

24 FEB 2003



166166

MAGNETIC RECORDING MEDIUM



G00002

FIELD OF THE INVENTION

The present invention relates to a magnetic recording
5 medium, and more specifically, the present invention relates
to a magnetic recording medium having excellent noise
properties.

BACKGROUND OF THE INVENTION

Most commercially available magnetic recording media are
10 an in-plane magnetic recording media where the magnetic easy
axis of the magnetic film is mainly oriented parallel to the
substrate. If such an in-plane magnetic recording medium is
fabricated to have a high recording density, the bit volume is
excessively reduced and the reproduction properties may
15 deteriorate due to a thermal fluctuation effect or the like.
Furthermore, it is also known that media with high recording
density suffer from an increase in the medium noise due to
expansion of the magnetization reversal transition region or
the like.

20 On the other hand, a so-called vertical magnetic recording
medium where the magnetic easy axis in the magnetic film is
oriented perpendicularly to the substrate is advantageous in
that low noise can be attained even with high recording density.

This is because a sharp magnetization transition is formed and as the recording density increases, the demagnetization field is decreased and stabilized. Moreover, high recording density can be attained even when the bit volume is relatively large.
5 As such, the vertical magnetic recording medium is drawing the attention of investigators in this field.

However, the vertical magnetic recording medium has a reproduction waveform different from that of the in-plane magnetic recording medium. More specifically, the isolated
10 waveform is not a single peak type but contains a di-pulse waveform. Accordingly, it is difficult to apply the signal processing system commonly used for in-plane recording media without modification.

To cope with this, a vertical and in-plane composite type
15 magnetic recording medium has been proposed, which comprises both an in-plane magnetic film and a vertical magnetic film. Such structure enables the use of the same signal processing system as used for in-plane magnetic recording media.

In recent years, the demand for magnetic recording media
20 with higher recording density has been increasing and in keeping with this tendency, there is a demand for improved noise properties.

However, conventional magnetic recording media are by no means entirely satisfactory with respect to noise properties, and there is also a demand for magnetic recording media having more excellent noise properties. The present invention has
5 been achieved in consideration of the above problems of the prior art.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide a magnetic recording medium adapted for use with the
10 signal processing system commonly used for in-plane magnetic recording media without modification and having excellent noise properties.

The above object has been achieved in a first embodiment of the invention by providing a magnetic recording medium
15 comprising a substrate having thereon an in-plane magnetic film having a magnetic easy axis oriented in the in-plane direction with respect to the substrate and a vertical magnetic film having a magnetic easy axis oriented perpendicularly to the substrate, the in-plane magnetic film being disposed closer to the
20 substrate than the vertical magnetic film and having a coercivity H_c of from 1,500 to 4,000 Oe and a remnant magnetization film thickness product BrT of from 20 to 100 G μ m,

and the vertical magnetic film having a coercivity H_c of from 1,500 to 4,000 Oe and a thickness of from 100 to 1,000 Å.

In this first embodiment, the vertical magnetic film preferably has a thickness of from 100 to 600 Å and the in-
5 plane magnetic film preferably has a remnant magnetization film thickness product BrT of from 20 to 50 Gµm.

A separation film comprising a material capable of growing non-epitaxially to the in-plane magnetic film is preferably disposed between the in-plane magnetic film and the vertical
10 magnetic film, and the separation film preferably has a thickness of from 5 to 200 Å.

A nonmagnetic intermediate layer having an hcp structure is preferably disposed between the separation film and the vertical magnetic film.

15 Furthermore, the clearance between the in-plane magnetic film and the vertical magnetic film is preferably from 10 to 500 Å.

In a second embodiment, the present invention provides a magnetic recording medium comprising a substrate having thereon
20 an in-plane magnetic film having a magnetic easy axis oriented in the in-plane direction with respect to the substrate and a vertical magnetic film having a magnetic easy axis oriented perpendicularly to the substrate, the in-plane magnetic film

being disposed closer to the substrate than the vertical magnetic film, a separation film being disposed between the in-plane magnetic film and the vertical magnetic film, and the separation film containing one or more of Ta, Re, CuTi, SiC, W, NiP, Zr, Ti and C as a main component.

In this second embodiment, the separation film preferably has a thickness of from 5 to 200 Å.

A nonmagnetic intermediate layer having an hcp structure is preferably disposed between the separation film and the vertical magnetic film.

Furthermore, an in-plane magnetic film underlayer is preferably disposed at the substrate side of the in-plane magnetic film, and the in-plane magnetic film underlayer preferably contains Cr or an alloy consisting of Cr and one or more of Ti, Mo, W and V, as a main component.

Furthermore, the in-plane magnetic film preferably contains a Co alloy consisting of from 12 to 25 at% of Cr, from 0 to 15 at% of Pt, from 1 to 10 at% of Ta, from 0 to 10 at% of one or more of Zr, Re, Cu and V, and the balance of Co, as a main component.

In a third embodiment, the present invention provides a magnetic recording medium a substrate having thereon an in-plane magnetic film having a magnetic easy axis oriented in the

in-plane direction with respect to the substrate, a separation film comprising a material capable of growing non-epitaxially to the in-plane magnetic film, a nonmagnetic intermediate layer having an hcp structure and a vertical magnetic film having a magnetic easy axis oriented perpendicularly to the substrate, the nonmagnetic intermediate layer containing a Co alloy consisting of from 25 to 50 at% of Cr, from 0 to 15 at% of Pt, from 0 to 10 at% of one or more of Ta, Zr, Cu and Re, and the balance of Co, as a main component, and the vertical magnetic film containing a Co alloy consisting of from 16 to 30 at% of Cr, from 0 to 15 at% of Pt, from 2 to 10 at% of Ta, from 0 to 5 at% of Zr and the balance of Co, as a main component.

The nonmagnetic intermediate layer preferably has a thickness of from 20 to 400 Å.

Furthermore, the clearance between the in-plane magnetic film and the vertical magnetic film is preferably from 10 to 500 Å.

BRIEF DESCRIPTION OF THE DRAWING

Fig. 1 is a partial cross section showing one example of the magnetic recording medium of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Fig. 1 shows an example of the magnetic recording medium of the present invention. The magnetic recording medium

comprises a substrate 1 having formed thereon an in-plane magnetic film underlayer 2, an in-plane magnetic film 3, a separation film 4, a nonmagnetic intermediate layer 5, a vertical magnetic film 6 and a protective film 7 in this order.

5 For the substrate 1, an aluminum alloy having an NiP-plating film, glass or ceramic may be used.

The surface of the substrate 1 may be subjected to texturing such as mechanical texturing.

