

LONGITUDINAL MAGNETIC RECORDING MEDIUM AND METHOD OF
MANUFACTURING THE SAME

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a longitudinal magnetic recording medium used in a hard disk drive (HDD) or the like, and a method of manufacturing the longitudinal magnetic recording medium.

2. Description of the Related Art

A hard disk magnetic recording medium has a structure in which, for example, a nonmagnetic metal underlayer, a metal magnetic recording layer, a protective layer, and a lubricant layer are formed on a substrate for which an aluminum alloy, glass, or the like is used. The nonmagnetic metal underlayer, the metal magnetic recording layer, and the protective layer are formed using, for example, a sputtering method in a high vacuum, and the lubricant layer is formed using, for example, dip coating. Recording and playback of signals are carried out using a magnetic head.

Ordinarily, for a magnetic recording medium substrate using an aluminum material, an aluminum alloy substrate is plated with Ni-P, and the surface thereof is subjected to texturing in which circumferential grooves known as texture are formed. In the case of a glass substrate, the surface of the glass substrate is textured directly. The nonmagnetic

metal underlayer, the metal magnetic recording layer, a carbon protective layer, and so on are formed in order on the textured surface in a high vacuum.

As a nonmagnetic metal underlayer, a Cr or Cr alloy underlayer (hereinafter referred to as a "Cr type underlayer") is well known. When forming the underlayer, by controlling process conditions for oxygen exposure, substrate heating and so on, the crystal orientation of the Cr type underlayer is made to be bcc (100), and then a Co alloy magnetic recording layer is grown epitaxially thereon with hcp (110) orientation. The hcp [001] axis of easy magnetization of the Co alloy magnetic recording layer becomes parallel to the substrate surface, and hence the remanent magnetization (M_r) in a direction parallel to the surface of the substrate can be made to be greater than that perpendicular to the surface of the substrate.

Moreover, when the Cr type underlayer is grown with the bcc (100) orientation, due to the circumferential grooves on the substrate surface produced through the texturing, the in-plane spacing of the bcc (011) planes in the circumferential direction of the substrate becomes less than the in-plane spacing of the bcc ($0\bar{1}1$) planes in the radial direction of the substrate. Due to this difference in the in-plane spacing, the hcp [001] direction of an intermediate layer or the Co alloy magnetic recording layer heteroepitaxially grown on the underlayer tends to be

oriented parallel to the circumferential direction. Because the hcp [001] direction of the Co alloy magnetic recording layer is the axis of easy magnetization, a difference arises in the Mr of the magnetic recording layer between the circumferential direction and the radial direction. Taking the product of the Mr in the circumferential direction and the thickness (t) to be Mrt_{cir} , and the product of the Mr in the radial direction and the thickness to be Mrt_{rad} , this difference is represented by $OR = Mrt_{\text{cir}} / Mrt_{\text{rad}}$. The higher the extent to which the hcp [001] direction of the polycrystalline Co alloy magnetic recording layer is oriented in the circumferential direction, the higher the OR.

By increasing the OR of a magnetic recording medium, Mrt_{cir} is increased, and hence the playback output of a recorded signal is increased, and thus the signal-to-noise ratio (SNR) is increased. Various ways have thus been attempted to increase the OR. For example, for a magnetic recording medium using a glass substrate, a method has been proposed in which the OR is increased by depositing one or a plurality of seed layer(s) between the Cr type underlayer and the textured substrate (see, for example, Japanese Patent Application Laid-open No. 2003-30825, Japanese Patent Application Laid-open No. 2004-39196, U.S. Patent Application Laid-open No. 2004/258925). Moreover, it is publicly known that the OR can be increased by exposing the surface of the seed layer to an oxygen-containing gas atmosphere before

forming the underlayer (see, for example, Japanese Patent Application Laid-open No. 2003-30825, Japanese Patent Application Laid-open No. 2004-39196).

With a longitudinal magnetic recording medium, to realize a high recording density of more than 100 Gbit/inch², the OR must be further increased. Moreover, as the OR is increased, the magnetic film thickness at which the same output is obtained decreases. As the magnetic layer becomes thinner, from the viewpoint of thermal stability, the coercivity (H_{cr}) of the medium must be increased. Furthermore, it is known that with regard to increasing the track density (TPI) in the radial direction of the medium, data written to a neighboring track is less prone to being deleted for a medium having a high H_{cr} , and hence this is effective for increasing the TPI.

