DESCRIPTION

Title of Invention

INFORMATION RECORDING MEDIUM DISK

Technical Field

[0001] The present invention relates to an information recording medium disk.

Background Art

[0002] Following the expansion of cloud computing in recent years, many hard disk drives (HDDs) are used in data centers for a cloud in order to increase the storage capacity. An information recording medium disk (also referred to as a "magnetic disk" hereinafter) in which a magnetic layer is provided on an annular substrate is used as a storage medium in an HDD. In order to increase the storage capacity of an HDD, it is preferable to increase the number of mounted magnetic disks by reducing the thickness of a magnetic disk, in addition to increasing the recording density of the magnetic layer in the magnetic disk.

[0003] In order to increase the recording density of the magnetic layer, shingled magnetic recording (SMR) is known as a recording system that increases the recording density in the track width direction. In shingled magnetic recording (SMR), when recording data, the track width is narrowed and the recording density is increased by overlapping the recorded data onto a portion of the previously recorded track, in a manner like laying roof shingles. Also, an energy-assisted magnetic recording system (EAMR), such as a heat-assisted magnetic recording system (HAMR) and a microwave-assisted magnetic recording system (MAMR), is known as a recording system in which the recording density is increased by increasing the density of magnetic particles. In the energy-assisted magnetic recording system (EAMR), the magnetic particles are made smaller to reduce the bit size, and when recording data, energy is added to the magnetic particles to lower their coercivity, thereby assisting in magnetization reversal and increasing recording density. Due to the magnetic particles having small sizes, the track width is narrower even in the energy-assisted magnetic recording system (EAMR). Note that it is possible to use shingled magnetic recording (SMR) and the energy-assisted magnetic recording system (EAMR) in combination.

[0004] Within an HDD, the ambient temperature around a magnetic disk changes due to the

high-speed rotation of the magnetic disk (see PTL 1). When the ambient temperature rises, the magnetic disk expands due to heat, and the tracks expand radially outwards accompanying this expansion. As a result, during data writing and reading, the magnetic head may become radially misaligned with the tracks beyond an allowable range, making it prone to errors. In the shingled magnetic recording (SMR) and the energy-assisted magnetic recording system (EAMR), the track width is narrow, and consequently, the allowable amount of misalignment of the magnetic head relative to the track (off-track tolerance) is small, and thus write or read errors (R/W errors) are likely to occur. On the other hand, from the viewpoint of increasing recording capacity, even when the positioning accuracy of the magnetic head using servo information for narrower tracks are improved, there is a risk that changes in the shape of the magnetic disk due to temperature changes may become unacceptable. Therefore, it is preferable that the thermal expansion of the magnetic disk due to temperature changes is as small as possible, and from the viewpoint of guaranteeing the quality of the magnetic disk, a low coefficient of thermal expansion over a wide temperature range is required.

Citation List

Patent Literature

[0005] [PTL1]: JP 2008-4139A

Summary of Invention

Technical Problem

[0006] However, it has become clear that even when the coefficient of thermal expansion of a magnetic disk is in a predetermined range, the magnitude of the coefficient of thermal expansion may differ depending on a circumferential position of the magnetic disk. If there is a variation in the coefficient of thermal expansion in the circumferential direction, when the magnetic disk expands due to heat, the perfectly circular tracks may become distorted, leading to a phenomenon in which data is written to other tracks or data cannot be read continuously from a single track. The thermal expansion amount of a magnetic disk increases towards the outer circumferential portion, and the distortion of the track shape also increases. Therefore, this phenomenon can occur more prominently at the outer circumferential portion of the magnetic disk. In particular, in magnetic disks where data is recorded using the shingled magnetic recording (SMR) and/or the energy-assisted magnetic recording system (EAMR), the track width is narrow. Thus, even

when the track shape is slightly distorted, the frequency of R/W errors increases due to this phenomenon. Furthermore, if the thickness of the disks is reduced in order to increase the number of disks mounted, the disks tend to flutter. As a result, even when the track shape is slightly distorted, a further increase in the frequency of R/W errors is predicted.

[0007] In view of this, the present invention aims to provide a thin information recording medium disk that can suppress the occurrence of errors in writing or reading information to or from the information recording medium disk.

Solution to Problem

[0008] The present disclosure includes the following aspects.

Aspect 1

An information recording medium disk having a thickness of 0.51 mm or less, the information recording medium disk including:

a substrate having one main surface, an opposite main surface, and a side wall surface connecting the two main surfaces; and

a recording layer,

wherein a variation in a thermal expansion amount in a radial direction of the disk over a circumferential direction of the disk when the temperature is increased by 5°C in a temperature range of -30°C to 70°C, the thermal expansion amount being calculated assuming that the disk has a diameter of 95 mm, is 0.3 μm or less, and

a ratio of the variation in the thermal expansion amount to a coefficient of thermal expansion of the disk at -30°C to 70°C is 1.1×10^4 μm•K or less.

[0009] Aspect 2

An information recording medium disk having a thickness of 0.51 mm or less, the information recording medium disk including:

a substrate having one main surface, an opposite main surface, and a side wall surface connecting the two main surfaces; and

a recording layer,

wherein a variation in a thermal expansion amount in a radial direction of the disk over a circumferential direction of the disk when the temperature is increased by 5°C in a temperature range of -30°C to 70°C, the thermal expansion amount being calculated assuming that the disk

has a diameter of 95 mm, is 0.3 μm or less, and

VTE×(E/d)/CTE expressed using the coefficient of thermal expansion CTE [$\times 10^{-6}$/K] of the disk at -30°C to 70°C, the variation in the thermal expansion amount VTE [μm], and a ratio E/d [$\times 10^{6}$ m^2/s^2] of a Young's modulus E [GPa] to a density d [g/cm^3] of the disk is 3.0×10^{5} [$m^3 \cdot K/s^2$] or less.

[0010] Aspect 3

The information recording medium disk according to aspect 1, wherein VTE×(E/d)/CTE expressed using the coefficient of thermal expansion CTE [$\times 10^{-6}$/K] of the disk at -30°C to 70°C, the variation in the thermal expansion amount VTE [μm], and a ratio E/d [$\times 10^{6}$ m^2/s^2] of a Young's modulus E [GPa] to a density d [g/cm^3] of the disk is 2.6×10^{5} [$m^3 \cdot K/s^2$] or less.

Aspect 4

The information recording medium disk according to Aspect 1 or 2, wherein the recording layer has a magnetic layer on at least a main surface of the substrate, the magnetic layer having a circumferential recording area, and

a track width for reading recorded information in the recording area is 60 nm or less, and the variation in the thermal expansion amount is smaller than the track width.

[0011] Aspect 5

The information recording medium disk according to Aspect 4, for use in a hard disk drive in which information is read from and written to the magnetic layer through shingled magnetic recording.

[0012] Aspect 6

The information recording medium disk according to Aspect 4, wherein information is recorded in the magnetic layer using an energy-assisted magnetic recording system.

[0013] Aspect 7

The information recording medium disk according to Aspect 1 or 2, wherein the variation in the thermal expansion amount is 0.040 μm or less, and

the substrate is made of a glass containing, in mole percent on an oxide basis:

SiO_2 in an amount of 55 mol% to 80 mol%, Al_2O_3 in an amount of 5 mol% to 25 mol%, and B_2O_3 in an amount of 0 mol% to 8 mol%;

at least one of MgO, CaO, SrO, and BaO in a total amount of 10 mol% to 25

mol%; and

at least one of Li_2O, Na_2O, and K_2O in a total amount of 0.001 mol% to 5.0 mol%.