The in-plane magnetic film underlayer 2 is disposed so as
10 to orient the c-axis of crystals in the in-plane magnetic film 3 toward the in-plane direction. In view of improvement of the crystallographic orientation in the in-plane magnetic film 3, the underlayer is preferably formed from Cr or a Cr alloy containing Cr as a main component, more preferably from Cr, a
15 Cr/Ti system alloy, a Cr/Mo system alloy, a Cr/W system alloy or a Cr/V system alloy.

Specific examples of the in-plane magnetic film underlayer 2 include a Cr alloy consisting of from 1 to 40 at% of Ti, Mo, W or V and the balance of Cr.

20 The in-plane magnetic film underlayer 2 preferably has a thickness of from 10 to 1,000 Å.

The term "main component" as used in the present invention means that the component is contained in excess of 50 at%.

In the in-plane magnetic film 3, the magnetic easy axis is mainly directed toward the in-plane direction. Specific examples of the material suitable for the in-plane magnetic film 3 include alloys of the Co/Cr system, Co/Cr/Ta system, 5 Co/Cr/Pt/Ta system, Co/Cr/Ni/Pt/Ta system and Co/Cr/Pt/Ta/Zr system.

In particular, a material containing a Co alloy consisting of from 12 to 25 at% of Cr, from 0 to 15 at% of Pt, from 1 to 10 at% of Ta, from 0 to 10 at% of one or more of Zr, Re, Cu and 10 V, and the balance of Co, as a main component is preferred as a material for the in-plane magnetic film 3 in view of improvement of the crystallographic orientation in this film.

The in-plane magnetic film 3 has a coercivity H_c of from 1,500 to 4,000 Oe (preferably from 2,000 to 3,500 Oe).

15 If the H_c is less than 1,500 Oe, similar to the vertical magnetic recording medium having only a vertical magnetic film, the isolated waveform obtained at the time of reproduction does not form a single peak. It then becomes difficult to apply the signal processing system used for reproduction of a 20 general-purpose in-plane magnetic recording medium.

On the other hand, if the H_c exceeds 4,000 Oe, the recording properties of the in-plane magnetic film 3 readily deteriorate to cause a low reproduction signal output. Furthermore,

problems are liable to occur, for example, because the reproduction waveform does not form a satisfactory single peak or the noise increases.

The in-plane magnetic film 3 has a remnant magnetization
5 film thickness product BrT of from 10 to 100 $G\mu m$ (second and third embodiments of the invention) or a remnant magnetization film thickness product BrT of from 20 to 100 $G\mu m$ (first embodiment of the invention).

If the BrT is less than 20 $G\mu m$, sufficiently high magnetic
10 flux cannot be obtained and similar to the vertical magnetic recording medium having only a vertical magnetic film, the isolated waveform obtained at the time of reproduction does not form a single peak. As a result, it becomes difficult to apply the signal processing system used for reproduction of a
15 general-purpose in-plane magnetic recording medium.

On the other hand, if the BrT exceeds 100 $G\mu m$, similar to the in-plane magnetic recording medium having only an in-plane magnetic film, the medium noise increases. Furthermore, the half value width Pw_{50} of the reproduction pulse output becomes
20 worse, and it is difficult to obtain sufficiently high output.

The BrT of the in-plane magnetic film 3 is more preferably from 20 to 50 $G\mu m$. This is because when the BrT is within this range, the medium noise can be further reduced.

The separation film 4 is disposed to attain good orientation of the c-axis of crystals in the vertical magnetic film 6 toward the direction perpendicular to the substrate. A material capable of growing non-epitaxially to the in-plane magnetic film 3 is used for the separation film 4.

The separation material is preferably a material having a surface free energy higher than the surface free energy of the constituent material of the nonmagnetic intermediate layer 5, or an amorphous material. This is because the crystallographic orientation of the nonmagnetic intermediate layer 5 and vertical magnetic film 6 formed on the separation film 4 can be improved and the medium noise ascribable to disorder in the magnetic anisotropy of the vertical magnetic film 6 can be minimized.

The separation material preferably contains one or more of Ta, Re, CuTi, SiC, W, NiP, Zr, Ti and C as a main component.

The "CuTi" as used herein means an alloy consisting of Cu and Ti. SiC is a material comprising Si and C and NiP is an alloy consisting of Ni and P.

The separation film 4 preferably has a thickness of from 5 to 200 Å.

If the thickness is less than 5 Å, the nonmagnetic intermediate layer 5 formed on the separation film 4 is

susceptible to influence of the in-plane magnetic film 3 having a crystallographic orientation toward the in-plane direction at the time of film formation. As a result, the crystallographic orientation may become disordered. In that case, the
5 crystallographic orientation of the vertical magnetic film 6 formed on the nonmagnetic intermediate layer 5 is in turn disordered, and consequently the magnetic recording medium thus obtained suffers from an increase in medium noise.

On the other hand, if the thickness exceeds 200 Å, the
10 clearance between the in-plane magnetic film 3 and the vertical magnetic film 6 increases and the recording properties of the in-plane magnetic film 3 deteriorate at the time of short wavelength recording.

The nonmagnetic intermediate layer 5 is disposed to attain
15 further improved crystallographic orientation of the vertical magnetic film 6. A nonmagnetic material having a hcp structure is used as the nonmagnetic intermediate layer 5, and a Co/Cr system, Co/Cr/Ta system or Co/Cr/Pt/X (X: one or more of Ta, Zr, Cu and Re) system alloy is preferably used.

20 In particular, a material containing a Co alloy consisting of from 25 to 50 at% of Cr, from 0 to 15 at% of Pt, from 0 to 10 at% of X and the balance of Co, as a main component is preferred as the nonmagnetic intermediate layer.

If the content of each component of the nonmagnetic intermediate layer 5 is not within the above-described range, the crystallographic orientation of the vertical magnetic film 6 is readily disordered due to mismatching of the lattice of the nonmagnetic intermediate layer 5 with the vertical magnetic film 6. In that case, the magnetic anisotropy of the vertical magnetic film 6 may deteriorate to thereby increase the medium noise.

The nonmagnetic intermediate layer 5 may have a single layer structure or may have a multi-layer structure obtained by laminating a plurality of layers each comprising the above-described material.

The nonmagnetic intermediate layer 5 preferably has a thickness of from 20 to 400 Å.

If the thickness is less than 20 Å, the crystallographic orientation of the vertical magnetic film 6 is readily disordered at initial growth in the process of forming the vertical magnetic film 6 on the nonmagnetic intermediate layer 5, and the magnetic recording medium thus obtained may suffer from an increase in medium noise.

On the other hand, if the thickness exceeds 400 Å, the clearance between the in-plane magnetic film 3 and the vertical magnetic film 6 increases and the recording properties of the

in-plane magnetic film 3 deteriorate for short wavelength recording.

The total thickness of the separation film 4 and the nonmagnetic intermediate layer 5, namely, the clearance between
5 the in-plane magnetic film 3 and the vertical magnetic film 6, is preferably from 10 to 500 Å.

