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MAGNETIC RECORDING MEDIUM AND METHOD OF MANUFACTURING THE SAME

Background of the Invention:

This invention relates to a magnetic recording medium for magnetically recording information, and a method of manufacturing the same.

Recently, a high recording density has been required for a magnetic recording medium. To this end, a great attention has been paid for a magnetic layer of a magnetic recording medium which is composed of multiple magnetic thin-film media successively deposited and which may be called a successive thin-film medium. Alloys of CoPtCr and CoCrTa system have been known as the magnetic layer of the above successive thin-film medium and is generally deposited by the known sputtering method.

In the magnetic recording medium having the high recording density, both a high coercive force and a low noise are required. However, it is conventionally difficult to satisfy both the high coercive force and the low noise at the same time. Namely, although the conventional ternary alloy of a CoPtCr system is excellent in the high coercive force, it is insufficient in the low noise. On the other hand, the conventional ternary alloy of a CoCrTa system is excellent in the low

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noise, but it is insufficient in the high coercive force.

It has been noticed that both the high coercive force and the low noise can be achieved by adjusting composition and the film thickness of an underlying layer which are parameters for realizing the high density of the magnetic recording medium.

Therefore, suggestion has been made in Unexamined Japanese Patent Publication (JP-A) No. H1-256017 about a magnetic recording medium having a magnetic layer of a CoCrTaPt quaternary alloy which is directed to the high coercive force by adjusting compositions of an underlying layer and a magnetic layer. Such a magnetic recording medium is formed by successively depositing a Cr layer as the underlying layer and a quaternary alloy magnetic layer on a nonmagnetic substrate. However, a lattice constant of the magnetic layer is increased in the above magnetic recording medium. Consequently, a difference of the lattice constants between the magnetic layer and the underlying layer becomes large. The number of crystal grains wherein C axes are inclined with respect to the film surface of the magnetic layer is increased because of the difference of the lattice constants (in this case, it is desirable that the C axis of each grain in the magnetic layer is parallel to the magnetic film to improve the coercive force). As a result, the coercive force becomes 1700 Oe at most and therefore, the coercive force can not be improved contrary to the expectation.

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To solve such a problem, another suggestion has been made in Unexamined Japanese Patent Publication (JP-A) No. H5-325163 about a magnetic recording medium wherein a magnetic characteristic and a record/reproduce characteristic are improved by matching a magnetic layer with an underlying layer in a lattice constant. In such a magnetic recording medium, a layer which contains Cr as a main component and includes at least one of Mo and W is used as an underlying layer of an alloy magnetic layer which includes a novel metal such as Pt, Pd and Rh and includes Co as a main component. Consequently, the magnetic layer has a lattice constant substantially equal to that of the underlying layer. As a result, the high coercive force can be obtained according to the above magnetic recording medium. However, the noise can not be sufficiently reduced in the above magnetic recording medium because the grain size of the underlying layer becomes large as compared with the Cr underlying layer.

Summary of the Invention:

It is therefore an object of this invention to provide a magnetic recording medium and a method of manufacturing the same which is capable of accomplishing both a high coercive force and a low noise.

In a magnetic recording medium according to this invention, a first underlying layer including Al is formed on a glass substrate. Further, a second underlying layer including Cr is formed on the first underlying layer. In addition, a third underlying layer

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of a Cr alloy is formed on the second underlying layer. Finally, a magnetic layer of a Co alloy is formed on the third underlying layer.

With such a structure, the grain size of the second underlying layer is relatively small and falls within the range between 50 and 300 Å . The third underlying layer and the magnetic layer are formed by reflecting the small grain size of the second underlying layer. Specifically, the grain sizes of the third underlying layer and the magnetic layer also become small in dependency upon the grain size of the second underlying layer. Specifically, the grain sizes fall within the range between 50 and 300 Å . As a result, the low noise can be realized.

Thus, the lattice constants between the third underlying layer and the magnetic layer are substantially identical to each other. Consequently, the direction of the crystal axis of the magnetic layer substantially becomes parallel to the film surface. As a result, the high coercive force can be realized.

Thus, both the high coercive force and the low noise can be realized at the same time according to this invention.

Brief description of the Drawings:

Fig. 1 is a schematic cross sectional view of a magnetic recording medium according to a first embodiment of this invention.

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Fig. 2 is a schematic cross sectional view of a magnetic recording medium according to a second embodiment of this invention.

Fig. 3 shows an in-line type DC magnetron sputtering apparatus which is used in manufacturing a magnetic recording medium according to this invention.

Description of the Preferred Embodiments:

Referring to Fig. 1, description will be made about a magnetic recording medium according to a first embodiment of this invention.

As shown in Fig. 1, an underlying layer 2 is formed on a glass substrate 1. The illustrated underlying layer 2 is formed by three layers.

A first underlying layer 2a includes Al as a main component and is deposited on the glass substrate 1. Further, a second underlying layer 2b includes Cr and is deposited on the first underlying layer 2a. A grain size of the second underlying layer 2b falls within the range between 50 and 300 Å. In addition, a third underlying layer 2c is deposited on the second underlying layer 2b. The third underlying layer 2c includes Cr and at least one material selected from a group consisting of Mo, Zr, B, Si, Zn, Ti, W, V, Ta, and Al. A magnetic layer 3 is formed on the underlying layer 2.

