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TITLE OF THE INVENTION:

MAGNETIC RECORDING MEDIUM

BACKGROUND OF THE INVENTION:

The present invention relates to a magnetic recording medium, and more particularly, to a magnetic recording medium for high-density recording, having a higher coercive force and a higher saturation magnetization, exhibiting a less amount of noise generated, a large output in a high recording frequency region and a less distortion of a reproduced waveform, and being suitable for use in current magnetic recording systems in which a ring-type magnetic write head is used.

In recent years, in magnetic recording apparatuses such as a hard disc drive, there has been a remarkable tendency that information devices or systems used therewith are miniaturized and required to have a high reliability. In association with such a recent tendency, in order to deal with a large capacity data, there is an increasing demand for magnetic recording media on which information can be stored with a high density.

In order to fulfill such requirements, the magnetic recording media have been strongly required to have as high a coercive force as possible.

As magnetic recording media having a large coercive force, there are widely known those comprising a substrate and a magnetic thin film formed on the substrate.

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The magnetic thin films which have been already put into practice, are generally classified into magnetic iron oxide thin films composed of maghemite, etc. (refer to "Technical Report of Electronic Telecommunication Institute", published by Electronic Telecommunication Institute, (1981) MR81-20, pp. 5 to 12), and alloy thin films composed of Co-Cr alloy or the like.

The magnetic iron oxide thin films are excellent in oxidation resistance or corrosion resistance because maghemite is already oxidized. Therefore, the magnetic iron oxide thin films can show an excellent stability independent to change in passage of time, i.e., less change in magnetic properties with passage of time. However, the coercive force of the magnetic iron oxide thin films is as low as at most about 700 Oe and the saturation magnetization of the magnetic iron oxide thin films is as low as at most about 240 emu/cm^3.

Whereas, the alloy thin films have a coercive force as high as not less than about 2,000 Oe and a saturation magnetization as high as not less than about 300 emu/cm^3. However, the alloy thin films tend to be readily oxidized, so that the stability independent to change in passage of time is deteriorated.

In order to prevent magnetic properties of these alloy thin films from being deteriorated due to the oxidation, the surfaces of the alloy thin films have been coated with a

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protective film, e.g., a carbon film having usually a thickness of about 100 to about 200 Å. However, in such a case, a distance between a magnetic write head and a magnetic recording layer becomes increased by the thickness of the carbon film, resulting in large loss due to the magnetic spacing, which disables the magnetic recording medium to be applied to high-density recording.

In consequence, it has been attempted to enhance the coercive force and saturation magnetization of the above-mentioned magnetic iron oxide thin films which are excellent in oxidation resistance, corrosion resistance and stability independent to change in passage of time, by incorporating cobalt or the like thereinto. The magnetic iron oxide thin films containing cobalt, etc., have been already put into practice. In addition, there have been extensively developed so-called perpendicular magnetic films which are free from demagnetization because these films are magnetized in perpendicular to the surface thereof, and which can be, therefore, recorded with a high density.

In the magnetic cobalt-containing iron oxide thin films, the more the cobalt content, the higher the coercive force thereof becomes. However, with the increase of cobalt content, the stability independent to change in passage of time of these magnetic iron oxide thin films tend to be deteriorated by adverse influences of heat or the like.

In the case where information recorded on the above-

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mentioned perpendicular magnetic films is read out using a magnetic recording system equipped with a ring-type magnetic write head which have been currently extensively used, there is caused the distortion of isolated reproduced waveform (i.e., a reproduced waveform of so-called "di-pulse"). For this reason, it is necessary to conduct a specific signal processing..

In order to avoid to conduct the specific signal processing, a single-pole magnetic write head used in a vertical magnetic recording system may be used appropriately. However, since the vertical magnetic recording system has not been extensively used yet, the single-pole magnetic write head is still very expensive.

Thus, at the present time,.. there has been a strong demand for providing magnetic recording media for high-density recording which are suitable for use in current magnetic recording systems equipped with a ring-type magnetic write head. For this reason, various kinds of magnetic recording media mentioned above have been extensively developed. Among them, the magnetic iron oxide thin films having excellent oxidation resistance and corrosion resistance have been considered to be most useful, so that it have been more strongly demanded to improve properties of these magnetic iron oxide thin films.

That is, as described above, the magnetic iron oxide thin films have been strongly required not only to have a high

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coercive force and a large saturation magnetization, but also to exhibit less noise and a large output in a high recording frequency region, and to be free from the distortion of isolated reproduced waveform.

Conventionally, as typical magnetic iron oxide thin films, there are known maghemite films. It is also known that cobalt can be incorporated into the maghemite in order to enhance the coercive force thereof (Japanese Patent Publications (KOKOKU) Nos. 51-4086(1976) and 5-63925(1993), and "CERAMICS", published by Japan Ceramics Institute (1986), Vol. 24, No. 1, pp. 21 to 24).

Further, it is known that the magnetic thin film composed of cobalt-containing maghemite is a so-called perpendicular magnetic film whose a (400) plane is predominantly oriented in parallel with the surface of substrate (Japanese Patent Publication (KOKOKU) No. 7-60768(1995) and Japanese Patent Application Laid-open (KOKAI) No. 7-307022(1995)).

More specifically, in Japanese Patent Publication (KOKOKU) No. 51-4086(1976), there is described a magnetic thin film memory comprising a ceramic substrate made of a high-purity alumina ceramic material which has a high density and is free from damaging memory properties of ferrite due to the reaction therewith even at an elevated temperature of 1,000 to 1,300°C to produce the ferrite, and a cobalt-based spinel-type ferrite film formed on the substrate and having a composition represented by the general formula of $Co_{(1-x)}Fe_{(2+x)}O_4$ where -

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$0.2 \leq x \leq 0.3$, the ferrite film being composed of fine crystalline aggregates of the ferrite.

In Japanese Patent Publication (KOKOKU) No. 5-63925(1993), there is described a process for producing a magnetic iron oxide thin film having a high coercive force, comprising reactive sputtering an iron alloy as a target in an oxidization atmosphere of argon and oxygen to directly form ferromagnetic oxide magnetite (Fe_3O_4) of a non-stoichiometric composition having a resistivity of 1×10^{-1} to 8×10^{-1} $\Omega \cdot cm$, and heat-treating the ferromagnetic oxide magnetite (Fe_3O_4) having the above-mentioned resistivity in an atmosphere at a temperature of 280 to 350°C, thereby producing ferromagnetic oxide γ-Fe_2O_3 having a high coercive force.

In Japanese Patent Publication (KOKOKU) No. 7-60768(1995), there is described a fixed magnetic disc comprising a substrate, an oxide thin film formed on the substrate and having an NaCl-type crystal structure composed of nickel oxide crystallographically predominantly oriented in the (100) plane, and a magnetic cobalt-containing iron oxide thin film formed on the nickel oxide thin film and having a spinel-type crystal structure.

Further, in Japanese Patent Application Laid-open (KOKAI) No. 7-307022(1995), there is described a magnetic recording medium comprising: a substrate; an NiO underlayer formed on the surface of the substrate, whose a (200) plane is

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predominantly oriented in parallel with the surface of the substrate; and a cobalt-containing maghemite thin film as a perpendicular magnetic film formed on the surface of the NiO underlayer, whose a (400) plane is predominantly oriented in parallel with the surface of a substrate and which has a molar ratio of Co to Fe of not less than 0.01 and less than 0.10 and a spacing of the (400) plane of not more than 2.082 Å.

At the present time, as the magnetic recording media for high-density recording which are suitable for use in current magnetic recording systems using a ring-type magnetic write head, there have been demanded those having a higher coercive force, a large saturation magnetization, an excellent stability independent to change in passage of time, less noise and a large output in a high recording frequency region, and being free from the distortion of isolated reproduced waveform. However, there have not been provided yet such magnetic recording media having all of the above-mentioned properties.

That is, the above-mentioned conventional cobalt-containing maghemite thin films are still unsatisfactory in magnetic properties, especially coercive force thereof. When it is attempted to obtain a high coercive force, especially not less than 2,000 Oe, it is necessary to incorporate a large amount of cobalt thereinto. In this case, such cobalt-containing maghemite thin film tend to be adversely affected by heat and the like, resulting in considerable deterioration in magnetic properties with passage of time.

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Also, there is a problem that the cobalt-containing maghemite thin film cannot show a sufficiently large output in a high recording frequency region.

Further, the above-mentioned conventional perpendicular magnetic films composed of iron oxides have a problem concerning the distortion of isolated reproduced waveform. Therefore, the perpendicular magnetic films cannot be applied to current magnetic recording systems using a ring-type magnetic write head.

As a result of the present inventors' earnest studies to solve the above problems, it has been found that by forming a nickel oxide underlayer on a substrate and then forming a cobalt-containing maghemite thin film on the nickel oxide underlayer so as to control a spacing of a (311) plane to not more than 2.510 Å, a spacing of a (222) plane to not more than 2.415 Å or a spacing of a (220) plane to not more than 2.950 Å and further to control the ratio of either of X-ray diffraction spectrum peak intensities of the (311), (222) and (220) planes to an X-ray diffraction spectrum peak intensity of a (400) plane, to more than 0.5:1, the obtained magnetic recording medium has a higher coercive force, e.g., not less than 2,000 Oe, a larger saturation magnetization, e.g., not less than 250 emu/cm^3, exhibits less amount of noise and a large output in a high recording frequency region, and is free from distortion of isolated reproduced waveform. The present invention has been attained on the basis of the finding.

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SUMMARY OF THE INVENTION

It is an object of the present invention to provide a magnetic recording medium for high density recording, which is suitable for use in current magnetic recording systems using a ring-type magnetic write head, has a high coercive force and a large saturation magnetization, exhibits less noise and a large output in a high recording frequency region, and is free from the distortion of reproduced waveform.