If the total thickness is less than 10 Å, the crystallographic orientation of the vertical magnetic film 6 is readily disordered and a sufficiently high coercivity may
10 not be obtained, whereas if it exceeds 500 Å, the clearance between the in-plane magnetic film 3 and the vertical magnetic film 6 increases and the recording properties of the in-plane magnetic film 3 deteriorate at the short wavelength recording.

In the vertical magnetic film 6, the magnetic easy axis
15 is directed mainly toward a direction perpendicular to the substrate. The material which can be used for the vertical magnetic film 6 includes Co/Cr system, Co/Cr/Ta system, Co/Cr/Pt/Ta system, Co/Cr/Ni/Pt/Ta system and Co/Cr/Pt/Ta/Zr system alloys.

20 In particular, a material containing a Co alloy consisting of from 16 to 30 at% of Cr, from 0 to 15 at% of Pt, from 2 to 10 at% of Ta, from 0 to 5 at% of Zr and the balance of Co, as a main component is preferred as the vertical magnetic film 6.

If the content of each component of the vertical magnetic film 6 is not within the above-described range, the crystallographic orientation of the vertical magnetic film 6 is readily disordered due to mismatching of the lattice of the vertical magnetic film 6 with the nonmagnetic intermediate layer 5. In that case, the medium noise may increase.

The vertical magnetic film 6 has a coercivity H_c of from 1,500 to 4,000 Oe (preferably from 2,000 to 3,500 Oe).

If the H_c is less than 1,500 Oe, the squareness S (=remnant magnetic flux density B_r /saturation magnetic flux density B_s) is reduced, the output decreases and the SNR becomes worse.

On the other hand, if the H_c exceeds 4,000 Oe, the recording properties of the vertical magnetic film 6 disadvantageously deteriorate.

The vertical magnetic film 6 has a thickness of from 100 to 1,000 Å.

If the thickness is less than 100 Å, a sufficiently high magnetic flux cannot be obtained and similar to the in-plane magnetic recording medium having only an in-plane magnetic film, the medium noise increases. Furthermore, the half value width PW_{50} of the reproduction pulse output becomes worse and sufficiently high output can be difficult to obtain.

On the other hand, if the thickness exceeds 1,000 Å, the isolated waveform obtained at reproduction does not form a single peak, and it becomes difficult to apply a signal processing system used in reproduction of a general-purpose in-plane magnetic recording medium.

The thickness of the vertical magnetic film 6 is more preferably from 100 to 600 Å. This is because when the thickness is within this range, the formation of coarse magnetic particles in the vertical magnetic film 6 can be prevented and the noise properties can be further improved.

The protective film 7 is preferably formed from carbon, and preferably has a thickness of from 20 to 100 Å.

A lubricating film comprising a perfluoropolyether (PFPE) or the like may also be formed on the protective film 7.

In the manufacture of a magnetic recording medium having the above-described structure, the layers from the nonmagnetic underlayer 2 to the vertical magnetic film 6 can be formed on the substrate 1 by sputtering, vacuum evaporation, ion plating or metal plating. Subsequently, the protective film 7 can be formed by sputtering, a plasma CVD method, an ion beam method or the like.

In the case of forming a lubricating film on the protective film 7, a dipping method or the like may be used.

In an example of a magnetic recording medium of the first embodiment of the invention having the above-described structure, an in-plane magnetic film 3 and a vertical magnetic film 6 are provided. The in-plane magnetic film 3 has a
5 coercivity H_c of from 1,500 to 4,000 Oe and a remnant magnetization film thickness product BrT of from 20 to 100 G μ m, and the vertical magnetic film 6 has a coercivity H_c of from 1,500 to 4,000 Oe and a thickness of from 100 to 1,000 Å. By virtue of this constitution, the isolated waveform obtained at
10 reproduction does not form a di-pulse, the signal processing system used in the reproduction of general-purpose in-plane magnetic recording media can be applied, and good noise properties can be obtained while reducing the medium noise ascribable to the expansion of the reversal magnetization
15 transition region or the grain noise resulting from formation of magnetic coarse particles.

Furthermore, by interposing a separation film 4 comprising a material capable of growing non-epitaxially to the in-plane magnetic film 3 between the in-plane magnetic film 3 and the
20 vertical magnetic film 6, the perpendicular orientation of the nonmagnetic intermediate layer 5 and vertical magnetic film 6 formed on the separation film 4 can be improved, the magnetic

anisotropy of the vertical magnetic film 6 can be increased, and the medium noise can be reduced.

On the other hand, if a material which grows epitaxially to the in-plane magnetic film 3 is used for the separation film 4, the orientation of the vertical magnetic film 6 may be disordered by the effect of the in-plane magnetic film 3 having in-plane anisotropy.

Also, by interposing a nonmagnetic intermediate layer having an hcp structure between the separation film and the vertical magnetic film, disorder in the orientation at initial growing of the vertical magnetic film 6 can be prevented, the magnetic anisotropy can be increased and the medium noise can be reduced.

In an example of the magnetic recording medium of the second embodiment of the invention having the above-described structure, a separation film 4 is interposed between the in-plane magnetic film 3 and the vertical magnetic film 6. The separation film 4 contains one or more of Ta, Re, CuTi, SiC, W, NiP, Zr, Ti and C as a main component. By virtue of this constitution, the orientation in the perpendicular direction of the nonmagnetic intermediate layer 5 and vertical magnetic film 6 formed on the separation film 4 can be improved, the

magnetic anisotropy of the vertical magnetic film 6 can be increased, and the medium noise can be reduced.

The reason why the magnetic anisotropy can be improved when the separation film 4 is formed from the above-described material is not clearly known, however, the following mechanism is considered to participate in this effect.

In the case where SiC, NiP or C is used as the material for the separation film 4, a dangling bond, namely, an unsaturated bond of an atomic group in the periphery of a lattice defect on the surface or inside of the separation film 4, intensifies the bonding strength between the separation film 4 and the nonmagnetic intermediate layer 5 formed thereon. As a result, the crystallographic orientation at the initial growing of the nonmagnetic intermediate layer 5 is improved, the nonmagnetic intermediate layer 5 can have excellent crystallographic orientation in the perpendicular direction, and in turn, the magnetic anisotropy of the vertical magnetic film 6 formed on the nonmagnetic intermediate layer 5 is improved.

Furthermore, the above-described material can grow non-epitaxially to the in-plane magnetic film 3. Accordingly, the orientation of the nonmagnetic intermediate layer 5 and the orientation of the vertical magnetic film 6 are hardly

disordered due to the effect of the in-plane magnetic film 3 having in-plane anisotropy.

