

Perpendicular Magnetic Recording Medium and Manufacturing method therefor

Field of the Invention

The present invention relates to a perpendicular magnetic recording medium mounted in various magnetic recording apparatuses and a manufacturing method therefor

Prior Art

As a technology for increasing the density of magnetic recording, perpendicular magnetic recording media has attracted attention as a potential alternative to the conventional longitudinal recording method.

A perpendicular magnetic recording medium is composed mainly of a magnetic recording layer of a hard magnetic material, an underlayer that directs the magnetic recording layer in the desired direction, protective layer that protects the surface of the magnetic recording layer, and lining layer of a soft magnetic material that causes the concentration of magnetic flux generated by a magnetic head used for recording on the magnetic recording layer.

In recent years, as the recording density of magnetic recording media based on the longitudinal recording method has increased, the loss of recorded data associated with thermal instability (i.e., thermal fluctuations) has increased. Conversely, it has been assumed that the thermal stability problem is less pronounced with perpendicular recording media than with the longitudinal recording method, since the stability of bits (recorded data) increases linearly with density. However, it is expected that the film thickness of a magnetic recording layer will be further reduced, rendering the current level of achieved thermal stability insufficient. There have also been demands for increasing the stability of low-density recording for servo patterns or similar applications.



Thus, even for perpendicular recording media, improving thermal stability is an important goal.

Since the thermal stability of a perpendicular recording medium is proportional to the uniaxial anisotropy constant (hereinafter referred to as "Ku"), Ku can be increased to improve thermal stability. Specific examples of recent approaches to increasing Ku include a Co/Pt multilayer stacked film, Co/Pd multilayer stacked film, CoPt ordered alloy, FePt ordered alloy, and use of such amorphous material as TbFeCo. However, manufacturing processes for multilayer stacked films are not suitable for mass production, the ordered alloy require an annealing process to ensure correct ordering, and the corrosion resistance of amorphous material must be improved. Accordingly, all of these proposed methods pose problems that need to be solved prior to practical use.

Problems to Be Solved by the Invention

As described previously, Co/Pt and Co/Pd multilayer stacked films, CoPt and FePt ordered alloy and similar materials, and such amorphous materials as TbFeCo, all of which have a high Ku, are disadvantageous for mass-producing recording media. If recording media are to be mass-produced, conventional CoCr-based magnetic recording material should be used to increase Ku, thereby improving thermal stability. However, the increase in Ku achieved by changing the composition of the material is limited. Thus, measures other than changing the composition have been sought.

Means of Solving the Problems

The following methods are proposed as means of solving the above problems:

- (1) An underlayer is composed of metal or an alloy having a hexagonal closest-packing (hereafter referred to as "hcp") type of crystal structure such as Ru, Ti,

TiCr, Re, CoCr, CuZn, IrMo, Ir₂W, MoPt, or MoRh₂, which has a larger a-axis lattice constant than the material used for a magnetic recording layer. The resulting magnetic recording layer has an increased a-axis lattice constant for a relative reduction in the c-axis lattice constant, thereby increasing magnetostriction and Ku. However, if the lattice constant differs excessively, the crystal structure (lattice constant) of the magnetic recording layer does not follow the underlayer. The ceiling for this difference is about 20%.

(2) An underlayer is composed of metal or an alloy having a face-centered cubic lattice (hereafter referred to as "fcc") type of crystal structure such as Pd, Cu, Au, Ir, Pt, Rh, Ag, Ni₃Al, or Co₃Ti, which has an (a-axis lattice constant) $\times 1/\sqrt{2}$ larger than the a-axis lattice constant of the material used for the magnetic recording layer. Thus, the magnetic recording layer has an increased a-axis lattice constant for a relative reduction in the c-axis lattice constant, thereby increasing magnetostriction and Ku. As in (2), the upper limit of the difference between the lattice constant of the magnetic recording layer and the (a-axis lattice constant of the underlayer) $\times 1/\sqrt{2}$ is about 20%.

(3) The underlayer in (1) or (2) is used and quenched immediately after the formation of the magnetic recording layer to distort the film to cause magnetostriction, thereby increasing Ku and coercive force Hc.

(4) The underlayer in (1) or (2) is used and quickly heated immediately after the formation of the magnetic recording layer and before quenching to produce effects similar to those in (3).