With the above method in which the seed layer is exposed to oxygen before forming the underlayer, the OR can be increased, but there is a problem that as the oxygen partial pressure or the exposure time is increased, the coercivity of the magnetic layer is reduced due to oxygen adsorbed onto the surface of the seed layer.

SUMMARY OF THE INVENTION

The present invention has been devised in view of the above problems; it is an object of the present invention to provide a high-recording-density magnetic recording medium for which a high OR is realized and yet there is little

reduction in the Hcr.

A longitudinal magnetic recording medium according to the present invention comprises a nonmagnetic substrate, a seed layer, an underlayer, and a magnetic recording layer in this order, wherein the seed layer comprises a first seed layer and a second seed layer formed in this order, the first seed layer comprises a single layer or a plurality of layers made of at least one material selected from the group consisting of Ni-Ti alloys, Cr-Al alloys, Cr-Ta alloys, and Cr-Ti alloys, the second seed layer comprises a single layer or a plurality of layers made of at least one material selected from the group consisting of Ni-W alloys, Ni-Ru-W alloys, and Co-W alloys, the underlayer comprises a first underlayer and a second underlayer formed in this order, the first underlayer comprises a single layer or a plurality of layers made of a Cr-Ru alloy, and the second underlayer comprises a single layer or a plurality of layers made of a Cr alloy comprising Cr and at least one element selected from the group consisting of Mo, B, Ti, and W.

Preferably, each of the first seed layer and the second seed layer has an amorphous structure.

Moreover, preferably, a surface of the nonmagnetic substrate is subjected to texturing in which circumferential grooves are formed, the grooves having a density of not less than 10 per μm , and a substrate roughness after the texturing being in a range of 0.1 to 1 nm.

Moreover, preferably, the first seed layer has a thickness in a range of 4 to 20 nm, and the second seed layer has a thickness in a range of 2 to 12 nm.

Moreover, preferably, the first seed layer contains an Ni-Ti alloy, the Ni-Ti alloy having a Ti content in a range of 20 to 80 at%.

Moreover, preferably, the second seed layer contains an Ni-W alloy, the Ni-W alloy having a W content in a range of 20 to 80 at%.

Moreover, preferably, the first underlayer has a Cr content in the Cr-Ru alloy in a range of 60 to 95 at%.

Moreover, preferably, the first underlayer has a thickness in a range of 1 to 7 nm.

Moreover, preferably, the second underlayer has a Cr content in a range of 60 to 95 at%.

Moreover, preferably, the magnetic recording layer comprises a single layer or a plurality of layers made of at least one material selected from the group consisting of Co-Cr-Pt-B alloys and Co-Cr-Pt-B-Cu alloys.

Moreover, preferably, the longitudinal magnetic recording medium further has an intermediate layer between the underlayer and the magnetic recording layer.

Moreover, a method of manufacturing the longitudinal magnetic recording medium as described in any of the above comprises forming the second seed layer using a sputtering method in which a substrate bias voltage is applied.

The substrate bias voltage is preferably in a range of -30 to -500 V.

Moreover, preferably, the method further includes a step of, after the second seed layer has been formed, subjecting a surface of the second seed layer to plasma processing.

Moreover, preferably, the plasma processing is carried out in an Ar gas atmosphere.

Moreover, preferably, the method further includes a step of, after the second seed layer has been formed, exposing a surface of the second seed layer to an oxygen-containing atmosphere. The oxygen-containing atmosphere preferably has an oxygen partial pressure in a range of 1×10^{-4} to 1 Pa.

Through the above constitution, there can be provided a longitudinal magnetic recording medium for which high OR and high Hcr are both achieved, and hence the longitudinal magnetic recording medium is suitable for high recording density.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic sectional view for explaining an example of the structure of a longitudinal magnetic recording medium of the present invention;

FIG. 2 consists of graphs for explaining the relationship between the oxygen partial pressure when exposing a seed layer 2 to oxygen and respectively the OR and the Hcr for magnetic recording media according to Working Example 1 and Comparative Example 1;

FIG. 3 consists of graphs for explaining the distribution of crystal grain sizes in a magnetic layer for the magnetic recording media of Working Example 1 and Comparative Example 2; and

