



TITLE OF THE INVENTION

PERPENDICULAR MAGNETIC RECORDING MEDIUM AND MAGNETIC
RECORDING-REPRODUCING APPARATUS USING THE SAME

BACKGROUND OF THE INVENTION

5 The present invention relates to a perpendicular
magnetic recording medium comprising a magnetic
recording layer and a soft magnetic layer and adapted
for a high-density magnetic recording and to a
magnetic recording-reproducing apparatus using the
10 particular perpendicular magnetic recording medium.

 In a perpendicular double-layer medium formed by
laminating a perpendicular recording layer on a soft
magnetic layer having a high permeability, the soft
magnetic layer plays the role of a part of the
15 function of the magnetic head such that the recording
magnetic field that has been generated from the
magnetic head and that has magnetized the
perpendicular recording layer is passed in a
horizontal direction and be brought back to the side
20 of the magnetic head, thereby improving the recording-
reproducing efficiency. On the other hand, the soft
magnetic layer tends to form domains for decreasing
the magnetostatic energy, and domain walls are formed
at the boundaries between the adjacent domains. It is
25 known in the art that a spike-like noise is generated
at the site where the domain wall is present. The
spike-like noise can be suppressed by suppressing the



formation of the domain walls in the soft magnetic layer. Some methods for suppressing the domain wall formation are proposed in, for example, Jpn. Pat. Appln. KOKOKU Publication No. 3-53686 and Jpn. Pat.

5 Appln. KOKAI Publication No. 5-258274. It is proposed that a hard magnetic layer or an antiferromagnetic layer is formed above or below a soft magnetic layer so as to fix the direction of the easy magnetization of the soft magnetic layer to the radial direction for
10 suppressing the formation of the domain wall in the soft magnetic layer.

In view of the control of the direction of the easy magnetization of the soft magnetic layer, it is convenient to use a hard magnetic layer that permits
15 easily controlling the direction of magnetization of the hard magnetic layer itself. Where a hard magnetic layer is formed below the soft magnetic layer, the hard magnetic layer is far from the magnetic head enough so as to inhibit the writing of the information
20 magnetization. However, the hard magnetic layer is basically equal to the longitudinal magnetic recording medium in the material and the magnetic characteristics, and therefore provide a source of medium noise. Also, it is desirable for the soft magnetic
25 layer to be thin in view of the manufacturing cost and the dust generation during the film forming process. However, the noise from the hard magnetic layer is

increased if the soft magnetic layer is made thinner
and the distance between the hard magnetic layer and
the magnetic head is decreased. It follows that the
use of a hard magnetic layer generates a problem
5 particular where the soft magnetic layer is made
thinner.

On the other hand, the use of an antiferro-
magnetic layer is advantageous over the use of a hard
magnetic layer in view that a noise is not generated
10 because magnetization does not take place. However,
since the antiferromagnetic layer does not have a
macroscopic magnetization unlike the hard magnetic
layer, it is difficult to control directly the
direction of the magnetic spin of the antiferro-
15 magnetic layer. Therefore, in order to fix the
direction of the magnetization of the soft magnetic
layer to the radial direction, a soft magnetic layer
is formed first, followed by forming an antiferro-
magnetic layer on the soft magnetic layer with a
20 magnetic field applied in the radial direction, as
disclosed in Japanese Patent Publication No. 3-53686
referred to above. However, where an antiferro-
magnetic layer is laminated on a soft magnetic layer
as proposed in the Japanese patent document quoted
25 above, the distance between the soft magnetic layer
and the magnetic head is increased because of the
presence of the antiferromagnetic layer and therefore

give rise to the problem that the recording magnetic field generated from the magnetic head tends to be diffused so as to lower the recording magnetic field intensity and the recording resolution.

5 As described above, in the conventional perpendicular double-layer medium comprising a soft magnetic layer and a perpendicular recording layer laminated on the soft magnetic layer, the spike-like noise was suppressed by magnetizing the soft magnetic
10 layer in the radial direction by using a hard magnetic layer or an antiferromagnetic layer. However, the use of the hard magnetic layer gives rise to the problem that noise is generated from the hard magnetic layer itself. On the other hand, in the case of using an
15 antiferromagnetic layer, it is difficult to control the direction of the magnetization. Also, an additional problem is located in that the distance between the magnetic head and the soft magnetic layer is increased.

20 BRIEF SUMMARY OF THE INVENTION

 An object of the present invention, which has been achieved in view of the situation described above, is to provide a perpendicular magnetic recording medium capable of suppressing the medium
25 noise and also capable of obtaining a high recording magnetic field intensity and a high recording resolution.

According to a first aspect of the present invention, there is provided a perpendicular magnetic recording medium, comprising:

a nonmagnetic substrate;

5 a longitudinal hard magnetic multi-layered film arranged on the nonmagnetic substrate, including at least two hard magnetic layers laminated one upon the other with a nonmagnetic intermediate layer interposed therebetween;

10 a longitudinal soft magnetic layer formed on the longitudinal hard magnetic multi-layered film; and

a perpendicular magnetic recording layer formed on the longitudinal soft magnetic layer.

According to a second aspect of the present invention, there is provided a magnetic recording-reproducing apparatus, comprising:

a perpendicular magnetic recording-reproducing medium;

20 driving mechanism to support and rotate the perpendicular magnetic recording-reproducing medium;

a magnetic head equipped with an element to record information in the perpendicular magnetic recording medium and with an element serving to reproduce the recorded information; and

25 a carriage assembly which supports the magnetic head such that the magnetic head is movable relative to the perpendicular magnetic recording medium;

wherein the perpendicular magnetic recording medium comprises:

a nonmagnetic substrate;

5 a longitudinal hard magnetic multi-layered film arranged on the nonmagnetic substrate, including at least two hard magnetic layers laminated one upon the other with a nonmagnetic intermediate layer interposed therebetween;

10 a longitudinal soft magnetic layer formed on the longitudinal hard magnetic multi-layered film; and

a perpendicular magnetic recording layer formed on the longitudinal soft magnetic layer.

15 Additional objects and advantages of the present invention will be set forth in the description which follows, and in part will be obvious from the description, or may be learned by practice of the present invention. The objects and advantages of the present invention may be realized and obtained by means of the instrumentalities and combinations
20 particularly pointed out hereinafter.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate embodiments of the present invention, and
25 together with the general description given above and the detailed description of the embodiments given below, serve to explain the principles of the present

invention.

FIG. 1 is a cross-sectional view exemplifying the constitution of a magnetic recording medium of the present invention;

5 FIG. 2 shows as a model an example of the direction of the magnetization in the radial direction of a disk-like substrate;

 FIG. 3 shows as a model another example of the direction of the magnetization in the radial direction
10 of a disk-like substrate;

FIG. 4 is a cross-sectional view showing another example in the constitution of a magnetic recording medium of the present invention;

 FIG. 5 is a cross-sectional view showing another
15 example in the constitution of a magnetic recording medium of the present invention;

 FIG. 6 is an oblique view showing in a dismantled fashion the constitution of an example of a magnetic recording-reproducing apparatus of the present
20 invention;

FIG. 7 is a cross-sectional view showing still another example in the constitution of a magnetic recording medium of the present invention; and

 FIG. 8 schematically shows the constitution of a
25 magnetizing apparatus used in the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The perpendicular magnetic recording medium of

the present invention comprises a structure in which a nonmagnetic substrate, a longitudinal hard magnetic multi-layered film are laminated in the order, a longitudinal soft magnetic layer and a perpendicular magnetic recording layer. The longitudinal hard magnetic multi-layered film includes at least, a nonmagnetic intermediate layer and two hard magnetic layers which are laminated one hard magnetic layer upon the other hard magnetic layer with a nonmagnetic intermediate layer interposed therebetween respectively.

