 % by weight, where the sum of the R_2O and RO is in the range of 10 ~ 30 % by weight. The above glass is called soda lime glass. The effect generated by adding the rare earth element is particularly significant with silicates glass wherein both the alkaline element and the alkaline earth element

are contained. A large portion of the added rare earth element is dissolved into the glass matrix as a solid solution, but a part of the rare earth element, which can not be dissolved into the glass matrix, is deposited as crystalline fine particles. The upper limit of dissolving the rare earth element into the glass matrix as a solid solution, that is an index indicating the easiness of depositing, varies depending on the kind of the matrix. As described previously, the strength of the glass is not increased significantly if the fine particles are not deposited sufficiently. When the silicates glass containing both the alkaline element and the alkaline earth element by the above composition is used as the matrix, the rare earth element can be deposited adequately, and a glass substrate which satisfies the required strength and chemical stability for the information recording disk can be manufactured.

In accordance with the first invention, the transmittance of the glass for visible white light is desirably at least 70 %. In order to use as the glass substrate for the photodisk, the amount and the particle size of the deposited particles should be controlled so that at least 70 % of the transmittance of the glass for the visible white light can be obtained. If the transmittance is less than 70 %, the laser beam for recording information onto the recording medium decays during transmitting the glass to cause decreasing the S/N ratio, and others.

In accordance with the second invention of the present invention, a magnetic disk provided with a film of a magnetic medium for recording information formed on the surface of the substrate in a shape of disk is provided, wherein the substrate is composed of a glass, the thickness of the substrate is utmost 0.38 mm, and the film of the magnetic medium for recording information is formed directly on the substrate.

In accordance with decreasing the thickness of the substrate, the number of the magnetic disks per volume can be increased. Therefore, if the recording density is same, the smaller and lighter magnetic disk apparatus than ever can be provided.

Conventional magnetic disk had such a problem that the magnetic recording medium was corroded by the alkaline element diffused from the glass substrate. Therefore, it was necessary to provide an intermediate layer composed of metallic chromium and others between the glass substrate and the magnetic recording medium. On the contrary, the alkaline element in the glass substrate relating to the present invention has a scarce possibility to diffuse into the magnetic recording medium. Therefore, it is not necessary to provide the intermediate layer, and the magnetic recording medium can be formed directly onto the substrate. Accordingly, deteriorating the magnetic characteristics of the magnetic recording medium by influence of the structure and the composition of the intermediate layer can be avoided.

In accordance with the third invention of the present invention, a photomagnetic disk comprising magnetic recording medium film for recording information, which is formed on one of surfaces of a disk-shaped substrate, wherein the substrate is composed of glass, the thickness of the substrate is utmost 0.38 mm, and the diameter of the substrate is at least 2,5 inches, is provided. Generally, the photomagnetic disk has a slight warp based on the condition of the manufacturing, and variation of the using environment. The angle formed by the optical axis of the light head and the disk surface is deviated from a perpendicular direction by a several mrad (milliradian) on account of the warp. When the light beam diameter is reduced to increase the capacity, the aberration and the birefringence caused by the warp is increased sharply. The aberration can be reduced by thinning the thickness of the disk. Accordingly, stable signal can be read out even if the light beam diameter is reduced. In accordance with the glass substrate of the present invention, the thickness of the disk substrate can be reduced from conventional 0.8 mm to 0.38 mm with keeping the disk diameter of at least 2.5 inches, and a width of an allowable error in manufacturing the disk can be broadened.

In accordance with the fourth invention of the present invention, a glass substrate of disk for recording information comprising medium film for recording information, which is formed on surface of a disk-shaped

substrate, wherein the substrate is composed of glass containing at least one of rare earth elements, is provided.

In accordance with the above composition, the strength of the substrate can be ensured sufficiently even if the thickness of the substrate is thin. Therefore, the production yield can be increased and the production cost can be decreased by facilitating the handling in the manufacturing process, for example, no cracks are generated even if the polishing velocity is increased to a certain level during the surface polishing step after the glass casting, and handling of the substrate in transportation after its manufacturing can be facilitated.

In accordance with the fifth invention of the present invention, an information recording disk apparatus comprising at least an information recording disk, a head reading out the information from the disk or inputting the information into the disk, a driver for the disk, and a driver for the head, wherein the information recording disk is the information recording disk described above in connection with the present invention, is provided.

In accordance with the above composition, an information recording disk apparatus having a large capacity can be provided with a low price because its production cost is low.

Brief Description of the Drawings

These and other objects, features and advantages of the present invention will be understood more clearly from the following detailed description with reference to the accompanying drawings, wherein,

FIG. 1 is a graph indicating a relationship between the additive amount of Er_2O_3, Al_2O_3, and Si_2O_4 and variation in micro-Vickers hardness,

FIG. 2 is a graph indicating a relationship between the additive amount of Er_2O_3, Al_2O_3, and Si_2O_4 and variation in thermal expansion coefficient,

FIG. 2 is a graph indicating a relationship between the additive amount of Er_2O_3, Al_2O_3, and Si_2O_4 and variation in thermal expansion coefficient,

FIG. 3 is a graph indicating a relationship between the additive amount of Er_2O_3 and variation in the average particle size of the deposited crystalline fine particles,

FIG. 4 is a graph indicating a relationship between the additive amount of Er_2O_3 and variation in the transmittance for white light,

FIG. 5 is a graph indicating a relationship between the additive amount of oxides of rare earth element and variation in the micro-Vickers hardness,

FIG. 6 is a graph indicating a relationship between the additive amount of oxides of rare earth element and variation in the glass transition temperature,

FIG. 7 is a graph indicating a relationship between the hardness (Hv) of the substrate and the defect fraction,

FIG. 8 is a schematic cross section indicating the film composition of the magnetic disk substrate manufactured by the present invention,

FIG. 9 is a schematic cross section indicating the film composition of the magnetic disk substrate manufactured by another embodiment of the present invention, and

FIG. 10 is a schematic perspective view of the magnetic disk apparatus manufactured by the present invention.