In the case where Ta, Re, W, CuTi, Ti or Zr is used as the material for the separation film 4, these materials have a surface free energy higher than the surface free energy of the constituent material (for example, Co alloy) of the nonmagnetic intermediate layer 5. Accordingly, the nonmagnetic intermediate layer 5 can be easily (002) oriented at the film formation. This is because when the nonmagnetic intermediate layer 5 in contact with the separation film 4 is (002) oriented, the total surface energy on the interface between the separation film 4 and the nonmagnetic intermediate layer 5 is minimized. The improvement in orientation of the nonmagnetic intermediate layer 5 effects an improvement in orientation of the vertical magnetic film 6 which grows epitaxially to the intermediate layer.

The magnetic anisotropy of the vertical magnetic film 6 is considered to be elevated by the mechanism described above.

Still further, by virtue of a constitution where the in-plane magnetic film underlayer 2 comprises Cr or an alloy consisting of Cr and one or more of Ti, Mo, W and V and the in-plane magnetic film 3 contains a Co alloy consisting of from 1 to 25 at% of Cr, from 0 to 15 at% of Pt, from 1 to 10 at% of Ta, from

0 to 10 at% of one or more of Zr, Re, Cu and V, and the balance of Co, as a main component, the in-plane magnetic film 3 can have good crystallographic orientation and the magnetic recording medium thus obtained can have reduced medium noise.

5 When a nonmagnetic intermediate layer 5 having an hcp structure is interposed between the separation film 4 and the vertical magnetic film 6, disorder in the orientation at initial growth of the vertical magnetic film 6 comprising a Co alloy or the like having the same hcp structure can be prevented, the
10 magnetic anisotropy thereof can be elevated, and the medium noise can be reduced.

 In an example of the magnetic recording medium of the third embodiment of the invention having the above-described structure, an in-plane magnetic film underlayer 2, an in-plane
15 magnetic film 3, a separation film 4, a nonmagnetic intermediate layer 5 and a vertical magnetic film 6 are formed. The nonmagnetic intermediate layer 5 comprises a Co alloy consisting of from 25 to 50 at% of Cr, from 0 to 15 at% of Pt, from 0 to
20 10 at% of one or more of Ta, Zr, Cu and Re, and the balance of Co. The vertical magnetic film 6 formed thereon comprises a Co alloy consisting of from 16 to 30 at% of Cr, from 0 to 15 at% of Pt, from 2 to 10 at% of Ta, from 0 to 5 at% of Zr and the balance of Co. By virtue of this constitution, the

crystallographic orientation of the vertical magnetic film 6 formed on the nonmagnetic intermediate layer 5 is improved.

As a result, the isolated waveform obtained at reproduction does not form a di-pulse, the signal processing system used in reproduction of a general-purpose in-plane magnetic recording medium can be applied, and good noise properties can be obtained while reducing the medium noise ascribable to expansion of the magnetization reversal transition region.

EXAMPLES

10 Test Example 1:

The surface of an aluminum alloy substrate (diameter: 84 mm, thickness: 0.8 mm) having formed on the surface thereof an NiP plating film (thickness: 15 μm) was subjected to mechanical texturing to have a surface average roughness R_a of 15 $\text{\AA}$. The resulting substrate 1 was set in a chamber of a DC magnetron sputtering device (3010, manufactured by ANELVA).

The chamber was evacuated until the ultimate vacuum reached 2×10^{-7} Pa, the substrate 1 was heated to 200°C, and then on the substrate 1, an in-plane magnetic film underlayer 2 (thickness: 500 $\text{\AA}$) comprising Cr-15 at%, Ti-3 at% and Mo (hereinafter referred to as Cr15Ti3Mo), an in-plane magnetic film 3 comprising Co-13 at%, Cr-6 at%, Pt-3 at% and Ta (Co13Cr6Pt3Ta), a separation film 4 comprising carbon, a nonmagnetic

intermediate layer 5 comprising Co-40 at% and Cr (Co₄₀Cr) and a vertical magnetic film 6 comprising Co-18 at%, Cr-6 at%, Pt-3 at% and Ta (Co₁₈Cr₆Pt₃Ta) were sequentially formed by sputtering.

5 Subsequently, a carbon protective film having a thickness of 100 Å was formed on the vertical magnetic film 6, and then a lubricant was coated on the carbon protective film to form a lubricating film (thickness: 20 Å) comprising PFPE, to thereby obtain a magnetic recording medium.

10 Test Examples 2 to 4:

Magnetic recording media were manufactured by changing the substrate heating temperature at film formation, to thereby vary the coercivity H_c of the in-plane magnetic film 3.

Test Examples 5 to 10:

15 Magnetic recording media were manufactured by varying the BrT of the in-plane magnetic film 3.

Test Examples 11 to 19:

Magnetic recording media were manufactured by varying the coercivity H_c or thickness of the vertical magnetic film 6.

20 Test Example 20:

A magnetic recording medium was manufactured in the same manner as in Test Example 16, except that a separation film 4 was not formed.

Test Example 21:

A magnetic recording medium was manufactured in the same manner as in Test Example 16, except that a nonmagnetic intermediate layer 5 was not formed.

5 Test Example 22:

A magnetic recording medium was manufactured in the same manner as in Test Example 16, except that a separation film 4 and a nonmagnetic intermediate layer 5 were not formed.

The magnetic recording media of the respective Test
10 Examples were evaluated with respect to magnetostatic properties using vibrating sample magnetometry (VSM). Furthermore, these magnetic recording media were evaluated with respect to recording and reproducing properties using a composite type thin film magnetic head having a magnetoresistive
15 (MR) element in a reproduction unit at a linear recording density of 240 kFCI. The results obtained are shown in Table 1.

In the measurement of SNR (signal noise ratio), the signal was determined with the isolated wave being the measuring object.