The magnetic recording-reproducing apparatus of the present invention is an apparatus having the above-noted perpendicular magnetic recording medium incorporated therein. Specifically, the magnetic recording-reproducing apparatus of the present invention comprises the perpendicular magnetic recording medium, driving mechanism to support and rotate the perpendicular magnetic recording medium, an element to record information in the perpendicular magnetic recording medium, a magnetic head to reproduce the recorded information, and a carriage assembly which supports the magnetic head such that the magnetic head is movable relative to the perpendicular magnetic recording medium.

In the perpendicular magnetic recording medium of the present invention, the longitudinal hard magnetic

layer arranged below the longitudinal soft magnetic layer is of a multi-layered structure prepared by alternately laminating hard magnetic layers and nonmagnetic layers and produces the interaction of aligning the directions of the magnetization of the adjacent hard magnetic layers in an antiparallel fashion. Because of the particular function, the present invention makes it possible to suppress the leakage of the magnetic flux from the hard magnetic layer and to improve the problem of the noise generation from the hard magnetic layer without increasing the distance between the magnetic head and the longitudinal soft magnetic layer.

Also, in the present invention, the hard magnetic layer included in the longitudinal hard magnetic multi-layered film can be magnetized easily in an optional direction so as to make it possible to suppress relatively easily the spike-like noise generation from the longitudinal soft magnetic layer.

FIG. 1 is a cross-sectional view exemplifying the construction of an example of a magnetic recording medium 10 of the present invention. As shown in the drawing, the magnetic recording medium 10 comprises a substrate 1, a longitudinal hard magnetic layer 8 formed on the substrate 1 and consisting of a first magnetic layer 2-1, a nonmagnetic layer 3-1, a second magnetic layer 2-2, which are laminated one upon the

other in the order mentioned, a longitudinal soft magnetic layer 4 formed on the longitudinal hard magnetic layer 8, an underlayer 5 formed on the longitudinal soft magnetic layer 4, and a
5 perpendicular magnetic recording layer 6 formed on the underlayer 5.

In the present invention, a hard magnetic layer included in the longitudinal hard magnetic multi-layered film may be in contact with the longitudinal
10 soft magnetic layer. As a result, the longitudinal soft magnetic layer is capable of achieving an exchange coupling with the longitudinal hard magnetic multi-layered film in the present invention. In order to magnetize the longitudinal soft magnetic layer in
15 one direction by using the hard magnetic multi-layered film, the exchange coupling or an exchange interaction between the longitudinal soft magnetic layer and the hard magnetic layer in contact with the longitudinal soft magnetic layer is utilized. In practice, the
20 exchange coupling or the exchange interaction produced between the atoms positioned adjacent to each other at the interface between the longitudinal soft magnetic layer and the hard magnetic layer is utilized for magnetizing the longitudinal soft magnetic layer in
25 one direction. Since the exchange interaction is produced in the present invention between the longitudinal hard magnetic multi-layered film and the

longitudinal soft magnetic layer, it is necessary for the layer included in the longitudinal hard magnetic multi-layered film, which is in contact with the longitudinal soft magnetic layer, to be a hard
5 magnetic layer, not a nonmagnetic layer.

Also, in the present invention, it is desirable for the directions of magnetization of the hard magnetic layer included in the longitudinal hard magnetic multi-layered film, which is in contact with
10 the longitudinal soft magnetic layer, to be aligned in a predetermined direction. Where the directions of the magnetization noted above are aligned, it is possible to suppress the spike-like noise.

Where the nonmagnetic substrate is in the shape
15 of a disk, it is desirable for the hard magnetic layer in contact with the longitudinal soft magnetic layer to be magnetized in the circumferential direction or in the radial direction. More preferably, it is desirable to align the directions of magnetization of
20 the hard magnetic layer in the radial direction.

Each of FIGS. 2 and 3 shows as a model that a disk-like substrate is magnetized in the radial direction. To be more specific, FIG. 2 shows that the disk-like substrate is radially magnetized from the
25 center of the substrate toward the periphery of the substrate, as denoted by arrows. Also, FIG. 3 shows that the disk-like substrate is radially magnetized in

the opposite direction from the periphery of the disk toward the center of the disk, as denoted by arrows. It is also possible for the disk-like substrate to be magnetized in the circumferential direction, i.e., in the clockwise or counterclockwise direction.

In the present invention, it is desirable for the hard magnetic multi-layered film to align the directions of magnetization of the adjacent hard magnetic layers in an antiparallel direction. It is also desirable for the hard magnetic layers positioned adjacent to each other with a nonmagnetic layer interposed therebetween to have approximately the same magnitude of magnetic moment.

Where the two adjacent hard magnetic layers have the same magnitude of magnetic moment, the magnetic moments of the two adjacent hard magnetic layers are canceled by each other so as to minimize the leaking magnetic flux. It follows that, where the hard magnetic multi-layered film includes an even number of hard magnetic layers, it can be assumed that every two hard magnetic layers form a pair, with the result that the leaking magnetic flux of the entire hard magnetic layers can be minimized so as to improve the problem of noise generation most effectively.

If the difference in magnitude of the magnetic moments exceeds 0%, the two adjacent hard magnetic layers is larger, media noise from the multi layered

hard magnetic layer tends to be larger.

5 A similar effect can be expected even if the longitudinal hard magnetic multi-layered film does not include an even number of the sum of the hard magnetic layers. For example, in the case of a disk-like substrate, a similar effect can be expected if the sum of the magnitudes of the magnetic moments of the hard magnetic layers that are magnetized radially outward is approximately equal to the sum of the magnitudes of
10 the magnetic moments of the hard magnetic layers that are magnetized radially inward. In this case, it is desirable for the difference between the sum of the magnitudes of the magnetic moments of the hard magnetic layers that are magnetized radially outward and the sum of the magnitudes of the magnetic moments
15 of the hard magnetic layers that are magnetized radially inward to be 0 or more 0 as possible. If the difference noted above, is larger, media noise from the multi layered hard magnetic layer tends to be
20 larger.

Incidentally, if the construction that the directions of magnetization of the adjacent hard magnetic layers are aligned antiparallel to each other through the nonmagnetic layer is applied to the
25 recording layer of the longitudinal magnetic recording medium, it is impossible to obtain a sufficient reproduction output. Thus the particular construction

is convenient only for the perpendicular magnetic recording medium.

In the present invention, it is desirable for the coercive force of the hard magnetic layer adjacent to the longitudinal soft magnetic layer to be larger than
5 the coercive force of the other hard magnetic layer.

In the absence of an external magnetic field, the soft magnetic layer and the hard magnetic layer are magnetized at random. Where an external magnetic
10 field is applied for magnetizing the hard magnetic layer in a predetermined direction, particularly, in the case of applying an external magnetic field having an intensity high enough to overcome the interaction for aligning the hard magnetic layers in an
15 antiparallel direction, each direction of the hard magnetic layers included in the hard magnetic multi-layered film faces in the direction of the external magnetic field so as to make the directions of magnetization parallel. If the external magnetic
20 field is removed later, the direction of magnetization of one of the adjacent hard magnetic layers is reversed by the interaction, though the direction of magnetization of the other hard magnetic layer remains to be equal to the direction of the external magnetic
25 field.