To accomplish the aims, in an aspect of the present invention, there is provided a magnetic recording medium comprising: a substrate; a nickel oxide underlayer formed on the substrate; and a cobalt-containing maghemite thin film formed on the nickel oxide underlayer, having either a spacing of a (311) plane of not more than 2.510Å, a spacing of a (222) plane of not more than 2.415Å or a spacing of a (220) plane of not more than 2.950Å, and having the ratio of either of X-ray diffraction spectrum peak intensities of the (311), (222) or (220) planes of the cobalt-containing maghemite thin film to an X-ray diffraction spectrum peak intensity of a (400) plane of more than 0.5:1.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows an isolated reproduced waveform upon reproduced signals recorded at a recording density of 1kFRPI on a magnetic recording medium in Example 1; and

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Fig. 2 shows an isolated reproduced waveform upon reproduced signals recorded at a recording density of 1kFRPI on a magnetic recording medium obtained in Comparative Example 5.

DETAILED DESCRIPTION OF THE INVENTION

First, the magnetic recording medium according to the present invention is described.

The magnetic recording medium according to the present invention comprises a substrate, a nickel oxide underlayer formed on the substrate and a cobalt-containing maghemite thin film formed on the nickel oxide underlayer.

The substrate used in the present invention may be made of materials ordinarily used for this purpose, such as glass or the like.

The nickel oxide underlayer of the magnetic recording medium of the present invention has a thickness of usually 0.01 to 0.5 μm, preferably 0.02 to 0.3 μm. When the thickness of the underlayer is less than 0.01 μm, it may become difficult to obtain the aimed magnetic recording medium having a higher coercive force. On the other hand, when the thickness of the underlayer is more than 0.5 μm, the grain size of the cobalt-containing maghemite particles of the magnetic thin film formed on the nickel oxide underlayer may become large, so that the noise from the resultant magnetic recording medium tends to be increased.

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It is preferred that the nickel oxide underlayer of the magnetic recording medium of the present invention be less oriented in its (200) plane parallel with the surface of the substrate, more preferably not oriented at all in the (200) plane. When the orientation of the (200) plane becomes large, there is caused a tendency that the (400) plane of the cobalt-containing maghemite thin film is grown, so that the di-pulse ratio is increased. Therefore, in view of the di-pulse ratio, the ratio of an X-ray diffraction peak intensity of the (111) plane to that of the (200) plane is preferably more than 0.5:1, more preferably not less than 1.0:1.

The magnetic thin film of the magnetic recording medium according to the present invention is a cobalt-containing maghemite thin film having a thickness of usually 0.005 to 1.0 μm, preferably 0.01 to 0.5 μm.

In general, maghemite is represented by the formula of γ-Fe_2O_3. However, in the present invention, there may also be used such maghemite containing a small amount of Fe^{2+}. The upper limit of the Fe^{2+} content at a molar ratio of Fe^{2+} to Fe^{3+} is preferably 0.3:1.

In addition, the cobalt-containing maghemite thin film may further contain at least one element selected from the group consisting of Mn, Ni, Cu, Ti and Zn which may be usually used to improve various properties thereof, in such an amount that the molar ratio of these elements to Fe is usually about

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0.005:1 to about 0.04:1.

The cobalt content in the maghemite thin film is usually 0.01:1 to 0.1:1, preferably 0.01:1 to 0.06:1, more preferably 0.03:1 to 0.06:1 at a molar ratio of Co to Fe. When the molar ratio of Co to Fe is less than 0.01:1, it may become difficult to obtain a magnetic recording medium having a coercive force as high as not less than 2,000 Oe. On the other hand, when the molar ratio of Co to Fe is more than 0.1:1, it may become difficult to obtain a magnetic recording medium having an excellent stability independent to change in passage of time.

The cobalt-containing maghemite thin film according to the present invention is controlled to satisfy at least one of the following conditions: i.e., a spacing of a plane (311) is not more than 2.510 Å; a spacing of a (222) plane is not more than 2.415 Å; or a spacing of a (220) plane is not more than 2.950 Å. In this case, if any one condition can be satisfied, it is not required to satisfy the other two conditions.

When all of the above-mentioned three conditions concerning the spacing of the (311), (222) and (220) planes are not satisfied, it is not possible to obtain a magnetic recording medium having a high coercive force. Further, such a magnetic recording medium undergoes a large amount of noise and cannot exhibit a sufficiently large output in a high recording frequency region.

There is a close relationship between the spacing of the (311) plane, the (222) plane or the (220) plane and the

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coercive force of the cobalt-containing maghemite thin film. In the case where the molar ratio of Co to Fe is the same, there is a tendency that the smaller the spacing, the larger the coercive force becomes.

The spacing of the (311) plane is usually not more than 2.510 Å, preferably not more than 2.509 Å, more preferably not more than 2.506 Å. The lower limit of the spacing of the (311) plane is preferably 2.490 Å.

The spacing of the (222) plane is usually not more than 2.415 Å, preferably not more than 2.400 Å, more preferably not more than 2.399 Å, still more preferably not more than 2.398 Å. The lower limit of the spacing of the (222) plane is preferably 2.385 Å.

The spacing of the (220) plane is usually not more than 2.950 Å, preferably not more than 2.943 Å, more preferably not more than 2.940 Å. The lower limit of the spacing of the (220) plane is preferably 2.920 Å.

The cobalt-containing maghemite thin film of the magnetic recording medium of the present invention is controlled to satisfy such a condition that the ratio of either of X-ray diffraction spectrum peak intensities of the (311), (222) or (220) planes to an X-ray diffraction spectrum peak intensity of the (400) plane is usually more than 0.5:1, preferably not less than 1:1. When the ratio is not more than 0.5:1, it is not possible to obtain the aimed magnetic recording medium for high density recording which is suitable for use in current

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magnetic recording systems using a ring-type magnetic write head.

The magnetic recording medium of the present invention, has a saturation magnetization (magnetization value measured at an applied magnetic field of 15 kOe) of preferably 250 to 400 emu/cm^3, more preferably 300 to 360 emu/cm^3, and a coercive force of usually not less than 2,000 Oe, preferably not less than 2,200 Oe, more preferably not less than 2,300 Oe. In the present invention, especially when the molar ratio of Co to Fe is 0.04, it has been determined that the upper limit of the coercive force is about 6,500 Oe. Incidentally, in the current magnetic recording systems using a ring-type magnetic write head, the upper limit of the coercive force is preferably about 4,000 Oe, more preferably 3,000 Oe.

Besides, the upper limit of the coercive force of the magnetic recording medium of the present invention, also means a value measured at an applied magnetic field of 15 kOe which is an upper limit of the coercive force measurable by "vibrating sample magnetometer" described in detail hereinafter. In addition, with respect to read-write properties of the magnetic recording medium of the present invention when measured by using a tester described in Examples hereinafter, the S_{p-p}/N_{rms} is preferably not less than 45 dB, more preferably not less than 47 dB; the recording density whose output is one half of an output obtained at a

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recording density of 1kFRPI, D_{50} is preferably not less than 130 kFRPI, more preferably not less than 140 kFRPI; and the di-pulse ratio is 0 as shown in Fig. 1.

Next, the process for producing the magnetic recording medium according to the present invention, is described.

The magnetic recording medium according to the present invention can be produced by depositing cobalt-containing magnetite on the substrate or on the nickel oxide underlayer formed by depositing nickel oxide on the substrate, by a so-called sputtering method using cobalt-containing iron alloy as a target while controlling a flow rate of oxygen (CCM) as an amount of oxygen introduced and a deposition rate (nm/min) of the cobalt-containing magnetite, to form a cobalt-containing magnetite thin film on the nickel oxide underlayer; and then heat-treating the obtained cobalt-containing magnetite thin film at a temperature of 200 to 450°C to transform the cobalt-containing magnetite thin film into a cobalt-containing maghemite thin film.

In order to obtain the aimed magnetic recording medium according to the present invention, it is important to control the flow rate of oxygen (CCM) relative to the deposition rate (nm/min) of the cobalt-containing magnetite.

The flow rate of oxygen (CCM) relative to the deposition rate (nm/min) of the cobalt-containing magnetite to obtain the aimed magnetic recording medium according to the present invention, is varied depending upon various conditions having

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an influence on the oxidation of the cobalt-containing magnetite thin film, such as kind and construction of apparatus used, a total gas pressure, a substrate temperature or an area of target to be sputtered. Therefore, it is difficult to specifically determine the preferred flow rate of oxygen.

However, as a result of many experiments conducted by the present inventors, it has been recognized that there is a tendency that the less the flow rate of oxygen (CCM) relative to the deposition rate (nm/min) of the cobalt-containing magnetite, the smaller the spacing of each of the (311), (222) and (220) planes of the obtained cobalt-containing maghemite thin film becomes.

Accordingly, by conducting various experiments to obtain the flow rate of oxygen (CCM) relative to the deposition rate (nm/min) of the cobalt-containing magnetite at which the spacing of each of (311), (222) and (220) planes becomes smaller than that of the bulk, the deposition rate (nm/min) of the cobalt-containing magnetite and the flow rate of oxygen may be respectively controlled so as to be smaller than the obtained values.

In accordance with the experiments conducted by the present inventors, as described in Examples and Comparative Examples hereinafter, when the deposition rate of the cobalt-containing magnetite is 3.5 nm/min, the flow rate of oxygen (CCM) is usually not more than 0.35, preferably not more than

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0.27, more preferably not more than 0.25. The lower limit of the flow rate of oxygen (CCM) is preferably 0.18. When the flow rate of oxygen is more than 0.35, hematite may tend to be formed in the obtained cobalt-containing maghemite thin film, resulting in decrease in saturation magnetization thereof. On the other hand, when the flow rate of oxygen is less than 0.18, metal iron (Fe) or wustite (FeO) may tend to be formed in the obtained cobalt-containing maghemite thin film, resulting in decrease in coercive force thereof.

