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Longitudinal Magnetic Recording Medium And A Method For Manufacturing The Same

Technical field of the invention

5 The present invention relates to a longitudinal magnetic recording medium mounted on a variety of magnetic recording devices such as an external memory device of a computer.

 The invention also relates to a method for manufacturing such a medium.

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Background of the invention

 The recording density of longitudinal magnetic recording medium is increasing at a remarkable rate. This trend is quite unlikely to slow down. There are some problems in achieving high recording
15 density. One of the big problems is enhancement of signal to noise ratio, SNR. Reduction of media noise through isolation and size reduction of magnetic particles is effective in SNR enhancement. Techniques for the noise reduction have been proposed including selection of appropriate composition of the underlayer and the
20 magnetic layer, control of conditions for depositing each layer, and multiplication or decrease of thickness of the underlayer and magnetic layer. Recently, a magnetic layer generally called as a granular magnetic layer has been proposed for an approach to the SNR reduction. The granular magnetic layer has a structure in



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which each ferromagnetic crystal grain is surrounded by nonmagnetic nonmetallic substance such as oxide or nitride

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5 255342, for example, discloses noise reduction by providing a granular recording layer in which ferromagnetic crystal grains are dispersed in a nonmagnetic film, the recording layer being formed by executing heat treatment after sequentially laminating a nonmagnetic film, a ferromagnetic film, and a nonmagnetic film. In
10 this case, the nonmagnetic film is an oxide or a nitride of silicon. United States Patent No. 5,679,473 discloses that noise reduction can be achieved by providing a granular recording film having a structure in which each of the magnetic crystal grains is surrounded and separated by nonmagnetic oxide region. The granular recording film
15 can be formed by means of RF sputtering using a CoNiPt target containing oxide such as SiO₂.

Because the nonmagnetic nonmetallic grain boundary phase physically separates each magnetic particle in this granular magnetic
20 layer, magnetic interaction acting between the magnetic particles decreases and a zigzag-shaped magnetic domain wall is suppressed to develop in a transition region of a recording bit. As a result, a low noise characteristic is considered to be attained. In a conventionally used metallic magnetic film of CoCr system, chromium segregates

from a magnetic particle of cobalt system and precipitates at the grain boundary by deposition at a high temperature, to reduce magnetic interaction between the magnetic particles. The granular magnetic layer has the advantage of easily promoting isolation of magnetic particles because the grain boundary phase of the granular magnetic layer uses nonmagnetic nonmetallic substance, which segregates more easily than conventional chromium. Raising substrate temperature to at least 200°C was indispensable in the deposition process of a conventional metallic magnetic layer of CoCr system for enough segregation of chromium. In contrast, the granular magnetic layer also has the advantage that the nonmagnetic metallic substance segregates even in a deposition process without heating as in the case with heating.

In addition to decrease of magnetic interaction between particles by virtue of promoting segregation structure in the magnetic layer, enhancement of recording density and noise reduction in a longitudinal magnetic recording medium also require control of crystal alignment of the ferromagnetic crystal grain of CoCr system, that is in-plane alignment of c-axis of the ferromagnetic crystal grains having hexagonal closest packed structure. Consequently, control of crystal alignment in the conventional metallic magnetic layer has been performed by controlling structure and crystal alignment of a nonmagnetic underlayer.

On the other hand, the effect of the nonmagnetic underlayer has been assumed little in a longitudinal magnetic recording medium having the granular magnetic film, because the nonmagnetic underlayer is separated from the ferromagnetic crystal grains by oxide or other grain boundary segregation substance. However, Journal of the Magnetism Society of Japan vol. 23, no. 4-2, p 1021 (1999) discloses that (100) plane and (101) plane of the ferromagnetic crystal grain are predominantly aligned in the granular magnetic layer by using an underlayer of CrMo alloy with a special composition having predominantly aligned (110) plane, leading to improvement in magnetic characteristics and electromagnetic conversion characteristics.