[0014] Aspect 8

The information recording medium disk according to Aspect 1 or 2, wherein the variation in the thermal expansion amount is 0.20 μm or less,

the substrate includes:

a substrate body made of an aluminum alloy; and

a nickel alloy film provided on a surface of the substrate body; and

the aluminum alloy contains:

at least one of Fe, Mn, and Ni in a total amount of 3.0% by mass to 8.0% by mass, or Si in an amount of more than 3.0% by mass, with the balance being Al and inevitable impurities.

[0015] Aspect 9

The information recording medium disk according to Aspect 8, wherein in a cross-section of the substrate body, a longest diameter of particles containing a metal other than Al that have been precipitated in the substrate body is 5 μm or less.

Aspect 10

The information recording medium disk according to Aspect 9, wherein in the cross-section of the substrate body, among the particles, a number density of particles with a longest diameter of 0.1 to 3 μm is 50 particles/mm^2 or more.

Aspect 11

The information recording medium disk according to Aspect 8, wherein the film has a thickness of 7.5 μm or less.

Brief Description of Drawings

[0016] [FIG. 1] is a diagram showing an external shape of an information recording medium disk according to an embodiment.

[FIG. 2] is a diagram illustrating a procedure for measuring a variation in the thermal expansion amount of the magnetic disk.

[FIG. 3] is a schematic cross-sectional view illustrating coarse particles precipitated in

a substrate of the magnetic disk.

Description of Embodiments

[0017] An information recording medium disk according to an embodiment will be described below in detail.

[0018] In the following description, a magnetic disk, in which information is recorded on a magnetic film formed on a main surface of a substrate, is described as an example of an information recording medium disk.

FIG. 1 shows an external shape of a magnetic disk 1 according to an embodiment. This embodiment includes a first embodiment and a second embodiment that will be described below.

[0019] (First Embodiment)

The magnetic disk 1 has a thickness of 0.51 mm or less. Because the magnetic disk 1 has a thickness of 0.51 mm or less, it is possible to increase the number of magnetic disks 1 mounted in an HDD, and to increase the storage capacity of the HDD. The thickness of the magnetic disk 1 is preferably 0.50 mm or less, 0.48 mm or less, 0.46 mm or less, 0.45 mm or less, 0.43 mm or less, 0.42 mm or less, 0.40 mm or less, 0.38 mm or less, 0.35 mm or less, 0.32 mm or less, 0.30 mm or less, 0.28 mm or less, 0.25 mm or less, 0.22 mm or less, 0.20 mm or less, or 0.18 mm or less. There is no particular limitation on the lower limit of the thickness of the magnetic disk 1, and for example, the lower limit is 0.15 mm. Since the thickness of the magnetic film on the magnetic disk 1 is extremely thin, approximately 100 nm or less, the thickness of the magnetic film can be ignored in determining the thickness of the magnetic disk 1.

[0020] The magnetic disk 1 includes a substrate 3 and a magnetic film (not shown). The substrate 3 is an annular plate member provided with an inner hole 1a. The substrate 3 includes one main surface 3a and an opposite main surface 3b, and side wall surfaces 3c and 3d connecting the two main surfaces 3a and 3b. The main surfaces 3a and 3b are two surfaces that are parallel to each other. The side wall surface 3c is an outer circumferential edge portion of the substrate 3, and the side wall surface 3d is an inner circumferential edge portion of the substrate 3.

[0021] A variation (the magnitude of the variation, which will be also referred to as a “variation in the thermal expansion amount VTE” hereinafter) in a radial direction of the magnetic disk 1 over a circumferential direction of the magnetic disk 1 when the temperature is increased by 5°C

in a temperature range of -30°C to 70°C, the thermal expansion amount being calculated assuming that the magnetic disk 1 has a diameter of 95 mm, is 0.3 μm or less. The temperature inside an operating HDD falls within a temperature range of approximately 5°C (typically 55°C to 60°C) in the temperature range of -30°C to 70°C, due to the high-speed rotation of the magnetic disk 1. Because the variation in the thermal expansion amount VTE over the circumferential direction in this temperature range is limited to 0.3 μm or less, when reading or writing data, the reader or writer mounted on the magnetic head is more easily positioned in an allowable range of the amount of misalignment in the radial direction (off-track tolerance) relative to a target track of the magnetic disk 1, thereby making it easier to suppress the occurrence of R/W errors.

[0022] The off-track tolerance is typically set in a range of 10% of the track width on both sides in the radial direction of the target track. From the viewpoint of increasing recording capacity, there is a need to improve the positioning accuracy of the magnetic head using servo information, and by utilizing this high positioning accuracy, the track width tends to become even smaller. When the magnetic head misalignment exceeds the off-track tolerance, an error will occur, and an HDD controller may repeatedly perform a process for attempting to read or write the data again (retries). When the error persists even after repeated retries, the primary function of the HDD, that is, correctly reading or writing recorded information, is compromised, and the reliability of the HDD cannot be guaranteed. Therefore, it is preferable that the amount of elongation of the magnetic disk in the radial direction caused through thermal expansion of the magnetic disk in the temperature range of the operating HDD is as small as possible. However, even when the amount of elongation of the overall magnetic disk in the radial direction caused by thermal expansion is small, if the amount of elongation varies over the circumferential direction of the magnetic disk, and thermal expansion is anisotropic, the shape of a perfectly circular track may become distorted when the magnetic disk expands due to heat, and this distortion can lead to a phenomenon in which data cannot be continuously read from one track or data is written to another track. Such distortion of the track shape results in an elliptical shape, for example, due to a difference in the amount of elongation of the magnetic disk between two mutually orthogonal directions within the plane of the main surface of the magnetic disk. The thermal expansion amount of the magnetic disk is greater at the outer circumferential portion of the magnetic disk, where the amount of elongation in the radial direction accumulates, and the

distortion of the track shape is also greater at the outer circumferential portion. Therefore, the above-mentioned phenomenon can occur more prominently at the outer circumferential portion of the magnetic disk. In particular, in magnetic disks where the track width has narrowed due to increased recording density, the off-track tolerance is extremely narrow, reaching a range of a few nanometers. Therefore, even slight distortion of the track shape can increase the frequency of R/W errors due to this phenomenon. Furthermore, if the thickness of the disks is reduced in order to increase the number of disks mounted, the disks tend to flutter. As a result, even when the track shape is slightly distorted, a further increase in the frequency of R/W errors is predicted.

[0023] The variation in the thermal expansion amount VTE is calculated as the difference between the maximum value and the minimum value of the thermal expansion amount at a plurality of circumferential positions around the center of the magnetic disk 1. The thermal expansion amount is measured at three or more positions that are equally spaced in the circumferential direction. In magnetic disks, thermal expansion occurs in the diametrical direction, and variations in the thermal expansion amount occur over the circumferential direction due to differences (distribution) in the material orientation and residual stress of the substrate. In this regard, the plurality of circumferential positions of the magnetic disk 1 for determining the thermal expansion amount are three points (120° intervals), preferably six points (60° intervals), and more preferably twelve points (30° intervals), which are equally spaced from each other in the circumferential direction, and the variation in the thermal expansion amount VTE is calculated using the values of the coefficient of thermal expansion (average coefficient of linear expansion) measured at these positions. FIG. 2 shows a diagram illustrating a procedure for measuring the variation in the thermal expansion amount VTE of the magnetic disk 1. In the measurement procedure shown in FIG. 2, portions (samples S) located at three circumferential positions 120 degrees apart from each other around a center O of the magnetic disk 1 are used as measurement targets.

