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MAGNETIC RECORDING MEDIUM AND THE METHOD OF MANUFACTURING THE SAME

Field of the Invention

5 The present invention relates to a magnetic recording medium mounted on various magnetic recording apparatuses and the method of manufacturing the magnetic recording medium.

Prior Art

10 Various compositions for the magnetic layer, various structures for the magnetic layer and various materials for the nonmagnetic underlayer have been proposed to obtain a magnetic recording medium exhibiting a high recording density. One of the magnetic layers used in practice employs a CoCr alloy and obtains isolated magnetic grains by segregating Cr to the
15 crystal grain boundary. Another one of the magnetic layers used in practice is the so-called granular magnetic layer that includes a nonmagnetic and nonmetallic material for the grain boundary thereof. For segregating sufficient amount of Cr into the grain boundary, it is necessary and indispensable to heat the substrate at 200°C or higher during forming the
20 conventional CoCr alloy magnetic layer. In contrast, the specific feature of the granular magnetic layer is that the nonmagnetic and nonmetallic material segregates even when the substrate is not heated during forming the granular magnetic layer. For realizing a higher recording density, research and development have been explored vigorously on the
25 perpendicular magnetic recording that orients the recording magnetization in perpendicular to the recording plane of the medium in place of the parallel magnetic recording that orients the recording magnetization in parallel to the recording plane of the medium. The CoCr magnetic layer and the granular magnetic layer described above are employable for the

perpendicular magnetic recording by controlling the crystal orientation therein by means of an underlayer.

It is required for both the CoCr magnetic layer and the granular magnetic layer to be thermally stable and to cause less media noises. For improving the thermal stability, it is necessary to improve the crystalline magnetic anisotropy K_u . For reducing the media noises, it is necessary to minimize the crystal grain diameter in the magnetic recording layer and to reduce the magnetic interaction between the crystal grains. The crystalline magnetic anisotropy K_u in the CoCr magnetic layer is improved by adding an appropriate amount of Pt thereto. The magnetic interaction between the ferromagnetic crystal grains in the CoCr magnetic layer is reduced by promoting Cr segregation into the grain boundary by means of heating the substrate before forming the CoCr magnetic layer or by means of adding Ta or B to the CoCr magnetic layer. The other technique for segregation promotion reported in Journal of Applied Physics, Vol. 87, No. 9. pp. 6869-6871 (May 1, 2000) effectively isolates ferromagnetic crystal grains by depositing Mn layer of 20 nm in thickness on a CoCrPt magnetic layer and by annealing the laminate at 350°C for several minutes to diffuse Mn into the grain boundary of the CoCrPt magnetic layer.

Problems to be solved by the Invention

For reducing the media noises and for realizing a high magnetic recording density, it is necessary to minimize the grain diameter in the magnetic recording layer and to magnetically isolate the crystal grains in the magnetic recording layer without impairing the thermal stability.

However, the productivity of the above described segregation promotion technique that deposits a Mn layer on a CoCrPt layer and

anneals the laminate is not so good, since it takes several minutes for diffusing Mn sufficiently into the grain boundary of the CoCrPt layer. Moreover, it is difficult for the segregation promotion technique that deposits a Mn layer on a CoCrPt layer to obtain large signal output, since
5 the spacing between the magnetic head and the magnetic recording layer is wide due to the Mn layer of 20 nm in thickness on the CoCrPt layer, causing a low signal to noise ratio (SNR). In addition, the magnetic head is prevented from floating stably, since the magnetic layer surface becomes more uneven with increasing layer thickness.

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As described above, a higher recording density would hardly be provided to magnetic recording media, if one wanted to manufacture the magnetic recording media with excellent productivity by any of the conventional techniques.

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In view of the foregoing, it is an object of the invention to provide a magnetic recording medium manufactured with excellent productivity and exhibiting a high recording density.

20 Means for solving the Problems

According to a first aspect of the invention, there is provided a magnetic recording medium including: a nonmagnetic substrate, an underlayer above the nonmagnetic substrate, a magnetic recording layer on the underlayer, and an overcoating layer on the magnetic recording layer,
25 wherein the magnetic recording layer is a granular magnetic layer including ferromagnetic crystal grains and an oxide nonmagnetic grain boundary or a nitride nonmagnetic grain boundary surrounding the ferromagnetic crystal grains, and the overcoating layer contains a nonmagnetic metal or a nonmagnetic alloy to be diffused into the nonmagnetic grain boundary.