The important point of the present invention resides in that in the case where the nickel oxide underlayer is formed on the substrate, and the cobalt-containing maghemite thin film formed on the nickel oxide underlayer is adjusted so that any of conditions of a spacing of a (311) plane of not more than 2.510 Å, a spacing of a (222) plane of not more than 2.415 Å and a spacing of a (220) plane of not more than 2.950 Å is satisfied, and the ratio of either of X-ray diffraction spectrum peak intensities of the (311), (222) and (220) planes to an X-ray diffraction spectrum peak intensity of a (400) plane is more than 0.5:1, there can be obtained a magnetic recording medium having a higher coercive force and a larger saturation magnetization, exhibits a less noise and a large output in a high recording frequency region, and is free from the distortion of isolated reproduced waveform.

The reason why the magnetic recording medium having such excellent properties can be obtained by satisfying the above

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requirements of the present invention, is considered by the present inventors as follows. That is, due to the fact that the aimed magnetic recording medium cannot be obtained in any of the cases where the cobalt-containing maghemite thin film satisfies the specified spacing and the specified ratio between the peak intensities but no nickel oxide underlayer is formed, where the nickel oxide underlayer is formed and the specified spacing of the cobalt-containing maghemite thin film is satisfied but the specified ratio between the peak intensities is not satisfied, and where the nickel oxide underlayer is formed and the specified ratio between the peak intensities is satisfied but the specified spacing is not satisfied, there exists a synergistic effect based on the nickel oxide underlayer, the specified spacing and the specified ratio between the peak intensities in the cobalt-containing maghemite thin film.

With respect to the spacing of the respective lattice planes of the cobalt-containing maghemite thin film according to the present invention, even though the cobalt-containing magnetite thin film is transformed into the cobalt-containing maghemite thin film at the same heating temperature, the spacing of each of the (311), (222) and (220) planes is caused to change by varying the flow rate of oxygen upon formation of the cobalt-containing magnetite thin film. Due to this fact, it can be recognized that the change of the spacing is not caused by the difference in thermal expansion coefficient

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between the substrate, the nickel oxide underlayer and the cobalt-containing maghemite upon the heat treatment, but is caused by reduction in spacing of the cobalt-containing maghemite thin film itself.

The magnetic recording medium of the present invention can have a higher coercive force and a larger saturation magnetization, exhibits a less noise and a large output in a high recording frequency region, and is free from distortion of isolated reproduced waveform and is, therefore, more suitable for use in current magnetic recording systems using a ring-type magnetic write head.

In addition, in the production of the magnetic recording medium according to the present invention, since the cobalt-containing magnetite thin film can be heat-treated and transformed into the cobalt-containing maghemite thin film at a temperature as low as not more than 450°C, it is not required to use a substrate having a heat-resistance, and ordinarily used materials such as glass, resulting in good productivity with industrial and economical advantages.

EXAMPLES:

The present invention will now be described in more detail with reference to the following examples and comparative examples, but the present invention is not restricted to those examples and various modifications are possible within the scope of the invention.

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(1) The magnetostatic properties such as coercive force and saturation magnetization (measured under an external magnetic field of 15 kOe) of the magnetic recording medium, are expressed by values measured by "Vibrating Sample Magnetometer VSM" (manufactured by TOEI KOGYO CO., LTD.).

(2) The X-ray diffraction spectrum of the magnetic recording medium is expressed by values measured by "X-ray Diffractometer RAD-IIA" (manufactured by RIGAKU DENKI CO., LTD.).

The measuring conditions of the X-ray diffraction spectrum are as follow: lamp used: Fe; lamp voltage: 40 kV; lamp current: 25 mA; sampling width of goniometer: 0.010°; scanning speed: 1.000°/min; light-emitting (divergent) slit: 1°; scattering slit: 1°; light-receiving slit: 0.30 mm.

The region corresponding to a diffraction angle (2θ) of 30.00° to 60.00° was measured under the above-mentioned conditions.

(3) The read-write properties such as noise, reproduced output or di-pulse of the magnetic recording medium are evaluated as follows.

That is, after a magnetic film was formed on a glass disc and then the surface of the magnetic film was coated with a perfluoropolyether-based lubricant "FOMBLIN Z DOL" (trade name: produced by AUSIMONT CO, LTD.), an MIG head for VCR was run on the resultant magnetic recording medium while

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contacting therewith at a gap length of about 0.2 μm and a track width of 21 μm. The respective read-write properties were evaluated by using "Recording and Reproducing Tester M-84V" (manufactured by FUJITSU AUTOMATION CO., LTD.).

Specifically, the noise value (N_{rms}) was analyzed by "Spectrum Analyzer TR4171" (manufactured by ADVANTEST CO., LTD.) at a velocity of 3.0 m/s.

The reproduced output (S_{p-p}) and di-pulse ratio were analyzed by "Oscilloscope VP5514A" (manufactured by PANASONIC CO., LTD.) at a velocity of 3.0 m/s.

For example, the reproduced output is expressed by a sum of the "a" value and the "b" value shown in Fig. 2, and the di-pulse ratio is expressed by the ratio of the "a" value to the "b" value shown in Fig. 2.

Example 1:

Using a high recording frequency high-rate sputtering apparatus SH-250H-T06 (manufactured by ULVAC JAPAN LTD.), a metal target (Ni) was reactive sputtered at a distance between a glass substrate and the target to 80 mm, at a temperature of 220°C in an atmosphere of argon and oxygen flow rate of 0.18 CCM, at an oxygen partial pressure of 0.15 mTorr and at a total pressure of 9 mTorr, thereby depositing an NaCl-type NiO film as an underlayer having a thickness of 0.1 μm on the glass substrate at a deposition rate of 4.0 nm/min. The NiO

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film was subjected to the measurement of X-ray diffraction spectrum, so that it was determined that the ratio of the diffraction peak intensity of the (200) plane to that of the (111) plane was 1:1.

Further, a metal alloy target (Fe+4wt.%Co) was sputtered at a temperature of 250°C in an atmosphere of argon and oxygen flow rate of 0.27 CCM, at an oxygen partial pressure of 0.23 mTorr and at a total pressure of 9 mTorr, thereby depositing a cobalt-containing magnetite thin film having a thickness of 0.1 μm on the NiO film at a deposition rate of 4.0 nm/min.

The resultant two-layered film was heat-treated at a temperature of 270°C for one hour in an atmosphere, thereby obtaining a cobalt-containing maghemite thin film formed on the NiO underlayer.

The cobalt-containing maghemite film was subjected to the measurement of X-ray diffraction spectrum, so that diffraction peaks of the (311) plane having a spacing of 2.505 Å and the (220) plane having a spacing of 2.934 Å were observed but no diffraction peak was observed with respect to the (400) plane.

The magnetostatic properties of the cobalt-containing maghemite were measured, so that it was determined that the coercive force thereof was 3,400 Oe and the saturation magnetization thereof was 300 emu/cm^3.

The read-write properties of the cobalt-containing maghemite film were measured, so that it was determined that

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the S_{p-p}/N_{rms} obtained upon reproduced signals recorded at a recording density of 100kFRPI was 49 dB, and the recording density whose reproduced output was one half of a reproduced output obtained upon reproduced signals recorded at a recording density of 1kFRPI, D_{50} was 150kFRPI.

In addition, the isolated reproduced waveform of the cobalt-containing maghemite upon reproduced signals recorded at a recording density of 1kFRPI, was observed by the oscilloscope, so that it was determined that the waveform exhibited a unimodal pulse shape corresponding to a di-pulse ratio of 0.

Examples 2 to 6 and Comparative Examples 1 to 5:

The same procedure as defined in Example 1 was conducted except that formation or non-formation and orientation condition of the nickel oxide underlayer, cobalt content of the cobalt-containing magnetite thin film, oxygen flow rate and film-depositing rate upon formation of the thin film, and heat-treating temperature and time were changed variously, thereby obtaining magnetic recording media.

The production conditions used and various properties of the obtained magnetic recording media are shown in Tables 1 and 2.

Incidentally, in Example 2 and Comparative Examples 1 and 4, no diffraction peak was observed with respect to the plane

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(400).

Table 1

Examples and Comparative Examples	Nickel oxide underlayer		
	Formation or non-formation of underlayer	Thickness (μm)	Orientation of underlayer (111)/(200)
Example 2	Formed	0.15	8
Example 3	Formed	0.1	1
Example 4	Formed	0.1	1
Example 5	Formed	0.1	1
Example 6	Formed	0.1	1
Comparative Example 1	Formed	0.1	1
Comparative Example 2	Formed	0.1	1
Comparative Example 3	Formed	0.15	8
Comparative Example 4	Formed	0.1	1
Comparative Example 5	Formed	0.15	0.03

Table 1 (continued)

Examples and Comparative Examples	Cobalt-containing magnetite thin film			Heat treatment	
	Cobalt content (molar ratio of Co to Fe)	Oxygen flow rate upon film formation	Film-deposition rate (nm/min)	Temperature (°C)	Time (min)
Example 2	0.04	0.23 CCM	3.5	300	60
Example 3	0.04	0.205 CCM	3.1	320	50
Example 4	0.04	0.22 CCM	3.3	270	120
Example 5	0.03	0.315 CCM	3.0	260	120
Example 6	0.08	0.315 CCM	3.6	300	60
Comparative Example 1	0.04	0.34 CCM	3.3	-	-
Comparative Example 2	0	0.22 CCM	4.0	300	60
Comparative Example 3	0.04	0.37 CCM	2.5	320	60
Comparative Example 4	0.08	0.315 CCM	3.6	-	-
Comparative Example 5	0.04	0.23 CCM	4.0	320	60

