

A PERPENDICULAR RECORDING MEDIUM

Field

The present invention relates to a perpendicular recording medium with improved writeability which has particular application in hard disk drives.

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Background

Perpendicular recording media are widely used in various applications, particularly in the computer industry. In perpendicular magnetic recording media, bits are formed by a magnetic field in a direction that is perpendicular to the plane of a perpendicular recording medium having perpendicular magnetizing anisotropy with typically a layer of magnetic material on a suitable substrate. Very high linear recording densities are achieved by utilizing a “single-pole” magnetic transducer or “head” with such perpendicular magnetic media. To support increase in the capacity of magnetic disk drives, continuous effort is needed for further improvement in recording density.

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In order to increase areal density, a perpendicular recording medium with a) smaller grains and b) a recording layer with high magnetic anisotropic material are needed. A recording layer that comprises smaller grains gives a higher signal to noise ratio with smaller bit size. However, thermal stability is a concern. Therefore, the recording layer should have high magnetic anisotropy for better thermal stability of grains in the recording layer. However, writing the high anisotropic recording medium is a major concern due to limitations of the magnetic head writing field. Therefore, improvement in perpendicular recording medium design is needed in order to write the high anisotropic recording layers. While striving to achieve improved writeability, it is also essential not to sacrifice cross-track reliability performance like adjacent/far-track interference (ATI/FTI) and wide area/adjacent track erasure (WATE).

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Summary of Invention

The present disclosure represents an approach to improve the writeability of a perpendicular magnetic recording medium. The perpendicular recording medium has a triple-layer soft underlayer (SUL) design with improved overwrite and track-width characteristics. Graded magnetization (M_s) of the top two layers of the triple-layer SUL helps to keep the dual characteristics of lower coupling for improved reverse over-write (ROW) and high M_s for

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flux collection. With this design, writeability of the high anisotropic recording layer is improved while ATI/FTI performance is also maintained. The combined benefits of ROW/track-width balance can be helpful in achieving higher areal density and reliability in hard disk drives. The crystal orientation and magnetic properties are also comparable with
5 conventional perpendicular recording media with a dual-layer SUL design.

According to a first aspect, there is provided a perpendicular recording medium comprising: a substrate; a soft underlayer comprising a first magnetic layer formed on top of the substrate, a second magnetic layer formed on top of the first magnetic layer, a third layer magnetic
10 formed on top of the second magnetic layer, and a Ru layer formed between one of: the first magnetic layer and the second magnetic layer, and, the second magnetic layer and the third magnetic layer; an orientation control layer formed on top of the soft underlayer; an intermediate layer formed on top of the orientation control layer; and a recording layer formed on top of the intermediate layer.

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Magnetisation of the second magnetic layer may be lower than magnetisation of the third magnetic layer.

MsT of the first magnetic layer and MsT of the third magnetic layer may be each higher than
20 MsT of the second magnetic layer.

MsT of the first magnetic layer may be higher than a combined MsT of the second magnetic layer and the third magnetic layer.

25 Cobalt content of the third magnetic layer may be higher than cobalt content of the second magnetic layer.

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Iron content of the second magnetic layer may be higher than iron content of the third magnetic layer.

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5 The third magnetic layer may comprise a high magnetization CoFe-based alloy with Co content ranging between 50 to 60% and Fe content ranging between 15 to 20% and wherein the second magnetic layer may comprise a CoFe-based alloy with Co content ranging between 25 to 30% and Fe content ranging between 50 to 55%.

10 The first magnetic layer may comprise a high magnetization CoFe-based alloy with Co content ranging between 50 to 60% and Fe content ranging between 15 to 20%.

Ratio of MsT of the second magnetic layer to MsT of the third magnetic layer may be between 0.66 and 1.5.

15 Drawings

The present invention will now be described by way of example with reference to the accompanying drawings in which:-

FIG. 1 (prior art) shows a schematic view of a conventional perpendicular recording medium;

20 FIG. 2 shows a schematic view of a perpendicular recording medium of the present invention;

FIG. 3 is a graph of ROW against track-width; and

FIG. 4 is a graph of signal-to-noise ratio dependence on track-width.

Description

25 Exemplary embodiments of a perpendicular recording medium 200 according to the present invention will be described with reference to FIGS. 1 to 4 below.