[0024] Each sample S is preferably cut out from the disk in a rectangular shape along the radial direction, as shown in the drawing. The dimensions of the sample S on the magnetic disk 1 are not particularly limited, but for example, the sample S may be cut to a length of 10 to 12 mm in the radial direction and a width of 5 to 6 mm (length in the direction orthogonal to the radial direction). An average coefficient α of linear expansion can be determined for each of the

samples S cut from the disk at different circumferential positions, through measurement using a thermomechanical analysis device in a temperature range of -30°C to 70°C.

[0025] The thermal expansion amount at each measurement target circumferential position is the thermal expansion amount when the temperature of the magnetic disk rises by 5°C in the temperature range of -30°C to 70°C. For example, it is the expansion amount when the temperature of the magnetic disk is changed from 55°C to 60°C. It is calculated using the average coefficient α of linear expansion of each sample S measured at each position in the circumferential direction, assuming that the magnetic disk 1 has a diameter of 95 mm. By calculating the thermal expansion amount of the magnetic disk 1 assuming that the magnetic disk 1 has a diameter of 95 mm, the variation in the thermal expansion amount VTE can be compared between magnetic disks with different diameters, allowing for a comparison of the degree of anisotropy in thermal expansion. The reason for calculating the thermal expansion amount assuming that the magnetic disk 1 has a diameter of 95 mm is that magnetic disks with a diameter of 95 mm or more are widely used because a magnetic layer with a larger area can be provided, thereby increasing the storage capacity of HDDs. On the other hand, for magnetic disks with a diameter of 95 mm or more, the magnetic disk 1 has a large thermal expansion amount at the outer circumferential portion, and tracks at the outer circumferential portion are also greatly distorted due to the anisotropy of thermal expansion. Therefore, limiting the variation in the thermal expansion amount VTE calculated assuming that the magnetic disk 1 has a diameter of 95 mm is effective from the viewpoint of suppressing the occurrence of errors in an operating HDD.

[0026] The thermal expansion amount of the magnetic disk 1 assuming that the magnetic disk 1 has a diameter of 95 mm is calculated specifically according to the following formula.

$$\Delta L = \alpha(T_2 - T_1)L$$

(In the formula, ΔL represents the thermal expansion amount [mm], α represents the average coefficient of linear expansion (hereinafter also simply referred to as the linear expansion coefficient) [$\times 10^{-6}$/K], T_1 is 55°C, T_2 is 60°C, and L is 95 mm.)

The linear expansion coefficient α is expressed as the slope of the thermal expansion amount of the sample S with respect to the temperature change from -30°C to 70°C in a linear expansion curve obtained through measurement in the temperature range of -30°C to 70°C. The

linear expansion curve is a curve that shows a relationship between temperature and elongation of the sample S obtained when the sample S is heated at a constant rate of 5°C per minute or less (e.g., 4°C per minute). It is preferable not to perform any pre-heat treatment for measurement on the sample S when measuring the linear expansion coefficient. This is because pre-heat treatment for measurement reduces differences in the linear expansion coefficient α obtained from the linear expansion curve among measurement target circumferential positions, making it impossible to accurately evaluate the anisotropy of thermal expansion. The linear expansion coefficient conforms to Japanese Industrial Standards JIS Z2285: 2003 or R3102: 1995 except as otherwise described herein.

[0027] The variation in the thermal expansion amount VTE is preferably 0.2 μm or less.

[0028] The ratio of the variation in the thermal expansion amount VTE to the coefficient of thermal expansion CTE (hereinafter also referred to as the ratio VTE/CTE) of the magnetic disk 1 at -30°C to 70°C is 1.1×10^4 μm•K or less. The studies conducted by the inventors of the present invention revealed that, even when the variation in the thermal expansion amount VTE of the magnetic disk 1 is small, when its magnitude is large relative to the coefficient of thermal expansion CTE, the error suppression effect may be insufficient. For example, magnetic disks with a small coefficient of thermal expansion CTE are suitable for use as magnetic disks with narrow track widths and high recording density. However, high recording density magnetic disks require high positioning accuracy of the magnetic head, and thus, even when the variation in the thermal expansion amount VTE is small, the error suppression effect may be insufficient. According to the magnetic disk 1 of the first embodiment, a sufficient error suppression effect can be obtained by limiting the ratio VTE/CTE at -30°C to 70°C to the above range. In this specification, the coefficient of thermal expansion CTE is the average of the average coefficients of linear expansion obtained through measurement at multiple circumferential positions of the magnetic disk 1 in a temperature range of -30°C to 70°C. The average coefficient of linear expansion in the temperature range of -30°C to 70°C is usually used as an index for guaranteeing the quality of the magnetic disk 1. As described above, the average coefficient of linear expansion is expressed as the ratio of the amount of change in the length of the magnetic disk 1 to a predetermined amount of change in temperature, and represents an average slope of the linear expansion curve over a predetermined temperature range.

[0029] Since the influence of the magnetic film on the variation in the thermal expansion amount VTE and the coefficient of thermal expansion CTE is negligible, the variation in the thermal expansion amount VTE and the coefficient of thermal expansion CTE can be determined using the substrate 3 that does not have a magnetic film formed on its surface.

[0030] The ratio VTE/CTE is preferably 1.0×10^4 μm•K or less, or 0.8×10^4 μm•K or less.

[0031] There is no particular limitation on the lower limit of the ratio VTE/CTE, and for example, the lower limit is 0.1×10^4 μm•K.

[0032] The coefficient of thermal expansion CTE of the magnetic disk 1 at -30°C to 70°C is preferably 0.5×10^{-6}/K or more and 25×10^{-6}/K or less. A magnetic disk 1 having a coefficient of thermal expansion CTE in the above range can keep the thermal expansion amount of the magnetic disk 1 in a predetermined range, and it is also possible to predict in advance the expansion amount of the substrate in the operating temperature range of the HDD. This makes it possible to design the track width and the like when recording servo information such that the magnetic head of the HDD is positioned on the target track of the magnetic disk 1.

[0033] As described above, the magnetic disk 1 includes a magnetic film. The magnetic film has a configuration in which, for example, at least an adhesive layer, an undercoat layer, a magnetic layer (magnetic recording layer), a protecting layer, and a lubricating layer are stacked in this order on a main surface of the substrate 3 from a side closer to the main surface. The substrate 3 is, for example, introduced into an evacuated film formation apparatus, and out of the above layers, the adhesive layer, the undercoat layer, and the magnetic layer are sequentially formed on the main surface of the substrate 3 by a DC (Direct Current) magnetron sputtering process in an Ar atmosphere. CrTi can be used for the adhesive layer, for example, and a material containing Ru or MgO can be used for the undercoat layer, for example. Note that a soft magnetic layer or a heat sink layer may also be added as appropriate. After the formation of the magnetic layer, for example, the protecting layer is formed using C_2H_4 by a CVD (Chemical Vapor Deposition) process, a nitriding treatment of introducing nitrogen to the surface is performed in the same chamber, and for example, PFPE (polyfluoropolyether) is applied onto the protecting layer through dip coating, thereby forming the lubricating layer. The magnetic disk 1 can be produced in this manner. The magnetic film may be formed on at least the main surface of the substrate 3, and may also be formed on the side wall surface.

