

MAGNETIC RECORDING MEDIUM AND METHOD FOR MANUFACTURING MAGNETIC RECORDING MEDIUM

This application is based upon and claims the benefit of priority from Japanese patent application No. 2006-262809, filed on September 27, 2006, the disclosure of which is incorporated herein in its entirety by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a magnetic recording medium and a method for manufacturing a magnetic recording medium.

2. Description of the Related Art

In recent years, the information-oriented society has become sharply advanced. Magnetic recording apparatuses are typified by a hard disk drive (HDD). Magnetic disks have been required to have a diameter of 2.5 inches and an information recording capacity exceeding 200 gigabytes per disk. In order to meet these needs for magnetic disks, realization of information recording density (areal density) exceeding 200 gigabits per square inch (200 Gbit/in²) is required. A perpendicular magnetic recording system including a double-layer perpendicular medium and a single-pole head can exhibit high recording resolution and therefore, has been researched as a next-generation high-density recording system.

An improvement of the areal density of the magnetic recording disk is achieved by an improvement of the linear density and an improvement of the track density. The improvement of the linear density needs to realize well-balanced three factors, a reduction of magnetic transition region noises of a recording layer, an improvement of thermal stability of recorded signals, and recording ease. For the purpose of realizing them, heretofore, coupled granular

and continuous (CGC) media including granular layers and continuous film layers have been proposed (refer to, for example, US patent No. 6468670 B1).

In such CGC media, magnetic transition region noises can be reduced by using a granular layer as a main recording layer. In the granular layer, nonmagnetic substances have segregated at grain boundaries of magnetic crystal grains. Thus, the influence of the magnetic transition region can be substantially eliminated in the main recording layer. Further, the thermal stability of recorded signals can be improved by using a continuous film layer as an auxiliary recording layer. The continuous film layer has magnetic bonding strength in a direction parallel to a main surface of a substrate, the continuous film layer and the granular layer are magnetically exchange-coupled, and the magnetization of the continuous film layer is pinned by the magnetization of the granular layer. In this manner, an increase in recording density of the CGC medium can be achieved.

In recent years, an exchange spring medium including a soft magnetic layer on a granular layer, an exchange coupled composite, and the like have been known as configurations for performing the function similar to, for example, the function of the continuous film layer of the CGC medium (refer to, for example, IEEETrans. Magn: Vol. 41, No. 10, pp 3166-3168, Oct. 2005). Hereinafter, these configurations are referred to as CGC media and the like. The exchange coupled composite may also be referred to as a hard/stacked medium.

SUMMARY OF THE INVENTION

The inventor of the present invention found out that the control of the magnetic recording region in a track width (erase width) direction is very difficult in the CGC media and the like as compared with the control in the case where, for example, no continuous film layer is included but merely a granular layer is

included. For example, in the CGC media and the like, the values of recorded signals become values between 0 and 1 in a gray region, the gray region may extend in the track width direction. Consequently, a reduction of track edge noises often becomes difficult. The reason for this is as described below. The continuous film layer and the soft magnetic layer are auxiliary recording layers for playing a supplementary role relative to the granular layer serving as a main recording layer, and have magnetic bonding strength in a direction parallel to the main surface of a substrate. Therefore, a recording region expands when viewed from a head. This expanded portion relative to the recording region is a gray region. An increase of this region corresponds to an increase of the track width. Consequently, in the CGC media and the like, an improvement of the track density may become difficult.

Accordingly, embodiments of the present invention seek to provide a magnetic recording medium useful for solving the above-described problems and a method for manufacturing a magnetic recording medium.

The inventor of the present invention conducted intensive research and found out that in CGC media and the like, formation of grooves or the like at track edges is able to appropriately suppress expansion of gray regions of recorded signals in the track width direction without impairing advantages, such as a reduction of magnetic transition region noises, an improvement of thermal stability of recorded signals, and recording ease, of the CGC media and the like. Consequently, track edge noises are reduced so that the track density can be increased. Further, it was found out that similar effects are able to be obtained in the following structure including a first magnetic layer and a second magnetic layer, besides the CGC media and the like. In order to solve the above-described problems, the present invention has the following structures.

(Structure 1)

A magnetic recording medium for perpendicular magnetic recording,

comprising:

a first magnetic layer which has magnetic crystal grains exhibiting perpendicular magnetic anisotropy and nonmagnetic substances for magnetically separating the magnetic crystal grains from each other at grain boundaries of the magnetic crystal grains;

a second magnetic layer which has magnetic grains exchange-coupled to the magnetic crystal grains, a grain boundary width of the magnetic grains being smaller than a grain boundary width of the magnetic crystal grains, and

separation regions which magnetically separate tracks from each other and which are disposed in regions between the tracks of the magnetic recording medium in at least the second magnetic layer.

The grain boundaries of magnetic crystal grains refer to, for example, regions having an irregular atomic arrangement at boundaries between magnetic crystal grains. The separation regions may be disposed in regions between recording bits in tracks. The separation region magnetically separates recording bits from each other in the tracks.

The above-described structure can reduce magnetic transition region noises because, for example, magnetic crystal grains in the first magnetic layer are magnetically separated from each other by nonmagnetic substances. Pinning of magnetization of the second magnetic layer by magnetization of the first magnetic layer can increase the density. Further, the thermal stability of recorded signals can be improved by, for example, decreasing the width of grain boundaries of magnetic grains in the second magnetic layer to be exchange-coupled to magnetic crystal grains. Such a structure can also appropriately achieve recording ease of signals. With such a structure, the linear density of magnetic recording can be appropriately improved.

According to such a structure, formation of separation regions in at least the second magnetic layer can suppress expansion of gray regions of recorded

signals in the track width direction in, for example, CGC media and the like as well. Consequently, track edge noises are reduced in this structure so that track density can be appropriately increased.

The track refers to a region in a magnetic recording medium and magnetic signals are recorded on the region. The track is extended in a direction of scanning of a head relative to the magnetic recording medium. In the magnetic recording medium, for example, a plurality of tracks are disposed in a such manner that predetermined spaces are formed between adjacent tracks. In the case where the magnetic recording medium is a magnetic disk, a plurality of tracks are disposed concentrically around the center of the magnetic disk. The region between tracks means a gap region between adjacent tracks.

This magnetic recording medium is a coupled granular and continuous (CGC) medium, but may be an exchange spring medium, an exchange coupled composite medium, or the like.

The perpendicular magnetic anisotropy refers to, for example, magnetic anisotropy in which a magnetic moment tends to point in a direction perpendicular to a main surface of a substrate. The phrase "magnetically separate magnetic crystal grains from each other" refers to the fact that, for example, a magnetic exchange interaction between magnetic crystal grains is weakened so that the magnetic crystal grains are substantially prevented from being exchange-coupled to each other.