As shown in FIG. 1, a perpendicular recording medium 100 typically comprises a substrate 10 and at least the following layers: an SUL 20, an intermediate layer 60 and the recording layer 70. For example, the perpendicular recording medium may comprise a substrate 10 on top of which the SUL 20 is formed. An orientation control layer 50 is formed on top of the SUL 20, and an intermediate layer 60 is formed on top of the orientation control layer 50.

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The recording layer 70, an exchange layer 80, a switching layer 90 and an overcoat layer 99 are subsequently and successively formed on top of the intermediate layer 60.

5 The substrate 10 is typically made of a material comprising aluminium, such as an aluminium alloy. Alternatively, it may be made of materials such as glass, silicon or silicon carbide. Average surface roughness of the substrate 10 should not be higher than 0.25 nm and should not be less than 0.07 nm. An average surface roughness below 0.15nm is preferable.

10 The conventional SUL 20 design comprises two high magnetization (M_s) layers 21, 22 of the same composition separated by an ultrathin Ru layer 25 that induces anti-ferromagnetic coupling (AFC) between the first and second soft underlayers 21, 22, and also helps to suppress DC noise generated during the read-write process. The strength of the AFC depends on the Ru thickness as well as the M_s of the SUL material. The two high M_s layers are made of a material with Co-base alloy with Fe and one or more element from the group of Ta, Cr, 15 Nb, Zr, Si, B, C, Al, C with 0 to 10 at%. They can be made of material with amorphous or crystalline phase structure. However, soft underlayer materials with amorphous phase structure are preferable. Amorphous soft under layer helps the lattice to grow on the surface uniformly and therefore results in better uniformity of grains in the perpendicular medium structure. Thickness of the soft underlayer 20 preferably should not be less than 20 nm, and 20 should not be higher than 80 nm. The SUL 20 helps to enhance writeability in order to enable use of a higher anisotropy recording layer 70. As a result, it is possible to reduce the grain size in a perpendicular recording medium than can possibly be achieved in conventional longitudinal media.

25 The orientation control layer 50 is typically made of materials comprising Ni-alloy, Pt, Ta, W or Pd-alloy. It helps to provide crystal orientation and crystal growth of grains in the recording layer 70 of the perpendicular recording medium 100. Thickness of the orientation control layer 50 should not be less than 2 nm, and should not be higher than 15 nm.

30 The intermediate layer 60 is normally made of Ru or a Ru alloy. The intermediate layer 60 helps to improve crystal orientation and segregation of grains in the recording layer 70. Usually, thickness of the intermediate layer 60 should not be less than 7 nm, and should not be higher than 30 nm.

A protective layer (not shown) protects the perpendicular recording medium from damage and corrosion. Normally, it is made of materials containing C, Ru, or SiO₂. Thickness of the protective layer should not be less than 1nm, and should not be higher than 5 nm.

- 5 A lubricant layer (not shown) provided on the protective layer may comprise one or more of the following materials: a perfluoropolyether, a fluorinated alcohol, tetraol, z-dol, A20H.

In a first exemplary embodiment of a perpendicular recording medium 200 of the present invention, as can be seen in FIG. 2, the SUL 20 is a triple-layer SUL having a first magnetic
10 layer 21, a Ru layer 25, a second magnetic layer 22 and a third magnetic layer 23. An orientation control layer 50 or seed layer and intermediate layers 60 are provided between the SUL 20 and the recording layer 70.

The recording layer 70 may comprise multiple granular layers and a top continuous layer 79.
15 The granular layers may be separated by an exchange breaking layer. Magnetic anisotropy and magnetization of each subsequent granular layer in a switching assist layer the recording layer 70 may be in decreasing order from bottom to top. Granular layers in the recording layer 70 typically comprise Co, Pt and an oxide. Easy axis orientation of grains in the granular layers is perpendicular to the film normal. Furthermore, the granular layers may
20 comprise additives of Cr, B, Zr, W, Ti, Ta, Ru for further improvement in the signal-to-noise ratio (SNR). The primary granular recording layer is typically made of high magnetic anisotropic material, and magnetic anisotropy and magnetization is much higher than those of granular layers above the primary recording layer. The top continuous layer 79 in the switching assist layer may comprise Co-alloy (Co content: 60 to 80%), with the one or more
25 additives of Cr (6 to 16%), Pt (15 to 25%), B (0 to 10%) and Cu (0 to 4%). Thickness of each granular layer in switching assist layer is typically in the range of 1 to 3nm, while the top continuous layer 79 has a thickness in the range of 1nm to 4 nm.