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Table 2

Examples and Comparative Examples	Magnetic recording medium		
	Composition	Cobalt content (molar ratio of Co to Fe)	Thickness (μm)
Example 2	cobalt-containing maghemite	0.04	0.1
Example 3	cobalt-containing maghemite	0.04	0.1
Example 4	cobalt-containing maghemite	0.04	0.1
Example 5	cobalt-containing maghemite	0.03	0.1
Example 6	cobalt-containing maghemite	0.08	0.1
Comparative Example 1	cobalt-containing maghemite	0.04	0.1
Comparative Example 2	cobalt-containing maghemite	0	0.1
Comparative Example 3	cobalt-containing maghemite	0.04	0.1
Comparative Example 4	cobalt-containing maghemite	0.08	0.1
Comparative Example 5	cobalt-containing maghemite	0.04	0.1

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Table 2 (continued)

Examples and Comparative Examples	Magnetic recording medium		
	Magnetic thin film		
	Spacing (Å)		
	(311)	(222)	(220)
Example 2	2.506	2.401	2.934
Example 3	2.504	-	2.933
Example 4	2.505	-	2.934
Example 5	2.510	-	2.938
Example 6	2.508	2.404	2.943
Comparative Example 1	2.530	-	2.973
Comparative Example 2	2.508	-	2.936
Comparative Example 3	2.518	2.418	-
Comparative Example 4	2.530	2.424	2.973
Comparative Example 5	-	-	-

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Table 2 (continued)

Examples and Comparative Examples	Magnetic recording medium				
	Magnetic thin film			Magnetostatic properties	
	Peak intensity ratio			Saturation magnetization (emu/cm^3)	Coercive force (Oe)
	(311)/(400)	(222)/(400)	(220)/(400)		
Example 2	4	3	2.5	311	2880
Example 3	1.5	0	1.1	300	3500
Example 4	0.8	0	3	293	3430
Example 5	∞	-	∞	272	2010
Example 6	1.2	1.1	1.5	351	3460
Comparative Example 1	∞	-	∞	345	930
Comparative Example 2	1	-	6.5	287	450
Comparative Example 3	∞	-	∞	148	1160
Comparative Example 4	1.4	1	1.5	410	1370
Comparative Example 5	0	0	0	345	2680

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Table 2 (continued)

Examples and Comparative Examples	Magnetic recording medium		
	Read-write properties		
	S_{p-p}/N_{rms} (dB)	D_{50} (kFRPI)	Di-pulse ratio
Example 2	50	140	0
Example 3	49	151	0
Example 4	49	146	0
Example 5	47	135	0
Example 6	48	150	0
Comparative Example 1	43	110	0
Comparative Example 2	39	100	0
Comparative Example 3	40	108	0
Comparative Example 4	44	115	0
Comparative Example 5	50	150	0.2

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Comparative Example 6:

Using a high recording frequency high-rate sputtering apparatus SH-250H-T06 (manufactured by ULVAC JAPAN LTD.), a metal target (Ni) was reactive sputtered at a distance between a glass substrate and the target to 80 mm, at room temperature in an atmosphere of argon and oxygen flow rate of 0.21 CCM, at an oxygen partial pressure of 0.18 mTorr and at a total pressure of 9 mTorr, thereby depositing an NaCl-type NiO film as an underlayer having a thickness of 0.1 μm on the glass substrate at a deposition rate of 4.0 nm/min. The NiO film was subjected to the measurement of X-ray diffraction spectrum, so that it was determined that only one diffraction peak was observed with respect to the (200) plane.

Further, a metal alloy target (Fe+4wt.%Co) was sputtered at a temperature of 250°C in an atmosphere of argon and oxygen flow rate of 0.27 CCM, at an oxygen partial pressure of 0.23 mTorr and at a total pressure of 9 mTorr, thereby depositing a cobalt-containing magnetite thin film having a thickness of 0.1 μm on the NiO film at a deposition rate of 4.0 nm/min.

The resultant two-layered film was heat-treated at a temperature of 300°C for one hour in an atmosphere, thereby obtaining a cobalt-containing maghemite thin film formed on the NiO underlayer.

The cobalt-containing maghemite film was subjected to the measurement of X-ray diffraction spectrum, so that only one diffraction peak was observed with respect to the (400) plane.

The magnetostatic properties of the cobalt-containing maghemite were measured, so that it was determined that the coercive force thereof was 3,300 Oe and the saturation magnetization thereof was 340 emu/cm^3.

The read-write properties of the cobalt-containing maghemite were measured, so that it was determined that the S_{p-p}/N_{rms} obtained upon reproduced signals recorded at a recording density of 100kFRPI was 51 dB, and the recording density whose reproduced output was one half of a reproduced output obtained upon reproduced signals recorded at a recording density of 1kFRPI, D_{50} was 163kFRPI.

In addition, the isolated reproduced waveform of the cobalt-containing maghemite upon reproduced signals recorded at a recording density of 1kFRPI, was observed by the oscilloscope, so that it was determined that the waveform exhibited a di-pulse shape corresponding to a di-pulse ratio of 0.2, as shown in Fig. 2.

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WHAT IS CLAIMED IS:

1. A magnetic recording medium comprising:

a substrate;

a nickel oxide underlayer formed on said substrate; and

a cobalt-containing maghemite thin film formed on said nickel oxide underlayer, and having either a spacing of a (311) plane of not more than 2.510Å, a spacing of a (222) plane of not more than 2.415Å or a spacing of a (220) plane of not more than 2.950Å, and having the ratio of either of X-ray diffraction spectrum peak intensities of the (311), (222) or (220) planes of said cobalt-containing maghemite thin film to an X-ray diffraction spectrum peak intensity of the (400) plane of more than 0.5:1.

2. A magnetic recording medium according to claim 1, wherein said cobalt-containing maghemite thin film further contains at least one element selected from the group consisting of Mn, Ni, Cu, Ti and Zn in such an amount that the molar ratio of said element to iron is 0.005:1 to 0.04:1.

3. A magnetic recording medium according to claim 1, wherein the molar ratio of cobalt to iron in said cobalt-containing maghemite thin film is 0.01:1 to 0.1:1.

4. A magnetic recording medium according to claim 1, wherein said cobalt-containing maghemite thin film has a thickness of 0.005 to 1.0 μm.

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5. A magnetic recording medium according to claim 1, wherein the spacing of the (311) plane is 2.490 to 2.509 Å.

6. A magnetic recording medium according to claim 1, wherein the spacing of the (222) plane is 2.385 to 2.400 Å.

7. A magnetic recording medium according to claim 1, wherein the spacing of the (220) plane is 2.920 to 2.943 Å.

8. A magnetic recording medium according to claim 1, wherein the saturation magnetization of said magnetic recording medium is 250 to 400 emu/cm^3.

9. A magnetic recording medium according to claim 1, wherein the coercive force of said magnetic recording medium is not less than 2,000 Oe.

10. A magnetic recording medium according to claim 1, wherein the ratio of an X-ray diffraction spectrum peak intensity of a (111) plane of said nickel oxide underlayer to that of a (200) plane thereof is more than 0.5.

11. A magnetic recording medium according to claim 1, wherein said nickel oxide underlayer has a thickness of 0.01 to 0.5 μm.

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ABSTRACT OF THE DISCLOSURE

A magnetic recording medium of the present invention comprises:

a substrate;

a nickel oxide underlayer formed on said substrate; and

a cobalt-containing maghemite thin film formed on said nickel oxide underlayer, having either a spacing of a (311) plane of not more than 2.510Å, a spacing of a (222) plane of not more than 2.415Å or a spacing of a (220) plane of not more than 2.950Å, and having the ratio of either of X-ray diffraction spectrum peak intensities of the (311), (222) or (220) planes of said cobalt-containing maghemite thin film to an X-ray diffraction spectrum peak intensity of the (400) plane of more than 0.5:1.

Such a magnetic recording medium has a higher coercive force, a higher saturation magnetization, less amount of noise generated, a large output in a high recording frequency region and less distortion of a reproduced waveform, and is suitable for use in current magnetic recording systems in which a ring-type magnetic write head is used.

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FIG.1

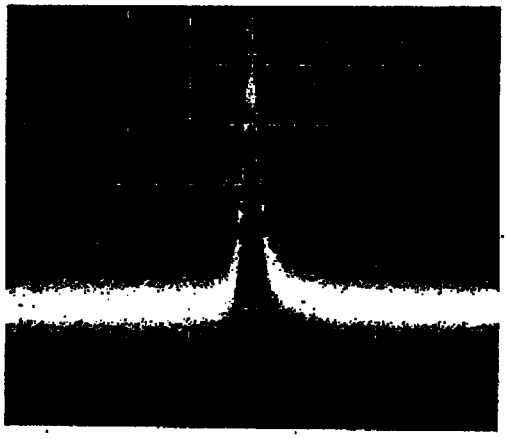
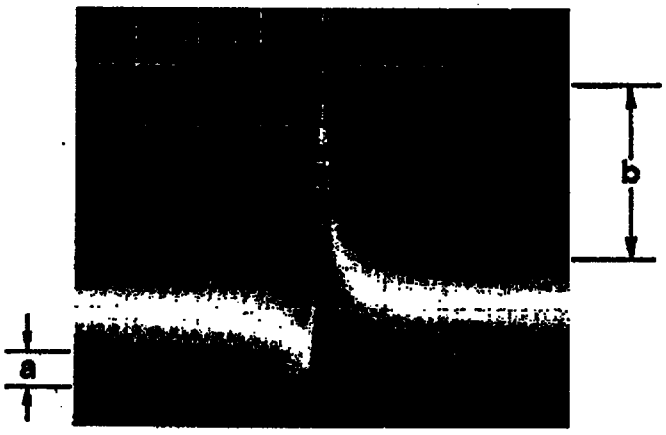


FIG.2



X : 1μm/div

REPLACEMENT SHEETS SG
☑ Description : paged ...1. to paged 31..
☑ Claim(s) : paged 32 to paged 33..
☑ Drawing(s) : paged ...1.. to paged ....
☑ Abstract : paged ...... to paged 34....