The magnetic crystal grains in the first magnetic layer are, for example, magnetic crystal grains in which the direction of magnetic moment is reversed in accordance with a signal to be recorded. The first magnetic layer may be a layer (granular layer) having a granular structure in which the nonmagnetic substances in the form of oxides are segregated at grain boundaries of the magnetic crystal grains. The separation regions are disposed in the second magnetic layer. For example, grooves are disposed between and along the

tracks in the separation regions. The grooves magnetically separate the tracks from each other. The grooves are formed by patterning the second magnetic layer through a patterning method by using nanoimprint, lithography, mechanical processing, or the like. The separation regions may also be formed by changing the crystal structure of a part of the second magnetic layer by, for example, ion irradiation.

The magnetic grains in the second magnetic layer may be crystallized magnetic crystal grains. In this case, grain boundaries of the magnetic grains in the second magnetic layer refer to grain boundaries of the magnetic crystal grains. In the case where magnetic grains do not become crystals because, for example, the second magnetic layer is thin, grain boundaries of the magnetic grains means, for example, regions occupied by impurities deposited between uniform magnetic grains having identical easy-to-magnetize axes. The phrase "the grain boundary width of the magnetic grains being smaller than that of the magnetic crystal grains of the first magnetic layer" also includes the case where, for example, the second magnetic layer is a layer having an amorphous structure or the like and substantially no grain boundary is present in the second magnetic layer.

(Structure 2)

The separation regions are disposed substantially only in the second magnetic layer of the first magnetic layer and the second magnetic layer.

In the CGC media and the like including a continuous film layer on a granular layer, the thickness of a perpendicular magnetic recording layer including the granular layer and the continuous film layer is, for example, 15 to 20 nm. With respect to the perpendicular magnetic recording layer having such a thickness, it is difficult to form narrow separation regions having predetermined widths in both the granular layer and the continuous film layer.

For example, in the case where separation regions are formed by

grooves for magnetically separating tracks from each other in both the granular layer and the continuous film layer, formation of deeper grooves is required when the thickness of the perpendicular magnetic recording layer increases. However, in the case where a groove having a predetermined width is formed, if the ratio of the depth to the width increases, it becomes difficult to keep the precision of the width. Further, in the case where the separation regions are formed by, for example, ion irradiation, deeper ion implantation is required when the thickness of the perpendicular magnetic recording layer increases. As a result, expansion of the separation region increases in the width direction, and it becomes difficult to keep the precision of the width of the separation region. Consequently, in the magnetic recording medium including the above-described first magnetic layer and the second magnetic layer, the separation regions may not be appropriately formed in the regions between the tracks if the perpendicular magnetic recording layer comprising the first magnetic layer and the second magnetic layer is increased in thickness.

On the other hand, the inventor of the present invention conducted intensive research and found out that expansion of gray regions of recorded signals in the track width direction is able to be appropriately suppressed by forming separation regions merely in the second magnetic layer even when separation regions are not disposed in both the first magnetic layer and the second magnetic layer. According to this structure, the separation regions can be formed with high precision. Consequently, the track density can be appropriately improved.

The phrase "forming separation regions substantially merely in the second magnetic layer" includes the case where, for example, separation regions are also disposed in a part of the first magnetic layer within a range of not affecting precision nor man-hour of formation of the separation regions. Preferably, the second magnetic layer is a multilayer film. In this case, for

example, the second magnetic layer is easily formed into a thinner layer by generating the interface magnetic anisotropy at interfaces of films constituting the multilayer film. Further, in the case where, for example, separation regions are formed by changing the crystal structure of a part of the second magnetic layer by ion irradiation, the crystal structure becomes easy to change.

(Structure 3)

The grain boundary width of the magnetic crystal grains in the first magnetic layer is 2 nm or more, and the grain boundary width of the magnetic crystal grains in the second magnetic layer is 1 nm or less.

According to such a structure, for example, magnetic transition region noises can be reduced by increasing the width of grain boundaries of the magnetic crystal grains in the first magnetic layer. Further, the thermal stability of recorded signals can be improved by decreasing the width of grain boundaries of the magnetic grains in the second magnetic layer. Consequently, the recording density of the magnetic recording medium can be appropriately increased in this structure.

(Structure 4)

The separation regions comprise grooves for magnetically separating the tracks from each other and the grooves are disposed along the tracks in the second magnetic layer. With this structure, the tracks can be appropriately magnetically separated from each other.

For example, the depth of this groove is adequate for penetrating the second magnetic layer. The tracks can be appropriately magnetically separated from each other in this structure. Alternatively, the depth of this groove may be up to some midpoint of the thickness of the second magnetic layer insofar as the tracks can be magnetically separated from each other with required precision. For example, in the case where the second magnetic layer is a multilayer film, the depth of this groove may be at a level adequate for reaching

a part of layers in the multilayer film.

(Structure 5)

The magnetic recording medium, further comprising:

a substrate for disposing the first magnetic layer and the second magnetic layer,

wherein the magnetic grains in the second magnetic layer exhibit perpendicular magnetic anisotropy and are exchange-coupled to each other with a strength larger than a bonding strength between the magnetic crystal grains in the first magnetic layer in a direction parallel to a main surface of the substrate, and

the magnetic crystal grains in the first magnetic layer and the magnetic grains in the second magnetic layer are exchange-coupled to each other in a direction perpendicular the main surface of the substrate.

According to this structure, the magnetization of the second magnetic layer can be appropriately pinned by the magnetic crystal grains in the first magnetic layer. Further, the thermal stability of recorded signals can be improved by a magnetic exchange interaction between the magnetic grains in the second magnetic layer. Consequently, the recording density of the magnetic recording medium is allowed to appropriately increase in this structure.

(Structure 6)

The first magnetic layer is a layer having a granular structure and the nonmagnetic substances in the form of oxides are segregated at grain boundaries of the magnetic crystal grains, and

the second magnetic layer is a laminated film comprising Co compound layers and Pd layers or Pt layers which are alternately laminated.

This magnetic recording medium is, for example, a CGC medium. The thermal stability of recorded signals can be particularly appropriately improved according to such a structure. However, in the case where, for example, no

separation region is disposed in regions between tracks, in particular, gray regions of recorded signals become easy to expand in the track width direction as compared with those in, for example, an exchange spring medium and an exchange coupled composite medium. On the other hand, according to such a structure, track edge noises are reduced so that the track density can be appropriately improved. Consequently, a magnetic recording medium exhibiting particularly excellent characteristics can be produced.