In this event, the magnetic layer 3 has a composition represented by the following chemical formula.

$$Co_{100-X-Y-Z}\ Cr_X\ Pt_Y\ Ta_Z \qquad (1)$$

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where X, Y and Z represent a composition ratio of each component by at%. Herein, it is to be noted that X falls within the range between 5 and 20 at%, Y falls within the range between 3 and 16 at%, and Z falls within the range between 1 and 7 at%.

A protection layer 4 of carbon is deposited on the magnetic layer 3. Further, a lubricant layer is coated on the protection layer 4.

It is desirable that a nonmagnetic material is used as a base substrate. As mentioned above, the magnetic recording medium has the glass substrate 1 as the base substrate. The glass substrate 1 is excellent in a mechanical, physical and chemical durability and is easy to obtain a surface having high plane accuracy. Therefore, a high recording density can be achieved by useing the glass substrate 1.

Specifically, a chemical reinforced glass substrate and a crystallized glass substrate may be used as the glass substrate 1. More specifically, aluminosilicate glass, aluminoborosilicate glass, borosilicate glass, silicate glass, soda-lime glass, and oxynitride glass are used as the material of the glass substrate 1. Further, a nonmetal substrate, such as a ceramic substrate, a glass ceramic substrate, a silicon substrate and a carbon substrate may be also used as the substrate if they have the same characteristic as the glass substrate.

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The first underlying layer 2a serves to avoid an undesirable invasion of an impurity gas (H_2O, O_2, N_2)into the magnetic layer 3 when such an impurity gas is released from the glass during a heat process. This means that deterioration of a magnetic characteristic can be prevented by the first underlying layer 2a. Further, the first underlying layer 2a functions as a buffer film for relieving an internal stress of a film imposed by a difference of thermal expansions which occurs during a heat treatment. In this event, it is suitable that the film thickness of the first underlying layer 2a falls within the range between about 10 and 100 Å . Where the film thickness is less than 10 Å , the coercive force is lowered and further, the noise is increased. On the other hand, where the film thickness exceeds 100 Å , the reproducing output is reduced.

The second underlying layer 2b of Cr serves to adjust the grain sizes of both the third underlying layer 2c and the magnetic layer 3 which are deposited thereon. A crystal of the second underlying layer (Cr layer) is finer than that of the third underlying layer 2c (Cr alloy layer including, for example, Mo). Under this circumstance, the third underlying layer 2c and the magnetic layer 3 reflects the fine crystal of the Cr included in the second underlying layer 2b. Specifically, the grain sizes of the third underlying layer 2c and the magnetic layer 3 become small in dependency upon the fine crystal layer of the second

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underlying layer 2b and thereby, the low noise is realized.

Preferably, the grain size of the second underlying layer 2b falls within the range between 50 and 300 Å. When the grain size is less than 50 Å, the coercive force and the reproducing output are lowered. On the other hand, when the grain size exceeds 300 Å, the low noise can not be accomplished because the grain sizes of the third underlying layer 2c and the magnetic layer 3 become large, as mentioned before.

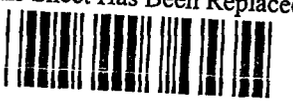
The third underlying layer 2c serves to make the lattice constants between the third underlying layer 2c and the magnetic layer 3 coincide each other.

Specifically, the lattice constant of the a axis of the crystal (cubic system) of the third underlying layer 2c becomes equal to the lattice constant of the c axis of the crystal (hexagonal system) of the magnetic layer 3. This is effective to improve the orientation of the c axis in the film surface of the magnetic layer 3. In this case, the above word "equal" means that the difference between the crystal lattice spacing of the magnetic layer 3 and the crystal lattice spacing of the third underlying layer 2c is less than 0.1 Å, preferably less than 0.05 Å, and more preferably less than 0.02 Å.

More preferably, the content of the other element, such as Mo, in the Cr based alloy falls within the range between 1 and 20 atomic %, and preferably between 5 and 15 atomic % to match the above two lattice

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constants with each other. CrMo, CrV, CrZr, CrMoZr, CrB, CrW, CrTa, CrTi, CrTiB and CrSi and the like are exemplified as the component of the third underlying layer 2c. Among them, the CrMo alloy is preferable.

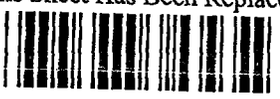
Further, it is suitable that the film thickness of the third underlying layer 2c is thinner than that of the second underlying layer 2b. This is because the third underlying layer 2c is not almost affected by the grain size of the second underlying layer 2b, and thereby, the grain size of the third underlying layer 2c becomes large when the film thickness of the third underlying layer 2c is thicker than that of the second underlying layer 2b. Where the grain size of the third underlying layer 2c becomes large, the noise also can not be reduced.

In this event, the third underlying layer 2c, such as CrMo, which directly contacts with the magnetic layer 3 gives influences crystal growth of the magnetic layer 3 and a magnetic characteristic.