DATE OF RECEIPT 06/01/99.....

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SG-980820-1

TITLE OF THE INVENTION:

MAGNETIC RECORDING MEDIUM

BACKGROUND OF THE INVENTION:

The present invention relates to a magnetic recording medium, and more particularly, to a magnetic recording medium for high-density recording, having a higher coercive force and a higher saturation magnetization, exhibiting a less amount of noise generated, a large output in a high recording frequeney region and a less distortion of a reproduced waveform, and being suitable for use in current magnetic recording systems in which a ring-type magnetic write head is used.

In recent years, in magnetic recording apparatuses such as a hard disc drive, there has been a remarkable tendency that information devices or systems used therewith are miniaturized and required to have a high reliability. In association with such a recent tendency, in order to deal with a large capacity data, there is an increasing demand for magnetic recording media on which information can be stored with a high density.

In order to fulfill such requirements, the magnetic recording media have been strongly required to have as high a coercive force as possible.

As magnetic recording media having a large coercive force, there are widely known those comprising a substrate and a magnetic thin film formed on the substrate.

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The magnetic thin films which have been already put into practice, are generally classified into magnetic iron oxide thin films composed of maghemite, etc. (refer to "Technical Report of Electronic Telecommunication Institute", published by Electronic Telecommunication Institute, (1981) MR81-20, pp. 5 to 12), and alloy thin films composed of Co-Cr alloy or the like.

The magnetic iron oxide thin films are excellent in oxidation resistance or corrosion resistance because maghemite is already oxidized. Therefore, the magnetic iron oxide thin films can show an excellent stability independent to change in passage of time, i.e., less change in magnetic properties with passage of time. However, the coercive force of the magnetic iron oxide thin films is as low as at most about 700 Oe and the saturation magnetization of the magnetic iron oxide thin films is as low as at most about 240 emu/cm^3.

Whereas, the alloy thin films have a coercive force as high as not less than about 2,000 Oe and a saturation magnetization as high as not less than about 300 emu/cm^3. However, the alloy thin films tend to be readily oxidized, so that the stability independent to change in passage of time is deteriorated.

In order to prevent magnetic properties of these alloy thin films from being deteriorated due to the oxidation, the surfaces of the alloy thin films have been coated with a

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protective film, e.g., a carbon film having usually a thickness of about 100 to about 200 Å. However, in such a case, a distance between a magnetic write head and a magnetic recording layer becomes increased by the thickness of the carbon film, resulting in large loss due to the magnetic spacing, which disables the magnetic recording medium to be applied to high-density recording.

In consequence, it has been attempted to enhance the coercive force and saturation magnetization of the above-mentioned magnetic iron oxide thin films which are excellent in oxidation resistance, corrosion resistance and stability independent to change in passage of time, by incorporating cobalt or the like thereinto. The magnetic iron oxide thin films containing cobalt, etc., have been already put into practice. In addition, there have been extensively developed so-called perpendicular magnetic films which are free from demagnetization because these films are magnetized in perpendicular to the surface thereof, and which can be, therefore, recorded with a high density.

In the magnetic cobalt-containing iron oxide thin films, the more the cobalt content, the higher the coercive force thereof becomes. However, with the increase of cobalt content, the stability independent to change in passage of time of these magnetic iron oxide thin films tend to be deteriorated by adverse influences of heat or the like.

In the case where information recorded on the above-

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mentioned perpendicular magnetic films is read out using a magnetic recording system equipped with a ring-type magnetic write head which have been currently extensively used, there is caused the distortion of isolated reproduced waveform (i.e., a reproduced waveform of so-called "di-pulse"). For this reason, it is necessary to conduct a specific signal processing.

In order to avoid to conduct the specific signal processing, a single-pole magnetic write head used in a vertical magnetic recording system may be used appropriately. However, since the vertical magnetic recording system has not been extensively used yet, the single-pole magnetic write head is still very expensive.

Thus, at the present time, there has been a strong demand for providing magnetic recording media for high-density recording which are suitable for use in current magnetic recording systems equipped with a ring-type magnetic write head. For this reason, various kinds of magnetic recording media mentioned above have been extensively developed. Among them, the magnetic iron oxide thin films having excellent oxidation resistance and corrosion resistance have been considered to be most useful, so that it have been more strongly demanded to improve properties of these magnetic iron oxide thin films.

That is, as described above, the magnetic iron oxide thin films have been strongly required not only to have a high

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coercive force and a large saturation magnetization, but also to exhibit less noise and a large output in a high recording frequency region, and to be free from the distortion of isolated reproduced waveform.

Conventionally, as typical magnetic iron oxide thin films, there are known maghemite films. It is also known that cobalt can be incorporated into the maghemite in order to enhance the coercive force thereof (Japanese Patent Publications (KOKOKU) Nos. 51-4086(1976) and 5-63925(1993), and "CERAMICS", published by Japan Ceramics Institute (1986), Vol. 24, No. 1, pp. 21 to 24).

Further, it is known that the magnetic thin film composed of cobalt-containing maghemite is a so-called perpendicular magnetic film whose a (400) plane is predominantly oriented in parallel with the surface of substrate (Japanese Patent Publication (KOKOKU) No. 7-60768(1995) and Japanese Patent Application Laid-open (KOKAI) No. 7-307022(1995)).

More specifically, in Japanese Patent Publication (KOKOKU) No. 51-4086(1976), there is described a magnetic thin film memory comprising a ceramic substrate made of a high-purity alumina ceramic material which has a high density and is free from damaging memory properties of ferrite due to the reaction therewith even at an elevated temperature of 1,000 to 1,300°C to produce the ferrite, and a cobalt-based spinel-type ferrite film formed on the substrate and having a composition represented by the general formula of $Co_{(1-x)}Fe_{(2+x)}O_4$ where -

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$0.2 \leq x \leq 0.3$, the ferrite film being composed of fine crystalline aggregates of the ferrite.

In Japanese Patent Publication (KOKOKU) No. 5-63925(1993), there is described a process for producing a magnetic iron oxide thin film having a high coercive force, comprising reactive sputtering an iron alloy as a target in an oxidization atmosphere of argon and oxygen to directly form ferromagnetic oxide magnetite (Fe_3O_4) of a non-stoichiometric composition having a resistivity of 1×10^{-1} to 8×10^{-1} $\Omega \cdot cm$, and heat-treating the ferromagnetic oxide magnetite (Fe_3O_4) having the above-mentioned resistivity in an atmosphere at a temperature of 280 to 350°C, thereby producing ferromagnetic oxide γ-Fe_2O_3 having a high coercive force.

In Japanese Patent Publication (KOKOKU) No. 7-60768(1995), there is described a fixed magnetic disc comprising a substrate, an oxide thin film formed on the substrate and having an NaCl-type crystal structure composed of nickel oxide crystallographically predominantly oriented in the (100) plane, and a magnetic cobalt-containing iron oxide thin film formed on the nickel oxide thin film and having a spinel-type crystal structure.

Further, in Japanese Patent Application Laid-open (KOKAI) No. 7-307022(1995), there is described a magnetic recording medium comprising: a substrate; an NiO underlayer formed on the surface of the substrate, whose a (200) plane is

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predominantly oriented in parallel with the surface of the substrate; and a cobalt-containing maghemite thin film as a perpendicular magnetic film formed on the surface of the NiO underlayer, whose a (400) plane is predominantly oriented in parallel with the surface of a substrate and which has a molar ratio of Co to Fe of not less than 0.01 and less than 0.10 and a spacing of the (400) plane of not more than 2.082 Å.

At the present time, as the magnetic recording media for high-density recording which are suitable for use in current magnetic recording systems using a ring-type magnetic write head, there have been demanded those having a higher coercive force, a large saturation magnetization, an excellent stability independent to change in passage of time, less noise and a large output in a high recording frequency region, and being free from the distortion of isolated reproduced waveform. However, there have not been provided yet such magnetic recording media having all of the above-mentioned properties.

That is, the above-mentioned conventional cobalt-containing maghemite thin films are still unsatisfactory in magnetic properties, especially coercive force thereof. When it is attempted to obtain a high coercive force, especially not less than 2,000 Oe, it is necessary to incorporate a large amount of cobalt thereinto. In this case, such cobalt-containing maghemite thin film tend to be adversely affected by heat and the like, resulting in considerable deterioration in magnetic properties with passage of time.

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Also, there is a problem that the cobalt-containing maghemite thin film cannot show a sufficiently large output in a high recording frequency region.

Further, the above-mentioned conventional perpendicular magnetic films composed of iron oxides have a problem concerning the distortion of isolated reproduced waveform. Therefore, the perpendicular magnetic films cannot be applied to current magnetic recording systems using a ring-type magnetic write head.

As a result of the present inventors' earnest studies to solve the above problems, it has been found that by forming a nickel oxide underlayer on a substrate and then forming a cobalt-containing maghemite thin film on the nickel oxide underlayer so as to control a spacing of a (311) plane to not more than 2.510 Å, a spacing of a (222) plane to not more than 2.415 Å or a spacing of a (220) plane to not more than 2.950 Å and further to control the ratio of either of X-ray diffraction spectrum peak intensities of the (311), (222) and (220) planes to an X-ray diffraction spectrum peak intensity of a (400) plane, to more than 0.5:1, the obtained magnetic recording medium has a higher coercive force, e.g., not less than 2,000 Oe, a larger saturation magnetization, e.g., not less than 250 emu/cm^3, exhibits less amount of noise and a large output in a high recording frequency region, and is free from distortion of isolated reproduced waveform. The present invention has been attained on the basis of the finding.

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SUMMARY OF THE INVENTION

It is an object of the present invention to provide a magnetic recording medium for high density recording, which is suitable for use in current magnetic recording systems using a ring-type magnetic write head, has a high coercive force and a large saturation magnetization, exhibits less noise and a large output in a high recording frequency region, and is free from the distortion of reproduced waveform.

