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PERPENDICULAR MAGNETIC RECORDING MEDIUM

FIELD OF THE INVENTION

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The present invention relates generally to a perpendicular magnetic recording medium and in particular, but not exclusively, to a perpendicular magnetic recording medium having a first intermediate layer and a second intermediate layer. The present invention has particular utility in hard disks utilizing perpendicular magnetic recording layers.

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BACKGROUND TO THE INVENTION

Perpendicular magnetic recording media are being increasingly used for various applications in consumer electronics and in particular hard disks. In contrast to traditional longitudinal magnetic recording media, where the magnetic orientation of individual magnetic domains is generally parallel to the surface of the medium, perpendicular magnetic recording media have magnetic orientation of individual magnetic domains perpendicular to the surface of the medium. This allows for a much higher storage density than have been achieved in longitudinal magnetic recording media.

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To meet the industry requirement for ever-increasing amounts of data storage in a given amount of hard disk area (also known as 'areal density'), continuous improvement in the arrangement of perpendicular magnetic recording media is needed. One technique in which to achieve higher areal density is to reduce the grain size of the magnetic recording media. However, applying this technique to perpendicular recording media results in a poor switching field distribution dH_c/H_c and poor crystal orientation $\Delta\theta_{50}$. This in turn results in higher media noise, which cancels any improvement in signal-to-noise ratio (SNR) obtained by using smaller grains.

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SUMMARY OF THE INVENTION

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In general terms, the present invention relates to the use of an intermediate layer comprising a first intermediate layer of a chromium (Cr) alloy, and a second intermediate layer of ruthenium (Ru) or a ruthenium alloy.

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In a first specific expression, the present invention relates to a perpendicular magnetic recording medium comprising a soft underlayer, a recording layer and an intermediate layer between the soft underlayer and the recording layer, wherein the intermediate layer comprises a first intermediate layer of a Cr-alloy, and a second intermediate layer of Ru or a Ru-alloy.



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Preferably the first intermediate layer comprises a first layer of a Cr-alloy and a second layer of a Cr-alloy, the first layer being formed by reactive sputtering with Ar and N₂. In another form, the second layer is formed by reactive sputtering with Ar and N₂. Preferably negative bias voltage is applied during the reactive sputtering process.

Preferably the Cr-alloy is CrMn with Mn content in the range 0 to 30 at%.

Preferably the first intermediate layer has a thickness between 3nm and 15nm, and the second intermediate layer has a thickness between 5nm and 30nm.

Preferably the recording layer comprises a Co-alloy and an oxide having a hexagonally-close packed (hcp) phase.

In a second specific expression, the present invention relates to a method of forming a perpendicular magnetic recording medium having a soft underlayer, and an orientation control layer on the soft underlayer, the method comprising forming a first intermediate layer of a Cr-alloy on the orientation control layer, and forming a second intermediate layer of Ru or a Ru-alloy on the first intermediate layer.

Preferably forming the first intermediate layer comprises reactive sputtering the Cr-alloy with Ar and N₂. In one form, the method may further comprise applying a negative bias voltage during reactive sputtering.

Preferably forming the first intermediate layer comprises forming a first layer of a Cr-alloy and a second layer of a Cr-alloy, the first layer being formed by reactive sputtering with Ar and N₂. Alternatively, forming the first intermediate layer comprises forming a first layer of a Cr-alloy and a second layer of a Cr-alloy, the second layer being formed by reactive sputtering with Ar and N₂. In either case, the method of forming the relevant layer may further comprise applying a negative bias voltage during the reactive sputtering.

Preferably the N₂ content during reactive sputtering is in the range of 0 to 10%, and the negative bias voltage has a magnitude in the range of 0 to -600V. In one non-limiting example, the negative bias voltage may be -300V.

Preferably the Cr-alloy comprises CrMn with Mn content in the range of 0 to 30 at%.

Preferably the recording layer is formed as a Co-alloy and an oxide having a hexagonally-close packed (hcp) phase.

5 As will be apparent from the following description, the provision of the first and second intermediate layers in the present invention results in better SNR (low frequency signal to high frequency noise i.e. LF/HF ratio) due to lower media noise. Where a negative bias voltage is applied during the formation of the first intermediate layer, crystal orientation ($\Delta\theta_{50}$), and switching field distribution (dHc/Hc) are improved. These and other related advantages will be readily apparent to skilled persons from the description below.