Problem to be solved by the invention

Minimization of the particle size of the magnetic particles is indispensable to achieve SNR enhancement accompanied by high recording density. It is known that minimization of the particle size is more easily attained in a granular magnetic layer than in a conventional magnetic layer of CoCrPt system when the structure of the medium has a usual layer structure that does not utilize antiferromagnetic coupling and consists of a nonmagnetic underlayer, a nonmagnetic intermediate layer, a magnetic layer, a protective film layer, and a liquid lubricant layer. However, the coercive force H_c of the medium decreases with the minimization of the magnetic

particles. This phenomenon is considered to arise due to thermal fluctuation of magnetization, in which thermal energy around the magnetic particle increases as the particle size decreases. When the effect of the thermal fluctuation increases, decay of the recording
5 signal becomes noticeable, which reduces the coercive force H_c of the medium. Thus, high recording density was hardly compatible with resistance to the thermal fluctuation.

Therefore, it has been demanded to produce a longitudinal
10 magnetic recording medium with minute magnetic particles and superior resistance to the thermal fluctuation. More specifically, the desired longitudinal magnetic recording medium exhibits improved SNR resulted from minute magnetic particles obtained by employing a granular magnetic layer and the superior resistance to the thermal
15 fluctuation.

A conventional production process of a longitudinal magnetic recording medium needs a step of preheating the nonmagnetic substrate. But, a production method without the heating step is
20 desired to reduce a manufacturing cost.

Therefore, an object of the present invention is to provide a longitudinal magnetic recording medium with high SNR that exhibits superior resistance to thermal fluctuation despite minute magnetic

particles obtained by the granular magnetic layer. The resistance to thermal fluctuation is ensured by a medium structure that utilizes antiferromagnetic coupling. Media noise is reduced by achieving minute magnetic particles employing a granular magnetic layer.

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Another object of the invention is to provide a method for manufacturing a longitudinal magnetic recording medium that exhibits high SNR and does not need a heating step.

10 Means to solve the problem

The first aspect of the present invention is a longitudinal magnetic recording medium that comprises a nonmagnetic substrate and the layers sequentially laminated on the substrate including at least a nonmagnetic underlayer, a nonmagnetic intermediate layer, a pair of a magnetic stabilizing layer and a nonmagnetic metallic
15 spacer layer, a granular magnetic layer, a protective film layer, and a liquid lubricant layer. The magnetic layer of the longitudinal magnetic recording medium of the invention has a granular structure consisting of ferromagnetic crystal grains with a hexagonal closest
20 packed structure and nonmagnetic grain boundary region mainly of oxide surrounding the grains. The magnetic layer is antiferromagnetically coupled with the stabilizing layer through the spacer layer.

The magnetic underlayer is preferably composed of at least a metal selected from W, Mo, and V, or an alloy containing 10 at % to 60 at % of Ti and a metal selected from W, Mo, Cr, and V. The nonmagnetic intermediate layer is preferably composed of at least a
5 metal selected from Ru, Ir, Rh, and Re, or an alloy containing 10 at % to 60 at % of Ti, C, W, Mo, or Cu and a metal selected from Ru, Ir, Rh, and Re

The stabilizing layer is preferably composed of an alloy
10 containing mainly cobalt and at least an additive of Cr, Ta, Pt, B, or Cu. Alternatively, the stabilizing layer is preferably composed of ferromagnetic grains and nonmagnetic grain boundary region of an oxide or a nitride of at least an element selected from Cr, Co, Si, Al, Ti, Ta, Hf, and Zr. The stabilizing layer preferably has coercive force
15 H_c smaller than H_c of a magnetic layer that is disposed on the spacer layer.

A material for the spacer layer is preferably composed of a metal selected from Ru, Re, and Os, or an alloy containing at least one
20 metal selected from Ru, Re, and Os. The material for the spacer layer preferably has a hexagonal crystal structure. The thickness of the spacer layer is preferably in the range from 0.5 nm to 2.0 nm.

The nonmagnetic grain boundary region in the magnetic layer is

preferably composed of an oxide or a nitride of at least an element selected from Cr, Co, Si, Al, Ti, Ta, Hf, and Zr.