Detailed Description of the Preferred Embodiments

(Embodiment 1)

Hereinafter, details of the present invention is explained referring to the embodiments.

In Table 1, the mixing ratio (by weight ratio) of the glass raw materials, the glass transition temperature (Tg/℃), the thermal expansion coefficient ($\alpha \times 10^{-7}$/℃), and micro-Vickers hardness (Hv) studied in the present invention are indicated.

Table 1

No.	Mixing ratio (by weight)						
	SiO_2	CaO	Al_2O_3	MgO	B_2O_3	BaO	SrO
1	72.5	8.0	1.4	4.1	-	-	-
2	72.5	8.0	1.4	4.1	-	-	-
3	72.5	8.0	1.4	4.1	-	-	-
4	72.5	8.0	1.4	4.1	-	-	-
5	72.5	8.0	1.4	4.1	-	-	-
6	72.5	8.0	1.4	4.1	-	-	-
7	72.5	8.0	1.4	4.1	-	-	-
8	72.5	8.0	1.4	4.1	-	-	-
9	72.5	8.0	1.4	4.1	-	-	-
10	75.9	8.0	1.4	4.1	-	-	-
11	79.5	8.0	1.4	4.1	-	-	-
12	72.5	8.0	4.4	4.1	-	-	-
13	72.5	8.0	8.4	4.1	-	-	-
14	67.8	-	14.5	-	-	-	-
15	50.0	6.0	16.5	7.0	-	-	-
16	40.0	10.0	17.0	10.0	-	-	-
17	72.5	8.0	1.4	4.1	7.0	-	-
18	72.5	8.0	1.4	4.1	-	15.2	-
19	72.5	8.0	1.4	4.1	-	-	10.3
20	67.8	-	14.5	-	-	-	-
21	50.0	6.0	16.5	7.0	-	-	-
22	40.0	10.0	17.0	10.0	-	-	-

23	72.5	8.0	1.4	4.1	7.0	-	-
24	72.5	8.0	1.4	4.1	-	15.2	-
25	72.5	8.0	1.4	4.1	-	-	10.3

Table 1 (continued)

No.	Mixing ratio (by weight)				Tg	α	Hv
	TiO_2	ZnO	Na_2O	Er_2O_3	(℃)		
1	-	-	14.0	0.0	550	85.0	615
2	-	-	14.0	1.0	560	88.6	621
3	-	-	14.0	2.0	556	90.2	635
4	-	-	14.0	5.0	585	91.3	673
5	-	-	14.0	10.0	582	92.2	683
6	-	-	14.0	15.0	590	93.0	707
7	-	-	14.0	16.0	598	93.5	712
8	-	-	14.0	21,0	608	93.8	722
9	-	-	14.0	32.0	-	-	-
10	-	-	14.0	0.0	563	85.4	613
11	-	-	14.0	0.0	570	87.0	617
12	-	-	14.0	0.0	572	90.3	627
13	-	-	14.0	0.0	583	90.6	642
14	-	-	17.7	10.0	530	96.6	792
15	6.5	14.0	-	10.0	545	110.0	720
16	7.0	16.0	-	10.0	520	126.5	706
17	-	-	7.0	5.0	594	59.5	721
18	-	-	7.0	5.0	605	76.9	686
19	-	-	7.0	5.0	617	76.0	685

20	-	-	17.7	-	520	95.4	735
21	6.5	14.0	-	-	521	103.0	652
22	7.0	16.0	-	-	502	122.4	634
23	-	-	7.0	-	594	57.0	710
24	-	-	7.0	-	588	77.9	644
25	-	-	7.0	-	597	72.0	597

The glass transition temperature and the thermal expansion coefficient were determined from thermal expansion curves of the glass. The thermal expansion coefficient was calculated from the elongation rate of the glass from 50 ℃ to 500 ℃. The temperature elevating velocity was 5 ℃/minute, and the loaded weight was 10 g. A quartz glass (thermal expansion coefficient; 5×10^{-7} /℃) was used as a standard sample. The size of the test pieces was 5 mm in diameter and 20 mm in height.
The micro-Vickers hardness (Hv) was determined as an average value of ten points measured under the condition of the loaded weight of 100 g, and the weight loading time of 15 seconds.

The glass was prepared in the manner described hereinafter. A mixture of respective predetermined amounts of powder of the raw materials was put into a crucible made of platinum, and was melted at 1600 ℃ in an electric furnace. After melting the raw materials completely, the molten glass was stirred for one hour with a platinum stirring blade. Then, the stirring blade was taken out from the molten glass, the molten glass was

stood still for 30 minutes, and a glass block was obtained by pouring the molten glass into a die made of graphite, which had been heated at approximately 300 ℃, and cooling the die rapidly. Subsequently, strain relief annealing was performed by reheating the glass block to a temperature near the glass transition temperature of the respective glass, and cooling the glass block gradually with a cooling velocity of 1 ~ 2 ℃/minute.

