

DESCRIPTION

[Title of Invention]

DISK FOR INFORMATION RECORDING MEDIUM, DISK INTERMEDIATE,
5 AND SUBSTRATE FOR INFORMATION RECORDING MEDIUM

[Technical Field]

[0001] The present invention relates to a disk for an information recording medium
(information recording medium disk), a disk intermediate, and a substrate for an
10 information recording medium (information recording medium substrate), in which
a substrate is coated with a coating layer.

[Background Art]

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

[0003] There is demand for magnetic disks, which are information recording
medium disks incorporated in HDD devices, to be unlikely to flutter (surface
oscillation) when magnetic disks are rotated at high speeds in order to stably read
25 information recorded in a magnetic layer. However, if the thickness of information
recording medium disks is reduced in order to increase the number of information
recording medium disks mounted, the information recording medium disks may
have insufficient strength and flutter significantly. Therefore, it is preferable to
use a substrate made of a hard material having a high Young's modulus when
30 producing a thin disk for an information recording medium. However, it is difficult

to grind a hard material, and polishing and grinding need to be performed for a long period of time in order to reduce the surface roughness of a substrate. Thus, there is a problem in that substrates cannot be efficiently produced.

[0004] A substrate having a layer structure in which a glass coating film is provided on a surface of a substrate made of a ceramic material is known as a substrate used in a conventional information recording medium disk (PTL1). Because glass coating films are softer and easier to grind than a ceramic material, it is possible to reduce the surface roughness of a stacked substrate in a short time, making it possible to efficiently produce information recording medium disks with favorable surface properties.

[Citation List]

[Patent Literature]

[0005] [PTL1]: JP S61-48123A

[Summary of Invention]

[Technical Problem]

[0006] However, if the thickness of the above conventional stacked substrate is reduced in order to increase the number of information recording medium disks mounted, substrates made of a ceramic material may be thin and have insufficient strength, and information recording medium disks flutter significantly. Here, it has been found that, even when the rigidity of an information recording medium disk is increased in order to suppress fluttering, it is not possible to effectively suppress fluttering of the information recording medium disk.

[0007] In view of this, the present invention aims to provide an information recording medium disk, a disk intermediate, and an information recording medium substrate, with which fluttering of the information recording medium disk is suppressed and issues of the information recording medium disk caused by the thinness of the substrate can be improved.

[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

5 coating layers covering the two main surfaces and the side wall surface of the substrate,

in which the disk has a specific elastic modulus E/d [$\times 10^6 \text{ m}^2/\text{s}^2$] of 40 or more, the specific elastic modulus being calculated from a Young's modulus E [GPa] and a density d [g/cm^3], and

10 a maximum amplitude is 0.25 mm or less, the maximum amplitude being caused by vibration of an outer circumferential edge portion of the disk in a thickness direction of the disk when an impact is applied to the disk under conditions of 30 [G] and 2 [ms] in a normal direction of the main surfaces of the disk in a state in which an inner circumferential edge portion of the disk is fixed.

15 [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

20 coating layers covering the two main surfaces and the side wall surface of the substrate,

in which the disk has a product $F \cdot D$ of a thickness D [mm] of the disk and a flutter characteristic F [nm] represented by a sum of amounts of flutter vibration of the disk from 1000 to 4000 Hz of 47.0 or less, and

25 a maximum amplitude is 0.25 mm or less, the maximum amplitude being caused by vibration of an outer circumferential edge portion of the disk in a thickness direction of the disk when an impact is applied to the disk under conditions of 30 [G] and 2 [ms] in a normal direction of the main surfaces of the disk in a state in which an inner circumferential edge portion of the disk is fixed.

30 [0010] Aspect 3

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

5 coating layers covering the two main surfaces and the side wall surface of the substrate,

in which the disk has a product $F \cdot D$ of a thickness D [mm] of the disk and a flutter characteristic F [nm] represented by a sum of amounts of flutter vibration of the disk from 1000 to 4000 Hz of 47.0 or less,

10 regarding the thickness in a thickness direction of the disk, a ratio T/t of a thickness T [mm] of each of the coating layers covering the two main surfaces to a thickness t [mm] of the substrate is 0.01 to 0.4, the thickness t of the substrate is 0.43 mm or less, and the thickness T of the coating layer is 0.1 mm or less, and

the disk has a specific elastic modulus E/d [$\times 10^6$ m²/s²] of 40 or more, the
15 specific elastic modulus being calculated from a Young's modulus E [GPa] and a density d [g/cm³].

[0011] Aspect 4

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

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

coating layers covering the two main surfaces and the side wall surface of the substrate,

in which, regarding the thickness in a thickness direction of the disk, a ratio
25 T/t of a thickness T [mm] of each of the coating layers covering the two main surfaces to a thickness t [mm] of the substrate is 0.01 to 0.4, the thickness t of the substrate is 0.43 mm or less, and the thickness T of the coating layers is 0.1 mm or less, and

the disk has a product $F \cdot D$ of a thickness D [mm] of the disk and a flutter characteristic F [nm] represented by a sum of amounts of flutter vibration of the
30 disk from 1000 to 4000 Hz of 47.0 or less.

[0012] Aspect 5

The information recording medium disk according to any one of Aspects 1 to 4,

in which the substrate is made of any one material of a ceramic material, an aluminum alloy, and glass, and

the coating layers are made of glass or a nickel alloy.

[0013] Aspect 6

The information recording medium disk according to any one of Aspects 1 to 4,

in which the disk has a product $F \cdot D$ of a thickness D [mm] of the disk and a flutter characteristic F [nm] represented by a sum of amounts of flutter vibration of the disk from 1000 to 4000 Hz of 45.0 or less.

[0014] Aspect 7

The information recording medium disk according to any one of Aspects 1 to 4,

in which the thickness D [mm] and the specific elastic modulus E/d [$\times 10^6$ m²/s²] of the disk, and Q_a satisfy Formula 1 below, Q_a being a Q -factor of the disk at 3000 Hz measured at 25°C,

$$65.0 < (Q_a \times E/d) / 1000 \times D < 270.0.$$

[0015] Aspect 8

The information recording medium disk according to any one of Aspects 1 to 4,

in which the thickness D [mm] and the specific elastic modulus E/d [$\times 10^6$ m²/s²] of the disk, and Q_a satisfy Formula 2 below, Q_a being a Q -factor of the disk at 3000 Hz measured at 25°C,

$$150 < (Q_a \times E/d) / 1000 \times D < 700.$$

[0016] Aspect 9

The information recording medium disk according to any one of Aspects 1 to 4,

in which the disk has a thickness of 0.45 mm or less.

[0017] Aspect 10

The information recording medium disk according to any one of Aspects 1 to 5,

in which the coating layers are made of glass and include a crystal phase in an interface layer region located at a depth of at least 5% of the thickness T of each of the coating layers in the thickness direction from the interface with the substrate.

[0018] Aspect 11

The information recording medium disk according to Aspect 10,

in which the crystal phase is present in a region having a length of 50% or more per unit length in an extending direction of the coating layer orthogonal to the thickness direction, in a cross section of the interface layer region in the thickness direction.

[0019] Aspect 12

The information recording medium disk according to any one of Aspects 1 to 7,

in which the coating layers are made of glass and do not include a crystal phase in a surface layer region located at a depth of at least 5% of the thickness T of each of the coating layers in the thickness direction from a surface of the coating layer opposite to an interface with the substrate.

[0020] Aspect 13

The information recording medium disk according to any one of Aspects 1 to 8,

in which the main surfaces of the substrate have an arithmetic average roughness Ra of 0.01 to 0.75 μm .

[0021] Aspect 14

The information recording medium disk according to any one of Aspects 1 to 9,

in which a difference between the longest distance and the shortest distance in the thickness direction from a surface of the coating layer opposite to an interface between the coating layer and the substrate to the substrate is 7.5 to 12.5 μm .

[0022] Aspect 15

The information recording medium disk according to any one of Aspects 1 to 10,

in which the main surfaces of the substrate have a portion where protrusions and recesses are present in an alternating manner in a waviness curve obtained from a profile curve showing the shape of a cross section passing through centers of the main surfaces in a thickness direction of the substrate, and

the length of a repeating unit of the protrusions and the recesses in an extending direction of each of the coating layers orthogonal to the thickness direction is 100 to 150 μm .

[0023] Aspect 16

The information recording medium disk according to any one of Aspects 1 to 11,

in which the thickness of the coating layer on the side wall surface is larger than the thickness T of each of the coating layers on the main surfaces of the substrate.

[0024] Aspect 17

The information recording medium disk according to any one of Aspects 1 to 12,

in which the disk has a diameter of 95 mm or more.

[0025] Aspect 18

The information recording medium disk according to any one of Aspects 1 to 13,

in which a maximum amplitude is 0.30 mm or less, the maximum amplitude being caused by vibration of the outer circumferential edge portion of the disk in the thickness direction when an impact is applied to the disk under conditions of 50 [G] and 2 [ms] in a normal direction of the main surfaces of the disk in a state in which the inner circumferential edge portion of the disk is fixed.

[0026] Aspect 19

The information recording medium disk according to any one of Aspects 1 to

14,

in which the disk has a diameter of 95 mm or more, and the disk has a flutter characteristic F of 80 nm or less, the flutter characteristic F being represented by a sum of amounts of flutter vibration of the disk from 1000 to 4000 Hz.

5 [0027] Aspect 20

The information recording medium disk according to any one of Aspects 1 to 15,

in which a surface roughness maximum height R_z of the main surface of the substrate forming an interface with each of the coating layers is 0.1 to 50 μm .

10 [0028] Aspect 21

A disk intermediate having a thickness of 0.59 mm or less, the disk intermediate serving as a blank for an information recording medium disk, the disk intermediate including:

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

coating layers covering the two main surfaces and the side wall surface of the substrate,

20 in which, regarding the thickness in a thickness direction, a ratio T/t of a thickness T [mm] of each of the coating layers to a thickness t [mm] of the substrate is 0.1 to 0.75, the thickness t of the substrate is 0.43 mm or less, and the thickness T of the coating layer is 0.15 mm or less, and

the disk intermediate has a specific elastic modulus E/d [$\times 10^6 \text{ m}^2/\text{s}^2$] of 40 or more, the specific elastic modulus being calculated from a Young's modulus E [GPa] and a density d [g/cm^3].

25 [Brief Description of Drawings]

[0029] FIG. 1 is a diagram showing an external shape of an information recording medium disk according to an embodiment.

FIG. 2 is a diagram showing a layer structure of the information recording medium disk.

30 FIG. 3 is a backscattered electron image showing a cross section of a coating

layer.

FIG. 4 is a micrograph showing a cross section of a stacked substrate.

[Description of Embodiments]

[0030] Hereinafter, an information recording medium disk, a disk intermediate,
5 and an information recording medium substrate according to embodiments will be described in detail.

[0031] An information recording medium disk according to this embodiment (simply referred to as a “magnetic disk” hereinafter) includes magnetic disks according to four embodiments described below.

10 [0032] (First Embodiment)

FIG. 1 is a diagram showing an external shape of a magnetic disk 1 according to a first embodiment. FIG. 2 is a diagram showing a layer structure of the magnetic disk 1. The magnetic disk 1 has a thickness of 0.51 mm or less, and includes a substrate 3, coating layers 5, and a metal film (not shown and later
15 described) as shown in FIG. 2.

[0033] 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 device, and to increase the storage capacity of the HDD device. 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
20 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.

25 [0034] The substrate 3 is an annular plate member provided with an inner hole. The substrate 3 includes one main surface 3a and an opposite main surface 3b, and side wall surfaces (not shown) 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 surfaces are respectively located on the outer circumferential edge portion and
30 the inner circumferential edge portion of the substrate 3.

[0035] The coating layers 5 are layers covering the two main surfaces 3a and 3b and the side wall surfaces of the substrate 3.