The nonmagnetic substrate can be made of crystallized glass,
5 chemically strengthened glass, or a plastic resin.

The second aspect of the present invention is a method for manufacturing a longitudinal magnetic recording medium described above. The method of the invention does not need a step of
10 preheating the nonmagnetic substrate.

Brief description of drawings

Figure 1(a) is a schematic cross-sectional view of a longitudinal
15 magnetic recording medium according to the present invention.

Figure 1(b) is a schematic cross-sectional view of a longitudinal magnetic recording medium of a prior art.

20 Figure 2(a) is a chart showing an M-H loop of Comparative Example 3 that has a layer structure of a prior art.

Figure 2(b) is a chart showing an M-H loop of Example 1 that uses antiferromagnetic coupling according to the invention.

Figure 3 is a graph showing the dependence of the product of residual magnetic flux density and film thickness $Br \cdot \delta$ on thickness of the spacer layer.

- 5 Figure 4 is a graph showing dependence of $Br \cdot \delta$ on the thickness of the stabilizing layer.

Aspects of embodiments of the invention

The following describes the present invention in detail.

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The first invention will be described.

- The first invention of the present application is a longitudinal magnetic recording medium that comprises a nonmagnetic substrate and layers laminated on the substrate including at least a
- 15 nonmagnetic underlayer, a nonmagnetic intermediate layer, a pair of a magnetic stabilizing layer and a nonmagnetic metallic spacer layer, a granular magnetic layer, a protective film layer, and a liquid lubricant layer. The magnetic layer has a granular structure consisting of ferromagnetic grains with hexagonal closest packed
- 20 structure and nonmagnetic grain boundary region composed mainly of oxide surrounding the grains. The magnetic layer is antiferromagnetically coupled with the stabilizing layer through the spacer layer.

When a spacer layer with a suitable thickness and a stabilizing layer with a proper magnetic characteristic are provided under the magnetic layer, antiferromagnetic coupling can be induced between the magnetic layer and the stabilizing layer separated by the spacer layer. The antiferromagnetic coupling is said to arise from RKKY interaction (Ruderman-Kittel, Kasuya, Yoshida interaction). The magnitude of the interaction is represented by a damping oscillation function of the thickness of the spacer layer. That is, the antiferromagnetic coupling occurs only in the limited range of the spacer layer thickness.

The magnetization of the portions that are antiferromagnetically coupled through the spacer layer takes antiparallel state each other and are not observed macroscopically. Consequently, the magnetization involved in a magnetic recording characteristic such as SNR is only carried by the magnetization of the portion that is not antiferromagnetically coupled. Specifically, the top layer of the magnetic layer or only a portion within the magnetic layer is involved in the recording and regeneration of signals.

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One of the indices to resistance to thermal fluctuation is $K_u V / k_B T$ value, where K_u : anisotropy constant, V : volume of a magnetic particle, k_B : Boltzmann constant, and T : absolute temperature. $K_u V$ represents magnetic energy and $k_B T$ represents thermal energy.

Consequently, the $KuV/k_B T$ value is a ratio of the magnetic energy to the thermal energy, and the larger this value is, the higher the resistance to thermal fluctuation is. Because the volume V in the $KuV/k_B T$ value can be considered incorporating the volume of the antiferromagnetically coupled portion, the $KuV/k_B T$ value of a medium including an antiferromagnetically coupled structure has a large value, whereby a thermally stable longitudinal magnetic recording medium can be obtained.

In a conventional structure, a magnetic layer bears both functions of magnetic recording and resistance to thermal fluctuation. In a medium of the invention, in contrast, the functions can be separately born by virtue of the antiferromagnetic coupling. Accordingly, high recording density is compatible with resistance to thermal fluctuation in the invented medium.

The accompanying drawings will be used to make explanation easier.

Figure 1(a) is a schematic cross-sectional view of a longitudinal magnetic recording medium according to the present invention. Figure 1(b) is a schematic cross-sectional view of a longitudinal magnetic recording medium of a prior art.