Where an even number of hard magnetic layers, e.g., two hard magnetic layers, are formed on a

disk-like substrate and if an external magnetic field
is applied to the disk-like substrate radially
outward, followed by removing the external magnetic
field, it is desirable for the direction of
magnetization of one hard magnetic layer alone to be
reversed so as to be magnetized radially inward.
However, where the two hard magnetic layers are equal
to each other in the magnetic characteristics, there
is no reason for the preferential reversal in the
direction of magnetization over the entire region of
one hard magnetic layer alone. It is considered
reasonable to understand that the directions of
magnetization are partially reversed in both hard
magnetic layers. In the present invention, a hard
magnetic layer included in the longitudinal hard
magnetic multi-layered film is in contact with the
longitudinal soft magnetic layer, and the hard
magnetic layer noted above is strongly coupled with
the longitudinal soft magnetic layer because of the
exchange interaction therebetween. It follows that
the direction of magnetization of the longitudinal
soft magnetic layer is strongly affected by the
magnetized state of the hard magnetic layer. Under
the circumstances, the state that the direction of
magnetization of the hard magnetic layer is partially
reversed is undesirable for magnetizing the

longitudinal soft magnetic layer in one direction.

Such being the situation, in the present invention, it is desirable for the coercive force of the hard magnetic layer in contact with the longitudinal soft magnetic layer to be larger than the coercive force of the other hard magnetic layer so as to suppress the reversal in the direction of magnetization of the longitudinal soft magnetic layer and the hard magnetic layer in contact with the longitudinal soft magnetic layer, thereby permitting the direction of magnetization of the other hard magnetic layer to be reversed preferentially.

In this case, it is desirable for the difference in coercive force between the hard magnetic layer in contact with the longitudinal soft magnetic layer and the other hard magnetic layer to be larger than about 1 kOe. If the difference in coercive force noted above is smaller than 1 kOe, partly reversal in the direction of magnetization in the soft magnetic layer and hard magnetic layer tends to be caused.

FIG. 4 is a cross-sectional view showing another example of the construction of a magnetic recording medium of the present invention. As shown in the drawing, the magnetic recording medium 20 is substantially equal in construction to the magnetic recording medium shown in FIG. 1, except that a nonmagnetic layer 3-2 and a third hard magnetic layer

2-3 are further arranged between the second hard magnetic layer 2-2 and the longitudinal soft magnetic layer 4 in the magnetic recording medium 20 shown in FIG. 4.

5 Where an even number of hard magnetic layers are included in the hard magnetic multi-layered film, it is desirable to increase the coercive force of only the hard magnetic layer in contact with the longitudinal soft magnetic layer. However, where an
10 odd number of hard magnetic layers are included in the hard magnetic multi-layered film, it is possible to make these hard magnetic layers approximately equal to each other in coercive force. Where the magnetic recording medium includes three hard magnetic layers
15 2-1, 2-2 and 2-3 as shown in FIG. 4, the interaction is exerted from the upper and lower hard magnetic layers 2-1 and 2-3 to the intermediate second hard magnetic layer 2-2, though the interaction is exerted from the second hard magnetic layer 2-2 alone to each
20 of the first and third hard magnetic layers 2-1 and 2-3, even if these three hard magnetic layers are approximately equal to each other in magnetic characteristics. It follows that the direction of magnetization tends to be reversed preferentially in
25 the second hard magnetic layer 2-2. Even where an odd number of hard magnetic layers are included in the hard magnetic multi-layered film, these hard magnetic

layers are not equal to each other in coercive force. As described previously, it is possible to allow the hard magnetic layer in contact with the longitudinal soft magnetic layer to have the largest coercive
5 force. The particular situation is established in principle in the case where an odd number of hard magnetic layers are included in the hard magnetic multi-layered film. However, if an excessively large number of hard magnetic layers are included in the
10 hard magnetic multi-layered film, it is considered that the direction of magnetization of the hard magnetic layer in contact with the longitudinal soft magnetic layer is unlikely to be reversed. In view of the manufacturing process of the medium and the
15 manufacturing cost, it is considered desirable for the hard magnetic multi-layered film to include 2 to 3 hard magnetic layers, more desirably two hard magnetic layers. In this case, it is desirable for the difference in coercive force between the hard magnetic
20 layer having the largest coercive force and the hard magnetic layer having the smallest coercive force to fall within a range of between about 1 kOe and 2 kOe. If the difference in coercive force noted above is smaller than 1 kOe partly reversal in the direction of
25 magnetization in the soft magnetic layer and hard magnetic layer tends to be caused..

Where the hard magnetic multi-layered film

includes an odd number of hard magnetic layers and where the hard magnetic layers have the same magnitude of magnetic moment, the magnetic flux for a single hard magnetic layer is not canceled so as to the
5 leaked. In this case, it is possible to suppress the leakage of the magnetic flux from the hard magnetic multi-layered film by changing appropriately the magnitude of the magnetic moment of each hard magnetic layer. Where, for example, the hard magnetic multi-
10 layered film includes three hard magnetic layers, it is possible to minimize the magnetic moment of the entire hard magnetic multi-layered film by allowing the saturation magnetization of the intermediate hard magnetic layer to be twice as much as that of each of
15 the upper and lower hard magnetic layers, or by allowing the intermediate hard magnetic layer to have a thickness twice as much as that of each of the upper and lower hard magnetic layers, with the result that the leakage of the magnetic flux can be minimized.
20 The magnitude of the magnetic moment can be changed by, for example, changing the material constituting the magnetic layer, or by changing the component ratio of the magnetic layer.

Where the hard magnetic layers are equal to each
25 other in composition, it is desirable to allow the sum in thickness of the odd-numbered hard magnetic layers as counted from the magnetic recording layer to be

approximately equal to the sum in thickness of the even-numbered hard magnetic layers even if the hard magnetic multi-layered film includes an odd number or even number of hard magnetic layers. In this case, 5 the magnetic moments of the entire hard magnetic layers are canceled by each other so as to minimize the leakage of the magnetic flux, thereby effectively improving the noise problem. Incidentally, it is desirable for the difference in the total thickness 10 between the odd-numbered hard magnetic layers and the even-numbered hard magnetic layers to be 0 or near 0.

In the hard magnetic multi-layered film used in the present invention, a desirable combination of the hard magnetic layer and the nonmagnetic layer includes 15 the combination of a Co-based alloy and Ru, V or Cr. If a Co-based alloy of a hexagonal close-packed structure is used for forming the magnetic layer, a large coercive force can be obtained. Also, in order to maintain the C-axis of the Co-based alloy formed on 20 a nonmagnetic layer in a planar direction, it is desirable to use Ru, V or Cr for forming the nonmagnetic layer. In the case of employing the particular combination, it is possible to obtain easily the antiferromagnetic coupled state so as to 25 obtain desired hard magnetic characteristics.

In the present invention, the thickness of the nonmagnetic layer interposed between the adjacent hard

magnetic layers preferably be determined to produce the interaction with the adjacent hard magnetic layers such that the directions of magnetization of these hard magnetic layers are aligned in the antiparallel direction.

For example, in a multi-layered film including a ferromagnetic transition metal layer formed of Fe or Co and a nonmagnetic metal layer formed of, for example, V, Cr, Cu, Mo, Ru, Rh or Re, a ferromagnetic coupling and an antiferromagnetic coupling have been found to appear periodically in the thickness direction of the nonmagnetic layer. It is known in the art that, in the multi-layered film noted above, the period of the antiferromagnetic coupling or the ferromagnetic coupling of the adjacent hard magnetic layers is about 1 nm, as reported in, for example, "A. Heinlich and J.A.C. Bland, Ultrathin Magnetic Structures II, Springer-Verlag (1994)". Also, the thickness of the nonmagnetic layer in which the antiferromagnetic coupling appears first is slightly smaller than 1 nm. In this case, the strongest coupling force can be obtained. Then, the intensity of the antiferromagnetic coupling tends to be lowered with increase in the thickness of the nonmagnetic layer to about 2 nm and, then, to about 3 nm.