The glass of No. 1 in Table 1 contains silicon oxide as a main component. Taking this glass as a standard glass having a fundamental composition, various rare earth elements were added to the standard glass of 100 parts by weight. Erbium oxide (Er_2O_3), i.e. one of the rare earth elements, was added to the glasses of No. 2 ~ 8 in Table 1 respectively within the range of 1 ~ 21 % by weight. The glass of No. 9 contained erbium oxide of 32 % by weight. However, a part of the raw erbium oxide powder was remained in the molten glass undissolved, and homogenous glass could not be obtained. The glasses of No. 10, 11, 12, and 13 were prepared by adding SiO_2 and Al_2O_3 increasingly to 100 parts by weight of the No. 1 glass.

The glass of No. 14 contained further increased amount of Al_2O_3, and erbium oxide of 10 % by weight. The glasses of No. 15 and 16 contained more increased amount of Al_2O_3, and more decreased amount of SiO_2 than the glass of No. 14. Furthermore, ZnO and TiO_2 were added as crystallizing components in addition to erbium oxide of 10 % by weight.

The glass of No. 17 contained a half amount of Na_2O of the glass of No. 1, and B_2O_3 in addition to erbium oxide of 5 % by weight. The glasses of No. 18 and 19 contained a half amount of Na_2O of the glass of No. 1, and additionally an alkaline earth metal oxide such as BaO, SrO, and the like. The glasses of No. 20 ~ 23 were the same glasses of No. 15 ~ 19 except no erbium oxide was contained.

As a comparative example, Tg, α, and Hv of a glass, which was chemically strengthened by alkali replacement of the glass of No. 1, are indicated in Table 2.

Table 2

No.	Tg (℃)	α	Hv	Remarks
26	557	85	670	Chemically strengthened glass

The chemically strengthened procedure was performed by immersing the glass, manufactured in a flat plate of approximately 0.63 mm thick, into molten potassium nitrate bath at 380 ℃ for 40 minutes. The thickness of the chemically strengthened layer was approximately 20 μm. The Hv of the chemically strengthened glass was 670. In comparison with the Hv of 615 of the glass before the chemical strengthening, it was revealed that the Hv was increased approximately 9 % by the chemical strengthening. The thermal expansion coefficient was not increased by the chemical strengthening. The glass transition temperature was increased somewhat by the chemical

strengthening.

On the basis of the Hv of the chemically strengthened glass, the strength of the glasses indicated in Table 1 was evaluated. When the additive amounts of Er_2O_3 were 1.0 % and 2.0 %, respectively by weight (No. 2, and 3), each of the micro-Vickers harnesses of the glasses was increased to 621 and 635 in comparison with the glass of No. 1. However, the increased amount was not significant, and the hardness did not reach at the hardness of the chemically strengthened glass. When the additive amount of Er_2O_3 was 5.0 % by weight (No. 4), the micro-Vickers harnesses of the glass was increased to 673, exceeding the Hv of the chemically strengthened glass. In accordance with the glasses of No. 5 ~ 8, wherein the additive amount of Er_2O_3 was increased further to 10 ~ 21 % by weight, the micro-Vickers harnesses of the glass were increased further such as 683, 707, 712, and 722, respectively.

FIG. 1 indicates a relationship between the additive amount of Er_2O_3, Al_2O_3, and Si_2O_4 and variation in micro-Vickers hardness. The additive amount indicated by the abscissa is expressed by mol % of oxide containing two cations. That means, for example, SiO_2 is expressed as Si_2O_4, and Er_2O_3 and Al_2O_3 are expressed as Er_2O_3 and Al_2O_3 with no change. In accordance with FIG. 1, the Hv of the Er_2O_3 added glass is increased linearly in relation to the additive amount of Er_2O_3. The Hv of the glass exceeds the Hv of the chemically strengthened glass by adding Er_2O_3 of at least 0.013 mol % (50 % by weight).

On the other hand, although an increasing tendency of the Hv can be observed with the glasses (No. 8 ~ 11), wherein Si_2O_4, or Al_2O_3 is added, the increased amount is not significant, and the Hv does not reach at the level of the chemically strengthened glass even if the additive amount of Si_2O_4, or Al_2O_3 exceeds 0.05 mol %.

FIG. 2 indicates a relationship between the additive amount of various oxides and variation in thermal expansion coefficient. The thermal expansion coefficient of the Er_2O_3 added glass is increased in accordance with increasing the additive amount of Er_2O_3. Because of the large thermal expansion coefficient of the information recording medium layer, matching of the substrate with the information recording medium layer has been improved by increasing the thermal expansion coefficient of the substrate.