[0034] In order to further increase the recording density of the magnetic disk 1, it is preferable that the magnetic layer contains a magnetic material with high magnetic anisotropy energy. Magnetic materials preferable from this viewpoint can include Fe-Pt-based magnetic materials and Co-Pt-based magnetic materials. The term "-based" means that an element written before "-based" is contained. With respect to a magnetic recording layer containing such magnetic materials and to a film formation method thereof, descriptions in paragraph 0074 of WO 2011/019010A1, and Examples in this publication can be referred to. The magnetic disk 1 having such a magnetic layer is suitable as a magnetic disk to be mounted in an HDD that performs magnetic recording using an energy-assisted magnetic recording system (EAMR). Among energy-assisted recording systems, a recording system in which magnetization reversal is assisted by irradiation with near-field light or the like is referred to as a heat-assisted magnetic recording system (HAMR), and a recording system in which magnetization reversal is assisted by microwaves is referred to as a microwave-assisted magnetic recording system (MAMR). With respect to details of these, paragraph 0075 of WO 2011/019010A1 can be referred to. Note that a conventional CoPtCr-based material may be used as a magnetic material for forming a magnetic layer.

[0035] According to the magnetic disk 1 of the first embodiment described above, it is possible to suppress the occurrence of errors in writing or reading information to or from the magnetic disk 1, thereby ensuring the reliability of the HDD.

[0036] (Second Embodiment)

A magnetic disk 1 according to a second embodiment is configured similarly to the magnetic disk 1 of the first embodiment, except that a later-described VTE×(E/d)/CTE is in a predetermined range, instead of the ratio VTE/CTE of the magnetic disk 1 of the first embodiment being in the above range.

[0037] In the magnetic disk of the second embodiment, VTE×(E/d)/CTE expressed using a coefficient of thermal expansion CTE [$\times 10^{-6}$/K] of the magnetic disk 1 at -30°C to 70°C, a variation in the thermal expansion amount VTE [μm], and a ratio E/d [$\times 10^{6}$ m^2/s^2] of a Young's modulus E [GPa] to a density d [g/cm^3] of the magnetic disk 1 is 3.0×10^{5} [$m^3 \cdot K/s^2$] or less. The studies conducted by the inventors of the present invention revealed that, even when the variation in the thermal expansion amount VTE of the magnetic disk 1 is small, when its magnitude is

large relative to the ratio CTE/(E/d), the error suppression effect may be insufficient. According to the magnetic disk 1 of the second embodiment, a sufficient error suppression effect can be obtained by limiting VTE×(E/d)/CTE at -30°C to 70°C to the above range. In order to increase the number of disks mounted in the hard disk drive housing, it is preferable to use a material with a large Young's modulus E [GPa] and a large specific elastic modulus E/d [$\times 10^6$ m^2/s^2] for the magnetic disk 1. This makes it possible to reduce the deformation of the magnetic disk 1 in response to external stress at a predetermined temperature. However, as the Young's modulus E [GPa] increases, the thermal stress generated in the magnetic disk 1 due to temperature changes also increases. In other words, when thermal expansion is restricted due to constraints on shape changes associated with temperature changes or when there is a temperature distribution, the energy not used for expansion is generated internally as thermal stress (compressive stress or tensile stress). Multiple magnetic disks 1 are stacked together, with their inner circumferences constrained via spacers while the magnetic disks are mounted inside the hard disk drive housing. Further, when material orientation or internal stress distribution occurs in the circumferential direction of the magnetic disk 1, part of the thermal expansion due to temperature changes will be constrained and will be generated as thermal stress. Since thermal stress is proportional to the Young's modulus E [GPa] and the coefficient of thermal expansion CTE [$\times 10^{-6}$/K], these values contribute to variations in the thermal expansion amount over the circumferential direction. Thus, when materials with a large Young's modulus E [GPa] and a specific elastic modulus E/d [$\times 10^6$ m^2/s^2] are used in accordance with a reduction of the thickness of the magnetic disk 1, thermal stress increases, and variations in the thermal expansion amount over the circumferential direction is exacerbated, leading to a higher frequency of errors. According to the studies conducted by the inventors of the present invention, it was found that a sufficient error suppression effect can be obtained by adjusting the range of (E/d)/CTE and achieving a balance between (E/d)/CTE and the variation in the thermal expansion amount VTE. Furthermore, the magnitude of the ratio CTE/(E/d) correlates with the likelihood of fluttering occurring when the magnetic disk 1 rotates at high speed. According to the second embodiment, it is possible to achieve a balance between the effect of suppressing error occurrence by suppressing distortion of the track shape caused by the anisotropy of thermal expansion and the effect of suppressing error occurrence by suppressing fluttering.

[0038] The Young's modulus E of the magnetic disk 1 can be measured based on Japanese Industrial Standards JIS R1602-1995. A test piece for measurement can be cut out from the magnetic disk 1 as a rectangular parallelepiped with a length of 50 mm, a width of 10 mm, and a thickness that is equal to the thickness of the magnetic disk 1, and the Young's modulus E of the test piece can be measured at room temperature. Since the influence of the magnetic film on the Young's modulus E and the density d of the magnetic disk 1 is negligible, the Young's modulus E and the density of the substrate 3 can be used as the Young's modulus E and the density d of the magnetic disk 1.

[0039] The upper limit of VTE×(E/d)/CTE is preferably 2.9×10^5 [m^3•K/s^2], or 2.6×10^5 [m^3•K/s^2].

[0040] There is no particular limitation on the lower limit of VTE×(E/d)/CTE, and for example, the lower limit thereof is 0.5×10^5 m^3•K/s^2.

[0041] The E/d of the magnetic disk 1 is preferably 27×10^6 m^2/s^2 or more, more preferably 27.5×10^6 m^2/s^2 or more, 30×10^6 m^2/s^2 or more, 34×10^6 m^2/s^2 or more, or 35×10^6 m^2/s^2 or more, in order to improve impact resistance and suppress fluttering of the magnetic disk 1 when the magnetic disk 1 rotates at high speed. There is no particular limitation on the lower limit of the ratio E/d, and for example, the lower limit is 26.5×10^6 m^2/s^2. There is no particular limitation on the upper limit of the ratio E/d, and for example, the upper limit is 40×10^6 m^2/s^2.

From the viewpoint of increasing the ratio E/d, the Young's modulus E of the magnetic disk 1 is preferably 74.0 GPa or more, and more preferably 75.0 GPa or more, 81.0 GPa or more, 85.0 GPa or more, 90.0 GPa or more, or 96.0 GPa or more.