Brief Description of the Drawings

Fig. 1 is a schematic sectional view of a perpendicular two-layer medium according to the present invention, where 1 is the nonmagnetic substrate; 2 is the soft magnetic lining layer; 3 is the underlayer; 4 is the magnetic recording

layer; 5 is the protective layer and 6 is the liquid lubricant layer

Fig. 2 is a graph showing the relationship between the c-axis lattice constant and coercive force H_c of a magnetic recording layer according to Example 3.

Embodiment of the Invention

The following describes a preferred embodiment of the present invention. Fig. 1 is a schematic sectional view of a perpendicular magnetic recording medium (i.e., perpendicular two-layer medium consisting of a magnetic recording layer and soft magnetic lining layer) according to the present invention. The perpendicular magnetic recording medium is composed of underlayer 3, magnetic recording layer 4, and protective layer 5, sequentially formed on nonmagnetic substrate 1, with liquid lubricant layer 6 formed on top of these layers. Soft magnetic lining layer 2 is provided between nonmagnetic substrate 1 and underlayer 3 to prevent the spread of magnetic flux generated by a head during recording to provide magnetic fields in the vertical direction. Accordingly, soft magnetic lining layer 2 would ideally be present, but recording can be achieved without this layer.

Nonmagnetic substrate 1 is composed of an Al alloy plated with NiP, reinforced glass, or crystallized glass, which is used for normal magnetic recording media. The surface of nonmagnetic substrate 1 may be treated as required to attain the desired roughness or shape.

Next, soft magnetic lining layer 2 may be provided on the surface of non-magnetic substance 1. As described previously, soft magnetic lining layer 2 is effective in concentrating magnetic flux from the head to provide vertical magnetic fields, but may be omitted. Material for soft magnetic lining layer 2 may include a crystal NiFe alloy, Sendust (FeSiAl) alloy, or amorphous Co alloy. The amorphous Co alloy may be CoZrNb or a similar material. The optimum value of the film thickness of soft magnetic lining

layer 2 varies depending on the structure or characteristics of the magnetic head used in recording. Productivity considerations make the ideal optimum value from about 10 nm to about 500 nm or less.

Soft magnetic lining layer 2 can be formed using arbitrary methods from associated technologies, including vapor deposition, sputtering, electron beam vapor deposition, or CVD. A sputtering process is preferred, and a DC magnetron sputtering process is recommended. Soft magnetic lining layer 2 may be formed while heating the substrate or applying bias voltage to the substrate. The temperature at which the substrate is heated depends on the desired characteristics. In general, the preferred temperature is between 150°C and 350°C.

Next, an underlayer is provided on a surface of nonmagnetic substrate 1 or soft magnetic lining layer 2. According to the present invention, underlayer 3 is used to distort the crystal structure of magnetic recording layer 4 formed on underlayer 3 to increase uniaxial anisotropy K_u and coercive force H_c of magnetic recording layer 4. Ideally, underlayer 3 has a film thickness between 5 nm and 30 nm. In the present invention, distortion is applied so that the hcp structure of the magnetic recording layer expands along the a -axis. Underlayer 3 may be composed of various metals or alloys having an hcp or fcc structure of the appropriate a -axis lattice constant.

Ru, which has an a -axis lattice constant amounting to 110% of the a -axis lattice constant of magnetic recording layer 4, has a good hcp structure for underlayer 3. Other materials having good hcp structures for underlayer 3 include metals or alloys having a -axis lattice constants greater than 100% and less than or equal to 120% of the a -axis lattice constant of the material for the magnetic recording layer such as Ti, TiCr, Re, CoCr, CuCr, CuZn, IrMo, Ir₂W, MoPt, and MoRh₂. More Ideally, the underlayer material having the hcp structure has an a -axis lattice constant larger than 105% and less than or equal to 110% of the a -axis lattice constant of the magnetic recording layer material. An a -axis lattice constant falling within the previously described range allows the crystal

structure of magnetic recording layer 4 to follow the crystal structure of underlayer 3, and enables the efficient application of distortion.

Materials having an fcc structure ideal for underlayer 3 include Pd, Cu, Au, Ir, Pt, Rh, Ag, Ni₃Al, and Co₃Ti. All these materials have an (a-axis lattice constant) $\times 1/\sqrt{2}$ greater than 100% and less than or equal to 120% of the a-axis lattice constant of the magnetic recording layer. More Ideally, the underlayer material having the fcc structure has an a-axis lattice constant $\times 1/\sqrt{2}$ larger than 105% and less than or equal to 110% of the a-axis lattice constant of the magnetic recording layer material. An a-axis lattice constant falling within the previously described range allows the crystal structure of the magnetic recording layer to follow the crystal structure of the underlayer, and enables the efficient application of distortion.