The Hv of the substrate could be increased significantly by adding Er_2O_3. However, the increase in Hv was scarcely observed when the additive amount of Er_2O_3 was less than 0.5 % by weight, in addition to the embodiments indicated in Table 1. Therefore, Er_2O_3 is preferably added at least 0.5 % by weight. On the contrary, when Er_2O_3 was added more than 30 % by weight, the Er_2O_3 was not dissolved completely, and the obtained glass was not homogeneous. Therefore, the additive amount of Er_2O_3 is desirably utmost 30 % by weight. The effect of adding Er_2O_3 in increasing the Hv and the Tg was compared with the same effect of adding each of SiO_2 and Al_2O_3, which

were regarded as components to increase the mechanical strength, and it was found that the increase in the Tg was almost same, but the addition of Er_2O_3 was more effective in increasing the Hv. The Hv of the glasses of No. 14 ~ 16, whereto an increased amount of Al_2O_3 was added respectively, were improved in comparison with the glasses of No. 20 ~ 22, whereto no Er_2O_3 was added. The glasses of No. 15 and 16 became opaque by a heat treatment at 900 ℃, because crystalline particles were deposited in the glass. The Hv were measured under the above condition, and it was found that the Hv were increased such as 760 and 720, respectively in comparison with the Hv before the heat treatment.

The contents of Na_2O in the glasses of No. 17 ~ 19 were decreased to a half of the glass of No. 1. Therefore, elevation of the characteristic temperature was expected, and a predetermined amount of respective of B_2O_3, BaO, and SrO, which were regarded as components to decrease the melting point, was added to the glasses of No. 17 ~ 19. Furthermore, Er_2O_3 of 5 % by weight was added to each of the glasses of No. 17 ~ 19. The Hv of all the glasses of No. 17 ~ 19 were improved in comparison with the glasses of No. 23 ~ 25, whereto no Er_2O_3 was added.

A three point bending strength test was performed on the glasses of No. 1 and 5, and the chemically strengthened glass (No. 12) for comparison. Average values of the three point bending strength (σ /Mpa) are indicated in Table 3.

Table 3

No.	n	σ (Mpa)
1	20	328
5	20	391
26	20	390

The test was performed using glass test pieces of 0.63 mm thick, 2 mm wide, and 3 mm long. The bottom span was 1.2 mm. The number of the test pieces (n) was 20 for all the glasses. The three point bending strength σ (Mpa) is expressed by the following equation:

$$\sigma = (3lw/2at^2)$$

where, w : loaded weight

l : bottom span

a : width of the test piece

t : thickness of the test piece

The average three point bending strength of the glass of No. 1 was 328 MPa. The average three point bending strength of the glass of No. 5, which contained Er_2O_3 of 10.0 % by weight, was 391 MPa, increased by approximately 19 % from the glass of No. 1, and an equivalent strength to the chemically strengthened glass (No. 26) was obtained.

In order to study the mechanism of mechanical

strength increment by adding rare earth element oxides, microstructures of the glasses of No. 1 - 8, and 10 were observed by a transmission electron microscope.

The glasses of No. 1 and 10, which contained no rare earth element oxides, were in a homogeneous amorphous condition. On the other hand, the glasses of No. 2 - 8 were in a condition that fine particles having a nano-order particle size were dispersed in an amorphous glass matrix. Based on the observation of high resolution images, the fine particles were determined as crystalline particles. As explained above, fine particles were observed in the glasses containing the rare earth element oxides, and the degree of improving the mechanical strength of these glasses were significant. The fine particles were not observed in the glass containing Al_2O_3 and others such as the glass of No. 10. and the degree of improving the mechanical strength of the glass was not significant. Therefore, it was concluded that the mechanical strength was increased based on the presence of the fine particles.

The particle sizes of the fine particles were different each from the others depending on the content of Er_2O_3. The average diameters of the fine particles generated in respective of the glasses and transmittance for white light are indicated in Table 4.

Table 4

No.	2	3	4	5	6	7	8
Er_2O_3 content (weight ratio)	1.0	2.0	5.0	10.0	15.0	16.0	21.0
Average diameter (nm)	1	3	8	15	38	51	103
Transmittance (%)	91	85	79	74	70	67	58

FIG. 3 indicates a relation ship between the average particle size of the fine crystalline particles and the Er_2O_3 content, and FIG. 4 indicates a relationship between the transmittance of the glass and the Er_2O_3 content. The average particle size was increased in proportion to approximately a square of the Er_2O_3 content. The transmittance was decreased in negative proportion to the Er_2O_3 content.

A relationship between an efficiency of recording information and the transmittance of light was studied. Then, it was found that the recording information was performed with a high efficiency when the transmittance for white light was at least 60 %, and the recording information was not performed efficiently when the

transmittance for white light was less than 60 %. Therefore, the transmittance for white light is desirably at least 60 %. The average diameter of the glass of No. 16 was 51 nm, and the volume fraction of the fine particles calculated from the TEM photograph was 22 %. On the basis of the above data, the volume fraction of the fine particles is increased and the transmittance for white light is decreased if the average diameter exceeds 50 nm. Therefore, it is not desirable if the Er_2O_3 content exceeds 16 % by weight, the average diameter of the deposited particles exceeds 50 nm, and the volume fraction of the deposited particles exceeds 20 %.

Various rare earth elements were added to the glass of No. 1 for studying their influence. Table 5 indicates the kind of added rare earth element, and the glass transition temperature (Tg), the thermal expansion coefficient, and micro-Vickers hardness (Hv) of the obtained glasses. FIGs. 5 and 6 indicate relationships between the kind of the added rare earth elements, and Hv and Tg, respectively. Each of the rare earth elements was added as an oxide expressed by the chemical formula of Ln_2O_3. The additive amount of all the rare earth elements was 0.026 mol %. The manufacturing method of the glass and the measuring method of the characteristics are as same as the table 1.