(Structure 7)

A magnetic recording medium for perpendicular magnetic recording, comprising:

a substrate;

a first magnetic layer which has magnetic crystal grains exhibiting perpendicular magnetic anisotropy and nonmagnetic substances for magnetically separating the magnetic crystal grains from each other at grain boundaries of the magnetic crystal grains;

a second magnetic layer which has magnetic grains exchange-coupled to the magnetic crystal grains and exchange-coupled to each other with a strength larger than a bonding strength between the magnetic crystal grains in the first magnetic layer in a direction parallel to a main surface of the substrate; and

separation regions which magnetically separate tracks from each other and which are disposed in regions between the tracks of the magnetic recording medium in at least the second magnetic layer. The separation regions may be further disposed in regions between recording bits in the tracks.

According to this structure, for example, the thermal stability of recorded signals can be improved by exchange coupling between magnetic grains in the second magnetic layer. Consequently, effects similar to the effects of the structure 1 can be obtained in this structure.

(Structure 8)

A method for manufacturing a magnetic recording medium for perpendicular magnetic recording, comprising the steps of:

forming a first magnetic layer which has magnetic crystal grains exhibiting perpendicular magnetic anisotropy and nonmagnetic substances for magnetically separating the magnetic crystal grains from each other at grain boundaries of the magnetic crystal grains;

forming a second magnetic layer which has magnetic grains exchange-coupled to the magnetic crystal grains, a grain boundary width of the magnetic grains being smaller than a grain boundary width of the magnetic crystal grains; and

forming separation regions which magnetically separate tracks from each other in regions between the tracks of the magnetic recording medium in at least the second magnetic layer. In this manner, effects similar to the effects of the structure 1 can be obtained.

(Structure 9)

A method for manufacturing a magnetic recording medium for perpendicular magnetic recording, comprising the steps of:

preparing a substrate;

forming a first magnetic layer which has magnetic crystal grains exhibiting perpendicular magnetic anisotropy and nonmagnetic substances for magnetically separating the magnetic crystal grains from each other at grain boundaries of the magnetic crystal grains;

forming a second magnetic layer which has magnetic grains exchange-coupled to the magnetic crystal grains and exchange-coupled to each other with a strength larger than a bonding strength between the magnetic crystal grains in the first magnetic layer in a direction parallel to a main surface of the substrate; and

forming separation regions which magnetically separate tracks from each

other in regions between the tracks of the magnetic recording medium in at least the second magnetic layer. In this manner, effects similar to the effects of the structure 7 can be obtained.

(Structure 10)

A magnetic recording medium comprising a recording layer including an auxiliary recording layer and a main recording layer,

wherein the auxiliary recording layer has magnetic portions corresponding to recording bits and separation portions for separating the magnetic portions from each other, and

the main recording layer are divided into regions serving as recording bits by a magnetic influence exerted by the auxiliary recording layer. The separation portions magnetically separate, for example, the magnetic portions from each other. The separation portions may spatially separate the magnetic portions from each other.

The magnetic portions corresponding to recording bits refer to regions in which magnetic signals are recorded, and are magnetic portions of the recording bits. The recording bits are regions separated from each other in, for example, tracks and patterned (bit patterned) medium. The separation portions separate the magnetic portions on a track or recording bit basis, for example. According to this structure, the recording layer can be partitioned on a magnetic portion corresponding to recording bit basis so as to form the magnetic recording medium as, for example, a discrete track recording (DTR) medium or a patterned medium. Consequently, the main recording layer becomes easy to record in regions including magnetic portions of the auxiliary recording layer.

(Structure 11)

A magnetic anisotropy constant K_u of the auxiliary recording layer is larger than a magnetic anisotropy constant K_u of the main recording layer. According to this structure, the magnetic wall generated in the auxiliary

recording layer is decreased in width to thereby reduce magnetic transition region noises.

(Structure 12)

The main recording layer has a granular structure. According to this structure, magnetic transition region noises can be reduced by substantially eliminating the influence of the magnetic transition region in the main recording layer.

(Structure 13)

The recording layer is a perpendicular magnetic recording layer. According to this structure, a high recording density can be realized.

(Structure 14)

The magnetic portion of the auxiliary recording layer is exchange-coupled to the main recording layer. According to this structure, the recording layer can be appropriately partitioned in accordance with the regions including magnetic portions of the auxiliary recording layer.

According to the present invention, for example, the track density can be increased by reducing track edge noises.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a diagram showing an example of the structure of a magnetic recording medium according to an embodiment of the present invention;

Fig. 2A is a diagram for illustrating the magnetic characteristic of the magnetic recording medium in detail and shows magnetization patterns of magnetic signals recorded on a track;

Fig. 2B is a diagram for illustrating the magnetic characteristic of the magnetic recording medium in detail and shows the magnetic characteristic of the magnetic recording medium;

Fig. 3A is a diagram for illustrating the effect of formation of separation

regions and shows a recording pattern of a granular medium;

Fig. 3B is a diagram for illustrating the effect of formation of separation regions and shows a recording pattern of a known CGC medium;

Fig. 4A is a diagram showing a modified example of the magnetic recording medium and shows the structure of a magnetic recording medium having an exchange spring medium structure; and

Fig. 4B is a diagram showing a modified example of the magnetic recording medium and shows the structure of a magnetic recording medium having an exchange coupled composite structure.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The embodiments according to the present invention will be described below with reference to the drawings. Fig. 1 shows an example of the structure of a magnetic recording medium 10 according to an embodiment of the present invention. The magnetic recording medium 10 is a magnetic disk of double-layer perpendicular medium system to be mounted on a hard disk drive (HDD) of perpendicular magnetic recording system.

In the present example, the magnetic recording medium 10 includes a substrate 12, an adhesion layer 14, a soft magnetic layer 16, an underlayer 18, a perpendicular magnetic recording layer 30, a protective layer 26, and a lubricant layer 28 in this order. The perpendicular magnetic recording layer 30 has a granular layer 20, a coupling control layer 22, and a continuous layer 24.

The substrate 12 is, for example, substrate glass. Examples of the substrate glass include aluminosilicate glass, aluminoborosilicate glass, and soda-lime glass. Among them, the aluminosilicate glass is preferable. Alternatively, amorphous glass or crystallized glass can be used. For example, in the case where the soft magnetic layer 16 has an amorphous structure, it is preferable that the substrate glass is amorphous glass. The use of chemically

strengthened glass is preferable because the rigidity is high.