To accomplish the aims, in an aspect of the present invention, there is provided a magnetic recording medium comprising: a substrate; a nickel oxide underlayer formed on the substrate; and a cobalt-containing maghemite thin film formed on the nickel oxide underlayer, having either a spacing of a (311) plane of not more than 2.510Å, a spacing of a (222) plane of not more than 2.415Å or a spacing of a (220) plane of not more than 2.950Å, and having the ratio of either of X-ray diffraction spectrum peak intensities of the (311), (222) or (220) planes of the cobalt-containing maghemite thin film to an X-ray diffraction spectrum peak intensity of a (400) plane of more than 0.5:1.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows an isolated reproduced waveform upon reproduced signals recorded at a recording density of 1kFRPI on a magnetic recording medium in Example 1; and

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Fig. 2 shows an isolated reproduced waveform upon reproduced signals recorded at a recording density of 1kFRPI on a magnetic recording medium obtained in Comparative Example 5.

DETAILED DESCRIPTION OF THE INVENTION

First, the magnetic recording medium according to the present invention is described.

The magnetic recording medium according to the present invention comprises a substrate, a nickel oxide underlayer formed on the substrate and a cobalt-containing maghemite thin film formed on the nickel oxide underlayer.

The substrate used in the present invention may be made of materials ordinarily used for this purpose, such as glass or the like.

The nickel oxide underlayer of the magnetic recording medium of the present invention has a thickness of usually 0.01 to 0.5 μm, preferably 0.02 to 0.3 μm. When the thickness of the underlayer is less than 0.01 μm, it may become difficult to obtain the aimed magnetic recording medium having a higher coercive force. On the other hand, when the thickness of the underlayer is more than 0.5 μm, the grain size of the cobalt-containing maghemite particles of the magnetic thin film formed on the nickel oxide underlayer may become large, so that the noise from the resultant magnetic recording medium tends to be increased.

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It is preferred that the nickel oxide underlayer of the magnetic recording medium of the present invention be less oriented in its (200) plane parallel with the surface of the substrate, more preferably not oriented at all in the (200) plane. When the orientation of the (200) plane becomes large, there is caused a tendency that the (400) plane of the cobalt-containing maghemite thin film is grown, so that the di-pulse ratio is increased. Therefore, in view of the di-pulse ratio, the ratio of an X-ray diffraction peak intensity of the (111) plane to that of the (200) plane is preferably more than 0.5:1, more preferably not less than 1.0:1.

The magnetic thin film of the magnetic recording medium according to the present invention is a cobalt-containing maghemite thin film having a thickness of usually 0.005 to 1.0 μm, preferably 0.01 to 0.5 μm.

In general, maghemite is represented by the formula of γ-Fe_2O_3. However, in the present invention, there may also be used such maghemite containing a small amount of Fe^{2+}. The upper limit of the Fe^{2+} content at a molar ratio of Fe^{2+} to Fe^{3+} is preferably 0.3:1.

In addition, the cobalt-containing maghemite thin film may further contain at least one element selected from the group consisting of Mn, Ni, Cu, Ti and Zn which may be usually used to improve various properties thereof, in such an amount that the molar ratio of these elements to Fe is usually about

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0.005:1 to about 0.04:1.

The cobalt content in the maghemite thin film is usually 0.01:1 to 0.1:1, preferably 0.01:1 to 0.06:1, more preferably 0.03:1 to 0.06:1 at a molar ratio of Co to Fe. When the molar ratio of Co to Fe is less than 0.01:1, it may become difficult to obtain a magnetic recording medium having a coercive force as high as not less than 2,000 Oe. On the other hand, when the molar ratio of Co to Fe is more than 0.1:1, it may become difficult to obtain a magnetic recording medium having an excellent stability independent to change in passage of time.

The cobalt-containing maghemite thin film according to the present invention is controlled to satisfy at least one of the following conditions: i.e., a spacing of a plane (311) is not more than 2.510 Å; a spacing of a (222) plane is not more than 2.415 Å; or a spacing of a (220) plane is not more than 2.950 Å. In this case, if any one condition can be satisfied, it is not required to satisfy the other two conditions.

When all of the above-mentioned three conditions concerning the spacing of the (311), (222) and (220) planes are not satisfied, it is not possible to obtain a magnetic recording medium having a high coercive force. Further, such a magnetic recording medium undergoes a large amount of noise and cannot exhibit a sufficiently large output in a high recording frequency region.

There is a close relationship between the spacing of the (311) plane, the (222) plane or the (220) plane and the

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coercive force of the cobalt-containing maghemite thin film. In the case where the molar ratio of Co to Fe is the same, there is a tendency that the smaller the spacing, the larger the coercive force becomes.

The spacing of the (311) plane is usually not more than 2.510 Å, preferably not more than 2.509 Å, more preferably not more than 2.506 Å. The lower limit of the spacing of the (311) plane is preferably 2.490 Å.

The spacing of the (222) plane is usually not more than 2.415 Å, preferably not more than 2.400 Å, more preferably not more than 2.399 Å, still more preferably not more than 2.398 Å. The lower limit of the spacing of the (222) plane is preferably 2.385 Å.

The spacing of the (220) plane is usually not more than 2.950 Å, preferably not more than 2.943 Å, more preferably not more than 2.940 Å. The lower limit of the spacing of the (220) plane is preferably 2.920 Å.

The cobalt-containing maghemite thin film of the magnetic recording medium of the present invention is controlled to satisfy such a condition that the ratio of either of X-ray diffraction spectrum peak intensities of the (311), (222) or (220) planes to an X-ray diffraction spectrum peak intensity of the (400) plane is usually more than 0.5:1, preferably not less than 1:1. When the ratio is not more than 0.5:1, it is not possible to obtain the aimed magnetic recording medium for high density recording which is suitable for use in current

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magnetic recording systems using a ring-type magnetic write head.

The magnetic recording medium of the present invention, has a saturation magnetization (magnetization value measured at an applied magnetic field of 15 kOe) of preferably 250 to 400 emu/cm^3, more preferably 300 to 360 emu/cm^3, and a coercive force of usually not less than 2,000 Oe, preferably not less than 2,200 Oe, more preferably not less than 2,300 Oe. In the present invention, especially when the molar ratio of Co to Fe is 0.04, it has been determined that the upper limit of the coercive force is about 6,500 Oe. Incidentally, in the current magnetic recording systems using a ring-type magnetic write head, the upper limit of the coercive force is preferably about 4,000 Oe, more preferably 3,000 Oe.

Besides, the upper limit of the coercive force of the magnetic recording medium of the present invention, also means a value measured at an applied magnetic field of 15 kOe which is an upper limit of the coercive force measurable by "vibrating sample magnetometer" described in detail hereinafter. In addition, with respect to read-write properties of the magnetic recording medium of the present invention when measured by using a tester described in Examples hereinafter, the S_{p-p}/N_{rms} is preferably not less than 45 dB, more preferably not less than 47 dB; the recording density whose output is one half of an output obtained at a

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recording density of 1kFRPI, D_{50} is preferably not less than 130 kFRPI, more preferably not less than 140 kFRPI; and the di-pulse ratio is 0 as shown in Fig. 1.

Next, the process for producing the magnetic recording medium according to the present invention, is described.

The magnetic recording medium according to the present invention can be produced by depositing cobalt-containing magnetite on the substrate or on the nickel oxide underlayer formed by depositing nickel oxide on the substrate, by a so-called sputtering method using cobalt-containing iron alloy as a target while controlling a flow rate of oxygen (CCM) as an amount of oxygen introduced and a deposition rate (nm/min) of the cobalt-containing magnetite, to form a cobalt-containing magnetite thin film on the nickel oxide underlayer; and then heat-treating the obtained cobalt-containing magnetite thin film at a temperature of 200 to 450°C to transform the cobalt-containing magnetite thin film into a cobalt-containing maghemite thin film.

In order to obtain the aimed magnetic recording medium according to the present invention, it is important to control the flow rate of oxygen (CCM) relative to the deposition rate (nm/min) of the cobalt-containing magnetite.

The flow rate of oxygen (CCM) relative to the deposition rate (nm/min) of the cobalt-containing magnetite to obtain the aimed magnetic recording medium according to the present invention, is varied depending upon various conditions having

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an influence on the oxidation of the cobalt-containing magnetite thin film, such as kind and construction of apparatus used, a total gas pressure, a substrate temperature or an area of target to be sputtered. Therefore, it is difficult to specifically determine the preferred flow rate of oxygen.

However, as a result of many experiments conducted by the present inventors, it has been recognized that there is a tendency that the less the flow rate of oxygen (CCM) relative to the deposition rate (nm/min) of the cobalt-containing magnetite, the smaller the spacing of each of the (311), (222) and (220) planes of the obtained cobalt-containing maghemite thin film becomes.

Accordingly, by conducting various experiments to obtain the flow rate of oxygen (CCM) relative to the deposition rate (nm/min) of the cobalt-containing magnetite at which the spacing of each of (311), (222) and (220) planes becomes smaller than that of the bulk, the deposition rate (nm/min) of the cobalt-containing magnetite and the flow rate of oxygen may be respectively controlled so as to be smaller than the obtained values.

In accordance with the experiments conducted by the present inventors, as described in Examples and Comparative Examples hereinafter, when the deposition rate of the cobalt-containing magnetite is 3.5 nm/min, the flow rate of oxygen (CCM) is usually not more than 0.35, preferably not more than

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0.27, more preferably not more than 0.25. The lower limit of the flow rate of oxygen (CCM) is preferably 0.18. When the flow rate of oxygen is more than 0.35, hematite may tend to be formed in the obtained cobalt-containing maghemite thin film, resulting in decrease in saturation magnetization thereof. On the other hand, when the flow rate of oxygen is less than 0.18, metal iron (Fe) or wustite (FeO) may tend to be formed in the obtained cobalt-containing maghemite thin film, resulting in decrease in coercive force thereof.