FIG. 4 is a graph for explaining the relationship between the substrate bias voltage when forming a seed layer and the OR for magnetic recording media according to Working Example 2.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Following is a description of embodiments of the present invention with reference to the drawings. FIG. 1 is a schematic sectional view for explaining an example of the structure of a longitudinal magnetic recording medium of the present invention. The magnetic recording medium has a structure in which a seed layer 2, an underlayer 3, an intermediate layer 4, a magnetic recording layer 5, a protective layer 6, and a lubricant layer 7 are formed in order on a nonmagnetic substrate 1. The seed layer 2 comprises a first seed layer 2a and a second seed layer 2b, the underlayer 3 comprises a first underlayer 3a and a second underlayer 3b, the intermediate layer 4 comprises a first intermediate layer 4a and a second intermediate layer 4b, and the magnetic recording layer 5 comprises a first magnetic recording layer 5a and a second magnetic recording layer 5b.

In the magnetic recording medium of the present invention, for the nonmagnetic substrate 1, there can be used

an NiP-plated Al alloy, glass, tempered glass, crystallized glass, or the like as used for an ordinary magnetic recording medium.

The substrate 1 is subjected to texturing. Before the texturing, it is preferable to polish the substrate using an ordinary method so as to smooth a surface of the substrate. The average surface roughness (Ra) after the polishing is preferably in a range of 0.2 to 0.5 nm. The surface-smoothed substrate is subjected to the texturing, so as to form substantially concentric circular grooves in a circumferential direction. The textured substrate preferably has not less than 10 concentric circular grooves per 1 μm formed thereon in the circumferential direction. At less than 10 per 1 μm , desired Mr anisotropy cannot be obtained, and hence the OR decreases. A large number of grooves is preferable, but if the number of grooves exceeds 60 per 1 μm , then it becomes difficult to obtain a desired groove depth.

Ra after the texturing is preferably in a range of 0.1 to 1 nm. If Ra is less than 0.1 nm, then the appearance of Mr anisotropy due to the texturing is suppressed, and hence the OR decreases. If Ra exceeds 1 nm, then the magnetic head flying height increases, and hence the read/write performance worsens.

The thus textured substrate is well washed so as to

remove foreign matter from the surface thereof, and then film formation is carried out.

The seed layer 2 comprises the first seed layer 2a and the second seed layer 2b formed in this order. The first seed layer 2a is a layer that contains a reactive metal and is provided for improving adhesion to the substrate. The second seed layer 2b is a layer provided for controlling the crystal orientation, crystal grain size and so on of the underlayer formed thereon, so as to obtain desired characteristics for the magnetic recording medium.

The first seed layer 2a is made of at least one material selected from the group consisting of Ni-Ti alloys, Cr-Al alloys, Cr-Ta alloys, and Cr-Ti alloys. The second seed layer 2b is made of at least one material selected from the group consisting of Ni-W alloys, Ni-Ru-W alloys, and Co-W alloys. Each of the first seed layer 2a and the second seed layer 2b may be formed on one another a plurality of layers in which different materials from among the above materials or different compositions are used.

The seed layer 2 is preferably amorphous. Here, "amorphous" means that other than a halo pattern, distinct diffraction peaks are not seen in an X-ray diffraction spectrum, or the mean grain size obtained from a lattice image taken by using a high-resolution electron microscope is not more than 5 nm. The amorphous film may contain microcrystallite grains. By making the seed layer 2 be an

amorphous or amorphous-like film, the surface thereof becomes smooth, and hence the grains of a Cr-Ru alloy layer comprising the first underlayer formed on the seed layer can be made minute, or the magnetic recording layer can be made to have a high OR.

It is undesirable for the seed layer to be a crystalline film, since then the Cr-Ru alloy of the first underlayer 3a thereon will be prone to growing epitaxially, and hence an increase in grain size will arise due to continued growth of the crystal grains, or the Cr-Ru alloy first underlayer 3a may become oriented with an orientation other than (100) due to the orientation of the crystal grains in the seed layer. Moreover, even in the case that the Cr-Ru alloy first underlayer 3a grows non-epitaxially on the seed layer, the roughness of the seed layer surface due to the growth of crystal grains in the seed layer will cause relaxation of circumferential compressive strain in the Cr-Ru alloy first underlayer caused by the grooves of the substrate texture, bringing about a decrease in the OR. For the above reasons, an amorphous or amorphous-like seed layer is preferable for achieving a high OR.