Preferably, the surface roughness of the main surface of the substrate 12 is 6 nm or less in terms of $R_{\max}$ and 0.6 nm or less in terms of R_a . $R_{\max}$ and R_a are defined in Japanese Industrial Standards (JIS). Such a smooth surface can make the gap between, for example, the perpendicular magnetic recording layer 30 and the soft magnetic layer 16 constant. Consequently, a suitable magnetic circuit can be formed between the head (magnetic head), the perpendicular magnetic recording layer 30, and the soft magnetic layer 16. Further, the substrate 12 may be a substrate having an isotropic surface and no texture.

In the case where annealing in a magnetic field is required to, for example, control the magnetic domain of the soft magnetic layer 16, it is particularly preferable to use the substrate 12 made of a glass member. Since the glass member exhibits excellent heat resistance, the substrate 12 can be heated to a high temperature.

The adhesion layer 14 is a layer (contact layer) for increasing the adhesion between the substrate 12 and the soft magnetic layer 16. Peeling of the soft magnetic layer 16 can be prevented by disposing the adhesion layer 14. For example, a Ti-containing material can be used as a material for the adhesion layer 14. The film thickness of the adhesion layer 14 preferably falls within a range of 1 to 50 nm from the viewpoint of practical use. In the present example, the adhesion layer 14 is an amorphous CrTi layer. The film thickness of the adhesion layer 14 is, for example, about 10 nm.

The soft magnetic layer 16 is a layer for forming a magnetic circuit between the head and the perpendicular magnetic recording layer 30. The soft magnetic layer 16 is not specifically limited as far as the soft magnetic layer 16 is formed by a magnetic substance exhibiting a soft magnetic characteristic. However, a preferable magnetic characteristic is, for example, 0.01 to 80

oersted in terms of coercive force H_c , desirably 0.01 to 50 oersted. Further, a preferable magnetic characteristic is 500 emu/cc to 1,920 emu/cc in terms of saturation magnetic flux density B_s .

Examples of materials for the soft magnetic layer 16 include Fe based materials and Co based materials. For example, use may be made of Fe based soft magnetic materials, e.g., FeTaC based alloys, FeTaN based alloys, FeNi based alloys, FeCoB based alloys, and FeCo based alloys, Co based soft magnetic materials, e.g., CoTaZr based alloys and CoNbZr based alloys, and FeCo based alloy soft magnetic materials.

The film thickness of the soft magnetic layer 16 is, for example, 10 to 200 nm, desirably 20 to 100 nm. If the film thickness is less than 10 nm, it may become difficult to form a suitable magnetic circuit between the head, the perpendicular magnetic recording layer 30, and the soft magnetic layer 16. If the film thickness exceeds 200 nm, the surface roughness may increase. Further, if the film thickness exceeds 200 nm, control of the magnetic domain often becomes difficult.

A large magnetic domain is easy to generate in the soft magnetic layer 16. When the large magnetic domain moves, noises may be generated. Therefore, the soft magnetic layer 16 preferably has a plurality of soft magnetic material layers which are anti-ferro magnetically coupled (AFC). According to this structure, movement of the magnetic domains becomes difficult. Thus, generation of noise can be suppressed.

In the present example, the soft magnetic layer 16 has a plurality of CoTaZr layers which are anti-ferro magnetically coupled with Ru layers therebetween. The Ru layer is, for example, a layer having a hcp crystal structure. The film thickness of the Ru layer is, for example, about 0.9 nm. Each CoTaZr layer is a layer having an amorphous structure. The film thickness of each CoTaZr layer is, for example, 20 to 27.5 nm.

The underlayer 18 is a layer for controlling the crystal structure of the perpendicular magnetic recording layer 30. The underlayer 18 may be a laminated film composed of a plurality of types of films. In the present example, the underlayer 18 comprises a first orientation control layer, a second orientation control layer, an isolation-promoting layer, and a fining-promoting layer in this order on the soft magnetic layer 16.

The first orientation control layer is a layer for controlling the crystal orientation of the second orientation control layer disposed as a layer on the first orientation control layer. In the present example, the first orientation control layer is, for example, a Ta layer or a CoCrTa layer having a bcc crystal structure close to amorphous. The film thickness of the first orientation control layer is, for example, about 3 nm.

The second orientation control layer is a layer for improving the orientation property of the layer further disposed thereon. In the present example, the second orientation control layer is a Ru layer having a hcp crystal structure. The film thickness of the second orientation control layer is, for example, about 10 nm.

The isolation-promoting layer is a layer for separating the composition of the upper layer and promoting isolation of crystal grains. The isolation-promoting layer is formed by, for example, sputtering at a gas pressure higher than the pressure during film formation of the Ru layer of the second orientation control layer. Consequently, the isolation-promoting layer becomes a layer containing small crystals in which crystal grains are isolated from each other. In the present example, the isolation-promoting layer is a Ru layer having a hcp crystal structure. The film thickness of the isolation-promoting layer is, for example, about 10 nm.

The fining-promoting layer promotes fining of crystal grains in a layer disposed thereon. In the present example, the fining-promoting layer is a

nonmagnetic crystal grain layer (CoCr-SiO₂ layer) having a granular structure in which SiO₂ is segregated at grain boundaries of nonmagnetic CoCr crystal grains. In the fining-promoting layer, the crystal structure of CoCr is, for example, a hcp crystal structure. A part of the fining-promoting layer may contain CoCr having a bcc crystal structure. The SiO₂ content in the fining-promoting layer is, for example, about 12 atomic percent (for example, 10 to 16 atomic percent). The film thickness of the fining-promoting layer is, for example, about 2 nm. The granular layer 20 of the perpendicular magnetic recording layer 30 is formed on the fining-promoting layer.

The granular layer 20 is a layer having a granular structure in which oxides are segregated at grain boundaries of fined crystal grains, and is an example of the first magnetic layer and the main recording layer. In the present example, the granular layer 20 is a CoCrPt-SiO₂ layer and contains magnetic crystal grains 102 and nonmagnetic substances 104 for magnetically separating the magnetic crystal grains 102 from each other at grain boundaries of the magnetic crystal grains 102. The film thickness of the granular layer 20 is, for example, 20 nm or less, desirably 8 to 16 nm, and further desirably 7 to 15 nm (for example, about 9 nm).

The magnetic crystal grains 102 are magnetic crystal grains exhibiting perpendicular magnetic anisotropy and the direction of magnetic moment is reversed in accordance with a signal to be recorded on the magnetic recording medium 10. In the present example, the magnetic crystal grain 102 is CoCrPt having a hcp crystal structure. The size (diameter) of the magnetic crystal grain 102 is, for example, 5 to 20 nm, and desirably 8 to 15 nm. The width of grain boundaries of the magnetic crystal grains 102 is 2 nm or more, for example, 2 to 20 nm, and desirably 4 to 15 nm. The width of grain boundaries of the magnetic crystal grains 102 refers to an average value of widths of grain boundaries of magnetic crystal grains 102 in, for example, the granular layer 20.