TABLE 1

	In-plane Magnetic Film Underlayer	In-plane Magnetic Film			Separation Film		Nonmagnetic Intermediate Layer		Vertical Magnetic Film			Reproduction Properties
		Composition	BrT (Gμm)	Hc (Oe)	Composition	Thickness (Å)	Composition	Thickness (Å)	Composition	Thickness (Å)	Hc (Oe)	
Test Example 1	Cr15Ti3Mo	Co13Cr6Pt3Ta	50	645	C	15	Co40Cr	200	Co18Cr6Pt3Ta	300	1800	13.5
Test Example 2	Cr15Ti3Mo	Co13Cr6Pt3Ta	50	2300	C	15	Co40Cr	200	Co18Cr6Pt3Ta	300	2300	15.4
Test Example 3	Cr15Ti3Mo	Co13Cr6Pt3Ta	50	2830	C	15	Co40Cr	200	Co18Cr6Pt3Ta	300	2520	15.7
Test Example 4	Cr15Ti3Mo	Co13Cr10Pt3Ta	50	4100	C	15	Co40Cr	200	Co18Cr6Pt3Ta	300	2250	14.2
Test Example 5	Cr15Ti3Mo	Co13Cr6Pt3Ta	15	540	C	15	Co40Cr	200	Co18Cr6Pt3Ta	300	2010	13.2
Test Example 6	Cr15Ti	Co13Cr6Pt3Ta	50	1800	C	15	Co40Cr	200	Co18Cr6Pt3Ta	300	2350	15.8
Test Example 7	Cr15Ti	Co13Cr6Pt3Ta	30	1595	C	15	Co40Cr	200	Co18Cr6Pt3Ta	300	2300	16.3
Test Example 8	Cr15Ti3Mo	Co13Cr6Pt3Ta	100	2309	C	15	Co40Cr	200	Co18Cr6Pt3Ta	300	2250	13.3
Test Example 9	Cr15Ti3Mo	Co13Cr6Pt3Ta	150	2462	C	15	Co40Cr	200	Co18Cr6Pt3Ta	300	2350	12.5
Test Example 10	Cr15Ti3Mo	Co13Cr6Pt3Ta	200	2385	C	15	Co40Cr	200	Co18Cr6Pt3Ta	300	2300	11.3
Test Example 11	Cr15Ti3Mo	Co13Cr6Pt3Ta	50	1595	C	15	Co40Cr	200	Co18Cr6Pt3Ta	300	726	11.3

TABLE 1 (cont'd)

	In-plane Magnetic Film Underlayer	In-plane Magnetic Film			Separation Film		Nonmagnetic Intermediate Layer		Vertical Magnetic Film			Reproduction Properties
		Composition	Composition	BrT (G μ m)	Hc (Oe)	Composition	Thickness ($\text{\AA}$)	Composition	Thickness ($\text{\AA}$)	Composition	Thickness ($\text{\AA}$)	
Test Example 12	Cr15Ti3Mo	Co13Cr6Pt3Ta	50	1595	C	15	Co40Cr	200	Co18Cr6Pt3Ta	300	1726	14.1
Test Example 13	Cr15Ti3Mo	Co13Cr6Pt3Ta	50	1595	C	15	Co40Cr	200	Co18Cr6Pt3Ta	300	2362	15.4
Test Example 14	Cr15Ti3Mo	Co13Cr6Pt3Ta	50	1595	C	15	Co40Cr	200	Co18Cr6Pt3Ta	50	726	11.5
Test Example 15	Cr15Ti3Mo	Co13Cr6Pt3Ta	50	1595	C	15	Co40Cr	200	Co18Cr6Pt3Ta	100	1950	15.0
Test Example 16	Cr15Ti3Mo	Co13Cr6Pt3Ta	50	1595	C	15	Co40Cr	200	Co18Cr6Pt3Ta	300	2350	15.4
Test Example 17	Cr15Ti3Mo	Co13Cr6Pt3Ta	50	1595	C	15	Co40Cr	200	Co18Cr6Pt3Ta	500	2530	15.6
Test Example 18	Cr15Ti3Mo	Co13Cr6Pt3Ta	50	1595	C	15	Co40Cr	200	Co18Cr6Pt3Ta	1000	2400	13.7
Test Example 19	Cr15Ti3Mo	Co13Cr6Pt3Ta	50	1595	C	15	Co40Cr	200	Co18Cr6Pt3Ta	1500	2461	13.0
Test Example 20	Cr15Ti3Mo	Co13Cr6Pt3Ta	50	1595	-	-	Co40Cr	200	Co18Cr6Pt3Ta	300	440	12.5
Test Example 21	Cr15Ti3Mo	Co13Cr6Pt3Ta	50	1595	C	15	-	-	Co18Cr6Pt3Ta	300	1450	13.5
Test Example 22	Cr15Ti3Mo	Co13Cr6Pt3Ta	50	1595	-	-	-	-	Co18Cr6Pt3Ta	300	410	12.4

It is seen from Table 1 that the magnetic recording media of Test Examples 2 and 3 in which the coercivity H_c of the in-plane magnetic film was from 1,500 to 4,000 Oe exhibited excellent noise properties as compared with the magnetic recording medium of Test Example 4 in which the coercivity H_c exceeded that range.

Furthermore, the recording media of Test Examples 2 and 3 provided a single peak isolated waveform at reproduction, whereas the magnetic recording medium of Test Example 1 in which the coercivity H_c was below the above-described range provided an isolated waveform containing a di-pulse waveform at reproduction but did not form a single peak waveform.

It is also seen that the magnetic recording media of Test Examples 6 to 8 in which the remnant magnetization film thickness product BrT of the in-plane magnetic film 3 was from 20 to 100 G μ m exhibited excellent noise properties as compared with the magnetic recording media of Test Examples 9 and 10 in which the BrT exceeded that range. In particular, the magnetic recording media of Test Examples 6 and 7 in which the BrT was from 20 to 50 G μ m exhibited more excellent noise properties.

Furthermore, the recording media of Test Examples 6 to 8 provided a single peak solitary waveform at reproduction, whereas the magnetic recording medium of Test Example 5 in which the BrT was below the above-described range provided an isolated

waveform containing a di-pulse waveform at reproduction but did not form a single peak waveform.

It is also seen that the magnetic recording media of Test Examples 12 and 13 in which the coercivity of the vertical magnetic film 6 was 1,500 Oe or more exhibited excellent noise properties as compared with the magnetic recording medium of Test Example 11 in which the coercivity Hc was less than 1,500 Oe.

It is also seen that the magnetic recording media of Test Examples 15 to 18 in which the thickness of the vertical magnetic film 6 was from 100 to 1,000 Å exhibited excellent noise properties as compared with the magnetic recording media of Test Examples 14 and 19 in which the thickness of the vertical magnetic film 6 was not within that range. In particular, the magnetic recording media of Test Examples 15 and 16 in which the thickness was from 100 to 600 Å exhibited more excellent noise properties.

It is also seen that the magnetic recording media having a separation film 4 exhibited excellent noise properties as compared with the magnetic recording media of Test Examples 20 and 22 in which a separation film 4 was not formed.

Furthermore, it is seen that the magnetic recording media having a nonmagnetic intermediate layer 5 exhibited excellent

noise properties as compared with the magnetic recording media of Test Examples 21 and 22 in which a nonmagnetic intermediate layer 5 was not formed.

Test Example 23:

5 The surface of an aluminum alloy substrate (diameter: 84 mm, thickness: 0.8 mm) having formed on the surface thereof an NiP plating film (thickness: 15 μm) was subjected to mechanical texturing to have a surface average roughness R_a of 15 $\text{\AA}$. The resulting substrate 1 was set in a chamber of a DC magnetron
10 sputtering device (3010, manufactured by ANELVA).