In the illustrated example, the magnetic layer 3 is composed of the quaternary alloy of CoCrTaPt. The lattice constant of the magnetic layer 3 is substantially equal to the lattice constant of the third underlying layer 2c. Therefore, a distribution of the c axis direction of the crystal grain of the magnetic layer 3 becomes parallel to the film surface. As a result, the high coercive force can be obtained. It is desirable that Cr falls within the range between 5 and 20 at%, Pt

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falls within the range between 3 and 16 at% and Ta falls within the range between 1 and 7 at% in the above quaternary alloy magnetic layer 3 of CoCrTaPt. When the content of Cr is less than 5 at%, the noise characteristic of the magnetic layer 3 is deteriorated. On the other hand, when the content of Cr exceeds 20 at%, magnetic moment in the magnetic layer 3 is excessively lowered and thereby, record/reproduce characteristics (particularly, the reproduce characteristic) are degraded. Further, when the content of Ta is less than 1 at%, the low noise can not be accomplished. On the other hand, when the content of Ta exceeds 7 at%, the magnetic moment is largely lowered and thereby, the coercive force and the record/reproduce characteristics (particularly, the reproducing output) are deteriorated, like the case of much addition of Cr. In this event, it is suitable that the film thickness of the magnetic layer 3 falls within the range between 150 and 600 Å , taking a variety of magnetic characteristics into consideration.

The protection layer 4 which is deposited on the magnetic layer 3 protects the magnetic layer 3 from destruction which might occur due to a contact and a slide operation of a magnetic head along the magnetic recording medium. A single layer, such as an amorphous carbon, a graphite carbon, a carbon fluoride, a carbon hydride, a carbon nitride, silica, chromium, zirconia, SiN, SiC, Si-O-N and Si-O-C is used as the protection layer 4. Alternatively, a multi-film consisting of the

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same or different films selected from the above may be used as the protection layer 4. In particular, where the composition of the magnetic layer 3 is formed by the quaternary alloy of CoCrTaPt, the carbon is suitable as the protection layer 4. In this event, it is preferable that the film thickness of the carbon protection layer falls within the range between 50 and 300 Å . When the film thickness is less than 50 Å , friction and corrosion are increased. On the other hand, when the film thickness exceeds 300 Å , the practical flying height is increased to reduce the recording density.

The lubricant layer 5 which is deposited on the protection layer 4 is formed to reduce a friction resistance between the magnetic head and the medium surface. The lubricant layer 5 is generally formed by diluting perfluoropolyether (liquid lubricating material) with a solvent, such as a freon-based solvent, applying it on the medium surface by a dipping method and heating if necessary. Alternatively, the known lubricant material or a lubricant material on the market including phlorocarbon based liquid lubricant material and a lubricant material consisting of alkali metal salt of sulfonic acid may be used as the lubricant layer 5.

It is suitable that the film thickness of the lubricant layer 5 falls within the range between about 5 and 30 Å . When the film thickness is less than 5 Å , abrasion is increased and further, a lubricating life time is shortened. On the other hand, when the film

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thickness exceeds 30 Å , the abrasion is increased and further, the magnetic head may adsorb to the lubricant layer 5. In this case, the lubricant layer 5 may not be always applied on the magnetic recording medium and therefore, may be omitted.

As mentioned above, the underlying layer 2 has the multiple structure of three layers as illustrated in Fig. 1, and the grain sizes of the magnetic layer 3 and the third underlying layer 2c become small because of the second underlying layer 2b so that the magnetic layer 3 is matched with the third underlying layer 2c in the lattice constant. Consequently, both the high coercive force and the low noise can be obtained in the magnetic recording medium of this invention.

Subsequently, description will be made about a method of manufacturing the above magnetic recording medium.

First, the first underlying layer 2a of Al and the second underlying layer 2b of Cr are successively deposited on the glass substrate 1 under an inactive gas pressure of 4 to 15mTorr. Next, the third underlying layer 2c including Cr and at least one selected from a group consisting of Mo, Zr, B, Si, Zn, Ti, W, V, Ta and Al is deposited on the second underlying layer 2b by use of the known sputtering method. Subsequently, the magnetic layer 3 represented by the above chemical formula (1) is deposited on the third underlying layer 2c under the sputtering condition of the inactive gas

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pressure of 5 to 6 mTorr. Further, the protection layer 4 is deposited on the magnetic layer 3 by the known sputtering method. Thereafter, the lubricant layer 5 is deposited on the protection layer 4 by dipping with the lubricating material.

According to such a manufacturing method, the first underlying layer 2a and the second underlying layer 2b are deposited on the glass substrate 1 under the sputtering condition of the inactive gas pressure of 4 to 15 mTorr. Consequently, the grain size of Cr of the second underlying layer can be controlled to the range between 50 and 300 Å . Consequently, the third underlying layer 2c and the magnetic layer 3 are formed in the condition that the grain size of the second underlying layer 2b is reflected. Accordingly, the grain sizes of the third underlying layer 2c and the magnetic layer 3 become small to reduce the noise. In this event, where the inactive gas pressure is less than 4 mTorr, the grain size of Cr of the second underlying layer 2a becomes large and further, the grain sizes of the third underlying layer 2c and the magnetic layer 3 also becomes large. As a result, the noise increases. On the other hand, where the gas pressure exceeds 15 mTorr, distortion of the crystal lattice occurs for the second underlying layer 2a. Consequently, the high coercive force can not be obtained and further, the record/reproduce output is lowered.