[0036] The magnetic disk 1 preferably has a specific elastic modulus E/d [$10^6 \cdot \text{m}^2/\text{s}^2$] of 40 or more, the specific elastic modulus being calculated from a Young's modulus E [GPa] and a density d [g/cm^3]. It is known that as the specific elastic modulus E/d increases, fluttering (flutter vibration) decreases. When the specific elastic modulus E/d of the magnetic disk 1 is 40 or more, fluttering of the magnetic disk 1 when the magnetic disk 1 rotates at high speed is greatly suppressed.

[0037] The Young's modulus E of the magnetic disk 1 can be measured based on Japanese Industrial Standards JIS R1602-1995. Note that a test piece 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. Also, the density d of the magnetic disk 1 is calculated using $d = \{(d_1 \times t) + (d_2 \times 2T)\} / (t + 2T)$ where the density of the substrate 3 is d_1 , the thickness of the substrate 3 is t , the density of the coating layer 5 is d_2 , and the thickness of the coating layer 5 is T . Note that the magnetic disk 1 includes a metal film including a magnetic layer (a magnetic recording layer). However, because the thickness of the metal film is about 100 nm or less, the metal film can be ignored in the thickness of the magnetic disk 1 and can be ignored regarding properties of the magnetic disk 1, such as the specific elastic modulus E/d , the maximum amplitude, and the product $F \cdot D$ that will be described later.

[0038] The specific elastic modulus E/d [$\times 10^6 \text{ m}^2/\text{s}^2$] of the magnetic disk 1 is preferably 25.0 or more, 27.0 or more, 28.0 or more, 37.5 or more, 38.2 or more, 38.5 or more, or 39.0 or more, and more preferably 40.0 or more, 41.0 or more, 45.0 or more, or 65.0 or more. Also, there is no particular limitation on the lower limit of the specific elastic modulus E/d , and for example, the lower limit is 20.0. From the viewpoint of increasing the specific elastic modulus E/d , the Young's modulus E of the magnetic disk 1 is preferably 75.0 GPa or more, and more preferably 78.0 GPa or more, 80 GPa or more, 86 GPa or more, 96.0 GPa or more, 101.0 GPa or more,

106.0 GPa or more, 110.0 GPa or more, 115.0 GPa or more, or 120.0 GPa or more. Meanwhile, even when the Young's modulus 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 4.5 g/cm^3 or less and 4.0
5 g/cm^3 or more, more preferably 4.2 g/cm^3 or less and 4.0 g/cm^3 or more when the substrate 3 is made of a ceramic material, preferably 2.90 g/cm^3 or less and 2.65 g/cm^3 or more, and more preferably 2.86 g/cm^3 or less and 2.80 g/cm^3 or more when the substrate 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
10 when the substrate 3 is made of glass.

[0039] With the magnetic disk 1 according to the first embodiment, the maximum amplitude is 0.25 mm or less, the maximum amplitude being caused by vibration of the outer circumferential edge portion of the magnetic disk 1 in the thickness direction when an impact is applied to the magnetic disk 1 under conditions of 30
15 $[\text{G}]$ and $2 [\text{ms}]$ in the normal direction of the main surfaces of the magnetic disk 1 in a state in which the inner circumferential edge portion of the magnetic disk 1 is fixed. Unlike steady-state flutter vibration caused by the rotating magnetic disk and the air flow around the magnetic disk in a steady rotational state, vibration caused by an external impact is dampened over time. Conventionally, it is known
20 that formation of particles in an HDD is suppressed by reducing the maximum amplitude when a strong impact is applied to a magnetic disk. Particles are formed when a magnetic disk comes into contact with a ramp inside the HDD or an adjacent magnetic disk due to vibration that displaces the magnetic disk in an outward direction of its main surfaces, and furthermore comes into contact with a ceiling
25 surface of a magnetic disk storage container, and thus a contact portion of the magnetic disks is chipped. However, it was found that a thin magnetic disk having a thickness of 0.51 mm or less had a high amplitude even when subjected to a weak impact, causing contact with other components such as a ramp in the HDD, as a result of which formation of particles cannot be suppressed in some cases.
30 Therefore, the maximum amplitude of the magnetic disk 1 according to the first

embodiment when an impact is applied to the magnetic disk 1 under the condition of 30 [G] is limited to 0.25 mm or less. The magnetic disk 1 according to the first embodiment having a specific elastic modulus E/d of 40 or more and a maximum amplitude of 0.25 mm or less can be obtained by adjusting, for example, materials and thicknesses of the substrate 3 and the coating layer 5. The maximum amplitude is preferably 0.30 mm or less, when an impact is applied to the magnetic disk 1 under the conditions of 50 [G] and 2 [ms] in the normal direction of the main surfaces of the magnetic disk 1 in a state in which the inner circumferential edge portion of the magnetic disk 1 is fixed. Because the amplitude when receiving a strong impact is also low in addition to a low amplitude when receiving a weak impact, it is possible to effectively suppress formation of particles in response to various external impacts.

[0040] The above impact test can be carried out using, for example, AVEX-SM-110-MP tester manufactured by AR Brown Co., Ltd. It is preferable that the maximum amplitude is measured using the magnetic disk 1 with a diameter of 95 mm or a diameter of 97 mm. It is preferable that an inner circumferential edge portion of the magnetic disk 1 fixed in an impact test corresponds to an inner region of a circle with a diameter of 25 mm (a region with a radius of 12.5 mm from the center of the magnetic disk 1). Such an inner circumferential edge portion is a region having substantially the same size as the inner circumferential edge portion that is fixed when the magnetic disk 1 with a diameter of 95 mm or a diameter of 97 mm is mounted in an HDD device.

[0041] Because the magnetic disk 1 according to the first embodiment has a specific elastic modulus E/d of 40 or more, and a maximum amplitude of 0.25 mm or less when an impact test is carried out under the condition of 30 [G], it is possible to suppress the formation of particles in the HDD while suppressing fluttering.

[0042] (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 product $F \cdot D$ of the magnetic disk 1 of the second embodiment is in a predetermined range,

instead of the specific elastic modulus E/d of the magnetic disk 1 of the first embodiment being within the above range.

[0043] As for the magnetic disk 1 of the second embodiment, a product $F \cdot D$ of the thickness D [mm] of the magnetic disk 1 and the flutter characteristic F [nm]

5 represented by a total RSS (Root of Sum of Squares) of the amounts of flutter vibration of the magnetic disk 1 from 1000 to 4000 Hz is 47.0 or less. The flutter characteristic F is specifically the square root of the sum of the amounts of vibration when the frequency is changed in a range of 1000 Hz to 4000 Hz, i.e., the square root of the integrated value of the squares of the amplitude of flutter vibration. It

10 is known that the RSS in a range of 1000 Hz to 4000 Hz can be reduced by, for example, setting $2 \cdot \rho(1-\nu)^2 \cdot Q/E$ of the magnetic disk 1 to less than 25 [g/cm³/GPa] (e.g., less than 80 nm) where ρ is the density [g/cm³] of the magnetic disk 1 at room temperature, Q is the Q -factor of the magnetic disk 1 at 3000 Hz at room temperature, E is the Young's modulus [GPa] of the magnetic disk 1 at room

15 temperature, and ν is the Poisson's ratio of the magnetic disk 1 at room temperature (JP 2020/032146X). The amplitude at the outer circumferential edge portion of the magnetic disk 1 is proportional to $\rho \cdot (1-\nu)^2/E/\xi$ (ξ is the damping ratio of the magnetic disk 1), the damping ratio ξ is expressed as $1/(2 \cdot Q)$ (Q is the Q -factor), and thus the amplitude is proportional to $2 \cdot \rho \cdot (1-\nu)^2 \cdot Q/E$.

20 [0044] The Q -factor (Quality Factor) is obtained by dividing the vibration energy stored in the magnetic disk 1 vibrating in one period by the energy dissipated from the vibrating magnetic disk 1, and the smaller the Q -factor is, the more the vibration is damped. For example, the Q -factor at 3000 Hz is obtained as follows. First, vibration is applied to the magnetic disk 1 rotated on a spin stand, and the vibration

25 of the magnetic disk 1 is measured using a laser Doppler vibrometer (LDV) by applying a laser beam to a substantially outer circumferential edge portion of the magnetic disk 1. The obtained data is subjected to the Fourier transformation as appropriate to obtain a frequency response function (horizontal axis: frequency (unit: Hz), vertical axis: NRRO (Non Repeatable Runout) Amplitude (unit: nm)).

30 Then, for each peak observed in the frequency response function, the Q -factor

($=f_0/(f_2-f_1)$) is determined using the half-width method (a calculation method using frequencies f_1 and f_2 ($>f_1$) corresponding to a value 3 dB lower than the peak value of NRRO, and a frequency f_0 (resonant frequency) corresponding to the peak value). The obtained measurement results are plotted on an XY plane where frequency is shown on the horizontal axis and the Q-factor is shown on the vertical axis, and an approximate straight line is determined through linear approximation using the method of least squares. The Q-factor at 3000 Hz can be obtained on the determined approximate straight line or by extrapolating the approximate straight line as needed. Note that the magnetic disk 1 used for evaluation using the laser Doppler vibrometer has an outer diameter of 95 to 97 mm, an inner diameter of 25 mm, and a thickness of 0.51 mm or less. Also, measurement is performed at room temperature under the conditions that the rotation speed of the magnetic disk is 6900 rpm and a measurement position is located 46.5 to 47.5 mm radially from the center of the magnetic disk (1 mm inward from the outer circumferential edge).

[0045] Note that the influence of flutter vibration in a frequency band of less than 1000 Hz has been reduced due to recent advances in head servo technology, while flutter vibration is weak in a frequency band of more than 4000 Hz in the first place. Therefore, it is important to reduce flutter vibration in a band of 1000 to 4000 Hz.

[0046] If the magnetic disk is thick, the magnitude of vibration is greatly influenced by the thickness, and vibration caused by fluttering is suppressed. On the other hand, if the magnetic disk is thin, vibration caused by fluttering will be strong. However, even when the magnetic disk is thin, by controlling the product $F \cdot D$ [nm·mm] of the flutter characteristic F [nm] and the thickness D [mm] to 47.0 or less, it is possible to prevent formation of scratches or particles due to contact between the magnetic disk and other members, as well as production of errors in reading of and writing to the magnetic disk. According to studies conducted by the inventor of the present invention, it was found that the magnitude of fluttering during rotation of a thin magnetic disk can be evaluated using the product $F \cdot D$ [nm·mm] of the flutter characteristic F [nm] and the thickness D [mm] where the thickness of the magnetic disk is D , and when the above product $F \cdot D$ is 47.0 or less,

it is possible to greatly suppress fluttering of the magnetic disk 1 when the magnetic disk 1 rotates at high speed. Thus, the above product $F \cdot D$ of the magnetic disk 1 according to the second embodiment is limited to 47.0 or less. That is, fluttering of the magnetic disk 1 when the magnetic disk 1 rotates at high speed can be greatly suppressed by setting the above product $F \cdot D$ to 47.0 or less. The flutter characteristic F depends on the materials and the thicknesses of the substrate 3 and the coating layer 5. Therefore, the magnetic disk 1 having a product $F \cdot D$ of 47.0 or less can be obtained by adjusting the materials and the thicknesses of the substrate 3 and the coating layer 5. The flutter characteristic F of the magnetic disk 1 having a diameter of 95 mm is preferably 80 nm or less. Because the magnetic disk 1 with a diameter of 95 mm or more is likely to flutter significantly, a small flutter characteristic F in this manner is effective in suppressing fluttering. From the viewpoint of further improving effects of suppressing fluttering of the magnetic disk 1 having a thickness of 0.51.0 mm or less, the product $F \cdot D$ is 45.0 or less, 43.0 or less, or 40.0 or less, preferably 35.0 or less, or 32.0 or less, and more preferably 30.0 or less, 24.0 or less, or 20.0 or less.

[0047] Because the magnetic disk 1 according to the second embodiment has a product $F \cdot D$ of 47.0 or less and a maximum amplitude of 0.25 mm or less when an impact test was carried out under the condition of 30 [G], it is possible to suppress the formation of particles in an HDD while suppressing fluttering.