 The chamber was evacuated until the ultimate vacuum reached 2×10^{-7} Pa, the substrate 1 was heated to 200°C, and then on the substrate 1, an in-plane magnetic film underlayer 2 (thickness: 200 $\text{\AA}$), an in-plane magnetic film 3, a separation film 4, a
15 nonmagnetic intermediate layer 5 comprising Co-40 at% and Cr (Co40Cr) and a vertical magnetic film 6 comprising Co-18 at%, Cr-6 at%, Pt-3 at% and Ta (Co18Cr6Pt3Ta) were sequentially formed by sputtering.

 Subsequently, a carbon protective film having a thickness
20 of 100 $\text{\AA}$ was formed on the vertical magnetic film 6, and then a lubricant was coated on the carbon protective film to form a lubricating film (thickness: 20 $\text{\AA}$) comprising PFPE, to thereby obtain a magnetic recording medium.

Test Examples 24 to 39:

Magnetic recording media were manufactured in the same manner as in Test Example 23, except for the changes indicated in Table 2 below.

5 Test Examples 40 and 41:

Magnetic recording media were manufactured in the same manner as in Test Example 23, except that a separation film 4 or a nonmagnetic intermediate layer 5 was not formed.

10 The magnetic recording media of the respective Test Examples were evaluated in the same manner as Test Examples 1 to 22. The results are set forth in Table 2 below.

TABLE 2

	In-plane Magnetic Film Underlayer	In-plane Magnetic Film			Separation Film		Nonmagnetic Intermediate Layer		Vertical Magnetic Film			Repro- duction Properties
		Composition	BrT (Gm)	Hc (Oe)	Composi- tion	Thick- ness (Å)	Composi- tion	Thick- ness (Å)	Composition	Thick- ness (Å)	Hc (Oe)	
Test Example 23	Cr	Co17Cr5Ta	50	1800	C	20	Co40Cr	200	Co18Cr6Pt3Ta	500	2550	14.8
Test Example 24	Cr	Co17Cr5Ta	50	1800	C	50	Co40Cr	200	Co18Cr6Pt3Ta	500	2670	15.3
Test Example 25	Cr	Co17Cr5Ta	50	1800	Ta	50	Co40Cr	200	Co18Cr6Pt3Ta	500	2150	14.3
Test Example 26	Cr	Co17Cr5Ta	50	1800	Ta	100	Co40Cr	200	Co18Cr6Pt3Ta	500	2245	14.6
Test Example 27	Cr	Co17Cr5Ta	50	1800	NiP	50	Co40Cr	200	Co18Cr6Pt3Ta	500	1950	14.3
Test Example 28	Cr	Co17Cr5Ta	50	1800	W	50	Co40Cr	200	Co18Cr6Pt3Ta	500	2315	14.9
Test Example 29	Cr	Co17Cr5Ta	50	1800	Re	50	Co40Cr	200	Co18Cr6Pt3Ta	500	2435	15.4
Test Example 30	Cr	Co17Cr5Ta	50	1800	CuTi	50	Co40Cr	200	Co18Cr6Pt3Ta	500	2050	14.4
Test Example 31	Cr	Co17Cr5Ta	50	1800	SiC	50	Co40Cr	200	Co18Cr6Pt3Ta	500	2250	14.8
Test Example 32	Cr	Co17Cr5Ta	50	1800	Ti	50	Co40Cr	200	Co18Cr6Pt3Ta	500	2450	14.7

TABLE 2 (cont'd)

	In-plane Magnetic Film Underlayer	In-plane Magnetic Film			Separation Film		Nonmagnetic Intermediate Layer		Vertical Magnetic Film			Reproduction Properties
		Composition	BrT (G μ m)	Hc (Oe)	Composition	Thickness ($\text{\AA}$)	Composition	Thickness ($\text{\AA}$)	Composition	Thickness ($\text{\AA}$)	Hc (Oe)	
Test Example 33	Cr	Co17Cr5Ta	50	1800	Zr	50	Co40Cr	200	Co18Cr6Pt3Ta	500	2350	15.0
Test Example 34	Cr	Co17Cr5Ta	50	1800	C	2	Co40Cr	200	Co18Cr6Pt3Ta	500	780	11.0
Test Example 35	Cr	Co17Cr5Ta	50	1800	W	300	Co40Cr	400	Co18Cr6Pt3Ta	500	2350	13.9
Test Example 36	Cr15Ti3Mo	Co18Cr5Pt2Ta2Zr	50	2200	C	20	Co40Cr	200	Co18Cr6Pt3Ta	500	2720	15.9
Test Example 37	Cr15W	Co20Cr8Pt2Ta3Zr	50	2000	C	20	Co40Cr	200	Co18Cr6Pt3Ta	500	2820	16.1
Test Example 38	Cr15V	Co17Cr8Pt3Ta	50	1900	C	20	Co40Cr	200	Co18Cr6Pt3Ta	500	2650	15.4
Test Example 39	Cr4Ti	Co19Cr6Pt2Ta2Re	50	2000	C	20	Co40Cr	200	Co18Cr6Pt3Ta	500	2520	15.6
Test Example 40	Cr	Co17Cr5Ta	50	1800	-	-	Co40Cr	200	Co18Cr6Pt3Ta	500	435	10.3
Test Example 41	Cr	Co17Cr5Ta	50	1800	C	20	-	-	Co18Cr6Pt3Ta	500	1850	12.6

It is seen from Table 2 that the magnetic recording media in which a separation film 4 comprising Ta, Re, CuTi, SiC, W, NiP, Zr, Ti or C was formed exhibited excellent noise properties.

Furthermore, the recording medium of Test Example 34 in which the thickness of the separation film 4 was 2 Å formed an isolated waveform slightly containing a di-pulse waveform at reproduction, however, the magnetic recording media of the other Test Examples provided a single peak isolated waveform.

Test Example 42:

The surface of an aluminum alloy substrate (diameter: 84 mm, thickness: 0.8 mm) having formed on the surface thereof an NiP plating film (thickness: 15 µm) was subjected to mechanical texturing to have a surface average roughness Ra of 15 Å. The resulting substrate 1 was set in a chamber of a DC magnetron sputtering device (3010, manufactured by ANELVA).

The chamber was evacuated until the ultimate vacuum reached 2×10^{-7} Pa, the substrate 1 was heated to 200°C, and then on the substrate 1, an in-plane magnetic film underlayer 2 (thickness: 200 Å) comprising Cr, an in-plane magnetic film 3 comprising Co-17 at%, Cr-5 at% and Ta (Co17Cr5Ta), a separation film 4 comprising carbon, a nonmagnetic intermediate layer 5 comprising Co-40 at% and Cr (Co40Cr) and a vertical magnetic film 6 comprising Co-18 at%, Cr-6 at%, Pt-3 at% and Ta

(Co18Cr6Pt3Ta) were sequentially formed by sputtering.