The nonmagnetic substances 104 are nonmagnetic oxides segregated at grain boundaries of the magnetic crystal grains 102. In the present example, the nonmagnetic substance is, for example, silicon oxide (SiO_2). For example, titanium oxide (TiO_2) may be used as the nonmagnetic substance 104 instead of SiO_2 . The content of SiO_2 and the like in the granular layer 20 is, for example, 10 to 16 atomic percent, and desirably 12 to 14 atomic percent.

For example, in the case where the content of SiO_2 is 6 atomic percent or more, the nonmagnetic substances 104 are made finer to thereby increase the SN ratio. However, deterioration may occur in the coercive force H_c , perpendicular magnetic anisotropy, or the like of the granular layer 20 alone. Consequently, the thermal stability of the granular layer 20 alone may thereby deteriorates. However, in the present example, the continuous film layer 24 is disposed on the granular layer 20. Therefore, even when the content of SiO_2 and the like increases in the granular layer 20, occurrences of these problems can be suppressed.

The coupling control layer 22 is a layer for controlling the strength of magnetic coupling between the granular layer 20 and the continuous film layer 24. In the present example, the coupling control layer 22 is, for example, a Pd layer having a fcc crystal structure. The film thickness of the coupling control layer 22 is, for example, 2 nm or less, for example, 0.5 to 1.5 nm, and desirably 0.7 to 1.0 nm (for example, about 0.8 nm). The coupling control layer 22 may be a Pt layer.

The continuous film layer 24 is a layer in which exchange coupling in a direction parallel to the main surface of the substrate 12 is continuously expanded. The continuous film layer 24 is an example of the second magnetic layer and the auxiliary recording layer and contains magnetic grains exhibiting perpendicular magnetic anisotropy. These magnetic grains are magnetically exchange-coupled to the magnetic crystal grains 102 in the granular layer 20 in

a direction perpendicular to the main surface of the substrate 12.

The width of grain boundaries of the magnetic grains are smaller than that of grain boundaries of the magnetic crystal grains 102 in the granular layer 20, and is, for example, 1 nm or less, for example, 0.1 to 1 nm, and desirably 0.3 to 0.8 nm. Consequently, magnetic grains of the continuous film layer 24 are exchange-coupled to each other with the strength larger than the bonding strength between the magnetic crystal grains 102 in the granular layer 20 in a direction parallel to the main surface of the substrate 12. As a result, according to this structure, the thermal stability of recorded signals can be appropriately improved by, for example, pinning the magnetization of the continuous film layer 24 with the magnetization of the granular layer 20. The film thickness of the continuous film layer 24 is, for example, 1 to 8 nm, desirably 3 to 6 nm, and further desirably 4 to 5 nm.

The ratio A/B of the film thickness A of the granular layer 20 to the film thickness B of the continuous film layer 24 is, for example, 2 to 5, and desirably 3 to 4. According to this structure, suitable perpendicular magnetic recording characteristic can be exhibited by exchange coupling. Preferably, the magnetic anisotropy constant (maximum anisotropic energy) K_u of the magnetic grains in the continuous film layer 24 is larger than that of, for example, the soft magnetic substance. According to this structure, the width of the magnetic wall generated in the continuous film layer 24 is can be decreased. The magnetic anisotropy constant K_u of the magnetic grains in the continuous film layer 24 may be smaller than that of the magnetic crystal grains 102 in the granular layer 20. The coercive force H_c of the material for constituting the continuous film layer 24 may be smaller than the coercive force H_c of, for example, the material constituting the magnetic crystal grains 102 in the granular layer 20.

In the present example, the continuous film layer 24 is a multilayer film and about 3 layers (for example, 2 to 3 layers) of CoCr layers 106 and about 3

layers (for example, 2 to 3 layers) of Pd layers 108 are alternately laminated. The CoCr layer 106 is a layer containing magnetic grains of CoCr. The film thickness of the CoCr layer 106 is, for example, about 0.35 nm. In the case where the CoCr layer 106 is very thin as described above, the magnetic grains of CoCr may not have a crystal structure. The CoCr layer 106 may contain magnetic crystal grains of CoCr having, for example, a hpc crystal structure. The Pd layer 108 is a layer of nonmagnetic Pd having a fcc crystal structure. The film thickness of the Pd layer 108 is, for example, about 0.8 nm. In this structure, interface magnetic anisotropy is generated at the interface between the CoCr layer 106 and the Pd layer 108. Furthermore, required perpendicular magnetic anisotropy can be obtained by laminating, for example, 3 layers of CoCr layer 106 and 3 layers of Pd layer 108. Moreover, the film thickness of the continuous film layer 24 can be decreased in the case where the continuous film layer 24 is composed of the multilayer film as in the present example.

The continuous film layer 24 may have, for example, Pt layers in place of the Pd layers 108. The continuous film layer 24 may have CoB layers in place of the CoCr layers 106. The continuous film layer 24 may be a laminated film, $n \times [\text{CoX/Pd or Pt}]$, wherein n layers of Co compound layer and n layers of Pd layer or Pt layer are alternately laminated. Alternatively, the continuous film layer 24 may be a single-layer film having, for example, a high Pt content. The continuous film layer 24 may be a single-layer film of, for example, CoCrPt, CoPt, CoPd, FePt, CoPt₃, CoPd₃, amorphous TbFeCoCr, SmCo₅, Nd₂Fe₁₄B, or Co₂₀Pt₈₀.

In the present example, separation regions 202 for magnetically separating tracks from each other are disposed in regions between the tracks of the magnetic recording medium 10. The separation regions 202 are nonmagnetic regions for magnetically separating the tracks from each other and, for example, grooves for magnetically separating the tracks from each other are

formed in the regions. The grooves are disposed between and along the tracks. The separation regions 202 may be formed by changing the crystal structure of a part of the continuous film layer 24 by ion irradiation, for example. In the case where ion irradiation is performed, the regions to be irradiated with the ion in the continuous film layer 24 are set by using, for example, a silicon stencil mask or a mask formed by nanoimprint technology. For example, an argon ion (Ar^+) accelerated with energy of 20 to 30 keV is used as the ion to be irradiated. In the continuous film layer 24, track regions serve as magnetic portions corresponding to recording bits. The separation regions 202 serve as separation portions for separating magnetic layers from each other.