The magnetic recording medium according to the first aspect of the invention does not employ the conventional CoCrPt layer for the magnetic layer thereof but a granular magnetic layer including ferromagnetic crystal grains and a nonmagnetic oxide grain boundary or a nonmagnetic nitride grain boundary surrounding the ferromagnetic crystal grains. The magnetic recording medium according to the first aspect of the invention includes also a nonmagnetic metal layer or a nonmagnetic alloy layer deposited on the granular magnetic layer. In contrast to the conventional CoCrPt magnetic recording layer, the coated atoms diffuse into the nonmagnetic crystal grain boundary of the granular magnetic layer without any help of annealing and promote isolating the ferromagnetic crystal grains from each other. The overcoating layer of 10 nm or less in thickness exhibits sufficient effects.

Advantageously, the overcoating layer has been removed after the diffusion of the nonmagnetic metal or the nonmagnetic alloy into the nonmagnetic grain boundary.

By removing a part of or the entire of the overcoating layer, the magnetic spacing is narrowed, the SNR is improved, the magnetic layer surface is flattened, and therefore, the head floating is stabilized.

According to a second aspect of the invention, there is provided a method of manufacturing a magnetic recording medium, the method including: the first step of forming an underlayer above a nonmagnetic substrate, the second step of forming a magnetic recording layer on the underlayer, and the third step of forming an overcoating layer on the magnetic recording layer, wherein the magnetic recording layer includes a granular magnetic layer including ferromagnetic crystal grains and an oxide nonmagnetic grain boundary or a nitride nonmagnetic grain boundary

surrounding the ferromagnetic crystal grains, and the overcoating layer contains a nonmagnetic metal or a nonmagnetic alloy to be diffused into the nonmagnetic grain boundary.

5 Advantageously, the method further includes the fourth step of removing the overcoating layer after diffusing the nonmagnetic metal or the nonmagnetic alloy into the nonmagnetic grain boundary.

 Advantageously, the nonmagnetic metal is an element selected from
10 the group consisting of (Sc, Ti, V, Cr, Mn, Cu, Zn, Al, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, In, Sn, Sb, Hf, Ta, W, Re, Os, Ir, Pt, and Au), and the nonmagnetic alloy contains at least an element selected from the above described group.

15 When the nonmagnetic metal is an element selected from the group consisting of (Sc, Ti, V, Cr, Mn, Cu, Zn, Al, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, In, Sn, Sb, Hf, Ta, W, Re, Os, Ir, Pt, and Au), and the nonmagnetic alloy contains at least an element selected from the above described group, the atoms coated on the granular magnetic layer diffuse easily into the
20 nonmagnetic grain boundary of the granular magnetic layer.

Brief Description of the Drawing Figure

 Fig. 1 is a schematic cross sectional view of a perpendicular magnetic recording medium according to an embodiment of the invention.

25 Fig. 2 is a set of curves relating the coercivity H_c and the thickness for the magnetic recording media according to the first through third embodiments of the invention and the comparative magnetic recording medium.

Fig. 3 is a set of curves relating the normalized media noises and the line recording densities for the magnetic recording media according to the first through fourth embodiments of the invention and the comparative magnetic recording medium.

5 Fig. 4 is a table listing the magnetic cluster size diameters d [nm] and the dispersions σ [nm] of the magnetic recording media according to the first through third embodiments of the invention and the comparative magnetic recording medium.

10 Fig. 5 is a table comparing the signal to noise ratios at the linear recording densities of 400 kilo flux changes per inch (kFCI) and 600 kFCI of the magnetic recording media according to the first through fourth embodiments and the comparative magnetic recording medium.

Modes for carrying out the Invention

15 Now the invention will be described in detail hereinafter with reference to the accompanied drawing figures. Throughout the drawing figures, the constituent elements exhibiting similar functions are designated by the same reference numerals.