In the case that the first seed layer 2a is made of an Ni-Ti alloy, the Ti content of the Ni-Ti alloy is preferably in a range of 20 to 80 at%. If the Ti content is less than 20 at%, or greater than 80 at%, then the film will be prone to crystallizing, and hence the OR will decrease.

In the case that the first seed layer 2a is made of a Cr-Al alloy, the Al content of the Cr-Al alloy is preferably in a range of 25 to 60 at%. The reason for this is as in the case of an Ni-Ti alloy.

In the case that the first seed layer 2a is made of a Cr-Ti alloy, the Ti content of the Cr-Ti alloy is preferably in a range of 30 to 80 at%. The reason for this is as in the case of an Ni-Ti alloy.

In the case that the first seed layer 2a is made of a Cr-Ta alloy, the Ta content of the Cr-Ta alloy is preferably in a range of 30 to 80 at%. The reason for this is as in the case of an Ni-Ti alloy.

By reducing the surface energy of the second seed layer 2b, the crystal orientation, crystal grain size and so on of the underlayer 3 formed on the seed layer 2 can be suitably controlled. The reason for this is thought to be as follows.

The underlayer 3 preferably has a bcc (100) orientation relative to the substrate surface, but in the case that a Cr alloy is used for the first underlayer 3a, the surface energy is lowest for the bcc (110) plane, and hence the orientation is prone to becoming bcc (110). However, by reducing the surface energy of the second seed layer 2b, the wettability of the first underlayer is changed, and furthermore by using a Cr-Ru alloy for the first underlayer, bcc (100) crystal nuclei can be formed well, and hence the orientation can be suitably controlled to be bcc (100).

To further reduce the surface energy of the second seed layer 2b, the surface of the seed layer 2 is preferably exposed to an oxygen-containing atmosphere. Through the oxygen exposure, activated bonds on the surface of the second seed layer 2b are bonded to oxygen and thus stabilized.

As the method of the oxygen exposure, it is preferable to expose for an exposure time in a range of 1 to 4 seconds with the oxygen partial pressure in a range of 1×10^{-4} to 1 Pa. If the oxygen partial pressure is less than 1×10^{-4} Pa or the exposure time is shorter than 1 second, then a sufficient effect of the exposure will not be obtained, and hence the OR will not be improved. If the oxygen partial pressure is higher than 1 Pa or the exposure time is longer than 4 seconds, then the Hcr of the magnetic recording medium will decrease.

When forming the second seed layer 2b, by applying a negative bias voltage to the substrate, the surface of the seed layer is collided by Ar^+ ions, and hence impurity gas molecules and the like become less prone to being adsorbed, and thus activated bonds are more readily formed on the surface. As a result, after being subjected to the oxygen exposure, the surface of the seed layer has a lower surface energy.

The substrate bias voltage applied is preferably in a range of -30 to -500 V. If the substrate bias voltage is higher than -30 V, then a sufficient effect of the bias voltage will

not be obtained, whereas if the substrate bias voltage is lower than -500 V, then process problems such as an abnormal electrical discharge will become prone to occur.

For similar reasons, before exposing the surface of the seed layer to the oxygen, plasma processing may be carried out so as to remove impurities from the surface, whereby the surface energy can be further reduced.

Moreover, after forming the seed layer 2, the substrate may be heated to 150 to 250 °C, so as to further promote the bcc (100) orientation of the first underlayer 3a.

In the case that the second seed layer 2b is made of an Ni-W alloy, the W content of the Ni-W alloy is preferably in a range of 20 to 80 at%. If the W content is less than 20 at%, then the OR will decrease. Moreover, if the W content is greater than 80 at%, then crystallization will be prone to occur, and hence the OR will again decrease. The W content is more preferably in a range of 30 to 80 at%. If the W content is less than 30 at%, then the second seed layer 2b will become magnetic, and hence the characteristics will worsen.

In the case that the second seed layer 2b is made of an Ni-Ru-W alloy, the W content of the Ni-Ru-W alloy is preferably in a range of 20 to 80 at%, and the Ru content is preferably not more than 50 at%. The total content of Ru and W is preferably not less than 30 at%. The reason therefor is as in the case of an Ni-W alloy. Moreover, it is further preferable to make the Ru content be in a range of 5 to 50

at%, since then the OR can be increased more effectively.