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BRIEF DESCRIPTION OF THE FIGURES

Preferred embodiments of the present invention will now be described with reference to the accompanying figures in which:

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Figure 1 is a schematic cross-section of a perpendicular recording head over a perpendicular recording medium,

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Figure 2 is a schematic cross-section of the preferred form perpendicular recording medium,

Figure 3 is a schematic cross-section of the first and second intermediate layers in a first embodiment,

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Figure 4 is a schematic cross-section of the first and second intermediate layers in a second embodiment,

Figure 5 is a schematic cross-section of the first and second intermediate layers in a third embodiment, and

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Figure 6 is a flow chart of the preferred method of fabricating the perpendicular recording medium.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

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The preferred embodiments are directed to a perpendicular magnetic recording medium for application in magnetic recording systems.

As shown in Figure 1, an exemplary perpendicular recording system 100 has a magnetic recording head (read-write device) 102 and a perpendicular recording medium 103. The magnetic recording head 102 has a reader unit consisting of a magnetoresistive sensor 104 flanked by shields 105a and 105b. The magnetic recording head 102 also has a writer unit consisting of a write pole 107 and a return pole 106. During a writing operation, write flux travels from the write pole 107 through a path 108 in the perpendicular recording medium 103 and returns to the return pole 106.

The perpendicular recording medium 103 comprises a substrate 109, a soft underlayer 110, an intermediate layer 111 and a recording layer 112. An exemplary schematic cross-section (not to scale) of the structure of a preferred form perpendicular recording medium 103 is shown in Figure 2. As can be seen from the figure, the soft underlayer 110 on the substrate 109 comprises a first soft underlayer 113 and a second soft underlayer 114 with a layer of Ru 115 between the first and second soft underlayers 113, 114. An orientation control layer 116 is arranged on the soft underlayer 110, with an intermediate layer 111 being arranged on the orientation control layer 116. The intermediate layer 111 of the preferred embodiment comprises a first intermediate layer 117 and a second intermediate layer 118. A recording layer 112, a protective layer 119, and a lubricant layer 120 are formed subsequently on the intermediate layer 111.

The substrate 109 of the perpendicular recording medium 103 is made of aluminium (Al) or aluminium alloy in the preferred embodiment. Where necessary or desired, the substrate 109 may be made of materials such as glass, silicon, or silicon carbide instead. The average surface roughness of the substrate 109 in the preferred embodiment is not higher than 0.3nm, and not less than 0.1nm (e.g. surface roughness between 0.2nm and 0.1nm is acceptable).

The soft underlayer 110 is formed of a soft magnetic material (i.e. a material that is easily magnetized and demagnetized). In the preferred embodiment, the soft magnetic material is cobalt ferrite (CoFe) with cobalt (Co) as the base alloy, and with one or more additives selected from the group consisting of: tantalum (Ta), niobium (Nb), zirconium (Zr), silicon (Si), boron (B), carbon (C), aluminium (Al). The additive is within the range of 0 to 10 at%. In the preferred embodiment, the soft underlayer 110 has a thickness between 20nm and 80nm and has an amorphous crystal structure. The advantage of having an amorphous crystal structure is that it helps the lattice making up the medium to settle uniformly on the surface of the substrate 109 and therefore results in better uniformity of grains in the perpendicular medium structure.

The orientation control layer 116 functions to improve crystal growth and grain orientation in the recording layer 112 and is chosen from nickel (Ni) alloy, platinum (Pt), tantalum (Ta), or

palladium (Pd) alloy. The thickness of the orientation control layer 116 is between 1nm and 15nm in the preferred embodiment. A thinner orientation control layer 116 may not provide the desired improved crystal growth and orientation of the grains in the recording layer 112, while a thicker orientation control layer 116 may result in an increase in the head-to-soft-underlayer spacing and therefore may undesirably decrease writability.