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The third underlying layer 2c is formed by adjusting the sputtering condition of the inactive gas pressure so as to reflect the grain size of the second underlying layer 2b and match the lattice constant of the magnetic layer 3. In this event, it is desirable that the second underlying layer 2b is formed to a laminate structure and further, a heating treatment is performed between steps for forming first and second layers. In this case, preferably, the second underlying layer 2b is deposited under the same condition as that for depositing the magnetic layer 3 in relation to the known in-line sputtering apparatus.

Further, the following two conditions are imposed for the deposition of the magnetic layer 3. First, the magnetic layer 3 must be CoCrTaPt which has at least the composition represented by the above chemical formula (1). Second, the inactive gas pressure must be set to 0.5 to 6 mTorr during the sputtering process. By a synergy of to the above two conditions, the growth of the grain size can effectively be suppressed and further, zig-zag magnetic domain walls which appear at a transition region of a recording bit become small to reduce the noise. In addition, the synergy of the above two conditions facilitates magnetic separation between magnetic grains and bring about improvement of the coercive force.

Although the magnetic layer 3 is formed by a single layer in the above first embodiment, the noise can

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be further reduced by interposing a spacer film of a nonmagnetic material in the magnetic layer 3. Therefore, description will be made about a second embodiment in which the spacer film is interposed in the magnetic layer 3.

In Fig. 2, a glass substrate 11, an underlying layer 12, a protection layer 16 and a lubricant layer 17 have the same compositions as the glass substrate 1, the underlying layer 2, the protection layer 4 and the lubricant layer 5 mentioned in conjunction with the first embodiment illustrated in Fig. 1. Further, a first underlying layer 12a, a second underlying layer 12b, and a third underlying layer 12c which constitute the underlaying layer 12 have the same compositions as the first underlying layer 2a, the second underlying layer 2b, and the third underlying layer 2c in Fig. 1. However, the magnetic layer of the second embodiment is structured by three films different from the first embodiment in which the magnetic layer 3 is structured by a single layer. Specifically, the magnetic layer is composed of the first magnetic film 13, the nonmagnetic spacer film 14 and the second magnetic film 15 in the second embodiment, as illustrated in Fig. 2.

The first magnetic film 13 is formed on the underlying layer 12. The first magnetic film 13 includes Co as a main component and is a Co alloy magnetic film consisting of Cr, Ta and Pt. The nonmagnetic spacer film 14 is deposited on the first magnetic film 13. Further,

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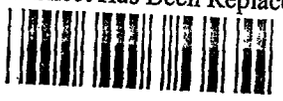
the second magnetic film 15 is deposited on the nonmagnetic spacer film 14. The second magnetic film 15 includes Co as a main component and is formed by a Co alloy magnetic film consisting of Cr, Ta and Pt, like the first magnetic film 13.

Thus, the magnetic layer is divided into the first magnetic film 13, the second magnetic film 15 and the nonmagnetic spacer film 14. Such interposition of the nonmagnetic spacer film 14 serves to reduce the noise. In this case, a Cr alloy based nonmagnetic layer, such as CrMo, CrV, CrMoZr, CrB, CrW, CrTa, CrSi, CrTi and CrTiB, is suitable as the component of the nonmagnetic spacer film 14. In particular, CrMo is desirable among them. It is preferable that the content of the other element, such as Mo, in the Cr-based alloy falls within the range between about 2 and 20 atomic %, taking consistency of the lattice constant with the magnetic film into account. It is suitable that the film thickness of the spacer film 14 (the Cr based alloy film) falls within the range between about 20 and 150 Å, taking a variety of magnetic characteristics of the magnetic recording medium into consideration. In this event, the film thickness of each magnetic film 13 and 15 which is divided by the spacer film 14 may be identical with each other or may be different from each other.

Subsequently, description will be made about a first example according to the second embodiment illustrated in Fig. 2.

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In the magnetic recording medium illustrated in Fig. 2, CoPt based magnetic layer having the high coercive force (the first magnetic film 13 and the second magnetic film 15) is divided by the nonmagnetic spacer film 14 to reduce the noise. The magnetic recording medium is preferably applicable for a MR head (magneto-resistive head)and a GMR head (giant magneto-resistive head).

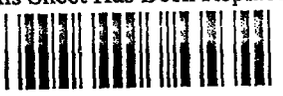
Description will be made about a method of manufacturing the magnetic recording medium according to the first example thereinafter.

First, a chemical reinforcement is made for an aluminosilicate glass by an ion exchange method. A glass substrate 11 of aluminosilicate glass is prepared which has a diameter of 5 inches and a thickness of 0.9mm and is chemically reinforced. Both principal surfaces and side surface of the glass substrate 11 are precisely polished into a mirror surface having a surface roughness (Ra) of about 5 Å .

In this event, the glass which is chemically reinforced by the ion exchange method is used as the glass substrate 11, as disclosed in Unexamined Japanese Patent Publication (JP-A) No. H5-32431. The above chemically reinforced glass contains, by weight, 62-75 % of SiO_2 %, 5-15 % of Al_2O_3, 4-10 % of Li_2O, 4-12 % of Na_2O, and 5.5-15 % of ZrO_2 as main components. Further, the weight ratio of Na_2O/ZrO_2 falls within the range between 0.5 and 2.0, and the weight ratio of Al_2O_3/ZrO_2

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falls within the range between 0.4 and 2.5 in the above chemically reinforced glass.