Unlike prior art perpendicular recording media 100 that have a dual-layer SUL anti-ferromagnetically coupled (AFC) by an ultra-thin Ru spacer layer in between, in the present
30 perpendicular recording medium 200, as shown in FIG. 2, the SUL 20 is a triple-layer SUL 20 having three magnetic layers 21, 22, 23, in which the top two magnetic layers 22, 23 are selected with different magnetization (M_s) values: a low M_s magnetic layer 22 below a

higher Ms magnetic layer 23. This low Ms magnetic layer 22 helps to improve writeability with respect to the conventional dual-layer SUL design. The SUL 20 of the present invention thus comprises a first magnetic layer 21 formed on top of the substrate 10, an ultra-thin Ru layer 25 formed on top of the first magnetic layer 21, a second magnetic layer 22 formed on top of the Ru layer 25, and a third magnetic layer 23 formed on top of the second magnetic layer 22 so that the Ru layer 25 is formed between the first magnetic layer 21 and the second magnetic layer 22.

The second and third magnetic layers 22, 23 are configured to have different magnetic compositions from each other. In the preferred embodiment, magnetization of the second magnetic layer 22 is lower than magnetisation of the third magnetic layer 23. However, even if magnetisation of the second magnetic layer 22 is higher than that of the third magnetic layer 23, ROW will still be improved although track-width will be wider. Preferably, the first and third magnetic layers 21, 23 each have a higher MsT (where Ms is the saturation magnetization and T is the layer thickness) than the MsT of the second magnetic layer 22. The MsT ratio of the second and third magnetic layers 22, 23 decides the exchange coupling with the first magnetic layer 21. The exchange coupling is dominantly an interfacial phenomena, therefore coupling between the first magnetic layer 21 and the second magnetic layer 22 will be a more dominant factor than between the first magnetic layer 21 and the second magnetic layer 22 and the third magnetic layer 23 together. Insertion of the second magnetic layer 22 with Co content ranging between 25 to 30% weakens the coupling between the first magnetic layer 21 and the third magnetic layer 23 which has Co content ranging between 50 to 60%. Thus, the MsT of the first magnetic layer 21 is preferably higher than a combined MsT of the second magnetic layer 22 and the third magnetic layer 23. In this way, track-width can be maintained while improving ROW. Where a ratio of MsT of the second magnetic layer 22 to MsT of the third magnetic layer 23 is between 0.66 and 1.5, an optimized ROW and track-width performance is obtained.

Preferably, the second magnetic layer 22 should have a lower Ms than the first magnetic layer 21 and the third magnetic layer 23. For a more pronounced effect, the second magnetic layer 22 should be Fe rich so as to reduce the coupling between the magnetic layers 21, 22, 23 accordingly on either side of the Ru layer 25. The MsT ratio has to maintained between the second and third magnetic layers 22, 23 to keep a balance of ROW advantage while at the

same time maintaining a desirable narrow track-width. The coupling between the first and second magnetic layers 21, 22 gradually reduces as the MsT of the second magnetic layer 22 is increased.

5 To achieve the different magnetic compositions of the layers in the SUL 20, the third magnetic layer 23 preferably has higher cobalt content than the second magnetic layer 22, while the second magnetic layer 22 has higher iron content than the third magnetic layer 23. Similarly, the first magnetic layer 21 preferably has higher cobalt content than the second magnetic layer 22, while the second magnetic layer 22 has higher iron content than the first
10 magnetic layer 21.

Accordingly, the third magnetic layer 23 may comprise a high magnetization CoFe-based alloy with Co content ranging between 50 to 60% and Fe content ranging between 15 to 20% while the second magnetic layer 22 comprises a CoFe-based alloy with Co content ranging
15 between 25 to 30%, Fe content ranging between 50 to 55% and Ta, Cr, B or a mixture of other additives ranging between 18-25%. The first magnetic layer 21 may comprise a high magnetization CoFe-based alloy with Co content ranging between 50 to 60%, Fe content ranging between 15 to 20% and Ta, Cr, B, Nb or a mixture of other additives ranging between 15-20%.