[0048] (Third Embodiment)

A magnetic disk 1 according to a third embodiment is configured similarly to the magnetic disk 1 of the first embodiment, except that the above product $F \cdot D$ of the magnetic disk 1 of the third embodiment is 47.0 or less, and the thickness T of the coating layer 5, the thickness t of the substrate 3, and the thickness ratio T/t of the magnetic disk 1 of the third embodiment are in predetermined ranges, instead of the maximum amplitude of the magnetic disk 1 of the first embodiment in the impact test being within the above range.

[0049] Regarding the thickness of the magnetic disk 1 of the third embodiment in the thickness direction, the ratio T/t of the thickness T [mm] of each of the coating

layers 5 on both sides of the substrate 3 to the thickness t [mm] of the substrate 3 is 0.01 to 0.4, the thickness t of the substrate 3 is 0.49 mm or less, and the thickness T of the coating layer 5 is 0.15 mm or less. Because the ratio T/t is 0.4 or less, even when the thickness of the magnetic disk 1 is limited, the thickness T of the coating layer 5 is not excessively increased, and the thickness t of the substrate 3 is ensured. This ensures the rigidity of the magnetic disk 1 and contributes to suppressing fluttering. On the other hand, because the ratio T/t is 0.01 or more, the thickness T of the coating layer 5 is not excessively reduced, thus making it possible to suppress deterioration of the flatness of the magnetic disk 1. According to studies conducted by the inventor of the present invention, it was found that if the thickness T of the coating layer 5 is excessively small when performing heat treatment on the metal film provided on the surface of the coating layer 5 in the production of the magnetic disk 1, the coating layer 5 may locally peel off from the substrate 3, as a result of which the flatness of the magnetic disk 1 may deteriorate. By setting the thickness t of the substrate 3 to 0.49 mm or less, the thickness T of the coating layer 5 can be easily ensured while the thickness of the magnetic disk 1 is set to 0.51 mm or less. If the thickness T of the coating layer 5 is excessively small, the flatness of the magnetic disk 1 may deteriorate as described above. Also, by setting the thickness T of the coating layer 5 to 0.15 mm or less, the thickness t of the substrate 3 can be easily ensured while the thickness of the magnetic disk 1 is set to 0.51 mm or less. If the thickness t of the substrate 3 is excessively small, it will be difficult to ensure the rigidity of the magnetic disk 1 as described above, and it will be difficult to suppress fluttering. That is, by setting the ratio T/t of the magnetic disk 1, the thickness t , and the thickness T in the above ranges, it is possible to suppress deterioration in surface properties of the magnetic disk 1 while suppressing fluttering of the magnetic disk 1. Note that from the viewpoint of effectively exhibiting the above effects, it is preferable that the Young's modulus of the substrate 3 is higher than the Young's modulus of the coating layer 5.

[0050] The above ratio T/t is preferably 0.01 to 0.4, or 0.01 to 0.3, and more preferably 0.085 to 0.3. The thickness t of the substrate 3 is preferably 0.49 mm or

less, more preferably 0.43 mm or less, and even more preferably 0.38 mm or less. The thickness T of the coating layer 5 is preferably 0.025 mm or less, more preferably 0.01 mm or less, and even more preferably 0.006 mm or less.

[0051] Note that the flatness (flatness deviation defined in JIS B0621-1984) of the magnetic disk 1 is 15 μm or less, and preferably 10 μm or less. The magnetic disk 1 having such flatness has the effect of further suppressing fluttering when the magnetic disk 1 is rotated at high speed. The flatness can be measured using, for example, an interferometric flatness measuring device through phase measurement interferometry (phase shifting interferometry) at a predetermined measurement wavelength (e.g., 680 nm). The thickness deviation (the difference between the maximum thickness and the minimum thickness) of the magnetic disk 1 is 15 μm or less, and preferably 10 μm or less.

[0052] According to the magnetic disk 1 of the third embodiment, the above ratio T/t is 0.01 to 0.4, the thickness t is 0.43 mm or less, the thickness T is 0.1 mm or less, the product $F \cdot D$ is 47.0 or less, the specific elastic modulus E/d is 40 or more, and thus it is possible to achieve suppression of fluttering of the magnetic disk 1 and provide favorable surface properties to the magnetic disk 1 while suppressing fluttering.

[0053] (Fourth Embodiment)

A magnetic disk 1 according to a fourth embodiment is configured similarly to the magnetic disk 1 of the third embodiment, except that the magnetic disk 1 of the fourth embodiment does not meet the requirement of the specific elastic modulus E/d being within the above range.

[0054] According to the magnetic disk 1 of the fourth embodiment, the above ratio T/t is 0.01 to 0.4, the thickness t is 0.43 mm or less, the thickness T is 0.1 mm or less, and the product $F \cdot D$ is 47.0 or less, and thus it is possible to achieve suppression of fluttering of the magnetic disk 1 and provide favorable surface properties to the magnetic disk 1 at the same time while suppressing fluttering.

[0055] Each of the magnetic disks 1 of the first to fourth embodiments described above preferably includes the following additional configurations.

Each of the magnetic disks 1 of the first and second embodiments preferably has a configuration similar to those of the magnetic disks 1 of the third and fourth embodiments such that the magnetic disk 1 has the ratio T/t , the substrate 3 has the thickness t , and the coating layer 5 has the thickness T . This achieves the effect of achieving suppression of fluttering of the magnetic disk 1 and providing favorable surface properties at the same time.

The magnetic disk 1 of the first embodiment preferably has a product $F \cdot D$ similar to that of the magnetic disks 1 of the second, third, and fourth embodiments. This improves the effect of suppressing fluttering.

Each of the magnetic disks 1 of the second and fourth embodiments preferably has a specific elastic modulus E/d similar to that of the magnetic disks 1 of the first and third embodiments. This improves the effect of suppressing fluttering.

Each of the magnetic disks 1 of the third and fourth embodiments preferably has a maximum amplitude similar to that of the magnetic disks 1 of the first and second embodiments, when an impact is applied. This provides the effect of suppressing the formation of particles in an HDD.

[0056] As described above, the magnetic disk 1 includes a metal film. The metal 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 that order from a main surface, on the main surface of the coating layer 5. A stacked substrate whose main surface is the main surface of the coating layer 5 is, for example, introduced into an evacuated film formation apparatus, and sequential film formation of the adhesive layer, the undercoat layer, and the magnetic layer out of the above layers is performed over the main surface of the coating layer 5 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 above-described film formation, for example,

the protecting layer is formed using C_2H_4 by a CVD (Chemical Vapor Deposition) process, and 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, and thus a lubricating layer can be formed. The magnetic disk 1 can be produced in this manner.

[0057] In order to achieve further higher density recording with the magnetic disk 1, a magnetic recording layer preferably 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.

Note that, here, “-based” means inclusion. Namely, the magnetic disk 1 can have a magnetic recording layer containing Fe and Pt, or Co and Pt, as the magnetic recording layer. With respect to a magnetic recording layer containing these magnetic materials and to a film formation method thereof, descriptions in paragraph 0074 in WO 2011/019010A1, and Examples in this publication can be referred to. Furthermore, a magnetic disk 1 having such a magnetic recording layer is preferably applied to a magnetic recording apparatus by a recording system referred to as 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 in 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 recording layer.

[0058] The substrate 3 and the coating layers 5 of the magnetic disk 1 of the first embodiment are preferably made of materials according to which the magnetic disk 1 has a specific elastic modulus E/d of 40 or more and the maximum amplitude of the magnetic disk 1 when an impact test is carried out under the condition of 30 [G] is 0.25 mm or less.

The substrate 3 and the coating layers 5 of the magnetic disk 1 of the second embodiment are preferably made of materials according to which the product $F \cdot D$ of the magnetic disk 1 is 47.0 or less and the maximum amplitude of the magnetic disk 1 when an impact test is carried out under the condition of 30 [G] is 0.25 mm or less.

5 The substrate 3 and the coating layers 5 of the magnetic disk 1 of the third embodiment are preferably made of materials according to which the magnetic disk 1 has a specific elastic modulus E/d of 40 or more and has a product $F \cdot D$ of 47.0 or less.

10 The substrate 3 and the coating layers 5 of the magnetic disk 1 of the fourth embodiment are preferably made of materials according to which the product $F \cdot D$ of the magnetic disk 1 is 47.0 or less.

[0059] The material of the substrate 3 is preferably any one of a ceramic material, an aluminum alloy, and glass because the specific elastic modulus E/d of the magnetic disk 1 can be easily set to 40 or more.

15 The ceramic material is preferably any one of silicon carbide (SiC), sapphire (Al_2O_3), alumina (Al_2O_3), aluminum nitride (AlN), silicon nitride (Si_3N_4), titanium carbide (TiC), and titanium nitride (TiN), and in particular, silicon carbide (SiC), sapphire (Al_2O_3), and alumina (Al_2O_3) are preferable because the product $F \cdot D$ of the magnetic disk 1 can be easily set to 47.0 or less.

20 The aluminum alloy material having high rigidity with a Young's modulus E [GPa] of 75 or more, such as aluminum alloys containing Si in an amount of 3.0% by mass to 40.0% by mass or aluminum alloys containing Fe in an amount of 0.1% by mass to 5.0% by mass, are preferable.

25 A glass material having high rigidity with a Young's modulus E [GPa] of 80 or more, such as silica-based glass containing silica (SiO_2) at high purity (e.g., 90% by mass or more), aluminosilicate glass containing an aluminum oxide component (Al_2O_3) in an amount of 20% by mass or more, or crystallized glass, is preferable.

[0060] The coating layers 5 are preferably made of glass or a nickel alloy.

30 The glass material is a preferable material because surface properties thereof can be easily adjusted through grinding or polishing. Aluminosilicate glass,

soda-lime glass, soda aluminosilicate glass, aluminoborosilicate glass, borosilicate glass, polysilazane SiO_2 , or the like are preferably used as a glass material. Also, from the viewpoint of ensuring heat resistance during heat treatment performed on a magnetic layer, the glass material preferably has a glass transition point (T_g) of 750°C or higher, and more preferably 770°C or higher.

Nickel alloys are preferable materials because the rigidity of the substrate 3 can be supplemented and the rigidity of the magnetic disk 1 can be increased. A nickel phosphorus (NiP) alloy is preferably used as the nickel alloy, and in order to prevent magnetization due to heating during production of a magnetic disk, a NiWP-based plating coating layer containing tungsten W in a range of 10% by mass to 30% by mass, or a NiPMo-based plating coating layer containing molybdenum Mo in a range of 0.1% by mass to 10% by mass is preferably used.

[0061] Examples of a preferable combination of materials for the substrate 3 and the coating layers 5 include

- A ceramic material such as alumina (substrate), and glass or a nickel alloy (coating layers),
- A high rigidity aluminum alloy (substrate), and glass or a nickel alloy (coating layers), and
- A high rigidity glass (substrate), and glass or a nickel alloy (coating layers). Here,

a high rigidity aluminum alloy and a high rigidity glass respectively refer to an aluminum alloy and glass such that the magnetic disk 1 has a specific elastic modulus E/d of 40 or more or the maximum amplitude of the magnetic disk 1 is 0.25 mm or less when an impact test is performed on the magnetic disk 1 having a thickness of 0.51 mm or less under the condition of 30 [G], or preferably the maximum amplitude of the magnetic disk 1 is 0.30 mm or less when an impact test is performed on the magnetic disk 1 under the condition of 50 [G]. As described above, a high rigidity aluminum alloy material having high rigidity with a Young's modulus E [GPa] of 75 or more, such as an aluminum alloy containing Si in an amount of 3.0% by mass to 40.0% by mass or an aluminum alloy containing Fe in an amount of 0.1% by mass to 5.0% by mass, is preferable. Also, a high rigidity

glass material with a Young's modulus E [GPa] of 80 or more, such as silica-based glass containing silica (SiO₂) at high purity (e.g., 90% by mass or more), aluminosilicate glass containing an aluminum oxide component (Al₂O₃) in an amount of 20% by mass or more, crystallized glass, or single crystal glass, is preferable.