Meanwhile, even when the Young's modulus E is high, if the density is high, the magnetic disk 1 may vibrate significantly under the weight of the magnetic disk 1. Thus, the density d of the magnetic disk 1 is preferably 2.90 g/cm^3 or less and 2.65 g/cm^3 or more, and more preferably 2.80 g/cm^3 or less and 2.71 g/cm^3 or more, when a substrate body 3e (see FIG. 3) is made of an aluminum alloy, and preferably 2.65 g/cm^3 or less and 2.45 g/cm^3 or more, and more preferably 2.60 g/cm^3 or less and 2.50 g/cm^3 or more, when the substrate 3 is made of glass.

[0042] According to the magnetic disk 1 of the second embodiment described above, it is possible to suppress the occurrence of errors in writing or reading information to or from the magnetic disk 1, thereby ensuring the reliability of the HDD.

[0043] Each of the magnetic disks 1 of the first and second embodiments preferably includes the following additional configurations.

[0044] When servo information is written to the magnetic layer of the magnetic disk 1 by a servo track writer, multiple circumferential recording areas (tracks) are formed concentrically. The magnetic disk 1 is preferable when the width of the area within the track width (length in the radial direction) where recorded information is held and used for reading data by the magnetic head (hereinafter referred to as the track width) is 60 nm or less, and more preferably 50 nm or less. There is no particular limitation on the lower limit of the track width, and for example, the lower limit thereof is 5 nm, and preferably 20 nm. The recording density of the magnetic layer can be increased by reducing the particle size of magnetic particles that form the magnetic layer depending on the recording system used, such as the perpendicular magnetic recording system (PMR) or energy-assisted magnetic recording system (EAMR), and forming the magnetic particles on the substrate. In particular, in the energy-assisted magnetic recording system (EAMR), the magnetic particles are made smaller to reduce the bit size, and energy is added to the magnetic particles during data recording to lower their coercivity and assist in magnetization reversal, thereby increasing recording density. Because the magnetic particles are small, the track width is narrower even in the energy-assisted magnetic recording system (EAMR). Furthermore, from the viewpoint of increasing the recording density of the magnetic layer, it is preferable to use shingled magnetic recording (SMR) in combination. In shingled magnetic recording (SMR), the track pitch is narrowed by recording data so as to overlap with a portion of the previously recorded track, thereby increasing the track density (TPI) and thus increasing the recording density. In the present invention, the track width in shingled magnetic recording (SMR) refers to the track pitch, and is the length in the radial direction of a data-readable recording area within the width of a track on which data has been written, excluding a portion overwritten by an adjacent track. The track width in shingled magnetic recording (SMR) is, for example, 55 nm or less, preferably 50 nm or less, preferably 45 nm or less, and more preferably 40 nm or less. As the track width is narrower in this manner, the off-track tolerance of the magnetic head is also reduced. Therefore, as described above, when distortion of the track shape of the magnetic disk occurs due to anisotropy of thermal expansion, even if the magnitude of the distortion is small, the frequency of R/W errors will increase. However, with the

magnetic disk 1, the variation in the thermal expansion amount VTE is limited (preferably the variation in the thermal expansion amount VTE is smaller than the track width), and the ratio VTE/CTE or VTE×(E/d)/CTE is limited as described above. Thus, the occurrence of R/W errors is suppressed. Therefore, the magnetic disk 1 is suitable for use in an HDD where information is read from and written to the magnetic layer by shingled magnetic recording (SMR), or when information is recorded in the magnetic layer by the energy-assisted magnetic recording system (EAMR).

[0045] The substrate 3 of the magnetic disk 1 is preferably made of a material such that the variation in the thermal expansion amount VTE is 0.3 μm or less, and either the ratio VTE/CTE is 1.1×10^4 μm•K or less or VTE×(E/d)/CTE is 3.0×10^5 m^3•K/s^2 or less.

[0046] Examples of a preferable material of the substrate 3 includes a glass containing, in mole percent on an oxide basis:

SiO_2 in an amount of 55 mol% to 80 mol%, Al_2O_3 in an amount of 5 mol% to 25 mol%, and B_2O_3 in an amount of 0 mol% to 8 mol%;

at least one of MgO, CaO, SrO, and BaO in a total amount of 10 mol% to 25 mol%; and

at least one of Li_2O, Na_2O, and K_2O in a total amount of 0.001 mol% to 5.0 mol%. Glass with this composition is advantageous because it allows for easy production of the substrate 3, as well as improving the heat resistance and rigidity of the magnetic disk 1.

[0047] In a magnetic disk 1 in which the substrate 3 is made of the above-mentioned glass, the variation in the thermal expansion amount VTE is 0.040 μm or less, preferably 0.040 μm or less, more preferably 0.030 μm or less, and more preferably 0.025 μm or less. Since glass has a relatively low coefficient of thermal expansion CTE, in order to limit the ratio VTE/CTE or VTE×(E/d)/CTE to the above range, it is preferable that the variation in the thermal expansion amount VTE is 0.040 μm or less. This can enhance the effect of suppressing the occurrence of R/W errors. The magnetic disk 1 having a variation in the thermal expansion amount VTE of 0.040 μm or less exhibits extremely small track distortion due to thermal expansion during HDD operation, making it suitable as a magnetic disk with a narrow track width and as a magnetic disk for performing magnetic recording using the shingled magnetic recording (SMR) or the energy-assisted recording system (EAMR).

[0048] Glass plate members produced using methods such as the downdraw method or the float method, which involve continuously shaping molten glass to obtain elongate glass sheets, may exhibit thermal expansion anisotropy due to variations in residual stress caused by differences in cooling rates between the direction of molten glass extraction during shaping and the width direction orthogonal thereto. Therefore, it is preferable that the glass plate member used for the substrate 3 is produced by controlling the cooling rate during the production of elongate glass sheets using methods such as the downdraw method or the float method to reduce the generation of residual stress. Furthermore, it is preferable that the produced glass sheets are subjected to an annealing process to adjust the variation in the thermal expansion amount to be in a predetermined range.

[0049] A preferred glass transition temperature (Tg) of the glass used for the substrate 3 is preferably 700°C or higher, more preferably 740°C or higher, and even more preferably 770°C or higher, or 782°C or higher, from the viewpoint of ensuring heat resistance when heat treatment is performed on the magnetic layer. The heat treatment temperature required to obtain a magnetic layer with an $L1_0$ structure, which is considered optimal for the energy-assisted magnetic recording system (EAMR), exceeds 600°C and may reach a temperature of 700°C or higher. Through heat treatment at such high temperatures, an irregular structure of the magnetic layer becomes more orderly.

[0050] According to an embodiment, the substrate 3 includes the substrate body 3e (see FIG. 3) made of an aluminum alloy and a nickel alloy film 3f (see FIG. 3) provided on the surface of the substrate body 3e. Examples of a preferred material of the substrate body 3e include an aluminum alloy containing:

at least one of Fe, Mn, and Ni in a total amount of 3.0% by mass to 8.0% by mass, or Si in an amount of more than 3.0% by mass, with the balance being Al and inevitable impurities. Aluminum alloys with this composition are superior in that they can increase the rigidity of the magnetic disk 1.

[0051] In the magnetic disk 1 in which the substrate body 3e is made of the above-mentioned aluminum alloy, the variation in the thermal expansion amount is preferably 0.20 μm or less, and more preferably 0.15 μm or less. Since the aluminum alloy has a relatively high coefficient of thermal expansion CTE, in order to limit the ratio VTE/CTE or VTE×(E/d)/CTE to the above

range, it is preferable that the variation in the thermal expansion amount VTE is 0.20 μm or less. This can enhance the effect of suppressing the occurrence of R/W errors. The magnetic disk 1 having a variation in the thermal expansion amount VTE of 0.20 μm or less is suitable as a magnetic disk for magnetic recording using a perpendicular magnetic recording system (PMR), also known as conventional magnetic recording system (CMR), because it exhibits small track distortion due to thermal expansion during HDD operation.