20 Fig. 1 is a schematic cross sectional view of a perpendicular magnetic recording medium according to the invention.

Referring now to Fig. 1, the perpendicular magnetic recording medium according to the invention includes at least a nonmagnetic substrate 1, an underlayer 2 above the nonmagnetic substrate 1, a magnetic recording layer 3 on the underlayer 2, and an overcoating layer 4 on the magnetic recording layer 3. The overcoating layer 4 may be removed by etching after the overcoating layer 4 has been formed. A protective layer 5 may be formed on the overcoating layer 4 and a liquid lubricant layer 6 on the protective layer

5. For forming a double-layered perpendicular magnetic recording medium, a soft magnetic underlayer 11 may be formed below the underlayer 2. The constituent layers will be described below in detail.

5 Stuffs such as an Al alloy plate provided with NiP plating and a reinforced or crystallized glass plate used for the conventional magnetic recording media are used for the nonmagnetic substrate 1. Since any heating step is not employed in manufacturing the magnetic recording medium according to the invention, plastic substrates such as a
10 polycarbonate plate and a polyolefin plate may be used for the nonmagnetic substrate 1.

 Metals having a hexagonal close packed lattice structure, alloys containing one of the metals having a hexagonal close packed lattice
15 structure, metals having a face-centered cubic lattice structure or alloys containing one of the metals having a face-centered cubic lattice structure are used preferably for the underlayer 2. The metals having a hexagonal close packed lattice structure include, for example, Ti, Zr, Ru, Zn, Tc, and Re. The metals having a face-centered cubic lattice structure include, for
20 example, Cu, Rh, Pd, Ag, Ir, Pt, Au, Ni, and Co. Although the underlayer 2 is preferably thin, the underlayer 2 of 3 nm or thicker in thickness is preferable for facilitating sufficient crystal growth therein. A seed layer 12 may be formed below the underlayer 2 to improve the crystalline orientation in the underlayer 2.

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 For obtaining a double-layered perpendicular magnetic recording medium, a soft magnetic underlayer 11 may be formed below the underlayer 2 to converge the magnetic flux generated from a magnetic head. NiFe alloy crystals, Sendust (FeSiAl) alloys, FeTaC microcrystals, CoTaZr

microcrystals and amorphous Co alloys such as CoZrNb are used for the soft magnetic underlayer 11. Although the optimum thickness of the soft magnetic underlayer 11 changes depending on the structure and the characteristics of the magnetic recording head, the soft magnetic underlayer 5 11 is preferably from 10 nm to 500 nm in thickness considering the productivity thereof.

A granular magnetic layer, including ferromagnetic crystal grains and a nonmagnetic oxide grain boundary or a nonmagnetic nitride grain 10 boundary surrounding the ferromagnetic crystal grains, is used for the magnetic recording layer 3. For example, alloys such as CoPt and FePt, CoPt alloys and FePt alloys, to which Cr, Ni, Nb, Ta, B and such an element are added, are preferable for the ferromagnetic crystal. For example, oxides and nitrides of Cr, Co, Si, Al, Ti, Ta, Hf, Zr, Y and Ce are preferable for the 15 nonmagnetic grain boundary. As far as the materials described above exemplary are used for the ferromagnetic crystal grains and the nonmagnetic grain boundary, the atoms of the nonmagnetic metal or the nonmagnetic alloy coated on the granular magnetic layer are diffused easily into the nonmagnetic grain boundary without any help of annealing, 20 isolation of the ferromagnetic grains is promoted, and the media noises are reduced. The materials for the ferromagnetic crystal grain and the oxide and the nitride for the nonmagnetic grain boundary are not limited to those described above. For obtaining a perpendicular magnetic recording medium, it is necessary for the c-axis of the Co crystal having a hexagonal close 25 packed lattice structure to orient in perpendicular to the recording plane of the medium.