The intermediate layer 111 of the perpendicular recording medium 103 functions to control grain size and grain distribution in the recording layer 112, including crystal orientation of the grains of the recording layer 112, and better segregation of grains in the recording layer 112. In the present invention, the intermediate layer 111 comprises a first intermediate layer 117 of a Cr-alloy, and a second intermediate layer 118 of Ru or a Ru-alloy. The Cr-alloy is preferably formed by reactive sputter with Ar and N₂ gas. Furthermore negative bias voltage is preferably applied during the reactive sputter process. It has been found that reactive-sputtered formed Cr-alloy in the presence of Ar and N₂ gas in the first intermediate layer 117 helps to control the grain size, and negative bias voltage during reactive sputter process helps to control the distribution of grains in the recording layer 112, and the use of Ru or a Ru-alloy in the second intermediate layer 118 provides better segregation of grains in the recording layer 112. The thickness of the first intermediate layer 117 is between 3nm and 15nm, while the thickness of the second intermediate layer 118 is between 5nm and 30nm in the preferred embodiments below.

Three preferred embodiments of the intermediate layer 111 of the present invention are shown in Figures 3 to 5. In Figure 3, the first intermediate layer 117 comprises a Cr-alloy (specifically CrMn with Mn content between 0 to 30 at%) and the second intermediate layer 118 comprises Ru or a Ru-alloy. The first intermediate layer 117 comprises multiple layers, namely a first layer 117a and a second layer 117b. Both first and second layers 117a, 117b are of a Cr-alloy, but the second layer 117b comprises a Cr-alloy that has been formed by reactive sputtering with argon (Ar) and N₂, with a negative bias voltage being applied during the reactive sputtering process. As is known in the art, a sputter process for the formation of plasma includes the use of an inert gas. Typically Ar gas is used for the discharge of sputter targets. However, in the preferred form of the present invention, both Ar and N₂ are used (with the N₂ content up to 10%). The resulting Cr-alloy therefore typically includes traces of N₂ while maintaining a Cr-alloy bcc (body-centered cubic) structure. In Figure 4, instead of the second layer 117b being formed by reactive sputtering with Ar and N₂ under a negative bias voltage, the first layer 117a is so formed. In Figure 5, the first intermediate layer 111 is shown not to include multiple layers but is a single layer resulting from reactive sputtering the Cr-alloy with Ar and N₂, with a negative bias voltage being applied during the reactive sputtering process.

The recording layer 112 comprises one or more of Co, Cr and Pt (preferably a Co-alloy) with an oxide having a hexagonally-close packed (hcp) phase, and has an easy axis orientation perpendicular to the film normal. In perpendicular recording media, grains in the recording layer have either a hcp structure or an fct (face-centered tetragonal) structure. The preferred form of the present invention provides an intermediate layer suitable for (but not limited to) orientation of grains in a recording layer having a hcp structure. The recording layer 112 also comprises the additives of B, Zr, W, Ti, Ta, Ru for further improvement in the SNR. The recording layer preferably comprises multiple granular recording layers, and an upper continuous recording layer. The thickness of the recording layer 112 is preferably between 20nm and 70nm to maintain sufficient signal output, SNR and overwrite characteristic.

The protective layer 119 functions to prevent damage to the surface of the perpendicular recording medium 103, and additionally helps to prevent corrosion. The protective layer 119 comprises one of the following materials: C, Ru, or SiO₂. The thickness of the preferred form protective layer 119 is between 1nm and 5nm.

The lubricant layer 120 comprises one of the following materials: perfluoropolyether, a fluorinated alcohol, tetraol, Z-dol, A20H.

A preferred method of fabricating the perpendicular recording medium will now be described with reference to the flow chart of Figure 6. The steps relevant to the present invention are shown in solid boxes while steps not relevant to the present invention are shown in dashed boxes.

The method begins with forming the soft underlayer 110 on the substrate 109 (601), including the first soft underlayer 113, the Ru layer 115 on the first soft underlayer 113, and a second soft underlayer 114 on the Ru layer 115. An orientation control layer 116, if desired, is then formed on the soft underlayer 110 (602). A decision (603) is then made as to the type of first intermediate layer to be formed. If the arrangement of Figures 3 and 4 (i.e. the first intermediate layer having two layers 117a and 117b) should be formed, the first layer 117a (604) and the second layer 117b (605) of a Cr-alloy are formed accordingly on the orientation control layer 116 (or on the soft underlayer 110 where there is no orientation control layer 116). At least one of the first and second layers 117a and 117b are formed by reactive sputtering with Ar and N₂. If the arrangement of Figure 5 should be formed, the method proceeds to form (606) the first intermediate layer 117 of a Cr-alloy as a single layer on the orientation control layer 116 (or on the soft underlayer 110 where there is no orientation control layer 116). In either case, once the first intermediate layer 117 is formed, the second intermediate layer 118 of Ru or a Ru-alloy is formed (607) on the first intermediate layer 117. Once this is done, the recording layer 112 is

formed (608) on the second intermediate layer 118, followed by the formation of the protective layer 119 (609) on the recording layer 112, and the formation of a lubricant layer 120 (610) on the protective layer 119.