[0052] The nickel alloy film 3f is necessary for forming, on the surface of the substrate body 3e made of an aluminum alloy, a smooth surface for forming the magnetic layer, and also contributes to increasing the rigidity of the magnetic disk 1 by supplementing the rigidity of the substrate 3. On the other hand, increasing the thickness of the nickel alloy film causes internal strain, leading to variations in the thermal expansion amount over the circumferential direction of the disk. Therefore, the thickness of the polished nickel alloy film 3f formed on the surface of the substrate body 3e made of the aluminum alloy is preferably 7.5 μm or less, more preferably 7.0 μm or less, even more preferably 6.0 μm or less, and further preferably 5.5 μm or less. There is no particular limitation on the lower limit of the thickness of the nickel alloy film 3f, but the lower limit thereof is, for example, 0.05 μm, and preferably 3.0 μm. The thickness of the nickel alloy film 3f is the thickness on one of the main surfaces, and the value used is the value measured at a position at least 10 mm inward from the outer circumferential side wall surface. Nickel-phosphorus (NiP) alloys are preferably used as nickel alloys. For nickel-phosphorus (NiP) alloy films, NiWP-based plating containing tungsten W in a range of 10% by mass to 30% by mass or NiPMo-based plating containing molybdenum Mo in a range of 0.1% by mass to 10% by mass is preferably used to prevent magnetization due to heating during manufacturing of magnetic disks.

[0053] The above-described aluminum alloy may contain elements other than the elements mentioned above as inevitable impurities. Examples of these elements include Ti, B, and Ga, and effects of the present invention will not be impaired when the content of each element is 0.10% by mass or less and the total content is 0.30% by mass or less.

[0054] Other preferred materials of the substrate body 3e include aluminum alloys containing Mg in an amount of 0.5% by mass to 8.0% by mass.

[0055] The aluminum alloy plate member, which is the material of the substrate body 3e, is

produced by rolling an aluminum alloy ingot. The rolled member produced is wound into a coil, then stretched again when it is drawn out, and punched out into a shape with predetermined outer and inner diameters, thereby producing an annular base member. Rolled members may exhibit thermal expansion anisotropy due to variations in residual stress caused by the difference in elongation between the rolling direction and the lateral direction orthogonal to the rolling direction. Therefore, it is possible to preferably use, as the base member for the substrate 3 produced from an aluminum alloy plate member, a base member that has been processed by stacking the base members for the substrate 3 with spacers interposed therebetween and then heat-treating the stack in a continuous heating furnace under conditions at 420°C for 30 minutes to reduce the variation in the thermal expansion amount VTE.

[0056] FIG. 3 is a schematic cross-sectional view illustrating coarse particles 5 precipitated in the substrate 3 of the magnetic disk 1.

According to one embodiment, in a cross-section of the aluminum alloy substrate body 3e, the precipitated particles precipitated in the substrate body 3e are particles containing metals other than Al (e.g., particles made of Al-Fe-based intermetallic compounds or the like), and it is preferable that their maximum diameter is 5 μm or less. The precipitated particles may contain Al. Components other than Al contained in aluminum alloys may be precipitated as coarser particles during the rolling process. When coarse particles 5 with a longest diameter greater than 5 μm are present in the cross-section of the substrate body 3e, the dispersibility of intermetallic compounds within the substrate body 3e is poor, and the number density of intermetallic compound particles with a longest diameter of 0.1 to 3 μm may be less than 50 particles/mm^2, making it easier for a difference in the thermal expansion amount in the radial direction to occur between portions where the coarse particles are present and surrounding areas where the number density is 50 particles/mm^2 or more. The presence of these coarse particles 5 is also considered to be one of the causes of anisotropy in thermal expansion. Therefore, from the viewpoint of reducing the variation in the thermal expansion amount VTE, it is preferable that there are no coarse particles 5, that is, the longest diameter of particles containing metals other than Al precipitated in the substrate body 3e (precipitated particles) is 5 μm or less, 3 μm or less, or 1 μm or less, and the number density of intermetallic compound particles with a longest diameter of 0.1 to 3 μm is preferably 50 particles/mm^2 or more, and more preferably 100

particles/mm^2 or more. The metals other than Al that form the precipitated particles include at least one of the above elements contained in the aluminum alloy, excluding Si, such as Fe, Mn, and Ni.

[0057] It is preferable to determine the longest diameter of the precipitated particles and calculate the number density using a cross-section in the radial direction of the magnetic disk 1 that passes through a position in the circumferential direction of the magnetic disk 1 exhibiting the highest coefficient of thermal expansion CTE among multiple circumferential positions where the coefficient of thermal expansion CTE was measured. Such a substrate cross-section is highly likely to contain coarse particles 5, making it suitable for determining the presence or absence of coarse particles 5. The determination of the longest diameter and the calculation of the number density can be performed using an image of the substrate cross-section at the same circumferential position as the sample S. The longest diameter of a particle can be determined, for example, by using a backscattered electron image of a SEM photograph of a cross-section of the substrate 3, and taking the maximum length of the particle in the image (double arrow in FIG. 3). It is preferable to determine whether the longest diameter of particles containing metals other than Al is 5 μm or less by focusing on a 0.04 mm^2 area within the cross-section of the substrate body 3e. The particle number density can be determined, for example, by taking the average of the number densities of multiple (e.g., three or more) regions selected from the above image of the cross-section of the substrate 3.

[0058] In the magnetic disk 1 of the first embodiment, VTE×(E/d)/CTE is preferably 2.6×10^5 [m^3•K/s^2] or less.

[0059] The magnetic disk 1 preferably meets the standard of a nominal diameter of 3.5 inches or 2.5 inches. The outer diameter of the magnetic disk 1 with a nominal diameter of 3.5 inches is, for example, 95 to 100 mm (e.g., 95 mm, 97 mm), and the diameter of the inner hole 1a is, for example, 24 to 26 mm (e.g., 25 mm). The outer diameter of the magnetic disk 1 with a nominal diameter of 2.5 inches is, for example, 65 to 70 mm (e.g., 65 mm, 67 mm), and the diameter of the inner hole 1a is, for example, 19 to 21 mm (e.g., 20 mm).

[0060] The magnetic disk 1 is produced, for example, as follows.

When producing a magnetic disk 1 in which a substrate 3 is made of glass, first, an annular base member is produced by scribing or coring a glass plate member, and chamfered

surfaces are formed on the inner and outer circumferential edge surfaces of the annular base member. Then, the main surface of the base member, which has the chamfered surfaces, is ground. In the grinding processing, the main surface of the annular base member is ground using a grinding member in which fixed abrasive grains are formed in a sheet shape, or a slurry containing loose abrasive particles. Then, the ground main surface of the base member is polished. In the polishing processing, polishing is performed using a slurry containing loose abrasive particles with a particle size smaller than that of loose abrasive particles used in the grinding processing, and a polishing pad. It is preferable to divide the polishing processing into multiple processes and use abrasive grains with different particle sizes or polishing pads with different hardnesses.