Any of the nonmagnetic metals Sc, Ti, V, Cr, Mn, Cu, Zn, Al, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, In, Sn, Sb, Hf, Ta, W, Re, Os, Ir, Pt, and Au or

nonmagnetic alloys containing at least one of Sc, Ti, V, Cr, Mn, Cu, Zn, Al, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, In, Sn, Sb, Hf, Ta, W, Re, Os, Ir, Pt, and Au are used for the overcoating layer 4. The atoms in the overcoating layer 4 diffuse into the grain boundary in the magnetic recording layer 3 and reduce the magnetic interaction between the ferromagnetic crystal grains in the magnetic recording layer 3. The overcoating layer 4 is preferably 10 nm or less in thickness for narrowing the magnetic spacing between the magnetic head and the magnetic recording medium.

Further for improving the SNR (signal to noise ratio) characteristics, a part of or the entire of the residual overcoating layer 4, left without being diffused into the nonmagnetic grain boundary of the magnetic recording layer 3, may be removed by etching. The removal of a part of or the entire of the residual overcoating layer 4 facilitates reducing the magnetic spacing and smoothing the surface of the magnetic recording medium. The removal is conducted by Ar plasma etching, ECR plasma etching, ion beam etching and such an etching technique.

A thin film containing carbon as its main component is used for the protective layer 5.

A perfluoropolyether lubricant and such a liquid lubricant are used for the liquid lubricant layer 6.

Embodiments of the Invention

Now the invention will be described more in detail hereinafter with reference to the accompanied drawing figures which illustrate the preferred embodiments of the invention.

First embodiment (E1)

A flat and smooth chemically reinforced glass substrate (N-5 Glass Substrate supplied from Hoya Corp.) is used as a nonmagnetic substrate. After being cleaned, the glass substrate is loaded in a vacuum chamber of a sputtering apparatus and a soft magnetic underlayer is formed by sputtering using a Co₅Zr₉Nb target, resulting in a CoZrNb soft magnetic underlayer. The resulting CoZrNb soft magnetic underlayer is 300 nm in thickness. Then, a seed layer is formed using a Ni₁₅Fe₅Cr target, which is a Ni-based soft magnetic alloy target, under the Ar gas pressure of 5 mTorr, resulting in a NiFeCr seed layer. The resulting NiFeCr seed layer is 10 nm in thickness. Then, an underlayer is formed using a Ru target under the Ar gas pressure of 30 mTorr, resulting in a Ru underlayer. The resulting Ru underlayer is 20 nm in thickness.

Then, a magnetic recording layer is formed by sputtering using a 92(Co₁₀Cr₁₆Pt)-8SiO₂ target, resulting in a CoCrPt-SiO₂ magnetic recording layer. The resulting CoCrPt-SiO₂ magnetic recording layer is 20 nm in thickness. Then, a Mn overcoating layer is formed under the Ar gas pressure of 30 mTorr. The thickness of the Mn overcoating layer is changed from 1 nm to 20 nm. Finally, a carbon protective layer of 8 nm in thickness is formed. Then, the laminate formed so far is taken out from the vacuum chamber. Then, a perfluoropolyether layer is formed by dip-coating, resulting in a perfluoropolyether liquid lubricant layer. The resulting perfluoropolyether liquid lubricant layer is 2 nm in thickness. Thus, double-layered perpendicular magnetic recording media E1 according to the first embodiment are obtained. The magnetic recording layer is formed by RF magnetron sputtering. The other layers except the liquid lubricant layer are formed by DC magnetron sputtering.

Second embodiment (E2)

Double-layered perpendicular magnetic recording media E2 according

to the second embodiment are fabricated in the same manner as the double-layered perpendicular magnetic recording media according to the first embodiment except that Ta is used for the overcoating layer according to the second embodiment.

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Third embodiment (E3)

Double-layered perpendicular magnetic recording media E3 according to the third embodiment are fabricated in the same manner as the double-layered perpendicular magnetic recording media according to the first embodiment except that Cu is used for the overcoating layer according to the third embodiment.

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Fourth embodiment (E4)

Double-layered perpendicular magnetic recording media E4 according to the fourth embodiment are fabricated in the same manner as the double-layered perpendicular magnetic recording media according to the first embodiment except that a Mn overcoating layer of 3 nm in thickness is formed and the Mn overcoating layer is removed by Ar plasma etching according to the fourth embodiment.

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Comparative example (C1)

Comparative double-layered perpendicular magnetic recording medium C1 is fabricated in the same manner as the double-layered perpendicular magnetic recording media according to the first embodiment except that any overcoating layer is not disposed in the comparative double-layered perpendicular magnetic recording medium.