In the case that the second seed layer 2b is made of a Co-W alloy, the W content of the Co-W alloy is preferably in a range of 20 to 80 at%.

The thickness of the first seed layer 2a is preferably in a range of 4 to 20 nm, and the thickness of the second seed layer 2b is preferably in a range of 2 to 12 nm. It is particularly preferable for the thickness of the first seed layer 2a to be in a range of 6 to 16 nm, and for the thickness of the second seed layer 2b to be in a range of 2 to 6 nm. In the case that either of the first seed layer 2a and the second seed layer 2b comprises a plurality of layers formed on one another, the total thickness of the films formed on one another is preferably made to be in a range as above.

The underlayer 3 comprises the first underlayer 3a and the second underlayer 3b formed in this order. The first underlayer 3a is made of a Cr-Ru alloy. The second underlayer 3b is made of a Cr alloy comprising Cr and at least one element selected from the group consisting of Mo, B, Ti, and W. The second underlayer 3b may comprise formed on one another a plurality of layers having different compositions of these elements.

The first underlayer 3a is preferably made of a Cr-Ru alloy comprising Cr and Ru, the Cr content being in a range of 60 to 95 at%. If the Cr content is less than 60 at%, then the orientation of the first underlayer 3a will not readily

become bcc (100). By making the Ru content be not less than 5 at%, the decrease in the Hcr due to the exposure of the seed layer to the oxygen can be reduced. It is thought that this is because due to the presence of the Ru in the underlayer, oxygen on the surface of the seed layer does not readily diffuse into the magnetic layer, thus preventing the Hcr from decreasing. The thickness of the first underlayer 3a is preferably in a range of 1 to 7 nm. If the first underlayer 3a is thinner than 1 nm, then the Cr-Ru layer will remain un-crystallized, and hence the OR will decrease. If the first underlayer 3a is thicker than 7 nm, then the grain size of the underlayer 3 will increase, and hence the SNR will worsen.

By adding Mo, Ti, or W, each of which is a metal having a large atomic radius, to the Cr alloy of the second underlayer 3b, the lattice constants of the second underlayer can be increased so as to match the lattice constants of the magnetic recording layer. By making the second underlayer 3b comprise a plurality of layers having different compositions formed on one another, the compatibility between the lattice constants can be further improved. Moreover, by adding B to the Cr alloy of the second underlayer 3b, the crystal grain size can be made smaller.

The second underlayer 3b preferably has a Cr content in a range of 60 to 95 at%.

One or a plurality of intermediate layer(s) 4 may be disposed between the underlayer 3 and the magnetic

recording layer 5. Each intermediate layer is preferably made of at least one element selected from the group consisting of Co, Cr, Ta, Ru, Pt, B, and Cu. The crystal structure of the intermediate layer is preferably hcp. In this case, a magnetic recording layer having an hcp structure epitaxially grows well on the hcp intermediate layer, and hence the SNR is improved.

The thickness of the intermediate layer 4 is preferably in a range of 1 to 6 nm. If the intermediate layer is thinner than 1 nm, then the intermediate layer will not sufficiently have an hcp structure due to the influence of an initial growth layer formed through heteroepitaxial growth from a bcc structure to an hcp structure. If the intermediate layer is thicker than 6 nm, then the crystal grain size will increase, and hence the SNR will worsen.

For the magnetic recording layer 5, an ordinarily used magnetic recording layer material can be used; a Co-Cr-Pt-B alloy or a Co-Cr-Pt-B-Cu alloy is particularly preferable. The magnetic recording layer may comprise a plurality of such layers formed on one another if desired.

From the viewpoint of the read/write performance, the composition of the magnetic recording layer is particularly preferably such that the total content of Cr and B is in a range of 15 to 30 at%, the Pt content is in a range of 10 to 25 at%, and the Cu content is not more than 8 at%.

Following is a more detailed description of the present

invention through working examples.

Working Example 1

An example in which a magnetic recording medium having the structure shown in FIG. 1 was manufactured will now be described.

As the substrate 1, an amorphous glass substrate having a diameter of 65 mm and a thickness of 0.635 mm was used, this being polished to a surface roughness Ra of 0.3 nm. Next, the glass substrate was textured by a suspended abrasive grain method using a nonwoven cloth and a diamond slurry, so as to form an average of 45 substantially concentric circular grooves per 1 μm in a circumferential direction. After the texturing, Ra was 0.4 nm.