As shown in Figure 1(a), a longitudinal magnetic recording

medium according to the invention has a structure in which a nonmagnetic underlayer 2a, a nonmagnetic intermediate layer 3a, a stabilizing layer 4a, a spacer layer 5a, a granular magnetic layer 6a, and a protective film layer 7a are sequentially laminated on a
5 nonmagnetic substrate 1a. On this laminate, a liquid lubricant layer 8b is formed. On the other hand, a longitudinal magnetic recording medium of a prior art (Figure 1(b)) has a structure in which a nonmagnetic underlayer 2b, a nonmagnetic intermediate layer 3b, a granular magnetic layer 6b, a protective film layer 7b, and a liquid
10 lubricant layer 8b sequentially formed on a nonmagnetic substrate 1b, and does not comprise a stabilizing layer and a spacer layer that are featured in the longitudinal magnetic recording medium of the invention shown in Figure 1(a).

15 A nonmagnetic substrate 1a may be composed of NiP-plated aluminum alloy, strengthened glass, or crystallized glass, which are all used in a usual magnetic recording medium for longitudinal recording. Since substrate heating is unnecessary, a substrate made by injection molding polycarbonate, polyolefin, or another resin can
20 also be used. The protective film layer 7a is a thin film of mainly carbon, for example. The liquid lubricant layer 8a is made of perfluoropolyether lubricant, for example.

The magnetic layer 4a is a granular magnetic layer consisting of

ferromagnetic crystal grains and nonmagnetic grain boundary region surrounding the grains, the grain boundary region being composed of oxide or nitride of metal. Such granular structure can be formed by means of, for example, a sputtering method using a target of
5 ferromagnetic alloy containing an oxide constituting the nonmagnetic grain boundary region.

An alloy of CoPt system can be preferably used for a material composing the ferromagnetic crystal grains, though not limited to a
10 special material. In order to form a stable granular structure, it is particularly favorable to use an oxide of an element selected from Cr, Co, Si, Al, Ti, Ta, Hf, and Zr for the grain boundary region in combination with the ferromagnetic crystal grains of the CoPt alloy. The magnetic layer needs to have a thickness that is necessary and
15 sufficient to produce enough strength of head regeneration output.

The nonmagnetic underlayer 2a needs to have a body-centered cubic (bcc) structure and the dominant crystal alignment plane of the underlayer is necessarily the (200) plane, because lattice misfit with
20 respect to the nonmagnetic intermediate layer or the magnetic layer can be reduced. Preferable material for the underlayer includes a metal selected from W, Mo, and V, and an alloy composed of 10 at % to 60 at % of Ti and a metal selected from W, Mo, Cr, and V.

Even if 10 at % to 60 at % of Ti, which has a hexagonal closest packed structure, is contained in W, Mo, Cr, or V, which has a body-centered cubic structure, the body-centered cubic structures is retained and the alignment inherent to the hexagonal closest packed structure does not appear. The predominant (200) alignment of the body-centered cubic structure arises more effectively and the lattice constant with small misfit to the nonmagnetic intermediate layer or the magnetic layer is obtained. The thickness of the nonmagnetic underlayer is preferably from 5 nm to 100 nm.

The nonmagnetic intermediate layer 3a preferably has the hexagonal closest packed structure, which is the same as the structure of the ferromagnetic crystal grains in the magnetic layer. The favorable material for the intermediate layer includes Ru, Ir, Rh, Re, and an alloy of Ru, Ir, Rh, or Re each containing 10 at % to 60 at % of Ti, C, W, Mo, or Cu. The thickness of the intermediate layer is preferably in the range from 2 nm to 50 nm.

The stabilizing layer, which is featured by the layer structure according to the invention, can be composed of an alloy of mainly Co with an appropriate addition of at least one element selected from Cr, Ta, Pt, B, and Cu. The stabilizing layer can be alternatively composed of ferromagnetic grains and an oxide or a nitride of at least one element selected from Cr, Co, Si, Al, Ti, Ta, Hf, and Zr. The

thickness of the stabilizing layer is confined in the range such that the coercive force H_c of the stabilizing layer is smaller than the H_c of the magnetic layer disposed on the spacer layer, and the preferable range is from 2 nm to 10 nm.