Subsequently, a carbon protective film having a thickness of 100 Å was formed on the vertical magnetic film 6. A lubricant was then coated on the carbon protective film to form a lubricating film (thickness: 20 Å) comprising PFPE, to thereby obtain a magnetic recording medium.

Test Examples 43 to 50:

Magnetic recording media were manufactured in the same manner as Test Example 42, except for changing the constituent material of the nonmagnetic intermediate layer 5 as shown in Table 3.

Test Examples 51 to 59:

Magnetic recording media were manufactured by varying the constituent material of the vertical magnetic film 6 as shown in Table 4.

Test Examples 60 to 63:

Magnetic recording media were manufactured by varying the thickness of the nonmagnetic intermediate layer 5 as shown in Table 5.

The magnetic recording media of the respective Test Examples were evaluated in the same manner as Test Example 1 to 42. The results are set forth in Tables 3 to 5 below.

TABLE 3

	In-plane Magnetic Film Underlayer	In-plane Magnetic Film			Separation Film		Nonmagnetic Intermediate Layer		Vertical Magnetic Film			Reproduction Properties
		Composition	Composition	BrT (G μ m)	Hc (Oe)	Composition	Thickness (Å)	Composition	Thickness (Å)	Composition	Hc (Oe)	
Test Example 42	Cr	Co17Cr5Ta	50	2015	C	25	Co40Cr	200	Co18Cr6Pt3Ta	300	2580	13.5
Test Example 43	Cr	Co17Cr5Ta	50	2015	C	25	Co25Cr10Pt3Ta	200	Co18Cr6Pt3Ta	300	2730	14.3
Test Example 44	Cr	Co17Cr5Ta	50	2015	C	25	Co30Cr8Pt3Zr	200	Co18Cr6Pt3Ta	300	2690	14.0
Test Example 45	Cr	Co17Cr5Ta	50	2015	C	25	Co35Cr5Pt3Ta2Cu	200	Co18Cr6Pt3Ta	300	2815	14.9
Test Example 46	Cr	Co17Cr5Ta	50	2015	C	25	Co35Cr5Pt2Ta2Re	200	Co18Cr6Pt3Ta	300	2735	15.6
Test Example 47	Cr	Co17Cr5Ta	50	2015	C	25	Co40Cr3Pt2Re	200	Co18Cr6Pt3Ta	300	2645	14.1
Test Example 48	Cr	Co17Cr5Ta	50	2015	C	25	Co65Cr5Ta	200	Co18Cr6Pt3Ta	300	1500	12.1
Test Example 49	Cr	Co17Cr5Ta	50	2015	C	25	Co10Cr2Pt	200	Co18Cr6Pt3Ta	300	2200	10.5
Test Example 50	Cr	Co17Cr5Ta	50	2015	C	25	Co60Cr20Pt15Ta	200	Co18Cr6Pt3Ta	300	1750	11.8

TABLE 4

	In-plane Magnetic Film Underlayer	In-plane Magnetic Film				Separation Film		Nonmagnetic Intermediate Layer		Vertical Magnetic Film			Repro- duction Properties
		Composi- tion	Composi- tion	BrT (Gμm)	Hc (Oe)	Composi- tion	Thick- ness (Å)	Composi- tion	Thick- ness (Å)	Composition	Thick- ness (Å)	Hc (Oe)	
Test Example 51	Cr	Co17Cr5Ta	50	2015	C	15	200	Co40Cr	200	Co20Cr8Pt4Ta	300	2195	15.2
Test Example 52	Cr	Co17Cr5Ta	50	2015	C	15	200	Co40Cr	200	Co25Cr10Pt2Ta	400	1760	15.3
Test Example 53	Cr	Co17Cr5Ta	50	2015	C	15	200	Co40Cr	200	Co22Cr9Pt3Zr	400	1895	15.1
Test Example 54	Cr	Co17Cr5Ta	50	2015	C	15	200	Co40Cr	200	Co18Cr5Pt4Ta2Zr	300	2850	15.6
Test Example 55	Cr	Co17Cr5Ta	50	2015	C	15	200	Co40Cr	200	Co22Cr10Pt2Ta2Zr	500	1975	16.1
Test Example 56	Cr	Co17Cr5Ta	50	2015	C	15	200	Co40Cr	200	Co38Cr6Pt3Ta	300	525	10.1
Test Example 57	Cr	Co17Cr5Ta	50	2015	C	15	200	Co40Cr	200	Co35Cr16Pt5Ta	300	610	9.5
Test Example 58	Cr	Co17Cr5Ta	50	2015	C	15	200	Co40Cr	200	Co30Cr10Pt15Zr	300	725	10.3
Test Example 59	Cr	Co17Cr5Ta	50	2015	C	15	200	Co40Cr	200	Co30Cr5Pt15Ta	300	253	8.1

TABLE 5

	In-plane Magnetic Film Underlayer	In-plane Magnetic Film			Separation Film		Nonmagnetic Intermediate Layer		Vertical Magnetic Film			Reproduction Properties
		Composition	Composition	BrT (Gum)	Hc (Oe)	Composition	Thickness (Å)	Composition	Thickness (Å)	Composition	Hc (Oe)	
Test Example 60	Cr	Co17Cr5Ta	50	2015	C	15	Co35Cr8Pt3Ta	15	Co19Cr6Pt3Ta2Zr	300	870	9.5
Test Example 61	Cr	Co17Cr5Ta	50	2015	C	15	Co35Cr8Pt3Ta	100	Co19Cr6Pt3Ta2Zr	300	1980	14.3
Test Example 62	Cr	Co17Cr5Ta	50	2015	C	15	Co35Cr8Pt3Ta	200	Co19Cr6Pt3Ta2Zr	300	2310	15.2
Test Example 63	Cr	Co17Cr5Ta	50	2015	C	15	Co35Cr8Pt3Ta	600	Co19Cr6Pt3Ta2Zr	300	2200	13.1

It is seen from Tables 3 to 5 that the magnetic recording media in which the nonmagnetic intermediate layer 5 was formed from a Co alloy consisting of from 25 to 50 at% of Cr, from 0 to 15 at% of Pt, from 0 to 10 at% of one or more of Ta, Zr, Cu and Re and the balance of Co and the vertical magnetic film 6 was formed from a Co alloy consisting of from 16 to 30 at% of Cr, from 0 to 15 at% of Pt, from 2 to 10 at% of Ta, from 0 to 5 at% of Zr and the balance of Co exhibited excellent noise properties as compared with the magnetic recording media in which the component ratio in the nonmagnetic intermediate layer 5 or the vertical magnetic film was not within the above-described range. Also, the magnetic recording media formed a satisfactory single peak signal waveform.