The glass substrate was next washed well, and was then introduced into a film forming apparatus. Unless specifically stated, a DC magnetron sputtering method was used as the film formation method, Ar gas was used as the sputtering gas, and the film formation was carried out at a gas pressure of 0.8 Pa. First, an $\text{Ni}_{40}\text{Ti}_{60}$ film was formed as the first seed layer 2a on the glass substrate. The formed $\text{Ni}_{40}\text{Ti}_{60}$ film had a thickness of 8 nm, and had an amorphous structure. Next, the second seed layer 2b was formed using an $\text{Ni}_{45}\text{W}_{55}$ sputtering target. First, the $\text{Ni}_{45}\text{W}_{55}$ was formed to 2.5 nm, and then while continuing the target electrical discharge, a -150 V bias voltage was applied to the substrate, and a further 2.5 nm of $\text{Ni}_{45}\text{W}_{55}$ was formed. The Ni-W had an

amorphous structure.

Before forming the underlayer 3, a step was carried out in which the substrate on which the two-layer seed layer 2 had been formed was exposed for 2 seconds using Ar gas with 30 vol% of O₂ added thereto, the oxygen partial pressure being in a range of 0.01 to 0.4 Pa, thus adsorbing oxygen onto the surface of the Ni₄₅W₅₅ second seed layer.

Next, the substrate was heated to 210 °C using a heater, and then the underlayer 3 was formed. First, a first underlayer 3a made of Cr₉₀Ru₁₀ was formed to a thickness of 3.8 nm using a sputtering target made of Cr₉₀Ru₁₀. Next, a CrMo second underlayer 3b of the two-layer structure was formed. The CrMo layer was formed to a thickness of 1.9 nm using a Cr₇₀Mo₃₀ sputtering target.

Next, the intermediate layer 4 was formed. First, a CoCrTa first intermediate layer 4a was formed to a thickness of 3 nm using a Co₇₄Cr₂₂Ta₄ sputtering target, and then an Ru second intermediate layer 4b was formed to a thickness of 0.8 nm using a pure Ru sputtering target.

Next, a magnetic recording layer 5 having a two-layer structure was formed. First, a first magnetic recording layer 5a was formed to a thickness of 10.8 nm using a Co₅₃Cr₂₅Pt₁₄B₈ sputtering target, and then a second magnetic recording layer 5b was formed to a thickness of 7.2 nm using a Co₆₄Cr₁₃Pt₁₃B₁₀ sputtering target.

A protective layer 6 made of carbon was then formed

using a PECVD method and a sputtering method. A layer was first formed to a thickness of 2.0 nm by the PECVD method using ethylene gas, and then a layer was formed to a thickness of 0.8 nm by the sputtering method using a carbon target.

Next, a lubricant made of a perfluoropolyether was coated to a thickness of 1.2 nm using a dip coating method, thus obtaining a magnetic recording medium, which was taken as Working Example 1.

Comparative Example 1

A magnetic recording medium was manufactured as in Working Example 1, except that the first underlayer 3a was formed to a thickness of 3.8 nm using a pure Cr sputtering target, and this was taken as Comparative Example 1.

Comparative Example 2

The first seed layer 2a was formed to a thickness of 3.8 nm in an N₂ atmosphere using a pure Cr target, and then the second seed layer 2b was formed to a thickness of 12 nm using an Ni₆₃Ta₃₇ sputtering target. Other than this, the magnetic recording medium was manufactured as in Working Example 1, and this was taken as Comparative Example 2.

Working Example 2

This is an example in which magnetic recording media were manufactured with the substrate bias voltage when forming the second seed layer 2b being changed.

The substrate bias voltage when forming the Ni₄₅W₅₅ second seed layer 2b was applied in a range of 0 to -200 V.

Moreover, the step of exposing the surface of the $\text{Ni}_{45}\text{W}_{55}$ second seed layer to oxygen was carried out with an oxygen partial pressure of 0.2 Pa. Other than that, the manufacture was carried out as in Working Example 1.

FIG. 2 shows data on the dependence of the OR and the Hcr respectively on the oxygen partial pressure in the oxygen exposure for the magnetic recording media of Working Example 1 and Comparative Example 1. In the case of the Working Example, the deterioration in the Hcr with increasing oxygen partial pressure was more gradual than in the case of Comparative Example 1.