The important point of the present invention resides in that in the case where the nickel oxide underlayer is formed on the substrate, and the cobalt-containing maghemite thin film formed on the nickel oxide underlayer is adjusted so that any of conditions of a spacing of a (311) plane of not more than 2.510 Å, a spacing of a (222) plane of not more than 2.415 Å and a spacing of a (220) plane of not more than 2.950 Å is satisfied, and the ratio of either of X-ray diffraction spectrum peak intensities of the (311), (222) and (220) planes to an X-ray diffraction spectrum peak intensity of a (400) plane is more than 0.5:1, there can be obtained a magnetic recording medium having a higher coercive force and a larger saturation magnetization, exhibits a less noise and a large output in a high recording frequency region, and is free from the distortion of isolated reproduced waveform.

The reason why the magnetic recording medium having such excellent properties can be obtained by satisfying the above

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requirements of the present invention, is considered by the present inventors as follows. That is, due to the fact that the aimed magnetic recording medium cannot be obtained in any of the cases where the cobalt-containing maghemite thin film satisfies the specified spacing and the specified ratio between the peak intensities but no nickel oxide underlayer is formed, where the nickel oxide underlayer is formed and the specified spacing of the cobalt-containing maghemite thin film is satisfied but the specified ratio between the peak intensities is not satisfied, and where the nickel oxide underlayer is formed and the specified ratio between the peak intensities is satisfied but the specified spacing is not satisfied, there exists a synergistic effect based on the nickel oxide underlayer, the specified spacing and the specified ratio between the peak intensities in the cobalt-containing maghemite thin film.

With respect to the spacing of the respective lattice planes of the cobalt-containing maghemite thin film according to the present invention, even though the cobalt-containing magnetite thin film is transformed into the cobalt-containing maghemite thin film at the same heating temperature, the spacing of each of the (311), (222) and (220) planes is caused to change by varying the flow rate of oxygen upon formation of the cobalt-containing magnetite thin film. Due to this fact, it can be recognized that the change of the spacing is not caused by the difference in thermal expansion coefficient

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between the substrate, the nickel oxide underlayer and the cobalt-containing maghemite upon the heat treatment, but is caused by reduction in spacing of the cobalt-containing maghemite thin film itself.

The magnetic recording medium of the present invention can have a higher coercive force and a larger saturation magnetization, exhibits a less noise and a large output in a high recording frequency region, and is free from distortion of isolated reproduced waveform and is, therefore, more suitable for use in current magnetic recording systems using a ring-type magnetic write head.

In addition, in the production of the magnetic recording medium according to the present invention, since the cobalt-containing magnetite thin film can be heat-treated and transformed into the cobalt-containing maghemite thin film at a temperature as low as not more than 450°C, it is not required to use a substrate having a heat-resistance, and ordinarily used materials such as glass, resulting in good productivity with industrial and economical advantages.

EXAMPLES:

The present invention will now be described in more detail with reference to the following examples and comparative examples, but the present invention is not restricted to those examples and various modifications are possible within the scope of the invention.

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(1) The magnetostatic properties such as coercive force and saturation magnetization (measured under an external magnetic field of 15 kOe) of the magnetic recording medium, are expressed by values measured by "Vibrating Sample Magnetometer VSM" (manufactured by TOEI KOGYO CO., LTD.).

(2) The X-ray diffraction spectrum of the magnetic recording medium is expressed by values measured by "X-ray Diffractometer RAD-ⅡA" (manufactured by RIGAKU DENKI CO., LTD.).

The measuring conditions of the X-ray diffraction spectrum are as follow: lamp used: Fe; lamp voltage: 40 kV; lamp current: 25 mA; sampling width of goniometer: 0.010°; scanning speed: 1.000°/min; light-emitting (divergent) slit: 1°; scattering slit: 1°; light-receiving slit: 0.30 mm.

The region corresponding to a diffraction angle (2θ) of 30.00° to 60.00° was measured under the above-mentioned conditions.

(3) The read-write properties such as noise, reproduced output or di-pulse of the magnetic recording medium are evaluated as follows.

That is, after a magnetic film was formed on a glass disc and then the surface of the magnetic film was coated with a perfluoropolyether-based lubricant "FOMBLIN Z DOL" (trade name: produced by AUSIMONT CO, LTD.), an MIG head for VCR was run on the resultant magnetic recording medium while

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contacting therewith at a gap length of about 0.2 μm and a track width of 21 μm. The respective read-write properties were evaluated by using "Recording and Reproducing Tester M-84V" (manufactured by FUJITSU AUTOMATION CO., LTD.).

Specifically, the noise value (N_{rms}) was analyzed by "Spectrum Analyzer TR4171" (manufactured by ADVANTEST CO., LTD.) at a velocity of 3.0 m/s.

The reproduced output (S_{p-p}) and di-pulse ratio were analyzed by "Oscilloscope VP5514A" (manufactured by PANASONIC CO., LTD.) at a velocity of 3.0 m/s.

For example, the reproduced output is expressed by a sum of the "a" value and the "b" value shown in Fig. 2, and the di-pulse ratio is expressed by the ratio of the "a" value to the "b" value shown in Fig. 2.

Example 1:

Using a high recording frequency high-rate sputtering apparatus SH-250H-T06 (manufactured by ULVAC JAPAN LTD.), a metal target (Ni) was reactive sputtered at a distance between a glass substrate and the target to 80 mm, at a temperature of 120°C in an atmosphere of argon and oxygen flow rate of 0.18 CCM, at an oxygen partial pressure of 0.15 mTorr and at a total pressure of 9 mTorr, thereby depositing an NaCl-type NiO film as an underlayer having a thickness of 0.1 μm on the glass substrate at a deposition rate of 4.0 nm/min. The NiO

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film was subjected to the measurement of X-ray diffraction spectrum, so that it was determined that the ratio of the diffraction peak intensity of the (200) plane to that of the (111) plane was 1:1.

Further, a metal alloy target (Fe+4wt.%Co) was sputtered at a temperature of 250°C in an atmosphere of argon and oxygen flow rate of 0.27 CCM, at an oxygen partial pressure of 0.23 mTorr and at a total pressure of 9 mTorr, thereby depositing a cobalt-containing magnetite thin film having a thickness of 0.1 μm on the NiO film at a deposition rate of 4.0 nm/min.

The resultant two-layered film was heat-treated at a temperature of 270°C for one hour in an atmosphere, thereby obtaining a cobalt-containing maghemite thin film formed on the NiO underlayer.

The cobalt-containing maghemite film was subjected to the measurement of X-ray diffraction spectrum, so that diffraction peaks of the (311) plane having a spacing of 2.505 Å and the (220) plane having a spacing of 2.934 Å were observed but no diffraction peak was observed with respect to the (400) plane.

The magnetostatic properties of the cobalt-containing maghemite were measured, so that it was determined that the coercive force thereof was 3,400 Oe and the saturation magnetization thereof was 300 emu/cm^3.

The read-write properties of the cobalt-containing maghemite film were measured, so that it was determined that

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the S_{p-p}/N_{rms} obtained upon reproduced signals recorded at a recording density of 100kFRPI was 49 dB, and the recording density whose reproduced output was one half of a reproduced output obtained upon reproduced signals recorded at a recording density of 1kFRPI, D_{50} was 150kFRPI.

In addition, the isolated reproduced waveform of the cobalt-containing maghemite upon reproduced signals recorded at a recording density of 1kFRPI, was observed by the oscilloscope, so that it was determined that the waveform exhibited a unimodal pulse shape corresponding to a di-pulse ratio of 0.

Examples 2 to 6 and Comparative Examples 1 to 5:

The same procedure as defined in Example 1 was conducted except that formation or non-formation and orientation condition of the nickel oxide underlayer, cobalt content of the cobalt-containing magnetite thin film, oxygen flow rate and film-depositing rate upon formation of the thin film, and heat-treating temperature and time were changed variously, thereby obtaining magnetic recording media.

The production conditions used and various properties of the obtained magnetic recording media are shown in Tables 1 and 2.

Incidentally, in Example 2 and Comparative Examples 1 and 4, no diffraction peak was observed with respect to the plane

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(400).

Table 1

Examples and Comparative Examples	Nickel oxide underlayer		
	Formation or non-formation of underlayer	Thickness (μm)	Orientation of underlayer (111)/(200)
Example 2	Formed	0.15	8
Example 3	Formed	0.1	1
Example 4	Formed	0.1	1
Example 5	Formed	0.1	1
Example 6	Formed	0.1	1
Comparative Example 1	Formed	0.1	1
Comparative Example 2	Formed	0.1	1
Comparative Example 3	Formed	0.15	8
Comparative Example 4	Formed	0.1	1
Comparative Example 5	Formed	0.15	0.03

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Table 1 (continued)

Examples and Comparative Examples	Cobalt-containing magnetite thin film			Heat treatment	
	Cobalt content (molar ratio of Co to Fe)	Oxygen flow rate upon film formation	Film-deposition rate (nm/min)	Temperature (°C)	Time (min)
Example 2	0.04	0.23 CCM	3.5	300	60
Example 3	0.04	0.205 CCM	3.1	320	50
Example 4	0.04	0.22 CCM	3.3	270	120
Example 5	0.03	0.315 CCM	3.0	260	120
Example 6	0.08	0.315 CCM	3.6	300	60
Comparative Example 1	0.04	0.34 CCM	3.3	-	-
Comparative Example 2	0	0.22 CCM	4.0	300	60
Comparative Example 3	0.04	0.37 CCM	2.5	320	60
Comparative Example 4	0.08	0.315 CCM	3.6	-	-
Comparative Example 5	0.04	0.23 CCM	4.0	320	60