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The material for the spacer layer 5a preferably has a hexagonal crystal structure and is selected from Ru, Re, Os, and alloys each containing at least one element selected from Ru, Re, and Os. The thickness is preferably in the range of from 0.5 nm to 2.0 nm.

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Next, the second aspect of the present invention is described in the following.

The second invention of the present application is a method for
15 manufacturing a longitudinal magnetic recording medium that is described above and shown in Figure 1(a). The method of the invention features to allow omitting a substrate heating step, which is essential in prior art methods.

20 Manufacturing a longitudinal magnetic recording medium according to the method of the invention can be conducted using a usual RF sputtering apparatus, for example.

Firstly, a substrate is introduced into the apparatus; a target of

predetermined material is mounted; argon gas pressure in the apparatus is adjusted to an appropriate value; and power is supplied to an electrode to deposit an underlayer. In the same manner as in the case of the underlayer described above, laminated are an
5 intermediate layer, a stabilizing layer, a spacer layer, a granular magnetic layer, and a protective film layer, successively changing to a target having an appropriate composition. Here, deposition of the granular magnetic layer containing oxide is conducted using RF power supply. Finally, liquid lubricant is applied to complete a
10 longitudinal magnetic recording medium.

According to the invented method, a longitudinal magnetic recording medium exhibiting high H_c and low media noise can be obtained if a step of substrate heating is omitted, the step being
15 essential in a method for manufacturing a conventional type longitudinal magnetic recording medium. As a result, simplification of the manufacturing process and reduction of manufacturing cost can be achieved.

20 Examples

Some specific examples of preferred embodiments of the present invention will be described in the following.

Example 1

A chemically strengthened glass substrate N-10 manufactured by HOYA Corporation, was used for a nonmagnetic substrate. After cleaning, the substrate was introduced into a sputtering apparatus, and an underlayer of tungsten 30 nm thick was formed under argon gas pressure of 15 mTorr (2.0 Pa). Subsequently, an intermediate layer of ruthenium 10 nm thick was formed under argon gas pressure of 15 mTorr (2.0 Pa); a stabilizing layer of $\text{Co}_{83}\text{Cr}_{13}\text{Ta}_4$ with a thickness of 5 nm was formed under argon gas pressure of 15 mTorr (2.0 Pa); and a spacer layer of ruthenium 1.0 nm thick was formed under argon gas pressure of 15 mTorr (2.0 Pa). A granular magnetic layer 15 nm thick was formed by means of an RF sputtering method using a target of $\text{Co}_{76}\text{Cr}_{10}\text{Pt}_{14}$ containing 7 mol % of SiO_2 under argon gas pressure of 30 mTorr (4.0 Pa). After laminating a carbon protective film layer 10 nm thick, the laminated substrate was taken out from the vacuum chamber. Applying liquid lubricant to the thickness of 1.5 nm, a longitudinal magnetic recording medium having a layer structure as shown in Figure 1(a) was produced. In this manufacturing process, a step of substrate heating before laminating process was not executed.

Example 2

A longitudinal magnetic recording medium was produced using the same compositions and deposition processes as in Example 1

except that the stabilizing layer was a granular magnetic layer 5 nm thick formed by means of an RF sputtering method using a target of $\text{Co}_{88}\text{Cr}_{10}\text{Pt}_{12}$ containing 6 mol % of SiO_2 under argon gas pressure of 30 mTorr (4.0 Pa).

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Comparative Example 1

A medium of Comparative Example 1 has a layer structure of the present invention, but its magnetic layer is not a granular magnetic layer. The longitudinal magnetic recording medium of the

10 Comparative Example 1 was produced using the same compositions and deposition processes as in Example 1 except that the magnetic layer 15 nm thick was formed by means of a DC sputtering method using a target of $\text{Co}_{64}\text{Cr}_{22}\text{Pt}_{10}\text{B}_4$ under argon gas pressure of 30 mTorr (4.0 Pa).