Underlayer 3 can be formed using arbitrary methods from associated technologies, including vapor deposition, sputtering, electron beam vapor deposition, or CVD. The sputtering process is preferred, and the DC magnetron sputtering process is recommended. Underlayer 3 may be formed while heating the substrate or applying bias voltage to the substrate. The temperature at which the substrate is heated depends on the desired characteristics. In general, the ideal temperature is between 150°C and 350°C.

The a-axis lattice constant herein is measured in a bulk (without distortion) state unless otherwise specified. The a-axis lattice constant is described in various documents. For notably complicated alloys, this constant can be determined by separately forming a film of the target alloy on a glass substrate, then analyzing the film formed by X-ray diffraction. The following shows the a-axis lattice constants of typical materials that can be used as the magnetic recording layer and underlayer according to the present invention. (Ni₁₅Fe₂₅Cr indicates an alloy composed of 15 atom% of Fe, 25 atom% of Cr, and the remaining amount of Ni on the basis of the number of all atoms.)

Table 1

	Crystal structure	a-axis lattice constant [Å]	a-axis lattice constant x (1/ $\sqrt{2}$) [Å]	Ratio of each lattice constant to CoCrPt lattice constant* [%]
CoCrPt	hcp	2.53	—	100
Ru	hcp	2.71	—	107
Pd	fcc	3.89	2.75	109
TiCr	hcp	2.95	—	117
Ni ₁₅ Fe ₂₅ Cr	fcc	3.59	2.54	100.3

*a-axis lattice constant for hcp and a-axis lattice constant x (1/ $\sqrt{2}$) for fcc

Next, magnetic recording layer 4 is provided on a surface of underlayer 3. Magnetic recording layer 4 is suitably composed of a ferromagnetic material of an alloy containing at least Co and Cr. The preferred alloy includes CoCr, CoCrPt, or CoCrTa having the hcp structure. If magnetic recording layer 4 is used for a perpendicular magnetic recording medium, the c-axis (i.e., the easy axis of magnetization) of the hcp structure of these alloys must be oriented perpendicular to the layer surface.

Magnetic recording layer 4 can be formed using arbitrary methods from associated technologies, including vapor deposition, sputtering, electron beam vapor deposition, or CVD. The sputtering process is preferred, and the DC magnetron sputtering process is recommended. Magnetic recording layer 4 may be formed while heating the substrate or applying bias voltage to the substrate. The temperature at which the substrate is heated depends on the desired characteristics. In general, the ideal temperature is between 150°C and 350°C.

In the present invention, magnetic recording layer 4 can be distorted to increase its magnetic anisotropy and coercive force when quenched immediately after formation. The term "quenching" as used herein means that the temperature of magnetic recording layer 4 is reduced by 100°C to 300°C at a rate of 10°C to 30°C/min. Ideally, the quenching operation reduces the temperature of the magnetic recording layer by 150°C to 200°C at a rate of 20°C to 25°C/min.

Such quenching operation can be performed by introducing such coolant as an inert gas into the film formation chamber, or by using coolant to cool a holder holding magnetic recording medium on which films are being formed. Alternatively, the magnetic recording medium on which films are being formed may be moved to a cooling chamber located next to the film formation chamber, where the above operation may be performed. Ideally, the quenching operation is performed in the cooling chamber.

Alternatively, in the present invention, magnetic recording layer 4 may be quickly heated immediately after formation and before quenching. This method is particularly effective in forming magnetic recording layer 4 at relatively low temperatures (between room temperature and 250°C). The term "quick heating" as used herein means that the temperature of magnetic recording layer 4 is increased by 100°C to 400°C at a rate of 10°C to 35°C/min. Ideally, the quick heating operation increases the temperature of the magnetic recording layer by 100°C to 200°C at a rate of 10°C to 20°C/min.

Such quick heating operation can be performed using arbitrary methods from associated technologies, including a lamp heater, sheath heater, use of a heat medium to heat the holder holding the magnetic recording medium on which films are being formed, or inductive heating.

After magnetic recording layer 4 has been quenched or quickly heated, then quenched, protective layer 5 is formed on the surface of magnetic recording layer 4. Protective layer 5 may be formed of material conventionally used for protective layers, such as material composed mainly of carbon. The film thickness and other conditions for protective layer 5 may be the same as those used for normal magnetic recording media.