[0062] On the other hand, when an aluminum alloy other than high rigidity aluminum alloys or glass other than high rigidity glass is used as a material of a substrate, if the magnetic disk 1 has a thickness of 0.51 mm or less even when combined with a coating layer, desired impact resistance and flutter characteristics cannot be obtained.

[0063] Each of the magnetic disks 1 of the first to fourth embodiments preferably includes a configuration described below.

[0064] It is preferable that the thickness D [mm] and the specific elastic modulus E/d [$\times 10^6$ m²/s²] of the magnetic disk 1, and Qa satisfy Formula 1 below, Qa being the Q-factor of the magnetic disk 1 at 3000 Hz measured at 25°C.

$$65.0 < (Q_a \times E/d) / 1000 \times D < 270.0 \quad (\text{Formula 1})$$

According to studies conducted by the inventor of the present invention, it is found that when the magnetic disk 1 has a small specific elastic modulus E/d, the product F·D is likely to be small when Formula 1 is satisfied. For example, the magnetic disk 1 having a specific elastic modulus E/d of less than 75 [$\times 10^6$ m²/s²] is preferable because such a magnetic disk satisfies Formula 1, and thus the product F·D is likely to be 40.0 or less. The magnetic disk 1 preferably has a small product F·D because the effect of suppressing fluttering of the magnetic disk 1 having a thickness of 0.51 mm or less can be further improved. By satisfying Formula 1, it is possible to obtain a thin magnetic disk 1 that is less likely to flutter even though the magnetic disk 1 has relatively low rigidity and a large maximum amplitude.

[0065] Meanwhile, it is preferable that the thickness D [mm] and the specific elastic modulus E/d [$\times 10^6$ m²/s²] of the magnetic disk 1, and Qa satisfy Formula 2 below, Qa being the Q-factor of the magnetic disk 1 at 3000 Hz measured at 25°C.

$$150 < (Q_a \times E/d) / 1000 \times D < 700 \quad (\text{Formula 2})$$

According to studies conducted by the inventor of the present invention, it is found that when the magnetic disk 1 has a large specific elastic modulus E/d , the product $F \cdot D$ is likely to be small when Formula 2 is satisfied. For example, the magnetic disk 1 preferably has a specific elastic modulus E/d of $75 [\times 10^6 \text{ m}^2/\text{s}^2]$ or more, because such a magnetic disk satisfies Formula 2, and thus the product $F \cdot D$ is likely to be 40.0 or less. The magnetic disk 1 preferably has a small product $F \cdot D$ because the effect of suppressing fluttering of the magnetic disk 1 having a thickness of 0.51 mm or less can be further improved.

[0066] FIG. 3 is a backscattered electron (BSE) image showing a cross section of the coating layer 5. As shown in FIG. 3, it is preferable that the coating layer 5 is made of glass and includes a crystal phase 5c in an interface layer region Ta located at a depth of at least 5% of the thickness T of the coating layer 5 in the thickness direction (the up-down direction in FIG. 3) from an interface 5a (a surface that is in contact with a main surface 3a of the substrate 3) with the substrate 3. In FIG. 3, the crystal phase 5c is a whitish-looking portion of the coating layer 5 near the interface 5a (see a rectangular portion in FIG. 3) in the coating layer 5. According to studies conducted by the inventor of the present invention, it was found that the interface layer region Ta includes the crystal phase 5c, and thus the coating layer 5 is firmly bonded to the substrate 3, making it difficult for the coating layer 5 to peel off from the substrate 3. Because the magnetic disk 1 is provided with such a coating layer 5, it is possible to suppress local peeling of the coating layer 5 when the magnetic layer is subjected to heat treatment, and to suppress deterioration of the flatness of the magnetic disk 1.

[0067] In this case, as shown in FIG. 3, the crystal phase 5c is preferably present in a region having a length of 50% or more per unit length in the extending direction of the coating layer 5 (the left-right direction in FIG. 3) orthogonal to the thickness direction, in a cross section of the interface layer region Ta in the thickness direction. The presence of the crystal phase 5c at a high density near the interface 5a in this manner increases the effect of suppressing peeling of the coating layer 5 off from the substrate 3. A total region where the crystal phase 5c is present is preferably 70%

or more, and more preferably 90% or more per unit length mentioned above. In order to obtain the interface layer region Ta containing such a crystal phase at a high density, for example, it is preferable that glass, which is to be the coating layer 5, is applied to the surface of the substrate 3, and then the substrate 3 is maintained at a predetermined temperature (e.g., 700°C to 1200°C) for a predetermined period of time (e.g., 30 to 120 minutes).

[0068] It is preferable that the coating layer 5 is made of glass and does not include the crystal phase 5c in a surface layer region Tb located at a depth of at least 5% of the thickness T of the coating layer 5 in the thickness direction (the up-down direction in FIG. 3) from a surface (a main surface of the coating layer 5) 5b that is opposite to the interface 5a of the coating layer 5 with the substrate 3. The glass forming the crystal phase 5c is harder and more difficult to cut than the glass forming an amorphous phase (a portion of the coating layer 5 that looks dark around the crystal phase 5c in FIG. 3). Thus, when the coating layer 5 formed on the main surface of the substrate 3 is ground or polished, the surface thereof has non-uniform surface properties, which may deteriorate the surface properties of the magnetic disk 1. In order to obtain the surface layer region Tb that does not contain such a crystal phase or contains a small amount of crystal phase, for example, glass, which is to be the coating layer 5, is applied to the surface of the substrate 3, the substrate 3 is maintained at a predetermined temperature for a predetermined period of time, and then the cooling rate is increased (e.g., 10°C/min to 30°C/min). Note that the wording “a small amount of crystal phase” means that the region where the crystal phase is present has a total length of 10% or less per unit length of the coating layer 5 in the extending direction of the coating layer 5, for example.

[0069] The arithmetic average roughness Ra (JIS B0601: 2001) of the main surfaces 3a and 3b of the substrate 3 are preferably 0.01 to 0.75 μm , and more preferably 0.05 to 0.5 μm . The main surfaces 3a and 3b of the substrate 3 having such an arithmetic average roughness Ra have relatively large protrusions and recesses, and a portion of the coating layer 5 that is in contact with the substrate 3 enters a recessed portion, which provides an anchor effect of the coating layer 5 firmly

binding to the substrate 3. Therefore, the effect of suppressing peeling of the coating layer 5 off from the substrate 3 is improved. In particular, the inventor of the present invention confirmed that crystal growth is likely to occur starting from portions that are in contact with protrusions and recesses of the main surfaces 3a and 3b of the substrate 3 in the interface layer region Ta of the coating layer 5 made of glass. Thus, when the arithmetic average roughness Ra of the main surfaces 3a and 3b of the substrate 3 is in the above range, it is possible to form a large amount of the crystal phase 5c in the interface layer region Ta of the coating layer 5, and to firmly bond the coating layer 5 to the substrate 3.

[0070] Although the surface of the substrate 3 is coated with the coating layer 5, it is possible to obtain cross-sectional images of the main surfaces 3a and 3b of the substrate 3, and to determine the arithmetic average roughness Ra. Specifically, first, a sample with the main surfaces 3a and 3b of the substrate 3 exposed is produced by, using an ion polishing method, cutting a main surface of the magnetic disk 1 along a plane that passes through the center of the magnetic disk 1 and is perpendicular to the main surfaces. A cross-sectional image of this cross section is obtained using a scanning electron microscope (SEM) at a magnification of, for example, 5000. A curve of protrusions and recesses of the surfaces 3a and 3b of the substrate 3 that form the interfaces where the substrate 3 is in contact with the coating layer 5 is obtained from this image through binarization or visual tracing on the image of the cross-section, for example, and a region having a width of 20 μm located at any portion on this curve of protrusions and recesses is extracted to obtain the arithmetic average roughness Ra.

[0071] The difference between the longest distance and the shortest distance in the thickness direction from the surface (the main surface of the coating layer 5) 5b that is opposite to the interface 5a between the coating layer 5 and the substrate 3, to the substrate 3 is preferably 7.5 to 12.5 μm , and more preferably 8.5 to 11.5 μm . Because such a magnetic disk 1 has large protrusions and recesses on the main surfaces 3a and 3b of the substrate 3, the anchor effect of the coating layer 5 to the substrate 3 is improved, and the effect of suppressing peeling of the coating layer 5

off from the substrate 3 is improved. The distance between the main surface of the coating layer 5 and the substrate 3 can be determined by obtaining the curves of protrusions and recesses on the main surfaces of the substrate 3 and the coating layer 5 according to the above-described method for determining the arithmetic average roughness Ra of the main surfaces 3a and 3b of the substrate 3, and extracting regions with a width of 20 μm located at any portion respectively on the curves of protrusions and recesses, for example.

[0072] FIG. 4 is a cross section of a stacked substrate. As shown in FIG. 4, the main surfaces 3a and 3b of the substrate 3 preferably have a portion where protrusions and recesses are present in an alternating manner in a waviness curve obtained from a profile curve showing the shape of a cross section passing through the centers of the main surfaces 3a and 3b in the thickness direction (the up-down direction in FIG. 4) of the substrate 3, in a cross-sectional image of the stacked substrate taken using a scanning electron microscope (SEM) at, for example, a magnification of 200 to 500. In this case, a length P (P indicates the length of the corresponding main surface 3a of the substrate 3 in FIG. 4) of a repeating unit of the protrusions and the recesses in the extending direction (the left-right direction in FIG. 4) of the coating layer 5 orthogonal to the thickness direction is preferably 100 to 150 μm . According to studies conducted by the inventor of the present invention, it has been confirmed that when the length P of the repeating unit of the protrusions and the recesses is 100 to 150 μm , the effect of the coating layer 5 firmly binding to the substrate 3 is improved. A scale bar added to a lower end portion of the micrograph in FIG. 4 indicates the length of 100 μm . A waviness curve can be calculated from a profile curve obtained as a measurement result by measuring surface properties of the main surfaces 3a and 3b of the substrate 3. Specifically, a profile curve is obtained through measurement performed using a stylus measuring device (JIS B0651: 2001). Then, in accordance with JIS B0632: 2001, a waviness curve constituted by wavelength components between λ_c and λ_f is calculated by setting predetermined cutoff values (λ_c and λ_f) and applying, to the profile curve, a phase compensation filter (bandwidth filter) that allows passage of

wavelength components between λ_c and λ_f . The length of the repeating unit of the protrusions and the recesses is, for example, the average length (wavelength of the waviness curve) P of the protrusions and the recesses present in a measurement length range.

5 [0073] A thickness T_2 of the coating layer 5 on the side wall surface of the substrate 3 is preferably larger than a thickness T_1 of the coating layer 5 on the main surfaces 3a and 3b of the substrate 3. Because the thickness T_2 of the coating layer 5 on the side wall surface of the substrate 3 is large, it is possible to reliably cover the substrate 3 with the coating layer 5 on the side wall surface of the magnetic disk 1
10 and prevent the substrate 3 from being exposed. When a chamfered surface is formed on an outer circumferential edge portion of the magnetic disk 1, the above maximum amplitude is 0.25 mm or less when an impact test is carried out under the condition of 30 [G], thus improving the effect of suppressing the formation of particles in an HDD. Chamfered surfaces refer to surfaces that are respectively
15 connected to two main surfaces of the magnetic disk 1, formed at two end portions of the side wall surface of the magnetic disk 1, and extend in directions inclined with respect to the thickness direction. Note that the thickness T_2 of the coating layer 5 on the side wall surface of the substrate 3 refers to the maximum thickness when the coating layer 5 has a thickness distribution in the thickness direction. The
20 ratio T_2/T_1 between the thickness T_2 and the thickness T_1 of the coating layer 5 is preferably 1.01 to 1.5, and more preferably 1.05 to 1.15 from the viewpoint of ensuring chamfered surfaces and the length in the main surface direction of the substrate 3 and maintaining favorable rigidity of the magnetic disk 1.