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Comparative Example 2

A medium of Comparative Example 2 has a layer structure of a prior art and its magnetic layer is not a granular magnetic layer. The longitudinal magnetic recording medium of the Comparative

20 Example 1 was produced forming an underlayer, an intermediate layer, a carbon protective film layer, and a liquid lubricant layer in the same deposition conditions and film thicknesses as in Example 1. The magnetic layer in the medium of Comparative Example 2 was formed to a thickness of 15 nm composed of $\text{Co}_{64}\text{Cr}_{22}\text{Pt}_{10}\text{B}_4$ under

argon gas pressure of 30 mTorr (4.0 Pa).

Comparative Example 3

A medium of Comparative Example 3 has a granular magnetic layer, but its layer structure is of a prior art. A longitudinal magnetic
5 recording medium of the Comparative Example 3 was produced using the same compositions and deposition processes as in Comparative Example 2 except that the magnetic layer that is a granular magnetic layer 5 nm thick was formed by means of an RF sputtering method using a target of $\text{Co}_{76}\text{Cr}_{10}\text{Pt}_{14}$ containing 7 mol % of SiO_2 under argon
10 gas pressure of 30 mTorr (4.0 Pa).

Evaluation

Figure 2(a) is a chart showing an M-H loop of Comparative Example 3 that has a layer structure of a prior art; and Figure 2(b) is
15 a chart showing an M-H loop of Example 1 that uses antiferromagnetic coupling according to the invention. Measurement was done by means of a vibrating sample magnetometer (VSM). The hysteresis loop of the medium provided with a stabilizing layer and a spacer layer showed a step-like drop of magnetization around zero
20 external magnetic field as observed in Figure 1(b), which is a noticeable characteristic that is not observed in the hysteresis loop of a medium with conventional structure shown in Figure 2(a).

The drop of the magnetization indicates existence of the

antiferromagnetic coupling within the medium. The magnitude of the drop of the magnetization depends on the film thickness and the magnetic properties of the stabilizing layer and the magnetic layer, and is not restricted in embodiments of the invention.

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Figure 3 shows the dependence of the product of residual magnetic flux density and film thickness: $Br^*\delta$ on thickness of the spacer layer for the medium of Example 2. The measurement was made using a VSM. Figure 3 shows that $Br^*\delta$ does not change in the thickness range up to 0.4 nm, while abrupt drop is observed around 0.5 nm. In the range from 0.6 nm to 1.8 nm the $Br^*\delta$ is substantially constant and then gradually increases. This result suggests that the antiferromagnetic coupling occurs in the limited range of the spacer layer thickness, and the coupling is weak outside the range.

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15 According to this Example, the spacer layer thickness is preferably in the range from 0.5 nm to 2.0 nm to set up the antiferromagnetic coupling.

Figure 4 shows dependence of $Br^*\delta$ on the thickness of the stabilizing layer. Measurement was made using a VSM. Figure 4 indicates that $Br^*\delta$ decreases with increase of the stabilizing layer thickness, while beyond certain thickness the $Br^*\delta$ increases. That is, the reduction of $Br^*\delta$ by virtue of the antiferromagnetic coupling increases with increase of the stabilizing layer thickness, while

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beyond certain thickness the coupling becomes weak and the reduction of $Br^*\delta$ decreases. The reduction in $Br^*\delta$ was maximum at the stabilizing layer thickness of 6.0 nm in this Example. However, the reduction in $Br^*\delta$ varies depending on the composition and thickness of the stabilizing layer and the magnetic layer, and no restriction is posed on embodiments of the present invention.

Table 1 gives coercive force H_c (Oe), average grain size in the magnetic layer (nm), $K_uV/k_B T$ value that is an index to thermal fluctuation, and electromagnetic conversion characteristics including normalized noise ($\mu V_{rms}/mV_{pp}$) and SNR (dB) for the Examples and Comparative Examples. The $K_uV/k_B T$ value was measured by a VSM, and the electromagnetic conversion characteristics were measured by a spinning stand tester equipped with a GMR head.