Such a chemically reinforced glass substrate 11 is excellent in both heat-resistance and Knoop hardness and further, can keep flatness without precipitation of Na during a heat treatment.

The above glass substrate 11 is attached to a substrate holder (pallet) and introduced into the known in-line type DC magnetron sputtering apparatus. As shown in Fig. 3, the sputtering apparatus 100 is structured by five chambers of a preparation chamber 110, a first vacuum chamber 120, a second vacuum chamber 130, a third vacuum chamber 140 and a preparation chamber 150. These chambers are separated by separation plates 102, 105 and ports 103, 104. The glass substrate 11 which is equipped on the pallet 101 moves from the lefthand side to the righthand side of the figure.

Next, the structure of each chamber will be explained along the moving direction of the pallet 101 thereinafter.

The preparation chamber 101 serves to exhaust the air into a vacuum. The first vacuum chamber 120, the second vacuum chamber 120 and the third vacuum chamber 140 serve to carry out the sputtering process. The first vacuum chamber 120 includes heaters 121a and 121b for enhancing the coercive force of the magnetic material, targets 122a, 122b of Al and targets 123a, 123b of Cr.

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The second vacuum chamber 130 includes lamp heaters 131a and 131b for improving the coercive force of the magnetic material, targets 132a and 132b of Cr, targets 133a and 133b of CrMo, targets 134a and 134b of CoCrTaPt, targets 135a and 135b of CrMo and targets 136a and 136b of CoCrTaPt. The third vacuum chamber 140 includes targets 141a and 141b of C (carbon). The final preparation chamber 150 serves to exhaust the air into a vacuum, like the preparation chamber 110.

The pallet which is equipped with the glass substrate 11 is first introduced into the preparation chamber 110. The preparation chamber 110 is exhausted from the atmosphere pressure to a degree of vacuum in the first vacuum chamber 120. Thereafter, the pallet 101 is introduced into the first vacuum chamber 120 by opening the separate plate 102. The glass substrate 11 on the pallet 101 is heated by the lamp heaters 121a and 121b at 375 ℃ for two minutes in the first vacuum chamber 120. Thereafter, the pallet 101 is transferred at the moving rate of 50 cm/min to pass between the Al targets 122a, 122b and the Cr targets 123a, 123b in the discharge condition. Thereby, the first underlying layer 12a of Al (the film thickness of 30 Å) and the second underlying layer 12b of Cr (the film thickness of 300 Å) are successively deposited on the both surfaces of the glass substrate 11 in accordance with the order of the arranged targets. In this event, an ultimate pressure inside the

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first vacuum chamber 120 is set to 5×10^{6} Torr or less, and the sputtering is performed at 4 mTorr by introducing Ar gas. In this condition, the grain size of the Cr underlying layer (the second underlying layer 12b) becomes 300 Å .

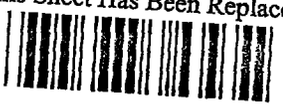
Subsequently, the pallet 101 is transferred to the second vacuum chamber 130 via the port 103 to heat the substrate 11 by the heaters 131a and 131b. In this event, the heating is performed at 350 ℃ for one minute.

Thereafter, the pallet 101 passes between each target (Cr targets 132a and 132b, CrMo targets 133a and 133b, CoCtTaPt targets 134a and 134b, CrMo targets 135a and 135b, CoCrTaPt targets 136a and 136b) in the discharge condition at the moving rate of 50 cm/min. The second underlying layer 12b (the film thickness of 300 Å) of Cr, the third underlying layer 12b (the film thickness of 300 Å) of CrMo, the first magnetic film 13 (the film thickness of 120 Å) of CoCrTaPt, the nonmagnetic spacer film 14 (the film thickness of 50 Å) of CrMo and the second magnetic film 15 (the film thickness of 120 Å) of CoCrTaPt are successively deposited on the both surfaces of the glass substrate 11 in accordance with the order of the arranged targets.

In this event, the composition of the CrMo targets of 133a, 133b, 135a and 135b is set to, by atomic %, 94 % of Cr and 6% of Mo. Further, the composition of CoCrTaPt targets of 134a, 134b, 136a and 136b is set to,

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by atomic %, 78% of Co, 13% of Cr, 6% of Pt and 3% of Ta. In this case, the ultimate pressure inside the second vacuum chamber 130 is set to 5×10^{-6} Torr, and the sputtering is performed at 2 mTorr by introducing the Ar gas.

Subsequently, the pallet 101 is transferred to the third vacuum chamber 140 via the port 104 to pass the pallet 101 between the C targets 141 and 141b in the discharge condition in the third vacuum chamber 140 at the moving rate of 50 cm/min. Next, the protection layer 16 of carbon (the film thickness of 150 Å)is deposited on the second magnetic film 15 of CoCrTaPt. In this event, the protection layer 16 is formed by sputtering with Ar gas and H_2 gas (H_2: 5%) in the third vacuum chamber 140. Finally, the lubricant layer 17 is deposited to the thickness of 20 Å by dipping the protection layer 16 with the lubricating material of perfluoropolyether (AM2001 made by Montedison Pharma).