[0074] The diameter of the magnetic disk 1 is preferably 95 mm or more (3.5-inch
25 nominal diameter standard or better). The magnetic disk 1 having such a large diameter can have a magnetic layer over a wide area, which contributes to increasing the storage capacity of the HDD device, but the magnetic disk 1 is likely to flutter significantly and read/write errors are likely to occur. Also, the amplitude of vibration of the magnetic disk 1 caused by an external impact increases as the
30 outer diameter of the magnetic disk 1 increases, and vibration is less likely to be

damped. As described above, fluttering of the magnetic disk 1 according to this embodiment is suppressed, and thus it is possible to increase the storage capacity while suppressing read/write errors in an HDD device. Also, if the above maximum amplitude of the magnetic disk 1 is 0.25 mm or less when an impact test is carried out under the condition of 30 [G], even when the magnetic disk 1 has a large diameter, it is possible to suppress the formation of particles in an HDD as described above. There is no particular limitation on the upper limit of the diameter of the magnetic disk 1, and for example, the upper limit is 98 mm.

[0075] The diameter of an inner hole of the magnetic disk 1 is, for example, 25 mm or 20 mm, and the diameter of an inner hole of a magnetic disk 1 having a diameter of 95 mm or more is preferably 25 mm.

[0076] The surface roughness maximum height R_z (JIS B 0601: 2001) of the main surfaces 3a and 3b of the substrate 3 is preferably 0.1 to 50 μm , and more preferably 5 to 50 μm . Locally large protrusions and recesses are present on the main surfaces 3a and 3b of the substrate 3 whose maximum height R_z is within the above range, and a portion of the coating layer 5 that is in contact with the substrate 3 deeply enters a recessed portion, which improves an anchor effect of firmly binding the coating layer 5 to the substrate 3. Also, it is possible to cause crystal growth to easily occur starting from portions that are in contact with large protrusions and recesses of the substrate 3 in the interface layer region Ta of the coating layer 5 made of glass. The surface roughness maximum height R_z of the main surfaces 3a and 3b of the substrate 3 can be determined as follows: a cross-sectional image is obtained using a scanning electron microscope (SEM) at a magnification of 5000 according to the above-described method for determining the arithmetic average roughness R_a of the main surfaces 3a and 3b of the substrate 3, and specifically, an average line from the image to the interface between the substrate 3 and the coating layer 5 is drawn, and the distance between a line that is parallel to the average line and passes through the highest point on the interface and a line that is parallel to the average line and passes through the lowest point on the interface, in a range of 20 μm in the length direction of the interface, is used as the maximum height R_z .

[0077] (Disk intermediate)

Next, a disk intermediate according to an embodiment will be described.

The disk intermediate according to this embodiment is a plate member that has a thickness of 0.59 mm or less and is to be a blank for forming the above-described magnetic disk 1 having a thickness of 0.51 mm or less. The magnetic disk 1 is produced by polishing main surfaces of the disk intermediate and forming a metal film that includes a magnetic layer.

The disk intermediate includes a substrate and coating layers.

The substrate is a plate having one main surface, an opposite main surface, and a side wall surface connecting the two main surfaces. The substrate is configured in a manner similar to that of the substrate 3 of the magnetic disk 1.

The coating layers cover the two main surfaces and the side wall surface of the substrate. Each coating layer is configured in a manner similar to that of the coating layer 5 of the magnetic disk 1, except for the thickness and surface properties of the coating layer.

Regarding the thickness of the disk intermediate in the thickness direction, the ratio T/t of the thickness T [mm] of each of the coating layers to the thickness t [mm] of the substrate is 0.1 to 0.75, the thickness t of the substrate is 0.43 mm or less, and the thickness T of the coating layer is 0.15 mm or less. By setting the ratio T/t of the disk intermediate, the thickness t , and the thickness T in the above ranges, it is possible to obtain the effect of suppressing deterioration in surface properties of the magnetic disk 1 while suppressing fluttering of the magnetic disk 1 produced from the disk intermediate.

The disk intermediate has a specific elastic modulus E/d [$\times 10^6$ m²/s²] of 40 or more, the specific elastic modulus E/d being calculated from a Young's modulus E [GPa] and a density d [g/cm³]. When the specific elastic modulus E/d is 40 or more, fluttering of the magnetic disk 1 occurring when the magnetic disk 1 produced from the disk intermediate rotates at high speed is greatly suppressed.

[0078] (Information recording medium substrate)

Next, an information recording medium substrate according to an

embodiment will be described.

The information recording medium substrate according to an embodiment (referred to as a “magnetic disk substrate” or a “substrate” hereinafter) is the above-described substrate 3 that is used for the above-described magnetic disk 1 and is made of any one material of a ceramic material, an aluminum alloy, and glass. The ceramic material, aluminum alloy, and glass are similar to the above-described ceramic material, aluminum alloy, and glass. According to the magnetic disk 1 produced using such a substrate 3, it is possible to obtain effects of the above-described magnetic disk 1.

[0079] (Method for producing magnetic disk, disk intermediate, and substrate)

The above-described magnetic disk 1, disk intermediate, and substrate 3 can be produced by performing the following processes, for example. First, a base member for the substrate 3 that is to be a blank for the substrate 3 is produced. Then, shaping is performed on the base member for the substrate 3. Then, the coating layer 5 is formed on the surface of the base member for the substrate 3, and a stacked substrate in which the coating layer 5 is stacked on the substrate 3 is obtained. Thereafter, the stacked substrate is subjected to edge surface polishing and main surface grinding, and the main surfaces of the stacked substrate are subjected to first polishing and second polishing. The above disk intermediate is provided with the coating layer (a stacked substrate), and edge surfaces thereof may have been polished, and main surfaces thereof may have been ground or polished. Note that it is not necessary to always perform the above processes, and the order of the above processes may be changed or omitted as needed. For example, among the above processes, edge surface polishing and second polishing performed on main surfaces may not be performed. After the process performed lastly, a metal film including a magnetic layer is formed on a main surface of the stacked substrate. Hereinafter, each process will be described.

[0080] (a) Production of base member for substrate

The base member for the substrate 3 is preferably prepared using a method for slicing a workpiece, which is a cylindrical lump of a ceramic material, an

aluminum alloy, or glass. It is possible to efficiently produce the base member for a plurality of thin substrates 3 by slicing the lump of substrate material. Also, by adjusting a cutting blade for slicing the workpiece and the cutting time, the main surfaces of the sliced base member for the substrate 3 can be adjusted to desired surface properties, and the ranges of the arithmetic average roughness Ra and the maximum height Rz described above for the substrate 3 for the magnetic disk 1 can be achieved. Also, in a waviness curve obtained for the substrate 3, it is possible to obtain the above-described length range of the repeating unit of the protrusions and the recesses. In the magnetic disk 1, the surface of the substrate 3 is coated with the coating layer 5, and the surface properties of the magnetic disk 1 can be adjusted by grinding or polishing the coating layer 5. Thus, grinding or polishing of the main surfaces of the base member for the substrate 3 can be omitted, and the productivity of the magnetic disk 1 can be improved. The base member for the substrate 3 may be produced using other methods such as press molding, instead of the above-described slicing method.

[0081] (b) Shaping

Next, shaping is performed. In shaping, first, the base member for the substrate 3 is produced, a circular hole and an outer circumference are then formed using known processing methods, and thus a disk-shaped substrate 3 provided with the circular hole is obtained. Then, chamfering is performed on an edge surface of the substrate 3. As a result, a side wall surface that includes chamfered surfaces that are respectively connected to the main surfaces 3a and 3b and are inclined in the thickness direction is formed on the edge surface of the substrate 3. In the chamfering process, the side wall surface including chamfered surfaces may be formed by grinding the edge surface of the substrate 3 using a formed grindstone. Note that shaping may be performed on the lump of substrate material before the above slicing is performed. That is, the base member for the substrate 3 may be produced using the lump of the shaped substrate material. In this case, shaping performed after production of the base member for the substrate 3 is omitted.

[0082] (c) Formation of coating layer

Next, the coating layer 5 is formed. The coating layer 5 made of glass is formed by, for example, spraying a glass paste onto a surface of the substrate 3, and calcining the substrate 3. Specifically, by moving a nozzle relative to the substrate 3 while spraying the glass paste onto the surface of the substrate 3 from a nozzle opening, the substrate 3 is coated with the glass paste to a thickness in a range of 10 to 300 μm . After the glass paste is applied, the coating layer 5 can be formed without any residual strain on the glass by heating the substrate 3 at a temperature higher than or equal to a glass transition point according to a material used for the glass paste and cooling the substrate 3 at a predetermined rate. Specifically, the cooling time is set longer than the heating time. The coating layer 5 is formed, and a stacked substrate is produced in this manner. Note that the thickness of glass applied is determined in consideration of the grinding or polishing allowance, and is 10 to 300 μm , for example, and is preferably 40 to 150 μm .

[0083] (d) Edge surface polishing

Next, edge surface polishing is performed on the stacked substrate. Edge surface polishing is processing for performing polishing by supplying a polishing liquid containing loose abrasive particles between a polishing brush and the outer circumferential edge surface and the inner circumferential edge surface of the stacked substrate and moving the polishing brush and the stacked substrate relative to each other, for example. In the edge surface polishing, the inner circumferential edge surface and the outer circumferential edge surface of the stacked substrate are to be polished, and the inner circumferential edge surface and the outer circumferential edge surface are formed into mirror surfaces.

[0084] (e) Grinding (rough grinding, precision grinding)

In rough grinding, main surfaces on both sides of the stacked substrate are ground. Loose abrasive particles are used as a grinding material, for example. In rough grinding, grinding is performed such that the stacked substrate is brought approximately closer to a target thickness and a target flatness of the main surfaces. Note that rough grinding is performed according to the dimensional accuracy or the surface roughness of the molded stacked substrate, and may be omitted in some

cases.

Then, precision grinding is performed on the main surfaces of the stacked substrate. Grinding is performed on the main surfaces of the stacked substrate, using a double-side grinding apparatus provided with a planetary gear mechanism, for example. In this case, grinding is performed using surface plates provided with fixed abrasive particles, for example. Alternatively, grinding may also be performed using loose abrasive particles. Note that precision grinding need not be performed in some cases.

[0085] (f) First polishing (rough polishing)

Then, first polishing is performed on the main surfaces of the stacked substrate. First polishing is performed using loose abrasive particles and polishing pads affixed to the surface plates. First polishing removes cracks and warping remaining on the main surfaces in the case where precision grinding is performed with fixed abrasive particles, for example. In first polishing, the surface roughness of the main surfaces, or, for example, the arithmetic average roughness Ra, can be reduced while the shape of the edge portions of the main surfaces is prevented from being excessively recessed or excessively protruding.

Although there is no particular limitation on the loose abrasive particles used in first polishing, cerium oxide abrasive particles, zirconia abrasive particles, or the like are used, for example. Note that first polishing need not be performed in some cases.

[0086] (g) Second polishing (mirror polishing)

Then, second polishing is performed on the stacked substrate. Second polishing is for performing mirror-polishing on the main surfaces. In second polishing as well, polishing is performed using a polishing apparatus having a configuration similar to that in first polishing. In second polishing, the type and the particle size of loose abrasive particles are changed relative to first polishing, and mirror polishing is performed using resin polishers having a low hardness as polishing pads. Doing so makes it possible to reduce the roughness of the main surfaces of the stacked substrate, while preventing the shape of edge portions of the

main surfaces from being excessively recessed or excessively protruding. The main surfaces preferably have an arithmetic average roughness Ra (JIS B 0601 2001) of 0.2 nm or less. Then, the stacked substrate is cleaned.

[0087] Then, the magnetic disk 1 is manufactured by stacking an adhesive layer,
5 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 stacked substrate and forming a metal film thereon. Then, an HDD that includes the magnetic disk 1 and a magnetic head is manufactured.