In the present example, the magnetic recording medium 10 is a discrete track recording (DTR) medium. Therefore, the separation regions 202 are formed only in regions between the tracks. In the case where the magnetic recording medium 10 is a patterned (bit patterned) medium, the separation regions 202 are further formed in, for example, the regions between the individual bits on the tracks in such a manner that single-magnetic-domain grains become a recording unit.

In the present example, the track width of the magnetic recording medium 10 is, for example, 100 to 200 nm, and desirably 135 to 165 nm. The distance between tracks is a distance from a center of a track to a center of an adjacent track and is, for example, 150 to 250 nm, and desirably 180 to 220 nm. The width of the separation region 202 is, for example, 30 to 70 nm, and desirably 40 to 60 nm in the track width direction.

The protective layer 26 and the lubricant layer 28 are further disposed on the continuous film layer 24. The protective layer 26 is a layer for protecting the perpendicular magnetic recording layer 30 from the impact of the head. The protective layer 26 is a carbon based film having, for example, a diamond-like structure. The lubricant layer 28 is a layer for improving the lubricity between

the head and the magnetic recording medium 10. The lubricant layer 28 is a perfluoropolyether (PFPE) film formed by, for example, a dip coating method.

According to this structure, a CGC medium is formed by the granular layer 20, the continuous film layer 24, and the like. Thus, a reduction of magnetic transition region noises and an improvement of thermal stability of recorded signals can be realized. Further, recording ease of signals can be appropriately obtained.

The separation regions 202 are disposed in the continuous film layer 24, so that track edge noises are reduced and the track density can be appropriately increased. In this case, the continuous film layer 24 is thinner than the entire perpendicular magnetic recording layer 30 and only the continuous film layer 24 is processed. Therefore, the separation regions 202 can be formed with ease and high precision as compared with the case where nonmagnetic regions are formed in both the granular layer 20 and the continuous film layer 24. Consequently, the recording density of the magnetic recording medium 10 can be appropriately increased.

In the production process of the magnetic recording medium 10, preferably, each of the adhesion layer 14 to the continuous film layer 24 is formed by sputtering. In particular, formation by DC magnetron sputtering is preferable because a uniform film can be formed. Preferably, the protective layer 26 is formed by CVD.

In the formation of the CoCr layer 106 and the Pd layer 108 of the continuous film layer 24, preferably, Kr is used as a sputtering gas. Consequently, the interface between the CoCr layer 106 and the Pd layer 108 is formed cleanly. Thus, interface magnetic anisotropy can be generated more appropriately. The CoCr layer 106 and the Pd layer 108 may also be formed by CVD.

The separation regions 202 of the continuous film layer 24 are formed by,

for example, forming the protective layer 26 and, thereafter, removing a part of the protective layer 26 and the continuous film layer 24 by patterning, e.g., patterning by using nanoimprint. The order of the film formation process of the protective layer 26 and the patterning process by using nanoimprint may be reversed. The patterning may be performed by using, for example, focused ion beam (FIB) in place of nanoimprint lithography.

Figs. 2A and 2B are diagrams for illustrating the magnetic characteristics of the magnetic recording medium 10 in detail. Fig. 2A is a diagram showing magnetization patterns of magnetic signals recorded on tracks 204. A sample for checking the magnetic characteristics of the magnetic recording medium 10 is prepared separately, and the magnetization patterns were observed by using the sample. In this sample, the separation regions 202 are formed by changing the crystal structure of a part of the continuous film layer 24 by ion irradiation instead of formation of grooves. Grooves 206 are disposed along the tracks 204 so as to sandwich the plurality of tracks 204 and the plurality of separation regions 202.

As shown in the drawing, magnetic signals are recorded as magnetization patterns in the tracks 204. No magnetic signal is recorded on the regions including the separation regions 202 between the tracks. White portions and black portions on the tracks 204 indicate that the directions of magnetization are different on the basis of the difference in the recorded information. The length of white portion and the length of black portion are different between the center track 204 and the right and left tracks 204 in the extension direction of the tracks 204 because of difference in the linear densities of the recording densities.

Fig. 2B shows the magnetic characteristic of the magnetic recording medium 10. The hysteresis curve 302 indicates a magnetic characteristic on the region not including the separation regions 202 in the continuous film layer

24. In this case, the saturation magnetic field H_s is about 7,000 Oe. Consequently, magnetic recording can be appropriately performed on this region with, for example, a normal head.

The hysteresis curve 304 indicates a magnetic characteristic on the region including the separation regions 202 in the continuous film layer 24. In this case, the saturation magnetic field H_s is about 12,000 Oe. Consequently, it is difficult to perform magnetic recording on this region.

Therefore, in the magnetic recording medium 10 according to the present example, magnetic recording is performed only on regions not including the separation region 202. Consequently, according to the present example, the continuous film layer 24 is a part of the perpendicular magnetic recording layer 30, and the separation regions are formed in the continuous film layer 24. In this manner, the magnetic recording medium 10 can function as a patterned medium or a DTR medium without forming grooves or the like all over the perpendicular magnetic recording layer 30. Thus, track edge noises are reduced and the track density is allowed to appropriately increase. As a result, according to the present example, the recording density of the magnetic recording medium 10 can be appropriately increased.

Figs. 3A and 3B are diagrams for illustrating the effect of formation of separation regions 202 and shows the simulation results of recording pattern of the information recorded on a magnetic recording medium having a structure different from the structure of the magnetic recording medium 10 in the present example. Fig. 3A shows a recording pattern of a granular medium. The granular medium refers to, for example, a magnetic recording medium including a perpendicular magnetic recording layer composed of merely a magnetic layer equivalent or similar to the granular layer 20 without disposing the coupling control layer 22 nor the continuous film layer 24 in contrast to the present example. In this granular medium, the film thickness of the granular layer is 30

nm.

In the granular medium, an exchange interaction between the magnetic crystal grains is satisfactorily small in a direction parallel to the main surface of the substrate. In this case, the gray region does not easily extend in the track width direction, while the values of recorded signals become values between 0 and 1 in the gray region. Therefore, in the granular medium, recording patterns are appropriately recorded in a recording track indicated by a rectangle 50. Consequently, in the granular medium, even when nonmagnetic regions are disposed between tracks as in a DTR medium or the like, the effect thereof is small.

However, in the granular medium, since the continuous film layer is not disposed, the thermal stability of recorded signals deteriorates as compared with, for example, the CGC media and the like. As a result, in the recording tracks, the magnetization of a part of the regions indicating individual bits of the recording pattern are reversed due to a thermal fluctuation phenomenon and the like. Such the reversal of magnetization may cause disappearance of the recorded information, so that an increase in recording density is hindered. Consequently, by the granular medium, it is difficult to realize a recording density exceeding, for example, 200 gigabits per square inch.