The coercive force (Oe) and the noise (μ vrms) of the above magnetic recording medium are represented by the following Table 1. In this case, the coercive force (Hc) was measured by cutting a sample of 8mmϕ from the magnetic recording medium and applying a magnetic field to the film surface direction. Such a measurement was performed with the maximum external applying magnetic field of 10 KOe by the use of a vibration sample type magnetometer.

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Table 1

		Film Structure of Underlying Layer	Coercive Force (Oe)	Noise (μ Vrms)
Example	1	Al/Cr/CrMo	2200	9.5
	2	Al/Cr/CrMo	2200	9.8
Compara-tive Example	1	Al/Cr	1700	9.2
	2	Al/CrMo	2200	14.0
	3	Cr/CrMo	2000	15.3

Further, the record/reproduce characteristic (medium noise) was measured as following. Namely, a thin-film magnetic head having a flying height of 0.055 μm was used for the magnetic disk. Under this condition, the record/reproduce output of a line recording density of 120 kfci (line recording density 120,000 bit per one inch) is measured in the condition that a relative rate between the thin-film head and the magnetic disk is set to 9.6 m/s. Further, a noise spectrum during recording and reproducing signals was measured under a carrier frequency of 23 MHz and a measuring bandwidth of 26 MHz by the use of a spectrum analyzer. In this event, the thin-film magnetic head which is used in the above measurement has a coil of 30 turns, a track width of 3.1/2.4 μm, and a magnetic head gap of 0.35/0.28 μm on the write/read side.

The coercive force (Oe) and the noise (μ Vrms) of examples and comparative examples which will be described thereinafter were measured in the above-mentioned manner.

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Next, the CoCrTaPt magnetic layer of a single layer was deposited on the underlying layer 12 of the first example as a second example by stopping the discharge of the CrMo target of the nonmagnetic spacer film 14 and the CoCrTaPt target of the second magnetic film 15 which were used in manufacturing the first example. In this event, the film thickness of the CoCrTaPt magnetic layer was identical with the total film thickness (240 Å) of the magnetic layer of the first example. The sputtering was performed in the same condition as the first example except the above condition.

Further, three comparative examples were made in addition to the above first and second examples. The first comparative example was made by stopping the discharge of the CrMo target to form only the Al/Cr underlying layer in the underlying layer 12 of the first example. The second comparative example was made by stopping the discharge of the Cr target to form only the Al/CrMo underlying layer. The third comparative example was made by stopping the discharge of the Al target to form only the Cr/CrMo underlying layer. The sputtering is performed in the same condition as the first example except the above condition.

As seen from the Table 1, the magnetic recording medium satisfies the both characteristics of the high coercive force of 2000 Oe or more and the low noise of

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10.0 (μ Vrms)or less by using Al/Cr/CrMo as the underlying layer of the CoCrTaPt magnetic layer.

The grain size of the second underlying layer 12b of Cr largely depends on the Ar gas pressure during formation of the Al underlying layer and the Cr underlying layer. Therefore, the characteristic was measured by changing the Ar gas pressure as following. In this event, the magnetic layer is the single layer of the second example, and the composition of each film is equal to that of the first example.

The Ar gas pressure during formation of the Al underlying layer (the first underlying layer 12a) and the Cr underlying layer (the second underlying layer 12b) is changed into 3 mTorr (fourth comparative example), 5 mTorr (third example), 8 mTorr (fourth example), 10 mTorr (fifth example), 12 mTorr (sixth example), 15 mTorr (seventh example), 18 mTorr (fifth comparative example). Further, the grain size of the second underlying layer 12b of Cr and the noise of the obtained magnetic recording medium were investigated. The result of the investigation is represented by Table 2.

In this case, the noise was measured in the same manner as the first example. The magnetic recording medium in the first to seventh examples and the fourth comparative example had the high coercive force of 2000 Oe or more. On the other hand, the coercive force of the fifth comparative example was 1850 Oe.

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Table 2

		Gas Pressure (mTorr)	Grain Size of Cr Layer (Å)	Noise (μ Vrms)
Comparative Example 4		3	400	11.0
Example	1	4	300	9.5
	3	5	250	9.3
	4	8	200	9.3
	5	10	150	8.9
	6	12	100	8.7
	7	15	50	8.2
Comparative Example 5		18	20	8.9

As seen from Table 2, the grain size of the Cr underlying layer (the second underlying layer 12b) falls within the range between 50 and 300 Å by setting the gas pressure to 4~15 mTorr during formation of the Al underlying layer and the Cr underlying layer. Consequently, the magnetic recording medium can satisfy the both characteristics of the high coercive force of 2000 (Oe) or more and the low noise of 10 (μ Vrms) or less. When the gas pressure is less than 4 mTorr, the grain size becomes large, and the grain sizes of the CrMo underlying layer and the CoCrTaPt magnetic layer also become large in dependency upon the grain size of Cr. Consequently, the noise exceeds 10 (μ Vrms) and the low noise can not be realized. On the other hand, when the gas pressure exceeds 15 mTorr, the grain size becomes

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small, but the grain size of the CrMo underlying layer becomes excessively small in dependency upon the gain size of Cr. Consequently, distortion of the orientation occurs in the film surface of the C axis of the crystal grain of the magnetic layer 3. As a result, the coercive force becomes less than 2000 Oe and thereby, the high coercive force can not be obtained. Although the specific example is not described, an excellent magnetic recording medium which has the high coercive force and the low noise can be obtained by interposing the nonmagnetic spacer between the magnetic films.