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Evaluation

First, the evaluation results on the magnetic characteristics of the

magnetic recording media E1 through E3 according to the first through third embodiments and the comparative magnetic recording medium C1 will be described below. The magnetic characteristics are measured in terms of the Kerr effect.

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Fig. 2 is a set of curves relating the coercivities H_c and the thickness for the magnetic recording media E1 through E3 according to the first through third embodiments and the comparative magnetic recording medium C1. The squareness ratio S of the magnetic recording media according to the first through third embodiments and the comparative magnetic recording medium is 1.0. The coercivities H_c of the magnetic recording media including an overcoating layer according to the first through third embodiments are improved as compared with the coercivity H_c of the comparative magnetic recording medium. The coercivities H_c increase with increasing thickness of the overcoating layer and reach the respective maximum values between the thickness 3 nm and the thickness 5 nm of the overcoating layers. Thus, provision of an overcoating layer improves the coercivity H_c .

Fig. 4 is a table listing the magnetic cluster size diameters d [nm] and the dispersions σ [nm] of the magnetic recording media, each including an overcoating layer of 3 nm in thickness, according to the first through third embodiments and the comparative magnetic recording medium. The magnetic cluster sizes are obtained from the magnetic force microscopic (MFM) measurements of the magnetic recording media demagnetized by AC demagnetization. The magnetic cluster size diameters d [nm] and the dispersions σ [nm] of the magnetic recording media including an overcoating layer according to the first through third embodiments are much smaller than the magnetic cluster size diameter d [nm] and the

dispersion σ [nm] of the comparative magnetic recording medium. This indicates that the atoms in the overcoating layer diffuse into the grain boundary of the CoCrPt-SiO₂ magnetic layer and promotes magnetic isolation of the magnetic grains.

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Next, the evaluation results on the magnetic parametric performances of the magnetic recording media E1 through E4 according to the first through fourth embodiments and the comparative magnetic recording medium C1 will be described below.

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Fig. 3 is a set of curves relating the normalized media noises obtained from the evaluation results on the magnetic parametric performances and the linear recording densities for the magnetic recording media, each including an overcoating layer of 3 nm in thickness, according to the first through fourth embodiments and the comparative magnetic recording medium C1. The magnetic parametric performances are measured by a spin stand tester using a giant magnetoresistive (GMR) head. As Fig. 3 clearly indicates, much less normalized media noises are caused in the magnetic recording media including an overcoating layer according to the first through fourth embodiments than in the comparative magnetic recording medium. Comparing the magnetic recording media according to the first through third embodiments with each other, there exists a certain correlation between the diameter d and dispersion σ of the magnetic cluster size and the normalized media noise. In detail, the normalized media noise becomes lower from the magnetic recording medium according to the third embodiment exhibiting larger d and σ to the magnetic recording medium according to the first embodiment exhibiting smaller d and σ . In other words, the promoted magnetic grain isolation facilitates reducing the media noises. The normalized media noise in the magnetic recording medium

according to the fourth embodiment, the overcoating layer thereof is etched off after its formation, is further reduced as compared with the normalized media noise in the magnetic recording medium according to the first embodiment. The further reduced normalized media noise in the magnetic recording medium according to the fourth embodiment is attributable to the large increment of the output signals due to the magnetic spacing narrowed by etching off the overcoating layer.

Fig. 5 is a table comparing the SNR's at the linear recording densities of 400 kilo flux changes per inch (kFCI) and 600 kFCI of the magnetic recording media according to the first through fourth embodiments and the comparative magnetic recording medium. The SNR's are obtained by evaluating the magnetic parametric performances in the similar manner as the normalized media noises. By virtue of the higher Hc and lower media noises, the SNR's in the magnetic recording media according to the first through third embodiments, each including an overcoating layer, are much higher than the SNR in the comparative magnetic recording medium that does not include any overcoating layer. The SNR's in the magnetic recording medium according to the fourth embodiment, the overcoating layer thereof is etched off after its formation, are higher than the SNR's in the magnetic recording medium according to the first embodiment. Thus, it has been confirmed that the removal of the overcoating layer is very effective to obtain a higher SNR.