Table 1

sample	H_c [Oe]	grain size [nm] (*)	$K_uV/k_B T$	normalized noise [$\mu V_{rms}/mV_{pp}$]	SNR [dB]
Example 1	3,873	6.92	94	36.8	22.5
Example 2	4,142	5.11	83	31.9	24.5
Comp Ex 1	3,642	8.01	101	37.1	21.6
Comp Ex 2	3,083	7.83	76	38.4	21.1
Comp Ex 3	3,742	6.08	62	36.2	22.7

(*) mean grain size in the magnetic layer

Concerning the H_c , the medium (Comparative Example 1) having a magnetic layer of $\text{Co}_{64}\text{Cr}_{22}\text{Pt}_{10}\text{B}_4$ that is a composition of the CoCrPt alloy system with a nongranular structure exhibited a smaller value of H_c than Example 1 having a granular magnetic layer. This
5 difference can be attributed to the difference in platinum content in the magnetic layer. Observing the grain sizes in the magnetic layer of the Examples and Comparative Examples, finer grain sizes are noticeable in Examples 1 and 2, and Comparative Example 3 that use a granular film for a magnetic layer. Comparing Comparative
10 Example 2 and Comparative Example 3, both having a layer structure of a conventional longitudinal magnetic recording medium, the use of a granular magnetic layer for a magnetic layer has brought about enhancement of H_c by optimization of the composition and reduction of noises, that is enhancement of SNR, by promoting grain
15 size reduction in the magnetic layer.

Next, the $K_uV/k_B T$ value is considered.

It is generally considered that the thermal fluctuation is not
20 problematic if the $K_uV/k_B T$ value is at least 60. In Comparative Example 3 that uses a granular magnetic layer for a magnetic layer, although noises were reduced by decrease of the grain size in the magnetic layer, the $K_uV/k_B T$ value was reduced to the value of 62 just due to the decrease of the grain size. This indicates that further

decrease of the grain size aiming at lower noises required by the higher recording density and makes the problem of thermal fluctuation serious if a granular structure is employed in the conventional layer structure of a medium.

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Comparative Example 2 using a CoCrPt alloy without an oxide for the magnetic layer has a little larger grain size than Comparative Example 3 and exhibits a $K_uV/k_B T$ value of 76, which is not very small. However, the influence of the thermal fluctuation becomes significant when the recording density is further raised, which is a similar situation to the above-mentioned case of the granular magnetic layer.

Examples 1 and 2 and Comparative Example 1 that comprises a stabilizing layer and a spacer layer according to the invention exhibits larger $K_uV/k_B T$ values than Comparative Examples 2 and 3, whereby thermal stability is improved.

Now look at the electromagnetic conversion characteristic. Example 1 having a stabilizing layer of CoCr alloy without an oxide and a magnetic layer of a granular magnetic layer exhibits larger $K_uV/k_B T$ value than Example 2, and larger grain size in the magnetic layer based on the difference in the composition. The SNR is not improved as compared with Comparative Example 3. In contrast to

the Example 1, in the Example 2, in which both stabilizing and magnetic layers are composed of a granular composition, enhancement of the $K_uV/k_B T$ value is compatible with improvement of SNR by virtue of the fine grain size, and the largest effect has been
5 demonstrated.

Because a structure with fine grain size can be readily obtained in a granular magnetic layer as compared with in a usual magnetic layer of CoCr alloy, the effect of the present invention is largest when
10 the stabilizing layer is composed of a granular film with optimized composition and the magnetic layer is also composed of a granular magnetic layer.

Reduction of the mean grain size in the magnetic layer can be
15 accomplished by optimization of the thickness of the nonmagnetic underlayer and other means, even when the stabilizing layer is composed of an alloy of CoCr system. Accordingly, resistance to thermal fluctuation can be compatible with reduction of noises also in the combination of a stabilizing layer of CoCr alloy and a granular
20 magnetic layer.