Table 3

		Composition (atomic %)				Coercive Force (Oe)	Noise (μ Vrms)
		Co	Cr	Pt	Ta		
Example	8	80	13	6	1	2100	9.8
	9	74	13	6	4	2300	9.0
	10	75	14	9	2	2350	9.6
	11	68	13	11	3	2450	9.7
	12	83	8	6	3	2050	9.8
	13	76	15	6	3	2250	8.0
Example	1	73	13	6	3	2200	9.5
Comparative Example	6	78	11	11	0	2000	15.9
	7	73	13	6	8	1200	9.0
	8	82	13	2	3	1300	10.0
	9	67	13	17	3	900	17.0
	10	87	4	6	3	1200	14.5
	11	60	21	6	3	800	16.0

Subsequently, the coercive force (Oe) and the noise (μ Vrms) is represented by Table 3 in the case that

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the composition of the first and second magnetic films is changed in the eighth to thirteenth examples and the sixth to eleventh comparative examples. The sputtering is performed in the same manner as the first example.

As seen from Table 3, the preferable composition range of the CoCrTaPt magnetic layer is represented by the following chemical formula to obtain the magnetic recording medium having the high coercive force of 2000 (Oe) or more and the low noise of 10 (μ Vrms) or less where Al/Cr/CrMo underlying layer is used.

$$Co_{100-X-Y-Z}\ Cr_X\ Pt_Y\ Ta_Z$$

where X = 5-20 atomic %, Y = 3-16 atomic %, Z = 1-7 atomic %.

Where the composition ratio departs from the above range, the high coercive force can not be obtained and further, the noise becomes large. Consequently, the magnetic recording medium can not satisfy the both characteristics of the high coercive force and the low noise.

The preferable composition range is the same as the above case where the magnetic layer is of a single layer. Further, the CrMo alloy is exemplified as the third underlying layer 12c and the nonmagnetic spacer film 14 in the above example, but the same result was obtained when Cr alloys such as CrV, CrTa and CrMoZr are used instead of the CrMo.

In addition, a texture layer, namely, an irregularity forming layer for adjusting the surface

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roughness of the magnetic recording medium may be formed between the glass substrate and the magnetic layer or on the magnetic layer to prevent the adsorption between the magnetic recording medium and the magnetic head and improve CSS (contact start and stop) durability. In this case, it is desirable that an average surface roughness Ra of the irregularity forming layer falls within the range between 10 and 50 Å , and more preferably between 10 and 30 Å . Where Ra is less than 10 Å , the magnetic recording medium adsorbs the magnetic head because the magnetic recording medium is absolutely flat. Thereby, the magnetic head and the magnetic recording medium are undesirably damaged. In addition, a head crash occurs by the adsorption. As a result, fatal damages occur for the magnetic head and the magnetic recording medium. On the other hand, where Ra exceeds 50 Å , a glide height becomes large to reduce the recording density.

The configuration of the irregularity forming layer may be a successive texture film or discretely island-like projections. It is suitable that the height of the projection falls within the range between 100 and 500 Å ,and more preferably between 100 and 300 Å in the case of the island-like projection.

Various kinds of materials and forming methods have been known about the irregularity forming layer and are not restricted. Metals such as Al, Ti, Cr, Ag, Nb, Ta, Bi, Si, Zr, Cu, Ce, Au, Sn, Pd, Sb, Ge, Mg, In, W, Pb and alloys of them or oxide, nitride and carbide of these

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metals and alloys can be used as the material of the irregularity forming layer. Materials containing Al as a main component such as a single substance of Al, Al alloy, oxide Al and nitrogen Al are preferable.

The surface roughness and the projection height can be controlled by the material and the content of the the irregularity forming layer and thermal process condition. A texture process due to chemical polishing, a texture process due to chemical etching, and a texture process due to energy beam irradiation are exemplified as the other forming method of the irregularity forming layer. Further, the combination of these methods may be used. The irregularity forming layer may be formed under or on the magnetic layer, and more preferably, may be formed under the magnetic layer to approve the high recording density. This is because the distance between the magnetic head and the magnetic recording medium becomes large with the film thickness of the irregularity forming layer where the irregularity forming layer is formed on the magnetic layer. In particular, it is desirable that the Cr layer of the second underlying layer has two layer structure, and the irregularity forming layer is interposed between the Cr layers.

Further, a silicon oxide (SiO_2) may be formed by dispersing colloidal silica fine grains in tetraalkoxy-silane diluted with an alcohol-based solvent, coating and baking the dispersed grains instead of the carbon protection layer in the example to function as the both

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the protection film and the irregularity forming layer.

In addition, although the magnetic recording medium has two magnetic layer structure of the first magnetic film, the nonmagnetic spacer film and the second magnetic film, the magnetic recording medium according to this invention is not limited to this structure and may have the magnetic spacer between three or more magnetic films.