Protective layer 5 can be formed using arbitrary methods from associated technologies, including vapor deposition, sputtering, electron beam vapor deposition, or CVD. The sputtering process is preferred, and the DC magnetron sputtering process is recommended. Protective layer 5 may be formed while heating the substrate or applying

bias voltage to the substrate. The temperature at which the substrate is heated depends on the desired characteristics. In general, the ideal temperature is between 250°C and 300°C.

Finally, liquid lubricant layer 6 is formed on the surface of protective layer 5. Liquid lubricant layer 6 is composed of such conventional material as a perfluoropolyether-based lubricant. The film thickness and other conditions for liquid lubricant layer 6 may be the same as those used for normal magnetic recording media.

Liquid lubricant layer 6 can be formed using arbitrary methods from associated technologies, including a dip coat process, spin coat process, or roll coating process. The dip coat process is preferred.

Further, in the present invention, any stacked layers starting with underlayer 3 or soft magnetic lining layer 2, if any, and ending with protective layer 5 can be formed within the same apparatus. In particular, if a reduced pressure condition is used to form each layer, the formation process is preferably executed so as to avoid deviation from this condition within the same apparatus.

Examples

The following gives examples of the present invention.

Example 1

A nonmagnetic substrate was composed of a chemically reinforced glass substrate with a smooth surface (e.g., N-10 glass substrate manufactured by HOYA CORPORATION). The substrate was washed, then introduced into a sputtering apparatus, where an Ru target was used to form an Ru underlayer of 5 nm in thickness. Subsequently, a lamp heater was used to heat the substrate until the surface of the

substrate measured 300°C. A Co₂₀Cr₁₀Pt target was then used to form a CoCrPt magnetic recording layer of 20 nm in thickness. Then the substrate on which films were being formed was introduced into the cooling chamber, where it was quenched so that its temperature decreased from 300°C to 150°C in seven seconds. The substrate, on which films were being formed, was again transferred to the film formation chamber. Finally, a carbon target was used to form a protective film composed of carbon and having a thickness of 10 nm, and the substrate was removed from the vacuum apparatus. Other than heating by the heater and quenching, these film formation steps were carried out under Ar gas pressure of 5 mTorr (0.67 Pa) using a DC magnetron sputtering process. Subsequently, a liquid lubricant layer composed of perfluoropolyether and having a thickness of 2 nm was formed using a dip coat process to form a single-layer perpendicular magnetic recording medium.

For the completed perpendicular recording medium, coercive force H_c was evaluated using a VSM (vibrating sample magnetometer), K_u was evaluated using a torque magnetometer, and the c-axis lattice constant of the magnetic recording layer was evaluated using an X-ray diffraction apparatus. Further, the structure was observed using TEM. Table 2 lists the characteristics of the medium of this example by comparing a case where the underlayer is composed of Ni₁₅Fe₂₅Cr, an alloy having an (a-axis lattice constant) $\times 1/\sqrt{2}$ substantially equal to the a-axis lattice constant of the magnetic recording layer, and having an fcc type of crystal structure (Comparative Example 1), when Ru is used as the underlayer and no quenching operation is performed (Comparative Example 2).

Table 2

	Example 1	Comparative Example 1	Comparative Example 2
Underlayer	Ru Quenching	Ni ₁₅ Fe ₂₅ Cr No quenching	Ru No quenching
Coercive force H_c [kA/m]	316.7	202.0	288.3
K_u [10^4 MJ/m ³]	2.2	1.7	1.9
c-axis lattice constant [Å]	4.122	4.143	4.130

The table indicates that both H_c and K_u are increased, and the c-axis lattice constant of the magnetic recording layer reduced by changing the $Ni_{15}Fe_{25}Cr$ underlayer, the crystal lattice of which substantially matches that of the magnetic recording layer, to the Ru underlayer having an a-axis lattice constant greater than that of the $Ni_{15}Fe_{25}Cr$ underlayer. Further, even with the same Ru underlayer, both H_c and K_u are increased by 10% or more and the c-axis lattice constant of the magnetic recording layer reduced by quenching the magnetic recording layer after formation. Since no normal X-ray diffraction apparatuses can measure the a-axis lattice constant of the magnetic recording layer, stacked in the magnetic recording medium, the a-axis can only be assumed to be elongated relative to the contraction of the c-axis (at such a rate that the volume remains constant), thereby increasing magnetostriction. Since TEM observations indicate that there is no major differences between the microstructures of these samples, it can be assumed that the changes in H_c and K_u are caused by magnetostriction resulting from distortion of the crystal lattice of the magnetic recording layer. Thus, K_u and H_c could be increased by changing the underlayer without changing the composition of the magnetic recording layer and quenching the magnetic recording layer immediately after formation. Since the thermal stability of magnetic recording media with magnetic recording layers having equivalent microstructures is proportional to their K_u , this example serves to improve the thermal stability of the magnetic recording medium.