As described above, a pair of a stabilizing layer and a spacer layer is provided in a longitudinal magnetic recording medium, and the thicknesses of the stabilizing layer and the spacer layer are

optimized. In this structure, antiferromagnetic coupling is induced between the stabilizing layer and the magnetic layer through the spacer layer. As a result, resistance to thermal fluctuation is raised. Further, this structure brings about fine magnetic particles that were
5 conventionally impossible, resulting in high SNR and leading to enhanced recording density.

Because excellent characteristics can be readily obtained by employing the layer structure of the invention, substrate heating is
10 unnecessary in the process of laminating a medium of the invention. Accordingly, inexpensive plastic can be used for a substrate as well as usual aluminum and glass substrates.

Advantageous Effect of the invention

15 A medium comprising a stabilizing layer, a spacer layer, and a granular magnetic layer according to the present invention provides resistance to thermal fluctuation that is compatible with noise reduction by virtue of fine grain size.

When the composition and the film thickness of the spacer layer,
20 the stabilizing layer, and the magnetic layer, and deposition conditions for these layers are optimized, antiferromagnetic coupling arises between the stabilizing layer and the magnetic layer, whereby resistance to thermal fluctuation is ascertained. Consequently, noise reduction, which means SNR enhancement, can be accomplished by

employing fine magnetic particles, use of which was impossible due to significant influence of thermal fluctuation in a usual layer structure.

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Claims

1. A longitudinal magnetic recording medium comprising:
a nonmagnetic substrate; and layers sequentially laminated on
said substrate including at least
5 a nonmagnetic underlayer,
a nonmagnetic intermediate layer,
a pair of a magnetic stabilizing layer and a nonmagnetic metallic
spacer layer,
a magnetic layer having a granular structure that consists of
10 ferromagnetic crystal grains with hexagonal closest packed structure
and nonmagnetic grain boundary region of mainly oxide surrounding
said grains,
a protective film layer, and
a liquid lubricant layer, wherein
15 said stabilizing layer and said magnetic layer is
antiferromagnetically coupled through said spacer layer.
2. A longitudinal magnetic recording medium according to claim 1,
wherein said underlayer is composed of a material selected from W,
20 Mo, V, and alloys each containing 10 at % to 60 at % of Ti and a metal
selected from W, Mo, Cr, and V.
3. A longitudinal magnetic recording medium according to claim 1
or claim 2, wherein said intermediate layer is composed of a material

selected from Ru, Ir, Rh, Re, and alloys each containing 10 at % to 60 at % of Ti, C, W, Mo, or Cu and a metal selected from Ru, Ir, Rh, and Re.

5 4. A longitudinal magnetic recording medium according to any one of claims 1 through 3, wherein said stabilizing layer is composed of an alloy of mainly Co added by at least one element selected from Cr, Ta, Pt, B, and Cu, or a granular structure consisting of ferromagnetic
10 crystal grains and an oxide or a nitride of at least one element selected from Cr, Co, Si, Al, Ti, Ta, Hf, and Zr, and coercive force Hc of said stabilizing layer is smaller than Hc of said magnetic layer disposed on said spacer layer.

15 5. A longitudinal magnetic recording medium according to any one of claims 1 through 4, wherein material for said spacer layer is selected from Ru, Re, Os, and alloys each containing at least one element selected from Ru, Re, and Os, and has a hexagonal closest packed structure; and thickness of said spacer layer is from 0.5 nm to 2.0 nm.

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6. A longitudinal magnetic recording medium according to any one of claims 1 through 5, wherein said grain boundary region in said magnetic layer is mainly composed of an oxide of at least an element selected from Cr, Co, Si, Al, Ti, Ta, Hf, and Zr.

7. A longitudinal magnetic recording medium according to any one of claims 1 through 6, wherein said substrate is made of crystallized glass, chemically strengthened glass, or plastic resin.

5 8. A method for manufacturing a longitudinal magnetic recording medium that is defined by any one of claims 1 through 7, wherein deposition of said layers is conducted without a step of preheating said substrate.

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