[0088] Here, a method for manufacturing the magnetic disk 1 in a case where the
10 above-described high rigidity aluminum alloy material is used as a material of the substrate 3 will be described. Aluminum alloys containing Si in an amount of 3.0% by mass to 40.0% by mass or aluminum alloys containing Fe in an amount of 0.1% by mass to 5.0% by mass are preferably used as high rigidity aluminum alloy materials, for example. It is possible to use, as a nickel-alloy film, a film plated
15 with a Ni-P (nickel-phosphorous)-based alloy, which contains at least phosphorus, for example.

[0089] First, a disk-shaped base member is cut out from a plate member made of a high rigidity aluminum alloy, heated and annealed at predetermined temperatures and predetermined time periods, and main surface cutting and edge surface shaping
20 are performed. In edge surface shaping, an edge surface is ground or cut into a predetermined shape using a tool such as a forming tool or a single point cutting tool. Annealing may be performed after an edge surface or a surface is processed. Then, the stacked substrate is produced by forming a nickel alloy plating film on a surface thereon at a thickness of 3 to 70 μm , for example. Here, because the
25 thickness of a plating film is sufficiently smaller than the thickness of the entire stacked substrate, the shape of an edge surface formed through grinding or cutting is maintained at substantially the same shape even after a plating film is formed. Then, a surface of the stacked substrate is polished. From the viewpoint of improving both surface quality and productivity, similarly to polishing performed on
30 the stacked substrate described above, it is preferable to adopt, as polishing

processing, a polishing process divided into two or more stages. With regard to a specific polishing method, polishing can be performed on the stacked substrate in a manner similar to that for polishing the stacked substrate described above, except that it is preferable to use a polishing liquid containing alumina abrasive particles in first polishing (rough polishing).

[0090] (Experiment 1)

In order to examine effects of the magnetic disk 1 according to the first embodiment, various magnetic disks having different specifications were produced. [0091] (Production of magnetic disk)

A base member for a substrate was produced by slicing a cylindrical substrate material lump having a diameter of 100 mm and a length of 30 mm using a cutting blade, and a substrate was produced by forming a circular hole with a diameter of 25 mm and an outer circumference with a diameter of 95 mm in the produced base member for the substrate (Examples 11 to 14, 17, and 18, and Comparative Examples 11, 12, and 15). In particular, except for Example 17, a stacked substrate was obtained by spraying a glass paste onto the surface of the substrate and forming coating layers through calcination. Note that in Example 17, a NiP film was formed through electroless plating such that the entire surface of the substrate was covered.

Separately from this, as described above, the substrate was produced by annealing a disk-shaped base member, which was cut out from an aluminum alloy plate member, and performing main surface cutting and edge surface shaping, and a NiP film was formed through electroless plating such that the entire surface of the substrate was covered (Example 16 and Comparative Examples 13 and 14).

Edge surface polishing, grinding, first polishing, and second polishing were performed on the stacked substrates of the examples and the comparative examples.

A metal film (with a thickness of 30 nm or less) including a magnetic layer was further formed on a main surface of each of the obtained stacked substrates of the examples and the comparative examples, to produce a magnetic disk.

[0092] Compositions or types of materials of the substrates and coating layers

shown in Tables are as follows.

(Substrate)

- “High rigidity aluminum alloy 1”: Aluminum alloy containing Si in an amount of 3.0% by mass to 40.0% by mass

5 • “High rigidity glass 1”: Silica-based glass containing SiO₂ in an amount of 90% by mass or more.

- “High rigidity glass 2”: Crystallized glass

- “Glass”: Aluminosilicate glass

10 • “Aluminum alloy”: Aluminum alloy containing Mg in an amount of 3.5% by mass or more

(Coating layer)

- “Glass”: Perhydropolysilazane

15 • “NiP”: Nickel alloy containing at least P in an amount of 3% by mass to 10% by mass, and Ni as the remaining portion.

[0093] (Specific elastic modulus E/d)

The specific elastic modulus E/d of a magnetic disk was determined as described above. When the specific elastic modulus E/d was 40 or more, it was evaluated that the magnetic disk had sufficient rigidity and fluttering can be suppressed, and when the specific elastic modulus E/d was less than 40, it was evaluated that the effect of suppressing fluttering was reduced.

20

[0094] (Maximum amplitude)

The magnetic disk was attached to an evaluation apparatus provided with a high-speed camera, and the maximum amplitude was determined. This evaluation apparatus can apply an external impact (acceleration) of any magnitude, and capture moving images of motion (vibration) of an outer circumferential edge portion of the magnetic disk that occurs accompanying the external impact. Then, the evaluation apparatus can measure shifting of the outer circumferential edge portion in the normal direction of the main surfaces by analyzing the moving images.

25

30 An impact test in which an impact was applied to a magnetic disk under the

conditions of 30 [G] and 2 [ms] in the normal direction of main surfaces of the magnetic disk was performed using this evaluation apparatus, and vibration of an outer circumferential edge portion in the normal direction of the main surfaces was measured. The maximum displacement amount in any normal direction to the center of zero displacement at the outer circumferential edge portion of the magnetic disk was determined as the maximum amplitude based on waveform data, which is the results of measurement. An impact test was performed under the condition that the magnitude of the impact was set to 50 [G] in the same manner, and the maximum amplitude was determined.

[0095] Note that a ramp for a ramp load mechanism for a magnetic head is incorporated in an actual HDD, and when magnetic disks are mounted, there are 0.25-mm gaps extending from both main surfaces. That is, a gap between ramps that a magnetic disk enters has a length that is the thickness of the magnetic disk + 0.5 mm. The actual HDD is designed to have a fixed gap, even if the thickness of a magnetic disk is changed. On the other hand, the evaluation apparatus was not provided with this ramp. Thus, whether or not a magnetic disk comes into contact with another member (an adjacent magnetic disk, a ramp, or an HDD storage container) such as a ramp in an actual HDD due to vibration of the magnetic disk is determined using the maximum amplitude of vibration of the magnetic disk, and if the maximum amplitude is 0.25 mm or less, it can be determined that no instances of contact with the ramp occur. When the maximum amplitude exceeds 0.25 mm, the magnetic disk is highly likely to come into contact with another member. The maximum amplitudes of three magnetic disks were examined, and the average of the maximum amplitudes was used. The magnetic disk did not rotate in this evaluation, and evaluation was made in a stationary state.

[0096] (Quality evaluation)

The quality of the produced magnetic disks was evaluated by disassembling a commercially available HDD, attaching the magnetic disk of each of the examples and the comparative examples and spacers to the spindle, and attaching, to the surface of the magnetic disk, a simulated ramp member made of engineering plastic

such that the ramp member protruded therefrom. The gap between the ramp member and the magnetic disk was set to 0.25 mm. Then, an impact test in which an impact was applied under the conditions of 30 [G] and 2 [ms] in the normal direction of main surfaces of the magnetic disk 1 was performed in a state in which the magnetic disk was held. This test was an acceleration test in which the outer circumferential edge portion of the magnetic disk 1 is caused to collide with the ramp member several times or more. Then, the distribution of surrounding particles that came into contact with the ramp member on the surface of the magnetic disk was observed. Note that it was difficult to quantify results, and that relative evaluation was performed.

Rank 1: Almost no particles

Rank 2: Medium number of particles

Rank 3: Large number of particles

Table 1 below shows the evaluation results.

The smaller the rank value is, the better the quality evaluation was, with rank 1 representing the highest quality.

[0097] [Table 1]

	Ex. 11	Ex. 12	Ex. 13	Ex. 14	Ex. 15	Ex. 16	Ex. 17
Thickness (mm)	0.35	0.42	0.26	0.17	0.15	0.43	0.43
Material of Substrate	alumina	alumina	alumina	alumina	alumina	high rigidity aluminum alloy 1	high rigidity glass 1
Material of Coating Layer	glass	glass	glass	glass	glass	NiP	NiP
Young's Modulus E (GPa)	277	298	259	263	273	114	105
Density d (g/cm ³)	3.52	3.62	3.43	3.45	3.50	2.8	2.58
Specific Elastic Modulus E/d (×10 ⁶ m ² /s ²)	78.8	82.4	75.5	76.2	78.0	40.7	40.7
Max. Amplitude (mm) (30 G)	0.16	0.11	0.21	0.25	0.27	0.18	0.16
Max. Amplitude (mm) (50 G)	0.22	0.18	0.28	0.32	0.34	0.25	0.22
Quality Evaluation	Rank 1	Rank 1	Rank 1	Rank 2	Rank 3	Rank 1	Rank 1

[0098] [Table 2]

	Ex. 18	Comp. Ex. 11	Comp. Ex. 12	Comp. Ex. 13	Comp. Ex. 14
Thickness (mm)	0.4	0.5	0.5	0.5	0.635
Material of Substrate	high rigidity glass 2	glass	glass	aluminum alloy	aluminum alloy
Material of Coating Layer	glass	glass	glass	NiP	NiP
Young's Modulus E (GPa)	108	92	75.4	76	76
Density d (g/cm ³)	2.6	2.50	2.40	2.80	2.80
Specific Elastic Modulus E/d (×10 ⁶ m ² /s ²)	41.5	36.8	31.4	27.1	27.1
Max. Amplitude (mm) (30 G)	0.14	0.07	0.15	0.17	0.09
Max. Amplitude (mm) (50 G)	0.21	0.17	0.21	0.23	0.14
Quality Evaluation	Rank 1	Rank 1	Rank 1	Rank 1	Rank 1

[0099] As is understood from comparison between Examples 11 to 14 and 16 to 18 and Comparative Examples 11 to 15, even when the magnetic disk was thin (0.43 mm or less in this case) in order to store many magnetic disks in an HDD, if the specific elastic modulus E/d is 40 or more and the maximum amplitude is 0.25 mm or less when an impact test is carried out under the condition of 30 [G], it is possible to reduce the number of particles while suppressing fluttering.

In Comparative Example 14, because the thickness exceeded 0.51 mm, it was difficult to increase the number of magnetic disks mounted in an HDD device and increase the storage capacity.

In Comparative Example 15, the maximum amplitude exceeded 0.25 mm, and the effect of reducing the number of particles was small.

Note that quality of the magnetic disks was evaluated by performing the above impact test under the condition that the impact magnitude was changed from 30 G to 50 G. Examples 11 to 13 and 16 to 18 were evaluated as rank 1, but Example 14 was evaluated as rank 2 and Comparative Example 15 was evaluated as rank 3.

[0100] (Experiment 2)

In order to examine effects of the magnetic disk 1 according to the second embodiment, various magnetic disks having different specifications were produced.

[0101] (Production of magnetic disk)

A base member for a substrate was produced by slicing a cylindrical substrate material lump having a diameter of 100 mm and a length of 30 mm using a cutting blade, and a substrate was produced by forming a circular hole with a diameter of 25 mm and an outer circumference with a diameter of 95 mm in the produced base member for the substrate (Examples 21 to 24 and 27 to 30, and Comparative Example 25). In particular, except for Examples 25 and 27, a stacked substrate was obtained by spraying a glass paste onto the surface of the substrate and forming coating layers through calcination. Note that in Examples 25 and 27, a NiP film was formed through electroless plating such that the entire surface of the substrate was covered. Edge surface polishing, main surface grinding, first

polishing, and second polishing were performed on the stacked substrates of the examples and the comparative examples.

Separately from this, as described above, the substrate was produced by annealing a disk-shaped base member, which was cut out from an aluminum alloy plate member, and performing main surface cutting and edge surface shaping (Examples 20, 25, and 26, and Comparative Example 23). In particular, a NiP film was formed through electroless plating such that the entire surface of the substrate was covered in Examples 25 and 23, and a stacked substrate was obtained by spraying a glass paste onto the surface of the substrate and forming coating layers through calcination in Examples 20 and 26. Edge surface polishing, main surface grinding, first polishing, and second polishing were performed on the stacked substrates of the examples and the comparative examples.