In the present invention, in order to suppress the leakage of the magnetic flux from the longitudinal

hard magnetic layer so as to improve the noise
problem, a multi-layered structure consisting of a
hard magnetic layer and a nonmagnetic layer can be
employed in the longitudinal hard magnetic layer so as
5 to align the magnetization of the adjacent hard
magnetic layers in an antiparallel direction. Also,
depending on the thickness of the nonmagnetic layer,
the adjacent hard magnetic layers can be ferro-
magnetically coupled. In the case of the
10 ferromagnetic coupling, it is impossible to suppress
the leakage of the magnetic flux from the entire hard
magnetic layers. Therefore, the thickness of the
nonmagnetic layer is set to be antiferromagnetically
coupled.

15 As described above, the thickness of the
nonmagnetic layer that permits the highest intensity
of the interaction for aligning the directions of the
magnetization of the adjacent hard magnetic layers
included in the hard magnetic multi-layered film in an
20 antiparallel direction, which slightly differs
depending on the material, is slightly smaller than
about 1 nm on the average. Where the nonmagnetic
layer is formed of, for example, Ru, it is known to
the art that the thickness of the nonmagnetic layer
25 that permits increasing the interaction is about
0.8 nm. If the thickness is slightly deviated from
the optimum thickness noted above, the interaction to

align the directions of the magnetization in an antiparallel direction tends to be further lowered. If the thickness is further deviated from the optimum thickness, the interaction to align the directions of the magnetization in a parallel direction begins to be produced, with the result that the effects of suppressing the leakage of the magnetic flux and the noise generation are rendered insufficient. In view of the facts that the state in the bonding interface between the magnetic layer and the nonmagnetic layer differs depending on the combination of the materials and that it is difficult to ensure the thickness accuracy of ± 0.1 nm on the entire substrate surface, it is necessary for the fluctuation in the thickness of the nonmagnetic layer within a certain range to be acceptable. Under the circumstances, the desirable thickness of the nonmagnetic layer included in the hard magnetic multi-layered film should be not smaller than 0.5 nm and can be smaller than 1.2 nm. If the thickness of the nonmagnetic layer falls within the range noted above, it can be considered possible to obtain the effect of suppressing the noise caused by the hard magnetic multi-layered film.

It is preferable for the hard magnetic layer to be formed of an alloy containing mainly Co, Cr and Pt. In the case of using a magnetic layer formed of the particular alloy, it is possible to control easily the

easy axis, to increase the coercive force and to suppress the noise.

FIG. 5 is a cross-sectional view showing as another example the construction of a magnetic recording medium of the present invention. As shown in the drawing, the magnetic recording medium 30 shown in FIG. 5 is substantially equal in construction to the magnetic recording medium shown in FIG. 1, except that a nonmagnetic underlayer 7 is formed between the substrate 1 and the first magnetic layer 2-1 in the medium 30 shown in FIG. 5.

In the present invention, it is possible to further form a nonmagnetic underlayer between the nonmagnetic substrate and the longitudinal hard magnetic multi-layered layer in order to control the crystal orientation such that the easy axis of the longitudinal hard magnetic layer extends in the longitudinal direction, as shown in the drawing. Since the direction of easy axis of the longitudinal soft magnetic layer is longitudinal to the film surface, it is preferable for the direction of easy axis of the hard magnetic layer to be longitudinal to the film surface in order to align the directions of the axes of the film in a predetermined direction. However, since the surface of the substrate of the magnetic recording medium can be amorphous in many cases, the easy axis is not necessarily directed in

longitudinal direction to the film surface if a hard magnetic layer is simply formed directly on the substrate. As a method of controlling the direction of the easy axis, it is possible to form a nonmagnetic underlayer of a different material below the magnetic layer.

In the present invention, it is preferable to form an underlayer consisting of an alloy containing mainly Cr as such a nonmagnetic underlayer. The underlayer formed of Cr is particularly effective for controlling the direction of the easy axis of the hard magnetic layer consisting essentially of an alloy containing mainly Co, Cr and Pt.

Also, in the present invention, it is preferable for the perpendicular magnetic recording layer to be formed of an alloy containing mainly at least one element selected from the group consisting of Co, Cr and Pt.

In the present invention, it is also possible to form the nonmagnetic underlayer 5 between the longitudinal soft magnetic layer 4 and the perpendicular magnetic recording layer 6, as shown in FIG. 1. Since the crystallinity in the surface region of the longitudinal soft magnetic layer differs depending on the material, it is preferable to form the nonmagnetic underlayer in order to control the crystal orientation such that the easy axis of the

perpendicular magnetic recording layer extends in the perpendicular direction. By forming the nonmagnetic underlayer, it is possible to improve such as the crystal grain diameter, the medium noise and the recording resolution. Also, where the magnetic recording layer is formed of a material containing at least one element from the group consisting of Co, Cr and Pt, it is desirable for the nonmagnetic underlayer to be formed of a material containing at least one of Co, Cr and Pt and providing a nonmagnetic composition in view of the lattice mismatch. On the other hand, it is possible to obtain satisfactory magnetic characteristics and recording-reproducing characteristics in the case of using any of Pt, Pd, Rh and Ru for forming the nonmagnetic underlayer. It follows that it is possible to further improve the magnetic characteristics and the recording-reproducing characteristics by forming an alloy layer containing Co, Cr, Pt, Pd, Rh and Ru in combination between the longitudinal soft magnetic layer and the perpendicular magnetic recording layer.

As described above, a hard magnetic multi-layered film prepared by laminating ferromagnetic layers with a nonmagnetic layer interposed therebetween is formed in the present invention below the longitudinal soft magnetic layer so as to make it possible to control easily the direction of magnetization of the hard

magnetic layer itself. As a result, it is possible to suppress the spike-like noise from the longitudinal soft magnetic layer to suppress the noise from the hard magnetic layer itself. It follows that it is possible to realize the magnetic recording of a high recording magnetic field intensity and a high recording resolution.

FIG. 6 is an oblique view showing in a dismantled fashion a magnetic recording-reproducing apparatus of the present invention. As shown in the drawing, the magnetic recording-reproducing apparatus of the present invention comprises a magnetic disk 121 of a hard construction for recording information, and a spindle 122 mounted on the magnetic disk 121. The spindle 122 is rotated at a predetermined angular velocity by a spindle motor (not shown). A magnetic head gaining access to the magnetic disk 121 for recording-reproducing information is mounted on a slider 123, which is mounted to the tip of a suspension 124 formed of a thin plated-like leaf spring. The suspension 124 is connected to one end of an arm 125 having, for example, a bobbin portion for holding a driving coil (not shown).

A voice coil motor 126, which is a kind of a linear motor, is mounted to the other end of the arm 125. The voice coil motor 126 comprises a driving coil (not shown) wound about the bobbin portion of the

arm 125 and a magnetic circuit consisting of a permanent magnet and a counter yoke arranged to have the driving coil interposed therebetween.

5 The arm 125 is held by upper and lower ball bearings (not shown) arranged in upper and lower portions of a stationary shaft 127 and is rocked by the voice coil motor 126. In other words, the position of the slider 123 on the magnetic disk 121 is controlled by the voice coil motor 126. Incidentally,
10 a reference numeral 128 shown in FIG. 6 denotes a lid.

The present invention will now be described in more detail with reference to Examples of the present invention.

Example 1:

15 A magnetic recording medium was prepared as follows.

FIG. 7 is a cross-sectional view showing the construction of a magnetic recording medium for Example 1.

20 As shown in the drawing, the magnetic recording medium 40 is substantially equal in construction to the medium shown in FIG. 1, except that a nonmagnetic underlayer 7 is further formed between the substrate 1 and the hard magnetic layer 2-1 in the magnetic
25 recording medium 40 for Example 1.