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WHAT IS CLAIMED IS:

1. A magnetic recording medium having a substrate, comprising:

a first underlying layer including Al formed on said substrate;

a second underlying layer including Cr formed on said first underlying layer, said second underlying layer having a predetermined grain size;

a third underlying layer of Cr alloy formed on said second underlying layer; and

a magnetic layer of Co alloy formed on said third under laying layer;

the predetermined grain size falling within the range between 50 and 300 Å .

2. The medium as claimed in claim 1, wherein:

said substrate comprises a glass substrate.

3. The medium as claimed in claim 2, wherein:

said first underlying layer serves to prevent an impurity of said glass substrate from entering into said magnetic layer.

4. The medium as claimed in claim 1, wherein:

said first underlying layer has a film thickness which falls within the range between 10 between 100 Å .

5. The medium as claimed in claim 1, wherein:

said second underlying layer serves to adjust grain sizes of said third underlying layer and said magnetic layer.

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6. The medium as claimed in claim 1, wherein:

said third underlying layer includes Cr and at least one material selected from a group consisting of Mo, Zr, B, Si, Zn, Ti, W, V, Ta and Al.

7. The medium as claimed in claim 1, wherein:

said third underlying layer serves to substantially match a lattice constant of said magnetic layer with that of said third underlying layer.

8. The medium as claimed in claim 1, wherein:

said third underlying layer has a grain size which falls within the range between 50 and 300 Å .

9. The medium as claimed in claim 1, wherein:

said third underlying layer is formed by the Cr alloy selected from a group consisting of CrMo, CrV and CrMoZr.

10. The medium as claimed in claim 1, wherein:

said third underlying layer is thinner than said second underlying layer.

11. The medium as claimed in claim 1, wherein:

said magnetic layer is formed by the Co alloy which contains Co as a main component and which includes Cr, Pt and Ta.

12. The medium as claimed in claim 11, wherein:

said magnetic layer has composition which is represented by the following chemical formula:

$$Co_{100-X-Y-Z}\ Cr_X\ Pt_Y\ Ta_Z$$

where X falls within the range between 5 and 20, Y falls within the range between 3 and 16, Z falls within the

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range between 1 and 7, by atomic %.

13. The medium as claimed in claim 1, wherein:

said magnetic layer has a lattice constant which is substantially equal to that of said third underlying layer.

14. The medium as claimed in claim 1, wherein:

said magnetic layer has a grain size which falls within the range between 50 and 300 Å .

15. The medium as claimed in claim 1, wherein:

said magnetic layer has a first magnetic film formed on said third underlying layer, a nonmagnetic spacer film formed on said first magnetic film and a second magnetic film formed on said spacer film.

16. The medium as claimed in claim 15, wherein:

each of said first and second magnetic films is formed by a Co alloy which contains Co as a main component and which includes Cr, Ta and Pt.

17. The medium as claimed in claim 15, wherein:

said spacer film is a Cr alloy which is selected from a group consisting of CrMo, CrV and CrMoZr.

18. The medium as claimed in claim 1, further comprising:

a protection layer formed on the magnetic layer.

19. The medium as claimed in claim 18, wherein:

said protection layer comprises a carbon film.

20. The medium sd claimed in claim 1, wherein:

an irregularity forming layer is formed under said magnetic layer to adjust a surface roughness of said

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medium.

21. A magnetic recording medium having a substrate, comprising;

a Cr underlying layer formed over said substrate, said Cr underlying layer having a first grain size;

a Cr alloy underlying layer formed on said Cr underlying layer, said Cr alloy underlying layer having a second grain size and first lattice constant; and

a magnetic layer of Co alloy formed on said Cr alloy underlying layer, said magnetic layer having a third grain size and a second lattice constant;

the second and third grain sizes depending on the first grain size so as to reduce noise;

the first and second lattice constants being substantially identical with each other in order to improve coercive force.

22. The medium as claimed in claim 21, wherein:

the first grain size falls within the range between 50 and 300 Å.

23. A method of manufacturing a magnetic recording medium having a substrate, comprising the steps of;

depositing a first underlying layer including Al under a first sputtering condition;

depositing a second underlying layer including Cr on said first underlying layer under the first sputtering condition;

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depositing a third underlying layer of Cr alloy on said second underlying layer by sputtering; and

depositing a magnetic layer of Co alloy on said third underlying layer under a second sputtering condition;

the first sputtering condition including an inactive gas pressure of 4-15 mTorr, while

the second sputtering condition including an inactive gas pressure of 0.5-6 mTorr.

24. A method as claimed in claim 23, wherein:

said second underlying layer has a grain size which falls within the range between 50 and 300 Å.

25. The method as claimed in claim 23, wherein:

said third underlying layer includes Cr and at least one material selected from a group consisting of Mo, Zr, B, Si, Zn, Ti, W, V, Ta and Al.

26. The method as claimed in claim 23, wherein:

said magnetic layer has composition which is represented by the following chemical formula:

$$Co_{100-X-Y-Z}\ Cr_X\ Pt_Y\ Ta_Z$$

where X falls within the range between 5 and 20, Y falls within the range between 3 and 16, Z falls within the range between 1 and 7, by atomic %.

27. The method as claimed in claim 23, wherein:

said magnetic recording medium has coercive force not smaller than 2000 Oe and noise not greater than 10 μ Vrms.

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