Fig. 3B shows a recording pattern of a CGC medium not including a separation region (hereafter referred to as a conventional CGC medium) in contrast to the present example. The conventional CGC medium is equivalent or similar to the magnetic recording medium 10 in the present example except that no separation region 202 is disposed. A perpendicular magnetic recording layer of the conventional CGC medium has a granular layer and a continuous film layer.

In the conventional CGC medium, since the continuous film layer has magnetic bonding strength in a direction parallel to the main surface of the

substrate, the gray regions of recorded signals easily extend in the track width direction. Consequently, recording patterns are formed while having gray regions, and the gray regions extend out from the recording track width indicated by a rectangle 50.

Such gray regions serve as sources of track edge noises. Therefore, in the case where a recording density exceeding, for example, 200 gigabits per square inch is intended to realize in the known CGC medium, the SN ratio decreases, and an appropriate improvement of the track density becomes difficult.

On the other hand, in the magnetic recording medium 10 of the present example, the separation regions 202 are disposed in regions between the tracks. The disposed separation regions 202 prevent extension out of the magnetic bonding strength from the track in the continuous film layer 24 in the direction parallel to the main surface of the substrate 12. In this manner, the gray regions are prevented from extending out from the recording track width. Consequently, according to the present example, track edge noises are reduced and the track density can be appropriately increased. As a result, the recording density of the magnetic recording medium 10 can be appropriately increased.

Figs. 4A and 4B show modified examples of the magnetic recording medium 10. The structures equivalent or similar to those in Fig. 1 are indicated by the same reference numerals as in Fig. 1 and explanations thereof are omitted except the points as described below.

Fig. 4A shows the structure of a magnetic recording medium 10 having an exchange spring medium structure. In this case, the magnetic recording medium 10 has a soft magnetic layer 32 as a second magnetic layer of the perpendicular magnetic recording layer 30 in place of the continuous film layer 24 (refer to Fig. 1). For example, a material equivalent or similar to the material for the soft magnetic layer 16 can be used as the material for the soft magnetic

layer 32. The film thickness of the soft magnetic layer 32 is, for example, 3 to 5 nm.

Separation regions 202 are formed in the soft magnetic layer 32 as in the continuous film layer 24. In this case also, track edge noises are reduced and the track density can be appropriately increased. Consequently, the recording density of the magnetic recording medium 10 can be appropriately increased.

Fig. 4B shows the structure of a magnetic recording medium 10 having an exchange coupled composite medium structure. In this case, the magnetic recording medium 10 has a soft magnetic layer 34 as a second magnetic layer of the perpendicular magnetic recording layer 30 in place of the continuous film layer 24.

The soft magnetic layer 34 is, for example, a NiFe layer containing SiO₂ at grain boundaries (NiFe-SiO₂ layer). The film thickness of the soft magnetic layer 34 is, for example, 2 to 4 nm (for example, about 3 nm). In this case also, track edge noises are reduced and the track density can be appropriately increased. Consequently, the recording density of the magnetic recording medium 10 can be appropriately increased.

Alternatively, the soft magnetic layer 34 may be a FeSiO layer. In this case, the film thickness of the soft magnetic layer 34 is, for example, 6 to 7 nm (for example, about 6.5 nm). The perpendicular magnetic recording layer 30 may have a laminated film (for example, 16 × [Co/PdSi]) in place of the granular layer 20. In the laminated film, 12 to 20 layers of Co layer and 12 to 20 layers of PdSi layer (for example, about 16 layers each) are laminated.

(Example 1)

An evacuated film formation apparatus was used. An adhesion layer 14 and a soft magnetic layer 16 were sequentially formed on an aluminosilicate glass substrate 12 by DC magnetron sputtering in an Ar atmosphere. At this case, the adhesion layer 14 was formed by using a CrTi target so as to become

a CrTi layer having a thickness of 10 nm. The soft magnetic layer 16 was formed by using a CoTaZr target so as to become an amorphous CoTaZr (Co: 88 atomic percent, Ta: 7 atomic percent, Zr: 5 atomic percent) layer having a total thickness of 50 nm. The soft magnetic layer 16 had a two-layer structure sandwiching a Ru layer having a thickness of 0.9 nm in order to control the magnetic domain.

After the formation of the soft magnetic layer 16, continuously, a Ta layer (thickness 3 nm) serving as a first orientation control layer and a Ru layer (thickness 20 nm) serving as a second orientation control layer and an isolation-promoting layer were formed as an underlayer 18 by DC magnetron sputtering in an Ar atmosphere. A granular layer 20 was formed by using a hard magnetic substance target formed from CoCrPt-SiO₂. The granular layer 20 had a thickness of 9 nm and contained magnetic crystal grains 102 having a hcp crystal structure. The composition of the target for forming the granular layer 20 was 62 atomic percent of Co, 10 atomic percent of Cr, 16 atomic percent of Pt, and 10 atomic percent of SiO₂.

A Pd layer (thickness 0.8 nm) was formed as the coupling control layer 22 and 3 × [CoCr/Pd] layers were formed as the continuous film layer 24 by using an Ar gas as a sputtering gas at a low pressure. The thickness of the CoCr layer was 0.4 nm, the thickness of the Pd layer was 0.9 nm. Three each of them were alternately laminated. The thickness of resulting continuous film layer 24 was 4 nm (3.9 to 4 nm).

A protective layer 26 was formed from hydrogenated carbon by using a mixed gas composed of Ar containing 30% of hydrogen and a carbon target as a sputtering target. The film hardness is improved by using hydrogenated carbon, so that the perpendicular magnetic recording layer 30 can be appropriately protected from the impact of the head.

After the protective layer 26 was formed, the resulting medium was

subjected to patterning by using nanoimprint. The protective layer 26 and the continuous film layer 24 were patterned so that grooves serving as separation regions 202 were formed in the regions between tracks. The width of this groove was 50 nm in the track width direction. The track width was 150 nm and the distance between the tracks was 200 nm.

Subsequently, a lubricant layer 28 composed of perfluoropolyether (PFPE) was formed by a dip coating method. The film thickness of the lubricant layer 28 was 1 nm. In this manner, the magnetic recording medium 10 according to Example 1 was formed. The magnetic recording medium 10 according to Example 1 was a DTR medium.

(Comparative Example 1)

A magnetic recording medium according to Comparative example 1 was formed as in Example 1 except that the coupling control layer 22 and the continuous film layer 24 were not formed. The magnetic recording medium according to Comparative example 1 was the granular medium explained with reference to Fig. 3A.