5 Examples

In the non-limiting examples described below, all of the layers of the perpendicular recording medium was fabricated by DC magnetron sputtering (INTERVAC, 250 B) except for the protective layer, which was formed by chemical vapour deposition. The fabrication was carried out in a vacuum chamber with a vacuum level of 10^{-5} or less.

The intermediate layer was formed having a first intermediate layer and a second intermediate layer, with the first intermediate layer comprising CrMn with Mn content between 0 and 30 at%, and a second intermediate layer comprising Ru or a Ru-alloy.

Two examples, Example A and Example B, of the first intermediate layer were fabricated in the absence of Ar and N₂ gas. For each of Examples A and B, two comparative examples (Comp. Example 1, 2 and 3, 4) were fabricated using a reactive sputter process in the presence of Ar and N₂. In a further comparative example, (Comp. Example 5), the first intermediate layer was made using a reactive sputter process in the presence of Ar and N₂ and further with a negative voltage bias being applied during the reactive sputter process.

Thermal stability factor K_uV/kBT of the resulting media was estimated by the Sharock equation with help of time dependent hysteresis loops measurement by P-KERR BH-810-CPC SD2 (Neork). Recording performance was determined by a USA GUZIK Co. read/write analyzer RWA2002 and a spin-stand V2002. A magnetic head with a single magnetic pole was used for writing, and a tunneling magnetoresistive (TMR) element in the reproducing section was used for the evaluation of recording characteristic. Recording density of 1400 kfc/i was used in the examples. The resulting measurements of thermal stability factor and signal-to-noise ratio SNR_m (LF/HF) for the examples and comparative examples are listed below in Table 1.

	N ₂ content	Bias Voltage (V)	V/kBT	SNR _m (LF/HF)
Example A (CrMn: Mn 0 to 30 at%)	0.00%	0	118	20.011
Comp. Example 1	2.50%	0	110	20.305
Comp. Example 2	5.00%	0	99	20.198

Example B (CrMn: Mn: 0 to 30 at%)	0.00%	0	117	20.3267
Comp. Example 3	2.50%	0	106	20.3491
Comp. Example 4	5.00%	0	105	19.9158
Comp. Example 5	2.50%	-300	109	20.6939

Table 1: Results of Examples and Comparative Examples

It is clear that, although desirable thermal stability values are observed for Examples A and B, the values are decreased when the intermediate layer is formed in the presence of Ar and N₂ (although still more than 60, the so-called thermal stability limit). Desirable SNR_m is also obtained and show a marked improvement in SNR_m in the presence of Ar and N₂.

The effect of applying the negative bias voltage during the reactive sputter process on the switching field distribution (dH_c/H_c) and crystal orientation of recording layer grains ($\Delta\theta_{50}$ of Co-c axis) is shown in Table 2 below. The switching field distribution (dH_c/H_c) was measured with P-KERR BH-810-CPC SD2 (Neork), while the Co c-axis orientation was measured using a Rigaku X-ray Diffractometer.

N₂ content	Bias Voltage (V)	dH_c/H_c	Co ($\Delta\theta_{50}$)
0.00%	0	0.077	3.739
2.50%	0	0.089	4.039
2.50%	-300	0.085	3.842

Table 2: Results of dH_c/H_c and $\Delta\theta_{50}$ of Co-c axis

The examples in Table 1 show that the formation of a Cr-alloy with Ar and N₂ results in lower KuV/kBT of grains in the recording layer as the N₂ content is increased. The lower KuV/kBT effectively represents grains in the recording layer having a smaller magnetic grain volume (V). As outlined earlier, perpendicular recording media with smaller grains are desirable for higher recording densities.