By using a granular magnetic layer for the magnetic recording layer and by depositing an overcoating layer on the granular magnetic recording layer as described above, the atoms in the overcoating layer diffuse into the grain boundary of the granular magnetic layer and promote isolating the ferromagnetic grain crystals in the magnetic recording layer from each other.

Since this scheme does not need any annealing treatment, the magnetic recording medium according to the invention is manufactured with excellent productivity. The magnetic recording medium according to the invention facilitates reducing the magnetic interaction therein, reducing the media noises and realizing a higher recording density. Since it is sufficient for the overcoating layer to be 10 nm or less in thickness, the magnetic spacing is prevented from being widened. A narrower magnetic spacing obtained by etching off the overcoating layer after its formation facilitates further improving the SNR and obtaining a higher recording density.

Advantageous Effects of the Invention

As described above, the magnetic recording medium according to the invention includes a nonmagnetic substrate, an underlayer above the nonmagnetic substrate, a magnetic recording layer on the underlayer, and an overcoating layer on the magnetic recording layer, wherein the magnetic recording layer is a granular magnetic layer including ferromagnetic crystal grains and an oxide nonmagnetic grain boundary or a nitride nonmagnetic grain boundary surrounding the ferromagnetic crystal grains, and the overcoating layer contains a nonmagnetic metal or a nonmagnetic alloy to be diffused into the nonmagnetic grain boundary. The atoms coated on the granular magnetic recording layer diffuse into the grain boundary and promote isolating the ferromagnetic crystal grains from each other.

The magnetic recording medium according to the invention is manufactured with an excellent productivity. The magnetic recording medium according to the invention facilitates reducing the media noises and realizing a higher recording density.

Claims

What is claimed is:

1. A magnetic recording medium comprising:
a nonmagnetic substrate,
5 an underlayer above the nonmagnetic substrate,
a magnetic recording layer on the underlayer, and
an overcoating layer on the magnetic recording layer, wherein
the magnetic recording layer comprises a granular magnetic layer
comprising ferromagnetic crystal grains and a nonmagnetic grain boundary
10 comprising an oxide or a nitride surrounding the ferromagnetic crystal
grains, and
the overcoating layer comprises a nonmagnetic metal or a nonmagnetic
alloy to be diffused into the nonmagnetic grain boundary.
2. The magnetic recording medium according to Claim 1, wherein the
15 overcoating layer has been removed after the diffusion of the nonmagnetic
metal or the nonmagnetic alloy into the nonmagnetic grain boundary.
3. The magnetic recording medium according to Claim 1 or 2, wherein the
nonmagnetic metal comprises an element selected from the group consisting
of (Sc, Ti, V, Cr, Mn, Cu, Zn, Al, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, In,
20 Sn, Sb, Hf, Ta, W, Re, Os, Ir, Pt, and Au), and the nonmagnetic alloy
comprises an element selected from said the group.
4. A method of manufacturing a magnetic recording medium, comprising:
the first step of forming an underlayer above a nonmagnetic substrate,
the second step of forming a magnetic recording layer on the
25 underlayer, and
the third step of forming an overcoating layer on the magnetic
recording layer, wherein

the magnetic recording layer comprises a granular magnetic layer comprising ferromagnetic crystal grains and a nonmagnetic grain boundary comprising an oxide or a nitride surrounding the ferromagnetic crystal grains, and

5 the overcoating layer comprises a nonmagnetic metal or a nonmagnetic alloy to be diffused into the nonmagnetic grain boundary.

5. The method according to Claim 4, further comprising the fourth step of removing the overcoating layer after diffusing the nonmagnetic metal or the nonmagnetic alloy into the nonmagnetic grain boundary.

10 6. The magnetic recording medium according to Claim 4 or 5, wherein the nonmagnetic metal comprises an element selected from the group consisting of (Sc, Ti, V, Cr, Mn, Cu, Zn, Al, Y, Zr, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, In, Sn, Sb, Hf, Ta, W, Re, Os, Ir, Pt, and Au), and the nonmagnetic alloy comprises an element selected from said the group.

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