The magnetic recording medium 40 shown in FIG. 7 was prepared as follows.

Specifically, a glass substrate 1 meeting the standard specification of a 2.5-inch magnetic disk was prepared as a nonmagnetic substrate. The glass substrate 1 was heated to 250°C, and a DC magnetron sputtering was applied to the heated glass substrate 1 under an Ar gas atmosphere having a gas pressure of 0.6 Pa so as to laminate successively various layers on the glass substrate 1, as follows.

In the first step, a CrMo alloy layer having a thickness of 40 nm was formed as the nonmagnetic underlayer 7 on the nonmagnetic substrate 1 (glass substrate).

Then, a longitudinal hard magnetic multi-layered film of a three-layer structure was formed on the nonmagnetic underlayer 7 by forming a Co-Cr-Pt hard magnetic layer 2-1 in a thickness of 10 nm with a Co-22at%-Cr-13at%Pt alloy used as a target, by forming a Ru nonmagnetic layer 3-1 in a thickness of 0.8 nm on the hard magnetic layer 2-1 with Ru used as a target, and further forming a hard magnetic layer 2-2 in a thickness of 10 nm on the Ru nonmagnetic layer 3-1 with a Co-18at%-Cr-13at%Pt alloy used as a target. Incidentally, targets of different compositions were used for forming the Co-Cr-Pt hard magnetic layers 2-1 and 2-2 so as to increase the coercive force of the hard magnetic layer 2-2 in contact with the longitudinal soft magnetic layer 4.

Further, a Co-Zr-Nb alloy layer was formed in a thickness of 100 nm as the longitudinal soft magnetic layer 4 on the Co-Cr-Pt hard magnetic layer 2-2 with a Co-5at%Zr-10at%Nb alloy used as a target.

5 Still further, a Co-Cr-Pt alloy layer was formed in a thickness of 20 nm as the nonmagnetic underlayer 5 on the longitudinal soft magnetic layer 4 with a Co-37wt%Cr-8at%Pt alloy of a nonmagnetic composition used as a target, followed by further forming a
10 Co-Cr-Pt-B alloy layer in a thickness of 30 nm as a perpendicular magnetic recording layer 6 on the nonmagnetic underlayer 5 with a Co-20at%Cr-10at%Pt-2at%B alloy used as a target.

 Finally, a carbon layer was formed in a thickness
15 of 10 nm as a protective layer 9.

 The perpendicular magnetic recording medium 40
having the various films formed successively within a vacuum container was taken out under the air atmosphere and, then, a magnetic field of 1.2 MA/m was
20 applied to the medium 40 radially outward by using a magnetizing apparatus utilizing an electromagnet prepared exclusively for this experiment so as to magnetize the longitudinal hard magnetic layer in a radial direction.

25 FIG. 8 schematically shows the construction of a magnetizing apparatus. As shown in the drawing, the magnetizing apparatus 50 comprises a pair of coils 51,

52 arranged to face each other. If an electric current is allowed to flow through these coils 51, 52, a magnetic field is generated in a direction denoted by arrows. As shown in the drawing, a magnetic recording medium 100 is arranged in parallel between these coils 51 and 52. If an electric current is allowed to flow through these coils 51, 52, it is possible to allow a predetermined magnetic field to flow radially outward through the magnetic recording medium 100.

The recording-reproducing characteristics of perpendicular magnetic recording medium 40 thus prepared were evaluated by using a magnetic head utilizing a magnetoresistance effect. Generation of spike-like noise was not recognized at all over the entire disk. Also, the S/Nm, reproduced signal output/medium noise ratio of the recording medium, was found to be 28 dB under the linear recording density of 400 kFCI.

Incidentally, the recording-reproducing characteristics were also evaluated for the perpendicular magnetic recording medium before application of the magnetizing treatment, with the result that a plurality of spike-like noise of a magnitude substantially equal to that of the reproduced signal was observed. This clearly supports that the longitudinal hard magnetic layer was actually magnetized uniformly

in the radial direction of the substrate by the magnetizing treatment so as to suppress formation of the domain wall.

Comparative Example 1:

5 A perpendicular magnetic recording medium was prepared as in Example 1, except that a single Co-Cr-Pt hard magnetic layer having a thickness of 20 nm was formed in place of the longitudinal hard magnetic multi-layered film by using a Co-22at%Cr-13at%Pt alloy
10 as a target.

 The recording-reproducing characteristics of the magnetic recording medium thus prepared were evaluated as in Example 1, with the result that generation of a spike-like noise was not recognized at all over the
15 entire disk. Also, the S/Nm under the linear recording density of 400 kFCI was found to be 22 dB, which was clearly inferior to that for Example 1.

 The experimental data clearly support that the use of the longitudinal hard magnetic layer of a
20 multi-layered structure comprising a nonmagnetic layer interposed between the adjacent hard magnetic layers is effective for suppressing the medium noise generated from the perpendicular magnetic recording medium.

25 Examples 2 and 3:

 A perpendicular magnetic recording medium was prepared as in Example 1, except that the thickness of

the Ru nonmagnetic layer was changed to 0.5 nm or 1.2 nm.

The recording-reproducing characteristics of each of the magnetic recording media thus prepared were
5 evaluated as in Example 1, with the result that spike-like noise was not recognized at all over the entire disk. Also, the S/Nm under the linear recording density of 400 kFCI was found to be 23 dB for each of Examples 2 and 3, which was clearly superior to that
10 for Comparative Example 1 and inferior to that for Example 1.

It is considered reasonable to understand that, if the thickness of the Ru layer is changed to 0.5 nm or 1.2 nm, the interaction for aligning the
15 magnetization of the adjacent hard magnetic layers in an antiparallel direction is lowered so as to provide the state close to that of the recording medium in which the longitudinal hard magnetic film does not include a nonmagnetic layer as in Comparative
20 Example 1.
Example 4:

A perpendicular magnetic recording medium was prepared as in Example 1, except that the thickness of the Ru nonmagnetic layer included in the longitudinal
25 hard magnetic multi-layered film was changed to 4 nm.

The recording-reproducing characteristics of the magnetic recording medium thus prepared were evaluated

as in Example 1, with the result that spike-like noise was not recognized at all over the entire disk. Also, the S/Nm under the linear recording density of 400 kFCI was found to be 24 dB.

5 It is considered reasonable to understand that Example 4 was inferior to Example 1 in the S/Nm because the Ru layer having a thickness of 4 nm scarcely produced the effect of aligning the magnetization of the adjacent hard magnetic layers in
10 an antiparallel direction. However, Example 4 including the longitudinal hard magnetic multi-layered film was superior to Comparative Example 1 in the S/Nm, supporting that the longitudinal hard magnetic multi-layered film is effective for suppressing noise.
15 Comparative Example 2:

 A perpendicular magnetic recording medium was prepared as in Example 1, except that a longitudinal hard magnetic multi-layered film of a four-layer structure consisting of a Co-Cr-Pt hard magnetic layer
20 having a thickness of 10 nm, which was equal to the Co-Cr-Pt hard magnetic layer 2-1, a Ru nonmagnetic layer having a thickness of 4 nm, a Co-Cr-Pt hard magnetic layer having a thickness of 10 nm, which was equal to the Co-Cr-Pt hard magnetic layer 2-1, and a
25 Ru nonmagnetic layer having a thickness of 4 nm, which were laminated one upon the other in the order mentioned, was formed on the nonmagnetic underlayer 7.

The recording-reproducing characteristics of the magnetic recording medium thus prepared were evaluated as in Example 1, with the result that a plurality of spike-like noise of a magnitude substantially equal to that of the reproduced signal were observed.