[0061] When producing a magnetic disk 1 in which a substrate body 3e is made of an aluminum alloy material, first, an annular base member is punched out from an aluminum alloy plate member, heated and annealed at a predetermined temperature for a predetermined period of time, and main surface cutting and edge surface shaping are performed to produce the substrate body 3e. Annealing may be performed after the edge surfaces and the main surface are processed. In edge surface shaping, each edge surface is ground or cut into a predetermined shape using a tool such as a forming tool or a single point cutting tool.

Then, a nickel alloy plating film is formed on a surface of the aluminum alloy substrate body 3e, for example, with a thickness of 0.5 to 12 μm. Then, a main surface of the substrate 3 is polished. From the viewpoint of improving both surface quality and productivity, similarly to polishing performed on the glass substrate 3, it is preferable to adopt, as a polishing step, a polishing step divided into multiple stages.

[0062] The magnetic disk 1 is manufactured by stacking an adhesive layer, an undercoat layer, a magnetic layer (magnetic recording layer), a protecting layer, and a lubricating layer in the stated order over the main surface of the substrate 3 produced as described above, thereby forming a magnetic film.

[0063] (Experimental Examples)

In order to examine effects of the magnetic disk 1, various substrates and various magnetic disks having different specifications were produced.

[0064] (Production of Substrate)

As described above, a substrate body was produced by annealing an annular base member, which was punched out from an aluminum alloy plate member, and performing main surface cutting and edge surface shaping, and a NiP film with a thickness of 9 μm was formed through electroless plating such that the entire surface of the substrate body was covered, and then a substrate with a predetermined NiP film thickness was produced by performing edge surface polishing, grinding, first polishing, and second polishing (Examples 1 and 5 and Comparative Examples 1 to 3). Of the thus produced substrates, the substrate of Example 5 was further annealed by maintaining the substrate at a temperature of 200°C for 30 minutes in a furnace.

Separately from this, as described above, a base member for an annular substrate was produced from a glass plate member, and then the substrate was produced by performing edge surface polishing, grinding, first polishing, and second polishing (Examples 2 to 4 and Comparative Examples 4 and 5). In particular, the substrate of Example 2 was further annealed by maintaining the substrate at a temperature of 700°C for 4 minutes in a furnace.

[0065] The dimensions of the produced substrates are as follows.

• The outer diameter was 97 mm, the inner diameter was 25 mm, and the substrate thickness was 0.44 mm (Examples 1 and 4). In particular, the thickness of the NiP film after polishing in Example 1 was 5.3 μm.

• The outer diameter was 97 mm, the inner diameter was 25 mm, and the substrate thickness was 0.5 mm (Examples 2, 3, and 5 and Comparative Examples 2 to 5), and in particular, the thickness of the NiP film after polishing in Example 5 and Comparative Examples 2 and 3 was 8.0 μm.

• The outer diameter was 96 mm, the inner diameter was 25 mm, and the substrate thickness was 0.635 mm (Comparative Example 1), and in particular, the thickness of the NiP film after polishing was 8.0 μm.

[0066] The compositions of the materials used for producing the substrate bodies or substrates, and the methods for producing the glass plate members, are as follows.

• An aluminum alloy contained Mg in an amount of 0.1% by mass, Si in an amount of 0.05% by mass, Fe in an amount of 1.2% by mass, Mn in an amount of 1.2% by mass, Ni in an amount of 1.95% by mass, Cr in an amount of 0.2% by mass, Ti in an amount of 0.2% by mass, and Zr in an amount of 0.2% by mass (Example 1).

• Alkali-free glass produced using the downdraw method (Example 2, Comparative Example 5) was used.

• To obtain a glass with a predetermined composition, SiO_2, Al_2O_3, $Al(OH)_3$, B_2O_3, HBO_3, MgO, $Mg(OH)_2$, $MgCO_3$, $CaCO_3$, $SrCO_3$, $BaCO_3$, ZnO, Li_2CO_3, Na_2CO_3, K_2CO_3, TiO_2, ZrO_2, and the like were used as starting materials to weigh out 300 to 1500 g, thoroughly mixed to form a compound batch, placed in a platinum crucible, and melted in air at a temperature of 1400°C to 1600°C for approximately 3 to 8 hours. After the mixture was melted, the molten glass was poured into a carbon mold having a rectangular parallelepiped recess with dimensions of 200 mm (length)×200 mm (width)×20 mm (depth), allowed to cool to the transition temperature of the glass, and then immediately placed in an annealing furnace. After being held for 1 hour, the glass was allowed to cool to room temperature in the furnace to obtain the resulting glass (Examples 3 and 4, and Comparative Example 4).

• In Example 3, a glass contained, in mol%, SiO_2 and B_2O_3 and/or Al_2O_3 in a total amount of more than 80 mol%, as well as RO in an amount of 10 mol% to 20 mol% (where R is at least one selected from Mg, Ca, Zn, Sr, and Ba), and R'_2O in an amount of 0 mol% to 1 mol% (where R' is at least one selected from Li, Na, and K), with a total content of the above components being 98 mol% or more.

• In Example 4, a glass contained, in mol%, SiO_2 and B_2O_3 and/or Al_2O_3 in a total amount of more than 70 mol%, as well as RO in an amount of 15 mol% to 25 mol% (where R is at least one selected from Mg, Ca, Zn, Sr, and Ba), and R'_2O in an amount of 1 mol% to 10 mol% (where R' is at least one selected from Li, Na, and K), with a total content of the above components being 98 mol% or more.

• In Comparative Example 4, a glass contained, in mol%, SiO_2 and B_2O_3 and/or Al_2O_3 in a total amount of more than 70 mol%, as well as RO in an amount of 1 mol% to 10 mol% (where R is at least one selected from Mg, Ca, Zn, Sr, and Ba), and R'_2O in an amount of 15 mol% to 25 mol% (where R' is at least one selected from Li, Na, and K), with a total content of the above components being 98 mol% or more.

• An aluminum alloy contained Si in an amount of 3.0% by mass to 40.0% by mass (Example 5, Comparative Example 3).

• An aluminum alloy contained Mg in an amount of 1.60% by mass, Si in an amount of 0.05%

by mass, Fe in an amount of 0.70% by mass, Mn in an amount of 0.30% by mass, Ni in an amount of 1.83% by mass, Cr in an amount of 0.15% by mass, Cu in an amount of 0.25% by mass, and Zn in an amount of 0.01% by mass (Comparative Example 1).

• An aluminum alloy contained Mg in an amount of 3.0% by mass or more, and the content of each of Ni, Fe, Mn, and Si is less than 0.1% by mass (Comparative Example 2).

[0067] Since the influence of the magnetic film on the following characteristics is negligible, the following characteristics were measured or calculated using each substrate produced above and defined as the characteristics of the magnetic disk. The measurement results are shown in Tables 1 and 2.

[0068] (Coefficient of Thermal Expansion CTE)

For each of the substrates in the examples and comparative examples, samples were cut at three circumferential positions at 120-degree intervals using the procedure described above. Using a thermomechanical analysis device by the TMA method, the linear expansion coefficient of each sample was determined from the amount of change in length in the temperature range of -30°C to 70°C, and the average of the three linear expansion coefficients was defined as the coefficient of thermal expansion CTE at -30°C to 70°C.