Table 5

No.	Ln	Ln_2O_3 content (weight ratio)	Tg (℃)	α	Hv
27	Sc	3.58	593	91.4	666
28	Y	5.89	582	81.6	653
29	La	8.47	583	90.2	650
30	Ce	8.53	582	91.3	648
31	Pr	8.61	585	92.2	651
32	Nd	8.78	587	86.4	646
33	Sm	9.07	584	93.5	651
34	Eu	9.19	585	95.5	652
35	Gd	9.46	580	90.9	685
36	Tb	9.51	583	90.3	682
37	Dy	9.70	581	90.6	683
38	Ho	9.82	584	91.6	682
39	Er	10.00	582	92.2	683
40	Tm	10.03	586	92.0	682
41	Yb	10.30	588	90.9	685
42	Lu	10.40	585	91.1	684

In accordance with Table 5, the micro-Vickers hardness were increased in all the cases when any of the rare earth element was added. The amount of the increment was significant when a heavier rare earth element than Gd_2O_3, so-called heavy rare earth elements, was added. The hardness when the heavy rare earth element was added was

at least 680, which was larger than the value of Hv of the chemically strengthened glass. On the other hand, the hardness when the light rare earth element from Sc_2O_3 to Eu_2O_3 was added was approximately 650, which was smaller than the value of Hv of the chemically strengthened glass.

The glass transition temperature was constant such as approximately 585 whichever rare earth element was added. The thermal expansion coefficient of the glasses were in the range of 81.6 ~ 92.2 X $10^{-7}/℃$, and the matching of the substrate with the information recording medium layer was preferable. In accordance with the study described above, Gd, Tb, Dy, Ho, Er, Tm, Yb, and Lu are the desirable rare earth elements to be added to the glass.

When the structure of the glass of No. 21 containing Gd_2O_3 was observed by the TEM, crystalline fine particles as same as the Er_2O_3 added glass were observed. The average particle size was 15 nm.

Composition of the base glass was studied. The content of SiO_2 less than 40 % by weight was not desirable, because the mechanical strength and chemical stability of the base glass were deteriorated. When the content of SiO_2 exceeds 80 % by weight, the fusibility of the glass was decreased, and many striae were generated. The thermal expansion coefficient of the glass was decreased so small that the glass became inadequate to be used as the glass for the substrate. On the basis of the above reason, the content of SiO_2 is desirably in the range of 40 % by weight ~ 80 % by weight.

When B_2O_3 was added to the base glass, a base glass having a superior fluidity and an adequate thermal expansion coefficient was obtained. However, when the content of B_2O_3 exceeded 20 % by weight, the effect of improving mechanical strength by adding the rare earth elements was decreased. Therefore, the content of B_2O_3 is desirably utmost 20 % by weight.

Alkali metal oxides were studied. When sum of the additive amount of the alkali metal oxides (Li_2O, Na_2O, K_2O) exceeded 20 % by weight, chemical stability was decreased. Therefore, the sum of the content of the alkali metal oxides is desirably in the range of 0 ~ 20 % by weight. Furthermore, when sum of the additive amount of the alkali earth metal oxides exceeded 20 % by weight, chemical stability was decreased as same as the case of adding alkali metal oxides. Therefore, the sum of the content of the alkali earth metal oxides is desirably in the range of 0 ~ 20 % by weight.

Adding each of alkali metal oxides, alkali earth metal oxides, and B_2O_3 has the same effect in decreasing the melting point of the glass. However, when sum of the additive amount of the above oxides was less than 10 % by weight, the fluidity was undesirable, and many striae were generated. On the contrary, when the sum exceeded 30 % by weight, the chemical stability was decreased. Therefore, the sum of the additive amount of the alkali metal oxides, alkali earth metal oxides, and B_2O_3 is desirably in the range of 10 ~ 30 % by weight.

Adding Al_2O_3 was effective in increasing mechanical strength and chemical stability of the glass. However, the content of Al_2O_3 exceeding 17 % by weight was undesirable, because the fluidity of the glass was decreased. Therefore, the content of Al_2O_3 is desirably utmost 17 % by weight.

When the content of rare earth oxides exceeded 30 % by weight, homogeneous glass was hardly obtained, because raw material powder remained in the glass when melting operation of the glass, and the content was undesirable. The less was the sum of the content of the alkali metal oxides, the significant effect of improving the mechanical strength was obtained by adding the less amount of rare earth oxides. When the sum of the additive amounts of the alkali metal oxides and the alkali earth metal oxides was 10 % by weight, the improvement in mechanical strength was observed by adding the rare earth oxides of 0.5 % by weight. However, when the adding amount of the rare earth oxides was less than 0.5 % by weight, the effect of improving the mechanical strength was not significant. Therefore, the content of the rare earth oxides is desirably in the range of 0.5 - 30 % by weight.