Example 2

A perpendicular medium was produced in the same manner as in Embodiment 1 except that a Pd target was used as the underlayer instead of Ru to form a Pd film of 5 nm in thickness, and that a $Co_{17}Cr_{17}Pt$ target was used to form a CoCrPt magnetic recording layer of 20 nm in thickness. Table 3 lists the H_c , K_u , and c-axis lattice constants obtained when performing quenching operation and when not performing quenching operation.

(Comparative Example 3)

Table 3

	Example 2	Comparative Example 3
	Quenching	No quenching
Coercive force Hc [kA/m]	388.3	324.8
Ku [10^4 MJ/m ³]	3.2	2.7
c-axis lattice constant [Å]	4.120	4.162

The above described characteristics were measured using a VSM, torque magnetometer, and X-ray diffraction apparatus, as in Example 1. The table indicates that the c-axis lattice constant of the magnetic recording layer decreases while Hc and Ku increase, as in Example 1. These results indicate that this example also improves the thermal stability of the medium.

Examples 3 and 4

A nonmagnetic substrate was composed of a chemically reinforced glass substrate with a smooth surface (e.g., N-10 glass substrate manufactured by HOYA CORPORATION). The substrate was washed, then introduced into a sputtering apparatus, where a Co₅Zr₈Nb target was used to form a CoZrNb soft magnetic lining layer of 200 nm in thickness. Then, an Ru target was used to form an Ru underlayer of 5 nm in thickness. Subsequently, a lamp heater was used to heat the substrate until the surface of the substrate measured 220°C. A Co₂₀Cr₁₀Pt target was then used to form a CoCrPt magnetic recording layer of 20 nm in thickness. Subsequently, the lamp heater was used to heat the substrate until the surface of the substrate measured 320°C. Then, the substrate on which films were being formed was introduced into the cooling chamber, where it was quenched, reducing its temperature from 320°C to 150°C in seven seconds. The substrate on which films were being formed was transferred to the film formation

chamber once again. Finally, a carbon target was used to form a protective film composed of carbon and having a thickness of 10 nm, and the substrate was then removed from the vacuum apparatus. These film formation steps other than heating by the heater and quenching were carried out under an Ar gas pressure of 5 mTorr (0.67 Pa) using the DC magnetron sputtering process. Subsequently, a liquid lubricant layer composed of perfluoropolyether and having a thickness of 2 nm was formed using the dip coat process to form a perpendicular magnetic recording medium.

Various magnetic recording media were produced using the same method described above, except for the heating temperature used before the formation of the magnetic recording layer, execution or omission of quick heating after film formation, and execution or omission of quenching. For these magnetic recording media, coercive force H_c was measured using the Kerr effect (i.e., measuring the rotation angle of the plane of polarization of incident light while simultaneously applying external magnetic fields), and the c -axis lattice constant of the magnetic recording layer was measured using an X-ray diffraction apparatus. Fig. 2 shows the relationship between the c -axis lattice constant and coercive force H_c of the magnetic recording layer. The points shown by the arrow in Fig. 2 indicate the characteristics of the magnetic recording medium of Example 3, produced in the above described manner. Table 4 lists the characteristics of a typical magnetic recording medium.