Therefore, it was impossible to evaluate the S/Nm properly. It is considered reasonable to understand that, since a Ru nonmagnetic layer was interposed between the hard magnetic layer included in the longitudinal hard magnetic layer and the longitudinal soft magnetic layer, the exchange interaction ceased to be produced between the two magnetic layers, with the result that a domain wall was formed in the longitudinal soft magnetic layer.

Example 5:

A perpendicular magnetic recording medium was prepared as in Example 1, except that the thickness of the second Co-Cr-Pt hard magnetic layer included in the longitudinal hard magnetic multi-layered film was set at 20 nm, said second Co-Cr-Pt hard magnetic layer being set at a high coercive force.

The recording-reproducing characteristics of the magnetic recording medium thus prepared were evaluated as in Example 1, with the result that generation of a spike-like noise was not recognized at all over the entire disk. Also, the S/Nm under the linear recording density of 400 kFCI was found to be 25 dB,

which was lower than that for Example 1. The interaction to align the magnetization of the two hard magnetic layers included in the longitudinal hard magnetic multi-layered film in an antiparallel direction was certainly produced between the two hard magnetic layers noted above. However, it is considered reasonable to understand that, since the second hard magnetic layer was formed thicker than the first hard magnetic layer, the effect of mutually canceling the magnetic moment was rendered insufficient, with the result that the magnetic flux partially leaked from the second hard magnetic layer so as to increase the medium noise, compared with Example 1 in which the first and second hard magnetic layers were formed in the same thickness. The experimental data clearly support that, where the longitudinal hard magnetic multi-layered film includes an even number of hard magnetic layers, the medium noise generated from the perpendicular magnetic recording medium can be suppressed by making the magnitudes of the magnetic moments of the adjacent hard magnetic layers included in the longitudinal hard magnetic multi-layered film substantially equal to each other.

Example 6:

A perpendicular magnetic recording medium was prepared as in Example 1, except that the longitudinal

hard magnetic multi-layered film was of a five-layer structure consisting of a Co-Cr-Pt hard magnetic layer having a thickness of 10 nm, which was equal to the Co-Cr-Pt hard magnetic layer 2-1, a Ru nonmagnetic layer having a thickness of 0.8 nm, a Co-Cr-Pt hard magnetic layer having a thickness of 10 nm, which was equal to the Co-Cr-Pt hard magnetic layer 2-1, a Ru nonmagnetic layer having a thickness of 0.8 nm, and a Co-Cr-Pt hard magnetic layer having a thickness of 10 nm, which was equal to the Co-Cr-Pt hard magnetic layer 2-2, which were laminated one upon the other in the order mentioned. The third Co-Cr-Pt hard magnetic layer in contact with the longitudinal soft magnetic layer was set at a high coercive force by using a target of a different composition in forming the third Co-Cr-Pt layer. The recording-reproducing characteristics of the magnetic recording medium thus prepared were evaluated as in Example 1, with the result that spike-like noise was not recognized at all over the entire disk. Also, the S/Nm under the linear recording density of 400 kFCI was found to be 26 dB, which was lower than that for Example 1. The interaction to align the magnetization of the three hard magnetic layers included in the longitudinal hard magnetic multi-layered film in an antiparallel direction was certainly produced among the three hard magnetic layers noted above. However, it is

considered reasonable to understand that, since the three hard magnetic layers having substantially the same magnetic moment were included in the longitudinal hard magnetic multi-layered film, the magnetic moment
5 of one hard magnetic layer is not canceled so as to cause leakage of the magnetic flux, leading to the increase in the medium noise, compared with Example 1 in which two hard magnetic layers were included in the longitudinal hard magnetic multi-layered film.

10 Example 7:

A perpendicular magnetic recording medium was prepared as in Example 1, except that the two Co-Cr-Pt hard magnetic layers were made substantially equal to each other in the magnitude of the coercive force.

15 The recording-reproducing characteristics of the magnetic recording medium thus prepared were evaluated as in Example 1, with the result that spike-like noise similar to the reproduced signal was somewhat observed over the entire disk. It is considered reasonable to
20 understand that, since the two hard magnetic layers included in the longitudinal hard magnetic multi-layered film were substantially equal to each other in the magnetic characteristics, the direction of magnetization of only one of the two hard magnetic
25 layers failed to be preferentially reversed after the magnetizing treatment, and the direction of magnetization of the two hard magnetic layers was

partially reversed so as to form a domain wall within the longitudinal soft magnetic layer. The experimental data clearly support that generation of spike-like noise from the perpendicular magnetic recording medium can be suppressed by making the coercive force of the hard magnetic layer in contact with the longitudinal soft magnetic layer larger than the coercive force of the other hard magnetic layer included in the longitudinal hard magnetic multi-layered film.

Example 8:

A perpendicular magnetic recording medium including a longitudinal hard magnetic multi-layered film of a five-layer structure was prepared as in Example 6, except that the thickness of each of the three Co-Cr-Pt hard magnetic layers was set at 10 nm, which was equal to the thickness of the Co-Cr-Pt hard magnetic layer 2-1. The recording-reproducing characteristics of the magnetic recording medium thus prepared were evaluated as in Example 1, with the result that the S/Nm was found to be 26 dB under the linear recording density of 400 kFCI, which was lower than that for Example 1.

It is considered reasonable to understand that the S/Nm was lowered because the medium noise was increased, compared with Example 1 in which the longitudinal hard magnetic multi-layered film included

two hard magnetic layers. Incidentally, in Example 8, the coercive force of the Co-Cr-Pt hard magnetic layer in contact with the longitudinal soft magnetic layer was made larger than that of each of the other hard magnetic layers unlike the Co-Cr-Pt hard magnetic layers used in the Examples described previously. In spite of the particular construction, spike-like noise was not generated in Example 8. It is considered reasonable to understand that the interaction from both the first and third hard magnetic layers is exerted on the intermediate second hard magnetic layer, though the interaction from the intermediate second hard magnetic layer alone is exerted on each the first and third hard magnetic layers, with the result that the direction of magnetization of the second hard magnetic layer is preferentially reversed so as to suppress the spike-like noise. In conclusion, the experimental data support that, where an odd number of hard magnetic layers are included in the longitudinal hard magnetic multi-layered film, the medium noise from the perpendicular magnetic recording medium can be suppressed even if the hard magnetic layers have substantially the same coercive force.

Example 9:

A perpendicular magnetic recording medium was prepared as in Example 1, except that V was used in place of Ru for forming the nonmagnetic layer. The

recording-reproducing characteristics of the magnetic recording medium thus prepared were evaluated, with the result that the S/Nm under the linear recording density of 400 kFCI was found to be 27 dB, which was
5 satisfactory, though the S/Nm value was slightly lower than that for Example 1. It follows that the medium noise of the perpendicular magnetic recording medium can be suppressed even in the case of using V in place of Ru for forming the nonmagnetic layer included in
10 the longitudinal hard magnetic multi-layered film.

Incidentally, it is considered reasonable to understand that the S/Nm was slightly lower than that for Example 1 because the exchange interaction produced between the adjacent hard magnetic layers
15 with the Ru layer interposed therebetween is stronger than the exchange interaction produced between the adjacent hard magnetic layers with the V layer interposed therebetween.

Example 10:

20 A perpendicular magnetic recording medium was prepared as in Example 1, except that Cr was used in place of Ru for forming the nonmagnetic layer. The recording-reproducing characteristics of the magnetic recording medium thus prepared were evaluated, with
25 the result that the S/Nm under the linear recording density of 400 kFCI was found to be 27 dB, which was satisfactory, though the S/Nm value was slightly lower

than that for Example 1. It follows that the medium noise of the perpendicular magnetic recording medium can be suppressed even in the case of using Cr in place of Ru for forming the nonmagnetic layer included
5 in the longitudinal hard magnetic multi-layered film.