The glass substrate relating to the present invention has a sufficient strength by adding the rare earth elements. Therefore, the chemically strengthening of the glass, which has been necessary for the conventional glass substrate, becomes unnecessary. That means, the glass substrate of the present invention is

characterized in having no compressive strengthening layer which generates a residual stress at surface of the glass. The presence of the compressive strengthening layer at the surface of the glass can be determined by a method, for example, wherein a laser beam is projected to the surface of the glass and the reflected beam is spectroscopically analyzed using a prism. Using the above method, the glass substrate of the present invention was confirmed that difference of the residual stresses between the inside of the glass substrate and the surface of the glass substrate hardly existed, in other words, no surface compressive strengthening layer existed.

The practical substrates were prepared actually with the glass obtained by the embodiments, and their characteristics were evaluated. The glasses of No. 1, 5, 7, 8, 18, and 35 were used. As the comparative examples, the chemically strengthened glass of No. 26, and SiO_2-Al_2O_3-ZnO-MgO-RO group crystallized glass substrate indicated in Table 6 were evaluated.

Shape of the prepared glass substrate was 65 mm in diameter and 0.635 mm in thickness. Water resistance, heat resistance, surface roughness, and transmittance for white light of the prepared substrates are indicated in Table 7.

Table 6

No.	Tg (℃)	α	Hv	Remarks
43	780	114	720	Crystallized glass

Table 7

No.	Water resistance Alkaline concentration (ppm)	Heat resist-ance	Surface roughness Ra (Å)	Transmittance (%)
5	10.0	○	4	74.0
35	15.0	○	4	94.0
26	312.0	△	4	95.0
43	2.0	○	9	15.0
1	11.0	○	4	94.0
7	11.5	○	5	67.0
8	10.7	○	10	58.0
18	4.0	○	5	79.0

The water resistance was evaluated by immersing the substrate into warm pure water of 80 ml at 70 ℃ for 20 hours, determining the dissolved amounts of total alkali elements and alkaline earth elements into the pure water, and indicating the total dissolved amount by ppm.

The heat resistance was evaluated by heating the substrate at 350 ℃ in a vacuum, and subsequently analyzing the surface portion of the substrate by secondary ions mass spectrometry. The test piece, wherein a diffusion of the alkaline ions was observed at the surface layer of the substrate, was indicated by △, and the test piece, wherein the diffusion was not observed, were indicated by ○.

The surface roughness was evaluated by an average surface roughness Ra (Å) using a surface roughness tester. The transmittance was evaluated as an intensity ratio of incident light and transmitted light by irradiating the surface of the substrate with a white light source.

The water resistance of the glass substrates of No. 1, 5, 7, 8, 18, 35, and 43 were desirable, because the dissolved amounts of the alkaline elements were small. The chemically strengthened glass substrate of No. 26 was not desirable, because the dissolved amounts of the alkaline elements was significant.

Similarly in the heat resistance evaluation, a large amount of alkaline elements were detected at the surface

layer of the chemically strengthened glass substrate of No. 26, and it was found that the ions moving occurred. As explained above, the chemically strengthened glass substrate was unstable because it readily caused moving alkaline elements. On the contrary, the glass substrate of the present invention was desirable in both thermal and chemical stability.

Regarding the surface roughness, preferable flatness such as Ra = 4 ~ 5 Å was obtained with the glass substrates of No. 1, 7, 18, 5, 35, and 26. On the contrary, the surface roughness of the glass substrates of No. 8 and 43 were as large as Ra = 9 ~ 10 Å.

The transmittance for white light of the glasses of No. 1, 7, 5, 18, 35, and 26 were as desirable as 67 ~ 95 %. The transmittance of the glasses of No. 8 and 43 were as low as 58 % and 15 %, respectively.

A relationship between the surface roughness and the depositing condition of the fine particles was studied. Regarding the glass of No. 7, the content of Er_2O_3 was 16 % by weight, and the average particle size of the deposited fine particles was 51 nm. The volume fraction of the fine particles was 40 %. The transmittance of the glass of No. 7 under the above condition was 67 %. On the other hand, regarding the glass of No. 8, the content of Er_2O_3 was 21 % by weight, the average particle size of the deposited fine particles was 103 nm, and the volume fraction of the fine particles was 72 %. The transmittance of the glass of No. 8 under the above condition was 58 %. Under the above

conditions, the surface roughness of the glass of No. 7 was 5.0 Å, and the glass of No. 8 was 10.0 Å as twice as that of the glass of No. 7. As explained above, it was found that when the content of Er_2O_3 exceeded 20 % by weight, the average particle size of the deposited fine particles exceeded 100 nm, and the transmittance was less than 60 %, the surface roughness of the glass was significant, and the glass was inferior in surface flatness.

In accordance with the above findings, the content of rare earth oxides such as Er_2O_3 is desirably less than 20 % by weight. The average particle size is desirably utmost 100 nm. The transmittance is desirably at least 60 %. When the above conditions are satisfied, the sufficiently small surface roughness can be obtained.

Using each of the above 8 kinds of glasses, a magnetic disk was manufactured by forming magnetic film on the glass substrate, and its characteristics was evaluated. The composition of the film of the manufactured magnetic disk is indicated in FIG. 8. In FIG. 8, the numeral mark 1 indicates the glass substrate, 2 is Cr precoat film, 3 is Cr base film, 4 is Co-Cr group magnetic film, 5 is C protective film, 6 is an etching texture, and 7 is lubricating film.