FIG. 3 shows data on the distribution of crystal grain sizes in the magnetic layer for the magnetic recording media of Working Example 1 and Comparative Example 2. FIG. 3A shows the case of Working Example 1, and FIG. 3B shows the case of Comparative Example 2. It can be seen that in the case of the seed layer of Working Example 1, the distribution of crystal grain sizes in the magnetic layer was narrower than in the case of Comparative Example 2.

FIG. 4 is a graph for explaining the relationship between the substrate bias voltage when forming the $\text{Ni}_{45}\text{W}_{55}$ second seed layer 2b and the OR for the magnetic recording media of Working Example 2. In a substrate bias voltage range of 0 to -150 V, as the absolute value of the bias voltage increases, the OR increases. When the bias voltage exceeds (in terms of the absolute value) -150 V, the OR saturates.

What Is Claimed Is:

1. A longitudinal magnetic recording medium comprising a nonmagnetic substrate, a seed layer, an underlayer, and a magnetic recording layer in this order, wherein:

said seed layer comprises a first seed layer and a second seed layer formed in this order;

said first seed layer comprises a single layer or a plurality of layers made of at least one material selected from the group consisting of Ni-Ti alloys, Cr-Al alloys, Cr-Ta alloys, and Cr-Ti alloys;

said second seed layer comprises a single layer or a plurality of layers made of at least one material selected from the group consisting of Ni-W alloys, Ni-Ru-W alloys, and Co-W alloys;

said underlayer comprises a first underlayer and a second underlayer formed in this order;

said first underlayer comprises a single layer or a plurality of layers made of a Cr-Ru alloy; and

said second underlayer comprises a single layer or a plurality of layers made of a Cr alloy comprising Cr and at least one element selected from the group consisting of Mo, B, Ti, and W.

2. The longitudinal magnetic recording medium

according to claim 1, wherein each of said first seed layer and said second seed layer has an amorphous structure.

3. The longitudinal magnetic recording medium according to claim 1, wherein a surface of said nonmagnetic substrate is subjected to texturing in which circumferential grooves are formed, said grooves having a density of not less than 10 per μm , and a substrate roughness after the texturing being in a range of 0.1 to 1 nm.

4. The longitudinal magnetic recording medium according to claim 1, wherein said first seed layer has a thickness in a range of 4 to 20 nm, and said second seed layer has a thickness in a range of 2 to 12 nm.

5. The longitudinal magnetic recording medium according to claim 1, wherein said first seed layer contains an Ni-Ti alloy, the Ni-Ti alloy having a Ti content in a range of 20 to 80 at%.

6. The longitudinal magnetic recording medium according to claim 1, wherein said second seed layer contains an Ni-W alloy, the Ni-W alloy having a W content in a range of 20 to 80 at%.

7. The longitudinal magnetic recording medium

according to claim 1, wherein said first underlayer has a Cr content in a range of 60 to 95 at%.

8. The longitudinal magnetic recording medium according to claim 1, wherein said first underlayer has a thickness in a range of 1 to 7 nm.

9. The longitudinal magnetic recording medium according to claim 1, wherein said second underlayer has a Cr content in a range of 60 to 95 at%.

10. The longitudinal magnetic recording medium according to claim 1, wherein said magnetic recording layer comprises a single layer or a plurality of layers made of at least one material selected from the group consisting of Co-Cr-Pt-B alloys and Co-Cr-Pt-B-Cu alloys.

11. The longitudinal magnetic recording medium according to claim 1, further having an intermediate layer between said underlayer and said magnetic recording layer.

12. A method of manufacturing the longitudinal magnetic recording medium according to claims 1, the method comprising forming said second seed layer using a sputtering method in which a substrate bias voltage is applied.

13. The method according to claim 12, wherein said substrate bias voltage is in a range of -30 to -500 V.

14. The method according to claim 12, further including a step of, after said second seed layer has been formed, subjecting a surface of said second seed layer to plasma processing.

15. The method according to claim 14, wherein Ar is used in said plasma processing.

16. The method according to claim 12, further including a step of, after said second seed layer has been formed, exposing a surface of said second seed layer to an oxygen-containing atmosphere.

17. The method according to claim 16, wherein said oxygen-containing atmosphere has an oxygen partial pressure in a range of 1×10^{-4} to 1 Pa.