Incidentally, it is considered reasonable to understand that the S/Nm was slightly lower than that for Example 1 because the exchange interaction produced between the adjacent hard magnetic layers
10 with the Ru layer interposed therebetween is stronger than the exchange interaction produced between the adjacent hard magnetic layers with the Cr layer interposed therebetween.

In each of Examples 9 and 10, a Co-Cr-Pt alloy
15 was used for forming the hard magnetic layer, and Ru, V or Cr was used for forming the nonmagnetic layer. However, it is also possible to use the ferromagnetic material and the nonmagnetic material other than those noted above. It is possible to obtain the similar
20 effect by selecting the thickness of the nonmagnetic layer such that an antiferromagnetic exchange interaction is produced between the adjacent hard magnetic layers. However, it is desirable to use Ru, V or Cr for forming the nonmagnetic layer because the
25 nonmagnetic layer formed of the particular element noted above permits effectively suppressing the medium noise.

Example 11:

A perpendicular magnetic recording medium was prepared as in Example 1, except that a Cr-Mo alloy nonmagnetic underlayer was not formed below the longitudinal hard magnetic multi-layered film.

The recording-reproducing characteristics of the magnetic recording medium thus prepared were evaluated, with the result that spike-like noise having a magnitude substantially equal to that of the reproduced signal was somewhat observed. It is considered reasonable to understand that, since the Co-Cr-Pt hard magnetic layer of a hexagonal close-packed structure was formed directly on the amorphous substrate, the easy axis of the hard magnetic layer was oriented mainly in a direction perpendicular to the film surface and partly at random, resulting in failure to align uniformly the directions of magnetization of the longitudinal soft magnetic layer radially outward, thereby forming the domain wall.

What should be noted is that the easy axis of the longitudinal hard magnetic multi-layered film can be controlled in the longitudinal direction by forming a nonmagnetic underlayer between the nonmagnetic substrate and the longitudinal hard magnetic multi-layered film, with the result that it is possible to suppress the medium noise from the perpendicular magnetic recording medium.

Example 12:

A perpendicular magnetic recording medium was prepared as in Example 1, except that the nonmagnetic underlayer made of a Co-Cr-Pt alloy was not formed
5 below the perpendicular magnetic recording layer.

The recording-reproducing characteristics of the magnetic recording medium thus prepared were evaluated, with the result that the S/Nm under the linear recording density of 400 kFCI was found to be
10 24 dB, which was lower than that for Example 1. It is considered reasonable to understand that, since the Co-Cr-Pt-B perpendicular magnetic recording layer was formed directly on the amorphous Co-Zr-Nb longitudinal soft magnetic layer, the perpendicular orientation of
15 the perpendicular magnetic recording layer was not controlled sufficiently and the crystal grains were not sufficiently diminished, leading to the S/Nm lower than that for Example 1. It follows that the recording-reproducing characteristics of the
20 perpendicular magnetic medium such as the capability of suppressing medium noise and the recording resolution can be improved by forming a nonmagnetic underlayer between the longitudinal hard magnetic layer and the perpendicular magnetic recording layer.

25 Example 13:

A perpendicular magnetic recording medium was prepared as in Example 1, except that a Co-Pt-CrO

layer having a thickness of 30 nm was formed in place of the Co-Cr-Pt-B layer as the perpendicular magnetic recording layer. The Co-Pt-CrO layer was formed under the conditions differing the conditions for forming the other layers. Specifically, the Co-Pt-CrO layer was formed by the sputtering method under a high pressure Ar atmosphere containing traces of O₂ with a Co-Pt-Cr alloy used as a target.

The recording-reproducing characteristics of the magnetic recording medium thus prepared were evaluated, with the result that the S/Nm under a linear recording density of 400 kFCI was found to be 27 dB. The value of 27 dB, which was slightly lower than the S/Nm for Example 1, was satisfactory. It follows that the medium noise from the perpendicular magnetic recording medium can be suppressed even in the case of using a magnetic recording layer differing in the material and the fine structure from the perpendicular magnetic recording layer made of a Co-Cr-Pt-B alloy. To be more specific, the medium noise can be suppressed even in the case of using a perpendicular magnetic recording layer made of a Co-Pt-CrO alloy.

Example 14:

A perpendicular magnetic recording medium was prepared as in Example 1, except that Pd was used in place of the Co-Cr-Pt alloy for forming the

nonmagnetic underlayer positioned below the perpendicular magnetic recording layer.

The recording-reproducing characteristics of the magnetic recording medium thus prepared were
5 evaluated, with the result that the S/Nm under a linear recording density of 400 kFCI was found to be 27 dB. The value of 27 dB, which was slightly lower than the S/Nm for Example 1, was satisfactory. It follows that the medium noise from the perpendicular
10 magnetic recording medium can be suppressed even in the case of using Pd for forming the nonmagnetic underlayer.

Example 15:

A perpendicular magnetic recording medium was
15 prepared as in Example 1, except that Rh was used in place of the Co-Cr-Pt alloy for forming the nonmagnetic underlayer positioned below the perpendicular magnetic recording layer.

The recording-reproducing characteristics of the
20 magnetic recording medium thus prepared were evaluated, with the result that the S/Nm under a linear recording density of 400 kFCI was found to be 26 dB. The value of 26 dB, which was slightly lower than the S/Nm for Example 1, was satisfactory. It
25 follows that the medium noise from the perpendicular magnetic recording medium can be suppressed even in the case of using Rh in place of the Co-Cr-Pt alloy

for forming the nonmagnetic underlayer.

Example 16:

5 A perpendicular magnetic recording medium was prepared as in Example 1, except that Ru was used in place of the Co-Cr-Pt alloy for forming the nonmagnetic underlayer positioned below the perpendicular magnetic recording layer.

10 The recording-reproducing characteristics of the magnetic recording medium thus prepared were evaluated, with the result that the S/Nm under a linear recording density of 400 kFCI was found to be 28 dB. The S/Nm was satisfactory as in Example 1. It follows that the medium noise from the perpendicular magnetic recording medium can be suppressed even in
15 the case of using Ru in place of the Co-Cr-Pt alloy for forming the nonmagnetic underlayer.

In each of the Examples described above, a glass substrate was used as the nonmagnetic substrate. Alternatively, it is also possible to use an Al-based
20 alloy, a Si single crystal substrate having the surface oxidized, or a substrate having the surface plated with Ni-P, with substantially the same effect. Also, the various layers were formed on the nonmagnetic substrate by the sputtering method in each
25 of the Examples described above. Alternatively, it is also possible to employ another method such a vacuum vapor deposition method in place of the sputtering

method, with substantially the same effect.

Additional advantages and modifications will readily occur to those skilled in the art. Therefore, the present invention in its broader aspects is not
5 limited to the specific details and representative embodiments shown and described herein. Accordingly, various modifications may be made without departing from the spirit or scope of the general inventive concept as defined by the appended claims and their
10 equivalents.

WHAT IS CLAIMED IS:

1. A perpendicular magnetic recording medium,
comprising:

a nonmagnetic substrate;

5 a longitudinal hard magnetic multi-layered film
arranged on said nonmagnetic substrate, including at
least, a nonmagnetic intermediate layer and two hard
magnetic layers, which are laminated one hard magnetic
layer upon the other hard magnetic layer with the
10 nonmagnetic intermediate layer interposed
therebetween;

a longitudinal soft magnetic layer formed on said
longitudinal hard magnetic multi-layered film; and

a perpendicular magnetic recording layer formed
15 on said longitudinal soft magnetic layer.