Furthermore, the recording media in which the thickness of the nonmagnetic intermediate layer 5 was from 20 to 200 Å and the clearance between the in-plane magnetic film 3 and the vertical magnetic film 6 was from 10 to 500 Å exhibited excellent noise properties and formed a complete single peak isolated waveform at reproduction. On the other hand, the magnetic recording media in which the thickness of the nonmagnetic intermediate layer 5 and the clearance between the in-plane magnetic film 3 and the vertical magnetic film 6 were not within the above-described range had a slightly reduced coercivity or the single peak tendency of the signal wave was slightly reduced.

As described in the foregoing, the recording medium of the present invention enables application of a signal processing system used in the reproduction of general-purpose in-plane magnetic recording media and ensures excellent noise properties.

5 While the invention has been described in detail and with reference to specific embodiments thereof, it will be apparent to one skilled in the art that various changes and modifications can be made therein without departing from the spirit and scope thereof.

WHAT IS CLAIMED IS:

1. A magnetic recording medium comprising a substrate having
 5 thereon an in-plane magnetic film underlayer, an in-plane magnetic film having
 a magnetic easy axis oriented in the in-plane direction with respect to the
 substrate, a vertical magnetic film having a magnetic easy axis oriented
 perpendicularly to the substrate and a separation film being disposed between
 said in-plane magnetic film and said vertical magnetic film,
 10 said in-plane magnetic film underlayer being disposed at the substrate
 side of said in-plane magnetic film,
 said in-plane magnetic film being disposed closer to the substrate than
 said vertical magnetic film and having a coercivity H_c of from 1,500 to 4,000 Oe
 and a remnant magnetization film thickness product BrT of from 20 to 100 $G\mu m$,
 15 and
 said vertical magnetic film having a coercivity H_c of from 1,500 to 4,000
 Oe and a thickness of from 100 to 1,000 Å and containing a Co alloy consisting
 of from 16 to 30 at% of Cr, from 0 to 15 at% of Pt, from 2 to 10 at% of Ta, from
 0 to 5 at% of Zr and the balance of Co, as a main component.
 20
2. The magnetic recording medium as claimed in claim 1, wherein
 said vertical magnetic film has a thickness of from 100 to 600 Å.
- 25 3. The magnetic recording medium as claimed in claim 1, wherein
 said in-plane magnetic film has a remnant magnetization film thickness product
 BrT of from 20 to 50 $G\mu m$.

4. The magnetic recording medium as claimed in claim 2, wherein said in-plane magnetic film has a remnant magnetization film thickness product BrT of from 20 to 50 G μ m.

5

5. The magnetic recording medium as claimed in claim 1 wherein the separation film comprising a material capable of growing non-epitaxially to said in-plane magnetic film.

10

6. The magnetic recording medium as claimed in claim 5, wherein said separation film has a thickness of from 5 to 200 Å.

15

7. The magnetic recording medium as claimed in claim 5, further comprising a nonmagnetic intermediate layer having an hcp structure disposed between said separation film and said vertical magnetic film.

20

8. The magnetic recording medium as claimed in claim 6, further comprising a nonmagnetic intermediate layer having an hcp structure disposed between said separation film and said vertical magnetic film.

9. The magnetic recording medium as claimed in claim 1, wherein the clearance between said in-plane magnetic film and said vertical magnetic film is from 10 to 500 Å.

10. A magnetic recording medium comprising a substrate having thereon an in-plane magnetic film underlayer, an in-plane magnetic film having a magnetic easy axis oriented in the in-plane direction with respect to the substrate and a vertical magnetic film having a magnetic easy axis oriented
5 perpendicularly to the substrate,

said in-plane magnetic film underlayer being disposed at the substrate side of said in-plane magnetic film,

said in-plane magnetic film being disposed closer to the substrate than said vertical magnetic film,

10 a separation film being disposed between said in-plane magnetic film and said vertical magnetic film,

said separation film containing one or more of Ta, Re, CuTi, SiC, W, NiP, Zr, Ti and C as a main component, and

said vertical magnetic film containing a Co alloy consisting of from 16 to
15 30 at% of Cr, from 0 to 15 at% of Pt, from 2 to 10 at% of Ta, from 0 to 5 at% of Zr and the balance of Co, as a main component.

11. The magnetic recording medium as claimed in claim 10, wherein said separation film has a thickness of from 5 to 200 Å.

20

12. The magnetic recording medium as claimed in claim 10, further comprising a nonmagnetic intermediate layer having an hcp structure disposed between said separation film and said vertical magnetic film.

13. The magnetic recording medium as claimed in claim 11, further comprising a nonmagnetic intermediate layer having an hcp structure disposed between said separation film and said vertical magnetic film.

5 14. The magnetic recording medium as claimed in claim 10, wherein the clearance between said in-plane magnetic film and said vertical magnetic film is from 10 to 500 Å.

15. The magnetic recording medium as claimed in claim 10, wherein
10 the in-plane magnetic film underlayer contains Cr or an alloy consisting of Cr and one or more of Ti, Mo, W and V, as a main component.

16. The magnetic recording medium as claimed in claim 15, wherein
15 said in-plane magnetic film contains a Co alloy consisting of from 12 to 25 at% of Cr, from 0 to 15 at% of Pt, from 1 to 10 at% of Ta, from 0 to 10 at% of one or more of Zr, Re, Cu and V, and the balance of Co, as a main component.

17. A magnetic recording medium comprising a substrate having
thereon an in-plane magnetic film underlayer, an in-plane magnetic film having
20 a magnetic easy axis oriented in the in-plane direction with respect to the substrate, a separation film comprising a material capable of growing non-epitaxially to the in-plane magnetic film, a nonmagnetic intermediate layer having an hcp structure and a vertical magnetic film having a magnetic easy axis oriented perpendicularly to the substrate,

said in-plane magnetic film underlayer being disposed at the substrate side of said in-plane magnetic film,

said separation film being disposed between said in-plane magnetic film and said vertical magnetic film,

5 said nonmagnetic intermediate layer containing a Co alloy consisting of from 25 to 50 at% of Cr, from 0 to 15 at% of Pt, from 0 to 10 at% of Ta, Zr, Cu and Re, and the balance of Co, as a main component, and

said vertical magnetic film containing a Co alloy consisting of from 16 to 30 at% of Cr, from 0 to 15 at% of Pt, from 2 to 10 at% of Ta, from 0 to 5 at% of
10 Zr and the balance of Co, as a main component.

18. The magnetic recording medium as claimed in claim 17, wherein said nonmagnetic intermediate layer has a thickness of from 20 to 400 Å.

15

19. The magnetic recording medium as claimed in claim 17, wherein the clearance between said in-plane magnetic film and said vertical magnetic film is from 10 to 500 Å.

20 20. The magnetic recording medium as claimed in claim 18, wherein the clearance between said in-plane magnetic film and said vertical magnetic film is from 10 to 500 Å.