The examples in Table 2 show the associated increase in the values of the switching field distribution (dH_c/H_c) and crystal orientation ($\Delta\theta_{50}$) as N₂ content is increased. As lower dH_c/H_c and $\Delta\theta_{50}$ are preferred, it is clear while the increase in N₂ is beneficial from a KuV/kBT viewpoint, it may be undesirable in some cases due to the degradation in dH_c/H_c and $\Delta\theta_{50}$ values. In such

cases, the application of a negative bias voltage may be implemented to reduce the dH_c/H_c and $\Delta\theta_{50}$ values as shown in Table 2. In other words, negative bias voltage may be applied during the reactive sputter process in the formation of the Cr-alloy first intermediate layer to improve Co-crystal orientation ($\Delta\theta_{50}$), and switching field distribution (dH_c/H_c), thereby improving the SNRm (i.e. lower media noise).

Skilled persons will appreciate from the foregoing description that the preferred formation of a first intermediate layer of a Cr-alloy in the presence of Ar and N_2 results in higher SNRm, and the application of a negative bias voltage during the reactive sputter process further improves SNRm. The second intermediate layer of Ru or a Ru-alloy improves the crystal orientation and segregation of grains in the recording layer, which in turn lowers media noise. While the specific formation of layers described is advantageous, what is important is the provision of the first intermediate layer of a Cr-alloy and the second intermediate layer of Ru or a Ru-alloy. Without these first and second intermediate layers, it has been found that the hcp structure of the recording layer cannot be desirably maintained.

The foregoing describes preferred embodiments, which, as will be understood by those skilled in the art, may be subject to variations or modifications in design, construction or operation without departing from the scope of the claims.

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CLAIMS

1. A perpendicular magnetic recording medium comprising a soft underlayer, a recording layer and an intermediate layer between the soft underlayer and the recording layer, wherein
5 the intermediate layer comprises a first intermediate layer of a Cr-alloy, and a second intermediate layer of Ru or a Ru-alloy.
2. The perpendicular magnetic recording medium of claim 1 wherein the first intermediate layer comprises a first layer of a Cr-alloy and a second layer of a Cr-alloy, the first layer being
10 formed by reactive sputtering with Ar and N₂.
3. The perpendicular magnetic recording medium of claim 1 wherein the first intermediate layer comprises a first layer of a Cr-alloy and a second layer of a Cr-alloy, the second layer being formed by reactive sputtering with Ar and N₂.
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4. The perpendicular magnetic recording medium of any one of the preceding claims wherein the Cr-alloy is CrMn with a Mn content in the range 0 to 30 at%.
5. The perpendicular magnetic recording medium of any one of the preceding claims
20 wherein the first intermediate layer has a thickness between 3nm and 15nm.
6. The perpendicular magnetic recording medium of any one of the preceding claims wherein the second intermediate layer has a thickness between 5nm and 30nm.
- 25 7. The perpendicular magnetic recording medium of any one of the preceding claims wherein the recording layer comprises a Co-alloy and an oxide having a hexagonally-close packed phase.
8. A method of forming a perpendicular magnetic recording medium having a soft
30 underlayer and an orientation control layer on the soft underlayer, the method comprising forming a first intermediate layer of a Cr-alloy on the orientation control layer, and forming a second intermediate layer of Ru or a Ru-alloy on the first intermediate layer.
9. The method of claim 8 wherein forming the first intermediate layer comprises reactive
35 sputtering the Cr-alloy with Ar and N₂.
10. The method of claim 9 wherein forming the first intermediate layer further comprises applying a negative bias voltage during the reactive sputtering.

11. The method of any one of claims 8 to 10 wherein forming the first intermediate layer comprises forming a first layer of a Cr-alloy and a second layer of a Cr-alloy, the first layer being formed by reactive sputtering with Ar and N₂.
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12. The method of any one of claims 8 to 10 wherein forming the first intermediate layer comprises forming a first layer of a Cr-alloy and a second layer of a Cr-alloy, the second layer being formed by reactive sputtering with Ar and N₂.
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13. The method of claim 11 or 12 further comprising applying a negative bias voltage during the reactive sputtering.
14. The method of any one of claims 9 to 13 wherein the N₂ content during reactive sputtering is in the range of 0 to 10%.
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15. The method of claim 10 or 13 wherein the negative bias voltage has a magnitude in the range of 0 to -600V.
16. The method of any one of claims 8 to 15 wherein the Cr-alloy comprises CrMn with a Mn content in the range of 0 to 30 at%.
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17. The method of any one of claims 8 to 16 further comprising forming a recording layer on the second intermediate layer, the recording layer being formed of a Co-alloy and an oxide having a hexagonally-close packed phase.
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