[0069] (Variation in Thermal Expansion amount VTE)

Using the linear expansion coefficient obtained through measurement for each sample in the temperature range of -30°C to 70°C, the thermal expansion amount of the substrate over a length of 95 mm when the temperature was changed to 55 to 60°C was calculated, and the difference between the maximum and minimum of the calculated values was defined as the variation in the thermal expansion amount VTE.

[0070] (Ratio VTE/CTE)

VTE/CTE was calculated using the variation in the thermal expansion amount VTE and the coefficient of thermal expansion CTE.

[0071] (Ratio E/d)

The ratio E/d was calculated using the Young's modulus E and the density d of the magnetic disk obtained using the procedure described above.

[0072] (VTE×(E/d)/CTE)

VTE×(E/d)/CTE was calculated using the variation in the thermal expansion amount

VTE, E/d, and the coefficient of thermal expansion CTE.

[0073] A plurality of substrates were prepared for each of the examples and comparative examples. Magnetic disks were then produced using substrates different from those used for the measurement and calculation of the above characteristics, and the effect of suppressing error occurrence was examined.

[0074] (Production of Magnetic Disk)

A magnetic film (thickness was 30 nm or less) including a magnetic layer was formed on a main surface of each of the substrates of the examples and the comparative examples using the procedure described above, to produce a magnetic disk. In Examples 1 and 5 and Comparative Examples 1 to 3, a magnetic layer containing the above-mentioned CoPtCr-based material was formed. In Examples 2 to 4 and Comparative Examples 4 and 5, a magnetic layer containing the above-mentioned Fe-Pt-based magnetic material was formed. In Examples 2 to 4 and Comparative Examples 4 and 5, in order to obtain a magnetic layer with an $L1_0$ structure, the substrate was heat-treated through preheating at 630°C for 5 seconds.

[0075] (Verification Test of Error Suppression Effect)

The produced magnetic disk was incorporated into an HDD equipped with an internal temperature sensor, and the effect of suppressing the occurrence of errors was examined.

When writing servo signals to a magnetic disk using a servo track writer, in Examples 1 and 5 and Comparative Examples 1 to 3, tracks were formed for performing magnetic recording using the conventional magnetic recording system (CMR). The track width was set to 60 nm. In Examples 2 to 4 and Comparative Examples 4 and 5, tracks were formed for performing magnetic recording using the heat-assisted magnetic recording system (HAMR). The track width was set to 50 nm.

[0076] The produced HDD was placed in a chamber equipped with a cooling device, and data was written to the magnetic disk while the chamber temperature was maintained at 20°C to 25°C. Magnetic recording was performed on the magnetic disks of Examples 1 and 5 and Comparative Examples 1 to 3 using the conventional magnetic recording system (CMR), while magnetic recording was performed on the magnetic disks of Examples 2 to 4 and Comparative Examples 4 and 5 using the heat-assisted magnetic recording system (HAMR).

The HDD, with data written to its magnetic disk, was taken out from the chamber, the

data was read, and the number of retries required to read the data correctly was measured. The results were evaluated as follows: when the number of retries was 2 or less, the samples were rated A, when the number of retries was 3 to 10, the samples were rated B, and when the number of retries was more than 10, the samples were rated C. The results are shown in Table 1. During the reading process, the temperature inside the HDD remained in a range of 55°C to 60°C in all of the examples and comparative examples.

[0077] [Table 1]

	Material	Variation in thermal expansion amount VTE (μm)	Coefficient of thermal expansion CTE (10^{-6}/K)	Young's modulus E (GPa)	E/d (10^6 m^2/s^2)	VTE/CTE (10^4 μ•mK)	VTE×(E/d)/CTE (10^5 m^3•K/s^2)	Error suppression effect
Ex. 1	Aluminum alloy	0.117	21.8	80	27.8	0.54	1.49	A
Ex. 2	Glass	0.022	2.8	84	32.9	0.79	2.59	A
Ex. 3	Glass	0.024	3.5	84	33	0.69	2.26	A
Ex. 4	Glass	0.005	0.9	98	38.2	0.56	2.12	A
Ex. 5	Aluminum alloy	0.194	18.5	86	28.2	1.05	2.96	B
Comp. Ex. 1	Aluminum alloy	0.462	21.2	76	27.6	2.18	6.01	C
Comp. Ex. 2	Aluminum alloy	0.289	22.5	69	26	1.28	3.34	C
Comp. Ex. 3	Aluminum alloy	0.227	17.0	95	29.2	1.34	3.90	C
Comp. Ex. 4	Glass	0.082	7.0	83	32.7	1.17	3.83	C
Comp. Ex. 5	Glass	0.043	2.8	84	32.9	1.54	5.05	C

[0078] From a comparison of the examples and the comparative examples, it can be seen that when the variation in the thermal expansion amount VTE is 0.3 μm or less, and furthermore, either the ratio VTE/CTE is 1.1×10^4 μm•K or less or VTE×(E/d)/CTE is 3.0×10^5 [m^3•K/s^2] or less, the number of retries required to achieve correct reading is reduced, and the error suppression effect is excellent.

[0079] In Example 1 and Comparative Example 1, observation of a backscattered electron image of a cross-section of the substrate in the thickness direction along the radial direction using SEM, the cross-section passing through the circumferential position where the average coefficient α of linear expansion was highest among the multiple circumferential positions where the linear expansion coefficient was measured revealed that, in Example 1, there were no coarse particles with a longest diameter of more than 5 μm per 0.04 mm^2 area, whereas in Comparative Example 1, there were coarse particles with a longest diameter of more than 5 μm. In Example 1, the intermetallic compound exhibited good dispersibility, with a number density of 50 particles/mm^2 or more for intermetallic compound particles with a longest diameter of 0.1 to 3 μm, whereas in Comparative Example 1, the number density of intermetallic compound particles with a longest diameter of 0.1 to 3 μm was less than 50 particles/mm^2. On the other hand, compared to Comparative Example 1, Example 1 had a smaller variation in the thermal expansion amount VTE, but a larger coefficient of thermal expansion CTE at -30°C to 70°C. These findings suggest that the absence of coarse particles with a longest diameter of more than 5 μm contributes to reducing the ratio VTE/CTE and VTE×(E/d)/CTE values. Furthermore, while the NiP thickness in Comparative Example 1 was 8.0 μm, it was 5.3 μm in Example 1. Thus, it is conceivable that, in Example 1, the influence of internal strain due to the NiP film is small, thereby contributing to reducing the values of the variation in the thermal expansion amount VTE and the ratio VTE/CTE.

[0080] As described above, although an information recording medium disk according to the present invention has been described in detail, the present invention is not limited to the above-described embodiments and examples, and it will be appreciated that various improvements and modifications can be made without departing from the gist of the present invention.

The information recording medium disk according to the present invention is not limited to magnetic disks, but may also be, for example, a disk (ferroelectric recording medium) that has

a ferroelectric layer (recording layer) on the main surface of a substrate and is capable of repeatedly recording information by changing the polarization of the ferroelectric.

[List of Reference Numerals]

[0081]

1	Information recording medium disk
1a	Inner hole
3	Substrate
3a, 3b	Main surface
3c, 3d	Side wall surface
3e	Substrate body
5	Coarse particle