A magnetic disk was produced by forming a metal film (with a thickness of 30 nm or less) including a magnetic layer on a main surface of each of the stacked substrates of the examples and the comparative examples obtained in the above manner.

[0102] Compositions or types of materials of the substrates and the coating layers shown in Tables are the same as the compositions or types of materials shown in Tables 1 and 2. In the materials of the substrates shown in Tables 3 and 4, “high rigidity aluminum alloy 2” refers to an aluminum alloy that contains at least one of Fe, Mn, and Ni, and in which the total content of Fe, Mn, and Ni is in a range of 3.5% by mass to 8.0% by mass.

[0103] (Calculation of flutter characteristic F)

The Q-factor at 0 to 4000 Hz was determined using a laser Doppler vibrometer as described above, and the Q-factor at 3000 Hz was defined as Qa. In addition to the obtained Q-factor, a total RSS of the amounts of flutter vibration of the magnetic disk 1 was calculated using the density, Young’s modulus, and Poisson’s ratio of the magnetic disk 1 calculated in advance, and the total RSS was defined as the flutter characteristic F [nm]. In the evaluation using a laser Doppler vibrometer, measurement was performed at room temperature (25°C) under the

conditions that the rotation speed of the magnetic disk 1 was 6900 rpm and a measurement position was located 46.5 mm radially from the center of the magnetic disk 1 (1 mm inward from the outer circumferential edge).

- 5 [0104] In order to evaluate magnetic disks having different thicknesses, the product $F \cdot D$ was calculated using the obtained flutter characteristic F and the thickness D of the magnetic disk 1. When the product $F \cdot D$ was 47.0 or less, it was evaluated that fluttering was suppressed, and when the product $F \cdot D$ exceeded 47.0, it was evaluated that the effect of suppressing fluttering was small.

[0105] [Table 3]

	Ex. 21	Ex. 22	Ex. 23	Ex. 24	Comp. Ex. 25	Ex. 25	Ex. 26
Thickness D (mm)	0.35	0.42	0.26	0.17	0.15	0.43	0.43
Material of Substrate	alumina	alumina	alumina	alumina	alumina	high rigidity aluminum alloy 2	high rigidity aluminum alloy 1
Material of Coating Layer	glass	glass	glass	glass	glass	NiP	glass
Flutter Characteristic F (nm)	89.1	71.8	146.6	215.2	273.2	87	92
F·D	31.2	30.2	38.1	36.6	41.0	36.5	39.6
Qa	1180	800	1300	1460	1420	1400	1000
(Qa·E/d)/(1000D)	265.3	156.8	377.6	654.7	738.4	93.7	94.7
Max. Amplitude (mm) (30 G)	0.16	0.11	0.21	0.25	0.27	0.24	0.18
Max. Amplitude (mm) (50 G)	0.22	0.18	0.28	0.32	0.34	0.3	0.25
Quality Evaluation	Rank 1	Rank 1	Rank 1	Rank 2	Rank 3	Rank 1	Rank 1

[0106] [Table 4]

	Ex. 27	Ex. 28	Ex. 29	Ex. 30	Comp. Ex. 23	Ex. 20
Thickness D (mm)	0.43	0.4	0.5	0.5	0.5	0.51
Material of Substrate	high rigidity glass 1	high rigidity glass 2	glass	glass	aluminum alloy	high rigidity aluminum alloy 2
Material of Coating Layer	NiP	glass	glass	glass	NiP	glass
Flutter Characteristic F (nm)	92	74.4	81.1	81.9	96.4	91.2
F·D	39.6	29.8	40.6	41.0	48.2	46.5
Qa	900	1250	870	900	980	1290
(Qa·E/d)/(1000D)	85.2	129.8	64.0	56.6	53.2	56.1
Max. Amplitude (mm) (30 G)	0.16	0.14	0.07	0.15	0.17	0.15
Max. Amplitude (mm) (50 G)	0.22	0.21	0.17	0.21	0.23	0.22
Quality Evaluation	Rank 1	Rank 1	Rank 1	Rank 1	Rank 2	Rank 1

[0107] As is understood from comparison between Examples 20 to 30 and Comparative Examples 23 and 25, even when the magnetic disk was thin (0.51 mm or less in this case) in order to store many magnetic disks in an HDD, the product $F \cdot D$ was 47.0 or less, and the maximum amplitude was 0.25 mm or less when an impact test was carried out under the condition of 30 [G], and thus it was possible to reduce the number of particles while suppressing fluttering.

In Comparative Example 23, the product $F \cdot D$ exceeded 47.0, and thus the effect of suppressing fluttering was small. Note that if the thickness exceeds 0.51 mm, it will be difficult to increase the number of magnetic disks mounted in an HDD device and increase the storage capacity.

In Comparative Example 25, the maximum amplitude exceeded 0.25 mm, and the effect of reducing the number of particles was small.

Note that the quality of the magnetic disks was evaluated by performing the above impact test under the condition that the impact magnitude was changed from 30 G to 50 G. Example 24 and Comparative Example 23 were evaluated as rank 2, and Comparative Example 25 was evaluated as rank 3.

[0108] The calculated specific elastic moduli E/d of Examples 21 to 24 and Comparative Example 25 were all 75 [$\times 10^6 \text{ m}^2/\text{s}^2$] or more. Comparison between Examples 21 to 24 and Comparative Example 25 revealed that when a magnetic disk had a large specific elastic modulus E/d and $(Q_a \cdot E/d)/(1000D)$ was 150 to 700, the product $F \cdot D$ was 40.0 or less, which is small.

Also, the calculated specific elastic moduli E/d of Examples 20 and 25 to 30 and Comparative Example 23 were all less than 75 [$\times 10^6 \text{ m}^2/\text{s}^2$]. Comparison between Examples 20, 25 to 28, 29 and 30 and Comparative Example 23 revealed that when a magnetic disk had a small specific elastic modulus E/d and $(Q_a \cdot E/d)/(1000D)$ was 65.0 to 270.0, the product $F \cdot D$ was 40.0 or less, which is small.

[0109] (Experiment 3)

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

[0110] (Production of magnetic disk)

A base member for a substrate was produced by slicing a cylindrical substrate material lump having a diameter of 100 mm and a length of 30 mm using a cutting blade, and a substrate was produced by forming a circular hole with a diameter of 25 mm and an outer circumference with a diameter of 95 mm in the produced base member for the substrate. A stacked substrate was obtained by spraying a glass paste onto the surface of the substrate and forming coating layers through calcination (Examples 31, 33, 34, 38, and 40, and Comparative Examples 32, and 37 to 39).

Separately from this, as described above, the substrate was produced by annealing a disk-shaped base member, which was cut out from an aluminum alloy plate member, and performing main surface cutting and edge surface shaping, and a NiP film was formed through electroless plating such that the entire surface of the substrate was covered (Example 35 and 36 and Comparative Examples 33 and 34).

Edge surface polishing, grinding, first polishing, and second polishing were performed on the stacked substrates or glass substrates of the examples and the comparative examples.

A magnetic disk was produced by forming a metal film (with a thickness of 30 nm or less) including a magnetic layer on a main surface of each of the stacked substrates or glass substrates of the examples and the comparative examples obtained in the above manner.

[0111] Compositions or types of materials of the substrates and the coating layers shown in Tables are the same as the compositions or types of materials shown in Tables 1 to 4.

[0112] (Thickness of coating layers and substrate)

The thickness T of the coating layers and the thickness t of the substrate were respectively the averages of the thicknesses thereof measured at multiple positions in a region having a measurement length, using a SEM image showing a cross section thereof.

[0113] (Evaluation of flatness and product $F \cdot D$)

The flatness of a produced magnetic disk was measured using a flatness measuring device. As a result, when the flatness was 15 μm or less, the flatness was evaluated as A, when the flatness exceeded 15 μm and 20 μm or less, the flatness was evaluated as B, and when the flatness exceeded 20 μm , the flatness was evaluated as C.

[0114] Also, when the product $F \cdot D$ of a magnetic disk determined as described above was 40.0 or less, the product $F \cdot D$ was evaluated as A, when the product $F \cdot D$ of a magnetic disk exceeded 40.0 and 45.0 or less, the product $F \cdot D$ was evaluated as B, and when the product $F \cdot D$ of a magnetic disk exceeded 45.0, the product $F \cdot D$ was evaluated as C.

[0115] Because the above evaluation was performed according to the magnitude of the specific elastic modulus E/d , as for magnetic disks having a large specific elastic modulus E/d ($75 [\times 10^6 \text{ m}^2/\text{s}^2]$ or more) and shown in Table 5, the product $F \cdot D$ was evaluated as A or B, and when the flatness was evaluated as A, it was evaluated that favorable flatness was obtained while fluttering was suppressed. Also, as for magnetic disks having a small specific elastic modulus E/d (less than $75 [\times 10^6 \text{ m}^2/\text{s}^2]$) and shown in Table 6, when the product $F \cdot D$ and the flatness were evaluated as A, it was evaluated that favorable flatness was obtained while fluttering was suppressed.

[0116] [Table 5]

	Ex. 31	Ex. 33	Ex. 34	Ex. 40	Comp. Ex. 37	Comp. Ex. 38	Comp. Ex. 39
Thickness D (mm)	0.35	0.26	0.17	0.15	0.38	0.44	0.426
Material of Substrate	alumina	alumina	alumina	alumina	alumina	alumina	alumina
Substrate Thickness t (mm)	0.31	0.21	0.14	0.13	0.2	0.24	0.42
Material of Coating Layer	glass	glass	glass	glass	glass	glass	glass
Coating Layer Thickness T (mm)	0.02	0.025	0.015	0.01	0.09	0.12	0.003
Thickness Ratio T/t	0.065	0.119	0.107	0.077	0.45	0.5	0.007
Flutter Characteristic F (nm)	89.1	146.6	215.2	273.2	110.5	103.2	85.8
F·D	31.2	38.1	36.6	41.0	42.0	45.4	36.6
Young's Modulus E (GPa)	277	259	263	273	260	265	280
Density d (g/cm ³)	3.52	3.43	3.45	3.50	3.40	3.47	3.65
Specific Elastic Modulus E/d (×10 ⁶ m ² /s ²)	78.8	75.5	76.2	78.0	76.5	76.4	76.7
Evaluation of Product F·D	A	A	A	B	B	C	A
Flatness Evaluation	A	A	A	A	C	C	B

[0117] [Table 6]

	Comp. Ex. 32	Comp. Ex. 33	Comp. Ex. 34	Ex. 36	Ex. 38	Ex. 35
Thickness D (mm)	0.5	0.5	0.635	0.43	0.4	0.43
Material of Substrate	glass	aluminum alloy	high rigidity aluminum alloy 2	high rigidity aluminum alloy 1	high rigidity glass 2	high rigidity aluminum alloy 2
Substrate Thickness t (mm)	0.48	0.484	0.625	0.39	0.38	0.41
Material of Coating Layer	glass	NiP	NiP	NiP	glass	NiP
Coating Layer Thickness T (mm)	0.01	0.008	0.005	0.02	0.01	0.01
Thickness Ratio T/t	0.021	0.017	0.008	0.051	0.026	0.024
Flutter Characteristic F (nm)	81.9	96.4	71.7	92	74.4	87.0
F·D	41.0	48.2	45.5	39.6	29.8	37.4
Qa	900	980	1290	1000	1250	1400
(Qa·E/d)/(1000D)	56.6	53.2	56.1	94.7	129.8	93.7
Young's Modulus E (GPa)	75.4	76	79	114	108	82
Density d (g/cm ³)	2.40	2.8	2.86	2.8	2.6	2.85
Specific Elastic Modulus E/d (×10 ⁶ m ² /s ²)	31.4	27.1	27.6	40.7	41.5	28.8
Evaluation of Product F·D	B	C	C	A	A	A
Flatness Evaluation	A	A	B	A	A	A

[0118] As is understood from comparison between Examples 31, 33, 34, and 40 and Comparative Examples 37 to 39, even when the magnetic disk was thin (0.43 mm or less in this case) in order to store many magnetic disks in an HDD, as for a magnetic disk having a large specific elastic modulus E/d , when the product $F \cdot D$ was 47.0 or less, the ratio T/t was 0.01 to 0.4, the thickness t of the substrate was 0.43 mm or less, and the thickness T of the coating layer was 0.1 mm or less, the product $F \cdot D$ was evaluated as A or B, the flatness was evaluated as A, and favorable surface properties were obtained while fluttering was suppressed.