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Experimental Verification

A first perpendicular recording medium (PRM) having a dual-layer SUL of the prior art and a second PRM having a triple-layer SUL according to the present invention were fabricated by DC magnetron sputtering. A protective layer was formed on each of the first and the second
25 PRM by Chemical Vapour Deposition at a vacuum level of about 10^{-5} Pa inside the vacuum chamber.

Recording performance of the first PRM and the second PRM was measured by a USA GUZIK Co. read/write analyzer RWA2002 and a spin-stand V2002. A magnetic head with a
30 single magnetic pole was used for writing, and a tunnelling magneto-resistive (TMR) element in the reproducing section was used for the evaluation of their recording characteristics. A recording density of 1500 kfc/i was used in the present evaluation. WATE performance was measured with a magnetic head showing WATE tendency. ROW and SNR dependence on

track-width (SNR) are shown in FIGS. 3 and FIGS. 4 respectively. As can be seen in FIG. 3, media with the triple-layer SUL of the present invention shows higher ROW with comparable to narrower track-width when compared with media with the conventional dual-layer SUL. ROW gain of 1dB with 1nm narrower track-width performance is observed on average. In

5 FIG. 4, for media with the triple-layer SUL, an average gain of 0.16 dB SNR is observed when compared to the media having a dual layer SUL structure. Overall, by providing a triple-layer of SUL in an otherwise conventional perpendicular recording medium, areal density gain can be achieved.

10 Whilst there has been described in the foregoing description preferred embodiments of the present invention, it will be understood by those skilled in the technology concerned that many variations in details of design, construction and/or operation may be made without departing from the present invention. For example, while it has been described above that the Ru layer is formed between the first magnetic layer and the second magnetic layer, the Ru

15 layer may alternatively be formed between the second magnetic layer and the third magnetic layer to achieve similar improved ROW while maintaining track-width.

Claims

MCSLLP

1. A perpendicular recording medium comprising:
 - a substrate;
 - 5 a soft underlayer comprising a first magnetic layer formed on top of the substrate, a second magnetic layer formed on top of the first magnetic layer, a third magnetic layer formed on top of the second magnetic layer, and a Ru layer formed between one of: the first magnetic layer and the second magnetic layer, and, the second magnetic layer and the third magnetic layer;
 - 10 an orientation control layer formed on top of the soft underlayer;
 - an intermediate layer formed on top of the orientation control layer; and
 - a recording layer formed on top of the intermediate layer,
 - wherein magnetisation of the second magnetic layer is lower than magnetisation of the third magnetic layer.
- 15 2. The perpendicular recording medium of claim 1, wherein MsT of the first magnetic layer and MsT of the third magnetic layer are each higher than MsT of the second magnetic layer.
- 20 3. The perpendicular recording medium of any preceding claim, wherein MsT of the first magnetic layer is higher than a combined MsT of the second magnetic layer and the third magnetic layer.
4. The perpendicular recording medium of any preceding claim, wherein cobalt content
- 25 of the first magnetic layer is higher than cobalt content of the second magnetic layer.
5. The perpendicular recording medium of any preceding claim, wherein iron content of the second magnetic layer is higher than iron content of the third magnetic layer.
- 30 6. The perpendicular recording medium of any preceding claim, wherein iron content of the second magnetic layer is higher than iron content of the first magnetic layer.
7. The perpendicular recording medium of any preceding claim, wherein the third magnetic layer comprises a high magnetization CoFe-based alloy with Co content

ranging between 50 to 60% and Fe content ranging between 15 to 20% and wherein the second magnetic layer comprises a CoFe- based alloy with Co content ranging between 25 to 30% and Fe content ranging between 50 to 55%.

- 5 8. The perpendicular recording medium of any preceding claim, wherein the first
magnetic layer comprises a high magnetization CoFe-based alloy with Co content
ranging between 50 to 60% and Fe content ranging between 15 to 20%.
- 10 9. The perpendicular recording medium of any preceding claim, wherein ratio of MsT of
the second magnetic layer to MsT of the third magnetic layer is between 0.66 and 1.5.