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Table 2

Examples and Comparative Examples	Magnetic recording medium		
	Composition	Cobalt content (molar ratio of Co to Fe)	Thickness (μm)
Example 2	cobalt-containing maghemite	0.04	0.1
Example 3	cobalt-containing maghemite	0.04	0.1
Example 4	cobalt-containing maghemite	0.04	0.1
Example 5	cobalt-containing maghemite	0.03	0.1
Example 6	cobalt-containing maghemite	0.08	0.1
Comparative Example 1	cobalt-containing maghemite	0.04	0.1
Comparative Example 2	cobalt-containing maghemite	0	0.1
Comparative Example 3	cobalt-containing maghemite	0.04	0.1
Comparative Example 4	cobalt-containing maghemite	0.08	0.1
Comparative Example 5	cobalt-containing maghemite	0.04	0.1

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Table 2 (continued)

Examples and Comparative Examples	Magnetic recording medium		
	Magnetic thin film		
	Spacing (Å)		
	(311)	(222)	(220)
Example 2	2.506	2.401	2.934
Example 3	2.504	-	2.933
Example 4	2.505	-	2.934
Example 5	2.510	-	2.938
Example 6	2.508	2.404	2.943
Comparative Example 1	2.530	-	2.973
Comparative Example 2	2.508	-	2.936
Comparative Example 3	2.518	2.418	-
Comparative Example 4	2.530	2.424	2.973
Comparative Example 5	-	-	-

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Table 2 (continued)

Examples and Comparative Examples	Magnetic recording medium				
	Magnetic thin film			Magnetostatic properties	
	Peak intensity ratio			Saturation magnetization (emu/cm^3)	Coercive force (Oe)
	(311)/(400)	(222)/(400)	(220)/(400)		
Example 2	4	3	2.5	311	2880
Example 3	1.5	0	1.1	300	3500
Example 4	0.8	0	3	293	3430
Example 5	∞	-	∞	272	2010
Example 6	1.2	1.1	1.5	351	3460
Comparative Example 1	∞	-	∞	345	930
Comparative Example 2	1	-	6.5	287	450
Comparative Example 3	∞	-	∞	148	1160
Comparative Example 4	1.4	1	1.5	410	1370
Comparative Example 5	0	0	0	345	2680

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Table 2 (continued)

Examples and Comparative Examples	Magnetic recording medium		
	Read-write properties		
	S_{p-p}/N_{rms} (dB)	D_{50} (kFRPI)	Di-pulse ratio
Example 2	50	140	0
Example 3	49	151	0
Example 4	49	146	0
Example 5	47	135	0
Example 6	48	150	0
Comparative Example 1	43	110	0
Comparative Example 2	39	100	0
Comparative Example 3	40	108	0
Comparative Example 4	44	115	0
Comparative Example 5	50	150	0.2

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Comparative Example 6:

Using a high recording frequency high-rate sputtering apparatus SH-250H-T06 (manufactured by ULVAC JAPAN LTD.), a metal target (Ni) was reactive sputtered at a distance between a glass substrate and the target to 80 mm, at room temperature in an atmosphere of argon and oxygen flow rate of 0.21 CCM, at an oxygen partial pressure of 0.18 mTorr and at a total pressure of 9 mTorr, thereby depositing an NaCl-type NiO film as an underlayer having a thickness of 0.1 μm on the glass substrate at a deposition rate of 4.0 nm/min. The NiO film was subjected to the measurement of X-ray diffraction spectrum, so that it was determined that only one diffraction peak was observed with respect to the (200) plane.

Further, a metal alloy target (Fe+4wt.%Co) was sputtered at a temperature of 250°C in an atmosphere of argon and oxygen flow rate of 0.27 CCM, at an oxygen partial pressure of 0.23 mTorr and at a total pressure of 9 mTorr, thereby depositing a cobalt-containing magnetite thin film having a thickness of 0.1 μm on the NiO film at a deposition rate of 4.0 nm/min.

The resultant two-layered film was heat-treated at a temperature of 300°C for one hour in an atmosphere, thereby obtaining a cobalt-containing maghemite thin film formed on the NiO underlayer.

The cobalt-containing maghemite film was subjected to the measurement of X-ray diffraction spectrum, so that only one diffraction peak was observed with respect to the (400) plane.

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The magnetostatic properties of the cobalt-containing maghemite were measured, so that it was determined that the coercive force thereof was 3,300 Oe and the saturation magnetization thereof was 340 emu/cm^3.

The read-write properties of the cobalt-containing maghemite were measured, so that it was determined that the S_{p-p}/N_{rms} obtained upon reproduced signals recorded at a recording density of 100kFRPI was 51 dB, and the recording density whose reproduced output was one half of a reproduced output obtained upon reproduced signals recorded at a recording density of 1kFRPI, D_{50} was 163kFRPI.

In addition, the isolated reproduced waveform of the cobalt-containing maghemite upon reproduced signals recorded at a recording density of 1kFRPI, was observed by the oscilloscope, so that it was determined that the waveform exhibited a di-pulse shape corresponding to a di-pulse ratio of 0.2, as shown in Fig. 2.

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WHAT IS CLAIMED IS:

1. A magnetic recording medium comprising:

a substrate;

a nickel oxide underlayer formed on said substrate; and

a cobalt-containing maghemite thin film formed on said nickel oxide underlayer, and having either a spacing of a (311) plane of not more than 2.510Å, a spacing of a (222) plane of not more than 2.415Å or a spacing of a (220) plane of not more than 2.950Å, and having the ratio of either of X-ray diffraction spectrum peak intensities of the (311), (222) or (220) planes of said cobalt-containing maghemite thin film to an X-ray diffraction spectrum peak intensity of the (400) plane of more than 0.5:1.

2. A magnetic recording medium according to claim 1, wherein said cobalt-containing maghemite thin film further contains at least one element selected from the group consisting of Mn, Ni, Cu, Ti and Zn in such an amount that the molar ratio of said element to iron is 0.005:1 to 0.04:1.

3. A magnetic recording medium according to claim 1, wherein the molar ratio of cobalt to iron in said cobalt-containing maghemite thin film is 0.01:1 to 0.1:1.

4. A magnetic recording medium according to claim 1, wherein said cobalt-containing maghemite thin film has a thickness of 0.005 to 1.0 μm.

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5. A magnetic recording medium according to claim 1, wherein the spacing of the (311) plane is 2.490 to 2.509 Å.

6. A magnetic recording medium according to claim 1, wherein the spacing of the (222) plane is 2.385 to 2.400 Å.

7. A magnetic recording medium according to claim 1, wherein the spacing of the (220) plane is 2.920 to 2.943 Å.

8. A magnetic recording medium according to claim 1, wherein the saturation magnetization of said magnetic recording medium is 250 to 400 emu/cm^3.

9. A magnetic recording medium according to claim 1, wherein the coercive force of said magnetic recording medium is not less than 2,000 Oe.

10. A magnetic recording medium according to claim 1, wherein the ratio of an X-ray diffraction spectrum peak intensity of a (111) plane of said nickel oxide underlayer to that of a (200) plane thereof is more than 0.5.

11. A magnetic recording medium according to claim 1, wherein said nickel oxide underlayer has a thickness of 0.01 to 0.5 μm.

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MAGNETIC RECORDING MEDIUM

ABSTRACT OF THE DISCLOSURE

A magnetic recording medium of the present invention comprises:

a substrate;

a nickel oxide underlayer formed on said substrate; and

a cobalt-containing maghemite thin film formed on said nickel oxide underlayer, having either a spacing of a (311) plane of not more than 2.510Å, a spacing of a (222) plane of not more than 2.415Å or a spacing of a (220) plane of not more than 2.950Å, and having the ratio of either of X-ray diffraction spectrum peak intensities of the (311), (222) or (220) planes of said cobalt-containing maghemite thin film to an X-ray diffraction spectrum peak intensity of the (400) plane of more than 0.5:1.

Such a magnetic recording medium has a higher coercive force, a higher saturation magnetization, less amount of noise generated, a large output in a high recording frequency region and less distortion of a reproduced waveform, and is suitable for use in current magnetic recording systems in which a ring-type magnetic write head is used.

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FIG.1

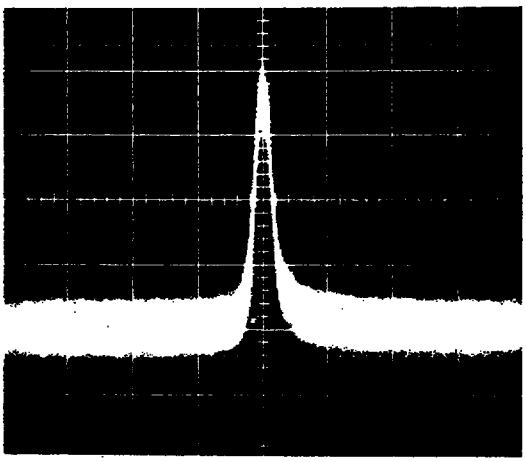
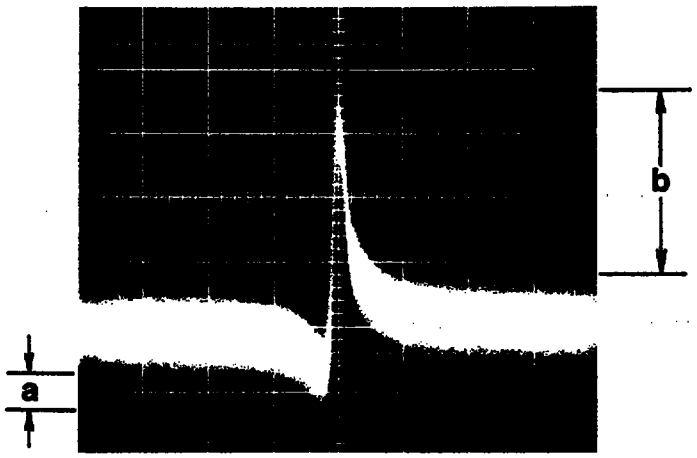


FIG.2



X ; 1μm/div

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