On the other hand, Comparative Examples 37 to 39 did not meet the requirement that the product $F \cdot D$ was 47.0 or less, the ratio T/t was 0.01 to 0.4, the thickness t of the substrate was 0.43 mm or less, and the thickness T of the coating layer was 0.1 mm or less, and the product $F \cdot D$ was evaluated as A or B, and the flatness was not evaluated as A. Thus, in Comparative Examples 37 to 39, favorable surface properties were not obtained while fluttering was suppressed.

In particular, in Comparative Example 39, the ratio T/t was less than 0.01 and the flatness was evaluated as B, and thus the effect of improving the flatness of a magnetic disk was small.

Also, in Comparative Example 38, the thickness T of the coating layer exceeded 0.1 mm and the product $F \cdot D$ was evaluated as C, and thus the effect of suppressing fluttering was small.

[0119] As is understood from comparison between Examples 35, 36, and 38 and Comparative Examples 32 to 34, even when the magnetic disk was thin (0.43 mm or less in this case) in order to store many magnetic disks in an HDD, as for a magnetic disk having a small specific elastic modulus E/d , the product $F \cdot D$ was 47.0 or less, the ratio T/t was 0.01 to 0.4, the thickness t of the substrate was 0.43 mm or less, and the thickness T of the coating layer was 0.1 mm or less, the product $F \cdot D$ and the flatness were evaluated as A, and favorable surface properties were obtained while fluttering was suppressed.

On the other hand, Comparative Examples 32 to 34 did not meet the requirement that the product $F \cdot D$ was 47.0 or less, the ratio T/t was 0.01 to 0.4, the

thickness t of the substrate was 0.43 mm or less, and the thickness T of the coating layer was 0.1 mm or less, and the product $F \cdot D$ and the flatness were not evaluated as A. Thus, in Comparative Examples 32 to 34, favorable surface properties were not obtained while fluttering was suppressed.

5 In particular, in Comparative Example 33, the product $F \cdot D$ exceeded 47.0, and thus the effect of suppressing fluttering was small.

In Comparative Example 34, because the thickness exceeded 0.51 mm, it was difficult to increase the number of magnetic disks mounted in an HDD device and increase the storage capacity.

10 In Comparative Example 34, the ratio T/t was less than 0.01 and the flatness was evaluated as B, and thus the effect of improving the flatness of a magnetic disk was small.

[0120] Note that comparison between Examples 35, 36, and 38 and Comparative Examples 32 to 34 revealed that when a magnetic disk had a small specific elastic modulus E/d (less than $75 [\times 10^6 \text{ m}^2/\text{s}^2]$) and $(Qa \cdot E/d)/(1000D)$ was 65.0 to 270.0, the product $F \cdot D$ was 40.0 or less, which is small.

[0121] As described above, although an information recording medium disk, a disk intermediate, and an information recording medium substrate according to the present invention have 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.

[List of Reference Numerals]

[0122]	1	Information recording medium disk
25	3	Information recording medium substrate
	5	Coating layer
	5a	Main surface of coating layer
	5b	Interface between coating layer and substrate
	5c	Crystal phase

CLAIMS

[Claim 1] An information recording medium disk having a thickness of 0.51 mm or less, the information recording medium disk comprising:

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

coating layers covering the two main surfaces and the side wall surface of the substrate,

wherein the disk has a specific elastic modulus E/d of $40 [\times 10^6 \text{ m}^2/\text{s}^2]$ or
10 more, the specific elastic modulus being calculated from a Young's modulus E [GPa] and a density d [g/cm^3], and

a maximum amplitude is 0.25 mm or less, the maximum amplitude being caused by vibration of an outer circumferential edge portion of the disk in a thickness direction of the disk when an impact is applied to the disk under
15 conditions of 30 [G] and 2 [ms] in a normal direction of the main surfaces of the disk in a state in which an inner circumferential edge portion of the disk is fixed.

[Claim 2] An information recording medium disk having a thickness of 0.51 mm or less, the information recording medium disk comprising:

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

coating layers covering the two main surfaces and the side wall surface of the substrate,

wherein the disk has a product $F \cdot D$ of a thickness D [mm] of the disk
25 and a flutter characteristic F [nm] represented by a sum of amounts of flutter vibration of the disk from 1000 to 4000 Hz of 47.0 or less, and

a maximum amplitude is 0.25 mm or less, the maximum amplitude being caused by vibration of an outer circumferential edge portion of the disk in a thickness direction of the disk when an impact is applied to the disk under
30 conditions of 30 [G] and 2 [ms] in a normal direction of the main surfaces of the

disk in a state in which an inner circumferential edge portion of the disk is fixed.

[Claim 3] An information recording medium disk having a thickness of 0.51 mm or less, the information recording medium disk comprising:

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

coating layers covering the two main surfaces and the side wall surface of the substrate,

10 wherein the disk has a product $F \cdot D$ of a thickness D [mm] of the disk and a flutter characteristic F [nm] represented by a sum of amounts of flutter vibration of the disk from 1000 to 4000 Hz of 47.0 or less,

regarding the thickness in a thickness direction of the disk, a ratio T/t of a thickness T [mm] of each of the coating layers covering the two main surfaces to a thickness t [mm] of the substrate is 0.01 to 0.4, the thickness t of the
15 substrate is 0.43 mm or less, and the thickness T of the coating layer is 0.1 mm or less, and

the disk has a specific elastic modulus E/d of $40 [\times 10^6 \text{ m}^2/\text{s}^2]$ or more, the specific elastic modulus being calculated from a Young's modulus E [GPa] and a density d [g/cm³].

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[Claim 4] An information recording medium disk having a thickness of 0.51 mm or less, the information recording medium disk comprising:

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

25 coating layers covering the two main surfaces and the side wall surface of the substrate,

wherein, regarding the thickness in a thickness direction of the disk, a ratio T/t of a thickness T [mm] of each of the coating layers covering the two main surfaces to a thickness t [mm] of the substrate is 0.01 to 0.4, the thickness
30 t of the substrate is 0.43 mm or less, and the thickness T of the coating layer is

0.1 mm or less, and

the disk has a product $F \cdot D$ of a thickness D [mm] of the disk and a flutter characteristic F [nm] represented by a sum of amounts of flutter vibration of the disk from 1000 to 4000 Hz of 47.0 or less.

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[Claim 5] The information recording medium disk according to any one of claims 1 to 4,

wherein the disk has a product $F \cdot D$ of a thickness D [mm] of the disk and a flutter characteristic F [nm] represented by a sum of amounts of flutter vibration of the disk from 1000 to 4000 Hz of 45.0 or less.

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[Claim 6] The information recording medium disk according to any one of claims 1 to 4,

wherein the thickness D [mm] and the specific elastic modulus E/d [$\times 10^6$ m²/s²] of the disk, and Q_a satisfy Formula 1 below, Q_a being a Q -factor of the disk at 3000 Hz measured at 25°C,

$$65.0 < (Q_a \times E/d) / 1000 \times D < 270.0.$$

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[Claim 7] The information recording medium disk according to any one of claims 1 to 4,

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wherein the thickness D [mm] and the specific elastic modulus E/d [$\times 10^6$ m²/s²] of the disk, and Q_a satisfy Formula 2 below, Q_a being a Q -factor of the disk at 3000 Hz measured at 25°C,

$$150 < (Q_a \times E/d) / 1000 \times D < 700.$$

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[Claim 8] The information recording medium disk according to any one of claims 1 to 4,

wherein the substrate is made of any one material of a ceramic material, an aluminum alloy, and glass, and

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the coating layers are made of glass or a nickel alloy.

[Claim 9] The information recording medium disk according to any one of claims 1 to 4,

wherein the disk has a thickness of 0.45 mm or less.

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[Claim 10] The information recording medium disk according to any one of claims 1 to 4,

wherein the coating layers are made of glass and include a crystal phase in an interface layer region located at a depth of at least 5% of the thickness T of each of the coating layers in the thickness direction from the interface with the substrate.

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[Claim 11] The information recording medium disk according to claim 10, wherein the crystal phase is present in a region having a length of 50% or more per unit length in an extending direction of the coating layer orthogonal to the thickness direction, in a cross section of the interface layer region in the thickness direction.

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[Claim 12] The information recording medium disk according to any one of claims 1 to 4,

wherein the coating layers are made of glass and do not include a crystal phase in a surface layer region located at a depth of at least 5% of the thickness T of each of the coating layers in the thickness direction from a surface of the coating layer opposite to an interface with the substrate.

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[Claim 13] The information recording medium disk according to any one of claims 1 to 4,

wherein the main surfaces of the substrate have an arithmetic average roughness Ra of 0.01 to 0.75 μm .

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[Claim 14] The information recording medium disk according to any one of claims 1 to 4,

wherein a difference between the longest distance and the shortest distance in the thickness direction from a surface of the coating layer opposite to an interface between the coating layer and the substrate to the substrate is 7.5 to 12.5 μm .

[Claim 15] The information recording medium disk according to any one of claims 1 to 4,

wherein the main surfaces of the substrate have a portion where protrusions and recesses are present in an alternating manner in a waviness curve obtained from a profile curve showing the shape of a cross section passing through centers of the main surfaces in the thickness direction of the substrate, and

the length of a repeating unit of the protrusions and the recesses in an extending direction of each of the coating layers orthogonal to the thickness direction is 100 to 150 μm .

[Claim 16] The information recording medium disk according to any one of claims 1 to 4,

wherein the thickness of the coating layer on the side wall surface is larger than the thickness T of each of the coating layers on the main surfaces of the substrate.

[Claim 17] The information recording medium disk according to any one of claims 1 to 4,

wherein the information recording medium disk has a diameter of 95 mm or more.

[Claim 18] The information recording medium disk according to any one of claims 1 to 4,

wherein a maximum amplitude is 0.30 mm or less, the maximum amplitude being caused by vibration of the outer circumferential edge portion of the disk in the thickness direction when an impact is applied to the disk under conditions of 50 [G] and 2 [ms] in a normal direction of the main surfaces of the disk in a state in which the inner circumferential edge portion of the disk is fixed.

[Claim 19] The information recording medium disk according to any one of claims 1 to 4,

wherein the disk has a diameter of 95 mm or more, and the disk has a flutter characteristic F of 80 nm or less, the flutter characteristic F being represented by a sum of amounts of flutter vibration of the disk from 1000 to 4000 Hz.

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[Claim 20] The information recording medium disk according to any one of claims 1 to 4,

wherein a surface roughness maximum height Rz of the main surfaces of the substrate forming an interface with each of the coating layers is 0.1 to 50 μm .

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[Claim 21] A disk intermediate having a thickness of 0.59 mm or less, the disk intermediate serving as a blank for an information recording medium disk, the disk intermediate comprising:

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

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coating layers covering the two main surfaces and the side wall surface of the substrate,

wherein, regarding the thickness in a thickness direction, a ratio T/t of a thickness T [mm] of each of the coating layers to a thickness t [mm] of the

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substrate is 0.1 to 0.75, the thickness t of the substrate is 0.43 mm or less, and the thickness T of the coating layer is 0.15 mm or less, and

the disk intermediate has a specific elastic modulus E/d of $40 [\times 10^6 \text{ m}^2/\text{s}^2]$ or more, the specific elastic modulus being calculated from a Young's modulus E [GPa] and a density d [g/cm^3].

[Claim 22] An information recording medium substrate to be used for the information recording medium disk according to any one of claims 1 to 4, the substrate being comprised of any one material of a ceramic material, an aluminum alloy, and glass.