After cleaning a magnetic glass substrate of 65 mm in diameter, each of Cr precoat film of 25 nm thick, Cr base film of 50 nm thick, and Co-Cr group magnetic film of 50 nm was formed on the magnetic glass substrate. Then, after forming carbon protective film of 10 nm thick, an

etching texture was provided. After performing tape cleaning, a magnetic disk was manufactured by applying the lubricating film 4. The film was formed on both surfaces of the substrate plane. Subsequently, corroded conditions of the magnetic film of the magnetic disk by an alkali, and the presence of the film splitting were evaluated.

Using the above magnetic disk, a magnetic disk apparatus was manufactured. A schematic perspective view of the manufactured magnetic disk apparatus is indicated in FIG. 10. In FIG. 10, the numeral mark 8 indicates the magnetic disk indicated in FIG. 8, 9 is a rotary shaft, 10 is a spindle motor, 11 is a magnetic head, 12 is a rotary shaft of the magnetic head, and 13 is an output terminal of electric system. Six magnetic disks 8 were fixed to the rotary shaft 9 in the apparatus. Two magnetic heads 11 were provided at each of the both surfaces of the substrate. The magnetic disk apparatus was manufactured by connecting a control system and others. The levitating amount of the head during rotating the magnetic disk was 40 nm.

Using the above magnetic disk apparatus, record regenerating characteristics was evaluated. The observed results on the alkali corrosion, the film splitting, and the record regenerating characteristics are indicated in Table 8.

Table 8

No.	Alkali corrosion	Film splitting	Record regenerating characteristics
5	○	○	○
21	○	○	○
12	△	△	○
29	○	○	△

When a ratio of the number of the magnetic disk wherein the alkali corrosion was observed was less than 5 % to the total number of the obtained magnetic disk, the alkali corrosion was indicated by ○, and when the ratio was 5 % or more, the alkali corrosion was indicated by △. The magnetic disk relating to the present invention scarcely had the alkali corrosion and/or the film splitting, and the record regenerating characteristics of the magnetic disk was preferable.

The alkali corrosion and the film splitting of the chemically strengthened glass of No. 12 were significant, and the glass was undesirable. The alkali corrosion and the film splitting of the crystallized glass of No. 29 were not observed, but the record regenerating characteristics of the glass was undesirable.

Using various kinds of glass relating to the present invention, glass substrates were prepared, and a shock

resistance test was performed. The shock resistance was evaluated using magnetic disks, which had the same film structure as indicated in FIG. 8, and were manufactured by forming the magnetic film, the protective film, and the others onto both surfaces of the glass substrate in accordance with the same method as above.

The test was performed by clamping the prepared disk with a jig, and colliding a dummy head to the disk by an accelerator. The test was performed 30 points for each of the various kind of magnetic disks, and the shock resistance was evaluated by the frequency of the points wherein any defects such as cracks, breakage, and the like were generated. As the glass for the substrate, the glasses of No. 1 ~ 5, 14, 18, 23 ~ 26, and 43 in Table 1 were used. The results of the shock resistance test are indicated in FIG. 7. The abscissa indicates the Hv of the respective glass, and the ordinate indicates the frequency of generating the defects in the test by %. The hardness of the glass of 670 can be regarded as a boundary of generating the defects. When the hardness of the glass is lower than 670, generating the defects were observed, and the frequency of generating the defects was increased in accordance with decreasing the hardness. When the hardness of the glass is higher than 670, generating the defects were not observed. In accordance with the above observation, if the hardness of the glass substrate is at least 670, the magnetic disk having sufficient shock resistance against the shock resistance test can be

manufactured.

In the same manner, optical disks, and an optical disk apparatus were manufactured. Using the glass substrates of the present invention, the optical disk, of which recording medium layers were scarcely split, could be manufactured, and the record was regenerated with a high efficiency.

As explained above, the information recording disk of the present invention was superior in chemical stability, and defects such as film splitting were scarcely generated. The record regenerating characteristics of the information recording disk apparatus was preferable. The disk and the apparatus could be manufactured with a low cost, because no chemical strengthening treatment nor crystallizing treatment were performed.

(Embodiment 2)

A magnetic disk of the shape indicated in FIG. 9 was manufactured using the glass substrate of the present invention. Thickness of the substrate was 0.38 mm. The glass of No. 5, which was not treated for chemical strengthening, was used in manufacturing the magnetic disk. The precoat film, which was generally formed in a routine operation, was not formed, and the magnetic thin film was formed directly onto the surface of the glass substrate. The surface roughness of the glass substrate was Ra = 4.0 Å.

As comparative examples, magnetic disks were manufactured using soda lime glass strengthened by alkali strengthening treatment, normal soda lime glass without the alkali strengthening treatment, and crystallized glass, as the substrates.

The results of evaluating the strength, flatness, alkali corrosion of the magnetic film, and magnetic characteristics of the magnetic disks are indicated in Table 9. Preferable characteristics is indicated by ○, and the characteristics of not preferable is indicated by △.