(Comparative Example 2)

A magnetic recording medium according to Comparative example 2 was formed as in Example 1 except that the separation region 202 was not formed. The magnetic recording medium according to Comparative example 2 was the conventional CGC medium explained with reference to Fig. 3B.

(Evaluation)

As described with reference to Fig. 3A, in the magnetic recording medium according to Comparative example 1, the thermal stability of recorded signals is unsatisfactory. As described with reference to Fig. 3B, in the magnetic recording medium according to Comparative example 2, gray regions of recorded signals extend in the track width direction so that track edge noises increase. Consequently, in these cases, it is difficult to realize a recording

density exceeding, for example, 200 gigabits per square inch.

On the other hand, in the magnetic recording medium 10 according to Example 1, satisfactory thermal stability can be obtained because of the CGC medium structure as compared with, for example, the magnetic recording medium according to Comparative example 1. Since the separation regions 202 are formed, track edge noises can be reduced as compared with, for example, the magnetic recording medium according to Comparative example 2. As a result, the SN ratio of the magnetic recording medium 10 according to Example 1 is improved by about 1.0 to 3.5 dB as compared with that of the magnetic recording medium according to Comparative example 2. Consequently, a recording density exceeding 200 gigabits per square inch, for example, a recording density of 500 gigabits per square inch or more, can be realized.

The present invention has been described with reference to the embodiments. However, the technical scope of the present invention is not limited to the scopes described in the above embodiments. It is clear that various changes or improvements can be applied to the above-described embodiments by one skilled in the art. The forms applied with such changes or improvements may be included within the technical scope of the present invention as defined in the claims.

The present invention can be favorably applied to, for example, magnetic recording media.

WHAT IS CLAIMED IS:

1. A magnetic recording medium for perpendicular magnetic recording, comprising:

a first magnetic layer which has magnetic crystal grains exhibiting perpendicular magnetic anisotropy and nonmagnetic substances for magnetically separating the magnetic crystal grains from each other at grain boundaries of the magnetic crystal grains;

a second magnetic layer which has magnetic grains exchange-coupled to the magnetic crystal grains, a grain boundary width of the magnetic grains being smaller than a grain boundary width of the magnetic crystal grains, and

separation regions which magnetically separate tracks from each other and which are disposed in regions between the tracks of the magnetic recording medium in at least the second magnetic layer.

2. The magnetic recording medium according to claim 1, wherein the separation regions are disposed substantially only in the second magnetic layer of the first magnetic layer and the second magnetic layer.

3. The magnetic recording medium according to claim 1, wherein the grain boundary width of the magnetic crystal grains in the first magnetic layer is 2 nm or more, and

the grain boundary width of the magnetic crystal grains in the second magnetic layer is 1 nm or less.

4. The magnetic recording medium according to claim 1, wherein the separation regions comprise grooves for magnetically separating the tracks from each other and the grooves are disposed along the tracks in the second magnetic layer.

5. The magnetic recording medium according to claim 1, further comprising:

a substrate for disposing the first magnetic layer and the second magnetic layer,

wherein the magnetic grains in the second magnetic layer exhibit perpendicular magnetic anisotropy and are exchange-coupled to each other with a strength larger than a bonding strength between the magnetic crystal grains in the first magnetic layer in a direction parallel to a main surface of the substrate, and

the magnetic crystal grains in the first magnetic layer and the magnetic grains in the second magnetic layer are exchange-coupled to each other in a direction perpendicular the main surface of the substrate.

6. The magnetic recording medium according to claim 1,

wherein the first magnetic layer is a layer having a granular structure and the nonmagnetic substances in the form of oxides are segregated at grain boundaries of the magnetic crystal grains, and

the second magnetic layer is a laminated film comprising Co compound layers and Pd layers or Pt layers which are alternately laminated.

7. A magnetic recording medium for perpendicular magnetic recording, comprising:

a substrate;

a first magnetic layer which has magnetic crystal grains exhibiting perpendicular magnetic anisotropy and nonmagnetic substances for magnetically separating the magnetic crystal grains from each other at grain boundaries of the magnetic crystal grains;

a second magnetic layer which has magnetic grains exchange-coupled to the magnetic crystal grains and exchange-coupled to each other with a strength larger than a bonding strength between the magnetic crystal grains in the first magnetic layer in a direction parallel to a main surface of the substrate; and

separation regions which magnetically separate tracks from each other

and which are disposed in regions between the tracks of the magnetic recording medium in at least the second magnetic layer.

8. A method for manufacturing a magnetic recording medium for perpendicular magnetic recording, comprising the steps of:

forming a first magnetic layer which has magnetic crystal grains exhibiting perpendicular magnetic anisotropy and nonmagnetic substances for magnetically separating the magnetic crystal grains from each other at grain boundaries of the magnetic crystal grains;

forming a second magnetic layer which has magnetic grains exchange-coupled to the magnetic crystal grains, a grain boundary width of the magnetic grains being smaller than a grain boundary width of the magnetic crystal grains; and

forming separation regions which magnetically separate tracks from each other in regions between the tracks of the magnetic recording medium in at least the second magnetic layer.

9. A method for manufacturing a magnetic recording medium for perpendicular magnetic recording, comprising the steps of:

preparing a substrate;

forming a first magnetic layer which has magnetic crystal grains exhibiting perpendicular magnetic anisotropy and nonmagnetic substances for magnetically separating the magnetic crystal grains from each other at grain boundaries of the magnetic crystal grains;

forming a second magnetic layer which has magnetic grains exchange-coupled to the magnetic crystal grains and exchange-coupled to each other with a strength larger than a bonding strength between the magnetic crystal grains in the first magnetic layer in a direction parallel to a main surface of the substrate; and

forming separation regions which magnetically separate tracks from each

other in regions between the tracks of the magnetic recording medium in at least the second magnetic layer.

10. A magnetic recording medium comprising a recording layer including an auxiliary recording layer and a main recording layer,

wherein the auxiliary recording layer has magnetic portions corresponding to recording bits and separation portions for separating the magnetic portions from each other, and

the main recording layer are divided into regions serving as recording bits by a magnetic influence exerted by the auxiliary recording layer.

11. The magnetic recording medium according to claim 10, wherein a magnetic anisotropy constant K_u of the auxiliary recording layer is larger than a magnetic anisotropy constant K_u of the main recording layer.

12. The magnetic recording medium according to claim 10, wherein the main recording layer has a granular structure.

13. The magnetic recording medium according to claim 10, wherein the recording layer is a perpendicular magnetic recording layer.

14. The magnetic recording medium according to claim 10, wherein the magnetic portion of the auxiliary recording layer is exchange-coupled to the main recording layer.