2. A perpendicular magnetic recording medium
according to claim 1, wherein the thickness of said
nonmagnetic layer is set to produce an interaction
between the two hard magnetic layers positioned to
20 face each other with said nonmagnetic layer interposed
therebetween to align the directions of magnetization
of these hard magnetic layers to be antiparallel.

3. A perpendicular magnetic recording medium
according to claim 1, wherein said nonmagnetic
25 substrate is disk-shaped, and the hard magnetic layer
in contact with said longitudinal soft magnetic layer
is magnetized in the radial direction of the

disk-shaped substrate.

4. A perpendicular magnetic recording medium according to claim 1, wherein said hard magnetic layers included in said longitudinal hard magnetic multi-layered film and positioned to face each other with said nonmagnetic layer interposed therebetween have about the same magnetic moment.

5. A perpendicular magnetic recording medium according to claim 1, wherein the sum of the magnetic moment of the hard magnetic layers included in said longitudinal hard magnetic multi-layered film and magnetized radially outward is substantially equal to the sum of the magnetic moment of the hard magnetic layers included in said longitudinal hard magnetic multi-layered film and magnetized radially inward.

6. A perpendicular magnetic recording medium according to claim 1, wherein the sum of the thicknesses of the hard magnetic layers included in said longitudinal hard magnetic multi-layered film and magnetized radially outward is substantially equal to the sum of the thicknesses of the hard magnetic layers included in said longitudinal hard magnetic multi-layered film and magnetized radially inward.

7. A perpendicular magnetic recording medium according to claim 1, wherein the coercive force of the hard magnetic layer in contact with said longitudinal soft magnetic layer is larger than the

coercive force of the other hard magnetic layer.

8. A perpendicular magnetic recording medium according to claim 1, wherein said nonmagnetic intermediate layer is formed essentially of at least
5 one element selected from the group consisting of ruthenium, vanadium and chromium.

9. A perpendicular magnetic recording medium according to claim 8, wherein said nonmagnetic intermediate layer is formed essentially of ruthenium
10 and has a thickness not smaller than 0.5 nm and smaller than 1.2 nm.

10. A perpendicular magnetic recording medium according to claim 1, wherein said hard magnetic layer is formed essentially of an alloy containing mainly
15 cobalt, chromium and platinum.

11. A perpendicular magnetic recording medium according to claim 1, wherein said hard magnetic layer has a thickness not larger than 10 nm.

12. A perpendicular magnetic recording medium
20 according to claim 1, wherein a nonmagnetic underlayer made of an alloy containing mainly chromium is further formed between said nonmagnetic substrate and said longitudinal hard magnetic multi-layered film.

13. A perpendicular magnetic recording medium
25 according to claim 1, wherein said perpendicular magnetic recording layer is formed essentially of an alloy containing mainly at least one element selected

from the group consisting of cobalt, chromium and platinum.

14. A perpendicular magnetic recording medium according to claim 1, wherein a nonmagnetic underlayer
5 made essentially of an alloy containing as a main component at least one element selected from the group consisting of cobalt, chromium, platinum, rhodium, and ruthenium is further formed between said longitudinal soft magnetic layer and said perpendicular magnetic
10 recording layer.

15. A perpendicular magnetic recording medium according to claim 1, wherein said longitudinal hard magnetic multi-layered film includes two hard magnetic layers.

16. A magnetic recording-reproducing apparatus, comprising:

a perpendicular magnetic recording-reproducing medium;

a driving mechanism to support and rotate said
20 perpendicular magnetic recording-reproducing medium;

a magnetic head equipped with an element which serves to record information in said perpendicular magnetic recording medium and with an element to reproduce the recorded information; and

25 a carriage assembly which supports said magnetic head such that the magnetic head is movable relative to said perpendicular magnetic recording medium;

wherein said perpendicular magnetic recording medium comprises:

a nonmagnetic substrate;

5 a longitudinal hard magnetic multi-layered film arranged on said nonmagnetic substrate, including at least, a nonmagnetic intermediate layer and two hard magnetic layers laminated one hard magnetic layer upon the other hard magnetic layer with the nonmagnetic intermediate layer interposed therebetween;

10 a longitudinal soft magnetic layer formed on said longitudinal hard magnetic multi-layered film; and

a perpendicular magnetic recording layer formed on said longitudinal soft magnetic layer.

15 17. A magnetic recording-reproducing apparatus according to claim 16, wherein the thickness of said nonmagnetic layer is set to produce an interaction between the two hard magnetic layers positioned to face each other with said nonmagnetic layer interposed therebetween to align the directions of magnetization
20 of these hard magnetic layers to be antiparallel.

18. A magnetic recording-reproducing apparatus according to claim 16, wherein said nonmagnetic substrate is disk-shaped, and the hard magnetic layer in contact with said longitudinal soft magnetic layer
25 is magnetized in the radial direction of the disk-shaped substrate.

19. A magnetic recording-reproducing apparatus

according to claim 16, wherein said hard magnetic layers included in said longitudinal hard magnetic multi-layered film and positioned to face each other with said nonmagnetic layer interposed therebetween have about the same magnetic moment.

20. A magnetic recording-reproducing apparatus according to claim 16, wherein the sum of the magnetic moments of the hard magnetic layers included in said longitudinal hard magnetic multi-layered film and magnetized radially outward is substantially equal to the sum of the magnetic moments of the hard magnetic layers included in said longitudinal hard magnetic multi-layered film and magnetized radially inward.

21. A magnetic recording-reproducing apparatus according to claim 16, wherein the sum of the thicknesses of the hard magnetic layers included in said longitudinal hard magnetic multi-layered film and magnetized radially outward is substantially equal to the sum of the thicknesses of the hard magnetic layers included in said longitudinal hard magnetic multi-layered film and magnetized radially inward.

22. A magnetic recording-reproducing apparatus according to claim 16, wherein the coercive force of the hard magnetic layer in contact with said longitudinal soft magnetic layer is larger than the coercive force of the other hard magnetic layer.

23. A magnetic recording-reproducing apparatus

according to claim 16, wherein said nonmagnetic intermediate layer is formed essentially of at least one element selected from the group consisting of ruthenium, vanadium and chromium.

5 24. A magnetic recording-reproducing apparatus according to claim 23, wherein said nonmagnetic intermediate layer is formed essentially of ruthenium and has a thickness not smaller than 0.5 nm and smaller than 1.2 nm.

10 25. A magnetic recording-reproducing apparatus according to claim 16, wherein said hard magnetic layer is formed essentially of an alloy containing mainly cobalt, chromium and platinum.

15 26. A magnetic recording-reproducing apparatus according to claim 16, wherein said hard magnetic layer has a thickness not larger than 10 nm.

20 27. A magnetic recording-reproducing apparatus according to claim 16, wherein a nonmagnetic underlayer made of an alloy containing mainly chromium is further formed between said nonmagnetic substrate and said longitudinal hard magnetic multi-layered film.

25 28. A magnetic recording-reproducing apparatus according to claim 16, wherein said perpendicular magnetic recording layer is formed essentially of an alloy containing mainly at least one element selected from the group consisting of cobalt, chromium and

platinum.

29. A magnetic recording-reproducing apparatus according to claim 16, wherein a nonmagnetic underlayer made essentially of an alloy containing as
5 a main component at least one element selected from the group consisting of cobalt, chromium, platinum, rhodium, and ruthenium is further formed between said longitudinal soft magnetic layer and said
perpendicular magnetic recording layer.

10 30. A magnetic recording-reproducing apparatus according to claim 16, wherein said longitudinal hard magnetic multi-layered film includes two hard magnetic layers.