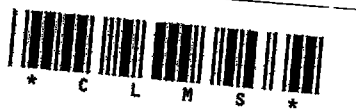
Table 9

Substrate	Strength	Flatness	corrosion[1)]	Magnetic characteristics	Remarks
No. 5 glass	○	○	○	○	Embodiment
Chemically strengthened soda lime glass	○	○	△	△	Comparative example
Soda lime glass without chemical strengthening	△	○	○	○	Comparative example
Crystallized glass	○	△	○	△	Comparative example

1): Alkali corrosion of the magnetic film

The magnetic disk of the present invention had a desirable strength, and thickness of 0.380 mm gave it a sufficient strength for practical use. Flatness was also preferable. Corrosion of the magnetic film was not observed, and the magnetic film was not deteriorated even if no precoat film was formed. The levitating amount of the magnetic head could be set as utmost 30 nm, because the flatness of the disk is preferable, and the magnetic characteristics was also superior.

The soda lime glass treated for chemically strengthening obtained a high mechanical strength. However, the magnetic film was corroded with the alkaline component of the glass, because no precoat film was formed, and, as the result, deposition of the alkaline components onto the surface of the levitating plane of the magnetic head after practical sliding test was frequently observed. Furthermore, after the sliding test, splitting the magnetic film was observed. Even for the magnetic disk, which did not cause any defects, its magnetic characteristics was generally deteriorated. The magnetic disk manufactured using the soda lime glass without the chemically strengthening treatment had not a sufficient strength for practical use. The crystallized glass had a large surface roughness, and the levitating amount of the magnetic head was too large to obtain preferable magnetic characteristics, because the flatness was undesirable.



What is claimed is;

1. A glass substrate of disk for recording information comprising a layer for recording information, which is provided on at least a portion of surface of the glass substrate, wherein

said substrate is made of glass containing at least one of rare earth elements selected from a group consisted of Sc, Y, La, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, and Lu.

2. A glass substrate of disk for recording information as claimed in claim 1, wherein

no compressive strengthened layer at surface portion of said glass substrate exists, and

a stress distribution in said glass substrate is substantially homogeneous.

3. A glass substrate of disk for recording information as claimed in claim 1, wherein

fine particles are dispersed in said glass, and said rare earth element is contained in said fine particles.

4. A glass substrate of disk for recording for information as claimed in claim 1, wherein

said rare earth element is contained in said glass in the range of 0.5 ~ 30 % by weight to the total amount of said glass on a basis of converted weight to oxide of

Ln_2O_3 (Ln is a rare earth element).

5. A glass substrate of disk for recording information as claimed in claim 1, wherein

said rare earth element is contained in said glass in the range of 0.5 ~ 20 % by weight to the total amount of said glass on a basis of converted weight to oxide of Ln_2O_3 (Ln is a rare earth element).

6. ~~A~~ glass substrate of disk for recording information as claimed in claim 1, wherein

said rare earth element is at least the one element selected from a group consisted of Gd, Tb, Dy, Ho, Er, Tm, Yb, and Lu.

7. A glass substrate of disk for recording information as claimed in claim 3, wherein

an average particle size of said fine particles is in the range of 1 ~ 100 nm.

8. A glass substrate of disk for recording information as claimed in claim 3, wherein

a volume fraction of said fine particles is in the range of 1 % ~ 40 % to the total volume of said glass.

9. A glass substrate of disk for recording information as claimed in claim 1, wherein

said glass contains:

* C L M S *

said rare earth element in the range of 0.5 ~ 20 % by weight to the total amount of said glass on a basis of converted weight to oxide of Ln_2O_3 (Ln is a rare earth element), further contains, as other components:

SiO_2 : 40 ~ 80 % by weight,

B_2O_3 : 0 ~ 20 % by weight,

R_2O (R is an alkali metal) : 0 ~ 20 % by weight,

RO (R is an alkali earth metal) : 0 ~ 20 % by weight, and

Al_2O_3 : 0 ~ 17 % by weight, and furthermore,

R_2O + RO is in the range of 10 ~ 30 % by weight.

10. A glass substrate of disk for recording information as claimed in claim 1, wherein

a transmittance for visible white light of said glass is at least 60 %.

11. A glass substrate of disk for recording information comprising a layer for recording information, which is provided on at least a portion of surface of the glass substrate, wherein

said substrate has:

a hardness of at least Hv 670,

a transmittance for visible white light of at least 60 %,

no compressive strengthened layer at surface portion of said glass substrate, and

a substantially homogeneous stress distribution in

said glass substrate.



12. A glass substrate of disk for recording information comprising a layer for recording information, which is provided on at least a portion of surface of the glass substrate, wherein

said substrate has:

a thickness of utmost 0.38 mm,

a surface roughness of said substrate of utmost 5 nm as Ra,

no compressive strengthened layer at surface portion of said glass substrate, and

a substantially homogeneous stress distribution in said glass substrate.

13. A magnetic disk provided with magnetic recording medium film for recording information on surface of a disk shaped substrate, wherein

said substrate is made of glass,

a thickness of said substrate is utmost 0.38 mm, and

said magnetic recording medium film is formed directly on the surface of said substrate.

14. A photodisk provided with magnetic recording medium film for recording information on one side surface of a round plane of a disk shaped substrate, wherein

said substrate is made of glass,

thickness of said substrate is utmost 0.38 mm, and



diameter of said substrate is at least 2.5 inches.

15. An information recording disk apparatus comprising at least a disk for recording information, a head for reading out information from said disk, or inputting information into said disk, a driver for said disk, and a driver for said head, wherein a layer for recording information is provided onto at least a portion of the surface of said disk for recording information, and a substrate of said disk is made of glass containing at least one of rare earth elements selected from a group consisted of Sc, Y, La, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, and Lu.