Table 4

	Example 3	Example 4	Comparative Example 4
Quick heating	320°C	Omitted	Omitted
Quenching	150°C	150°C	Omitted
H_c [kA/m]	318.6	261.8	256.5
c -axis lattice constant [Å]	4.123	4.126	4.127

As shown in Fig. 2, coercive force H_c tends to increase with decreases in the c -axis lattice constant of the magnetic recording layer. The magnetic recording medium of

Example 3 had a c-axis lattice constant of 4.123 [Å] and Hc of 318.6 [kA/m] (4004[Oe]). Further, it has been determined that the magnetic recording medium of Example 3, for which a quick heating operation was performed, had a larger Hc and a smaller c-axis lattice constant than Example 4, in which the magnetic recording layer was not quickly heated after formation. For media with a soft magnetic lining layer, the Ku cannot be measured using a torque meter. Thus, there is no other option but to rely on qualitative determination. Nevertheless, it has been confirmed that no change occurred in the microstructures of the media shown in the figure. Consequently, the increase in Hc presumably corresponds to an increase in uniaxial anisotropy caused by magnetostriction as in Example 1. In other words, it is assumed that in Example 3, Ku increased as in Example 1. Therefore, the quick heating step in Example 3 improved thermal stability of the media.

Example 5

A perpendicular recording medium was produced in the same manner as in Example 3, except that a Ti10Cr target was used as the underlayer instead of Ru to form a TiCr film of 10 nm in thickness. Table 3 lists the Hc, c-axis lattice constants of the magnetic recording layer, and D 50 obtained with a sample in which the magnetic recording layer, which was not quickly heated or quenched immediately after formation (Comparative Example 5), and with a sample of this example. D50 represents the frequency (unit: inches per change in flux (FCI)) with which output from the medium has a value equal to half the maximum value when the dependency of output on recording frequency is measured on a spin stand tester. A larger D50 value enables denser recording.

Table 5

	Example 5	Comparative Example 5
	Quick heating and quenching executed	Neither quick heating nor quenching executed
Coercive force [kA/m]	302.2	270.5
c-axis lattice constant [Å]	4.134	4.151
D50 [kFCI]	216	197

As in Example 3, quick heating and quenching operations improved H_c while reducing the c-axis lattice constant. Since the medium of this example was also provided with a soft magnetic lining layer, its K_u could not be measured using a torque magnetometer. However, it is assumed that this example improved the thermal stability of the medium similarly to Example 3. Further, Table 3 indicates that the heating and quenching operations increased D50 by about 10%, thereby enabling much denser recording. Therefore, this example can improve recording characteristics as well as thermal stability.

Advantageous Effects of the Invention

As described above, according to the present invention, the thermal stability of the magnetic recording layer is improved to make the medium more reliable. Further, the present invention can be used with conventional CoCr-based magnetic recording material to form film using conventional apparatuses. Therefore, the present invention is suitable for mass production.

CLAIMS

1. A method of manufacturing perpendicular magnetic recording media characterized by the steps of:

forming an underlayer on a nonmagnetic substrate;

forming a magnetic recording layer on the underlayer;

quenching the magnetic recording layer;

forming a protective layer on the magnetic recording layer; and

forming a liquid lubricant layer on the protective layer;

the steps being carried out in this order to improve uniaxial anisotropy K_u and coercive force H_c of the magnetic recording layer.

2. A method of manufacturing perpendicular magnetic recording media characterized by the steps of:

forming an underlayer on a nonmagnetic substrate;

forming a magnetic recording layer on the underlayer;

quickly heating the magnetic recording layer;

quenching the magnetic recording layer;

forming a protective layer on the magnetic recording layer; and

forming a liquid lubricant layer on the protective layer;

the steps being carried out in this order to improve uniaxial anisotropy K_u and coercive force H_c of the magnetic recording layer.

3. A perpendicular magnetic recording medium characterized by its manufacture by the manufacturing method according to Claim 1 or 2, and

in that the underlayer is formed of metal or alloy material having a hexagonal closest-packing structure having an a-axis lattice constant greater than 100% and less than or equal to 120% of the a-axis lattice constant of the material for a magnetic recording layer.

4. The perpendicular magnetic recording medium according to Claim 3, characterized in that said metal or alloy material is selected from a group consisting of Ru, Ti, TiCr, Re, CoCr, CuZn, IrMo, Ir₂W, MoPt, and MoRh₂.

5. A perpendicular magnetic recording medium characterized by its manufacture by the manufacturing method according to Claim 1 or 2, and

in that the underlayer is formed of metal or alloy material having a face-centered cubic lattice structure having an (a-axis lattice constant) $\times 1/\sqrt{2}$ greater than 100% and less than or equal to 120% of the a-axis lattice constant of the material for a magnetic recording layer.

6. The perpendicular magnetic recording medium according to Claim 3, characterized in that said metal or alloy material is selected from a group consisting of Pd, Cu, Au, Ir, Pt, Rh, Ag, Ni₃Al, and Co₃Ti.