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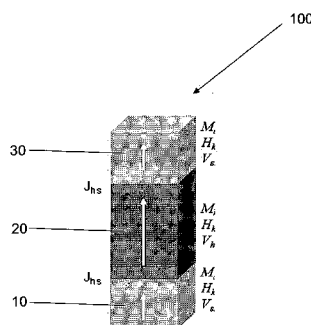
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(54) Title: AN IMPROVED EXCHANGE-COUPLED COMPOSITE MEDIUM AND A MAGNETIC RECORDING MEDIUM COMPRISING THE SAME

FIGURE 1



(57) Abstract: It is disclosed an improved exchange-coupled composite medium comprising a multilayer structure having at least a first layer, an intermediate layer, and a last layer, wherein the intermediate layer is on and in contact with the first layer, thereby forming a first exchange-coupling interface therebetween, and the last layer is on and in contact with the intermediate layer, thereby forming a second exchange-coupling interface therebetween. A magnetic recording medium comprising the same and its fabricating method are also provided.

AN IMPROVED EXCHANGE-COUPLED COMPOSITE MEDIUM AND A MAGNETIC RECORDING MEDIUM COMPRISING THE SAME

CROSS-REFERENCE TO RELATED APPLICATION

- 5 This application claims the benefit of Singapore Patent Application No. 200906129-2 filed on 15 September 2009, the entire contents of which are incorporated herein by reference.

FIELD OF INVENTION

- 10 The invention relates to an improved exchange-coupled composite medium for use in magnetic recording media. The invention also relates to a method for fabricating a magnetic recording medium comprising the improved exchange-coupled composite medium.

BACKGROUND TO THE INVENTION

- The following discussion of the background to the invention is intended to facilitate an understanding of the present invention. However, it should be appreciated that the discussion is not an acknowledgment or admission that any of the material referred to was published, known or part of the common general
20 knowledge in any jurisdiction as at the priority date of the application.

- In existing hard disk drive (HDD) products, the magnetic recording media consist of single domain magnetic grains at nanometer level. When the easy axis of the magnetic grains is substantially perpendicular to the surface of a disk
25 medium substrate, the medium is called a perpendicular recording medium.

- One data bit in a recording medium requires a certain number of magnetic grains in order to have sufficient signal-to-noise ratio (SNR). A bit-error rate (BER) of a magnetic recording system largely depends on the medium SNR. To meet the BER requirement specified by a user, the magnetic grain number per
30 bit has to be maintained at a certain value. In such circumstances, as the areal

density of a magnetic recording system increases, the in-plane area of each grain has to be reduced accordingly.

Magnetic anisotropy energy of each magnetic grain is defined as the product of the material anisotropy energy density K_u and its volume. In order to keep the recorded data thermally stable, the magnetic anisotropy energy of a magnetic grain has to be more than 40 times its thermal energy. Otherwise, thermal agitation may flip the magnetization direction of the magnetic grains and result in the loss of recorded data. In order to maintain sufficient thermal stability at a reduced grain area (or grain size) at higher areal density, the anisotropy energy density K_u of a recording medium has to be increased. But a larger anisotropy energy density K_u leads to a higher switching field of magnetic grains and this places tremendous burden on write-ability of a recording head.

The write-ability of the recording head depends on saturation flux density of the head material, in which the highest value is about 2.5 Tesla (T). This limits the anisotropy energy density K_u value of the medium material and also the achievable areal density of the HDD product. The need to improve the write-ability becomes a critical challenge in the magnetic recording industry.

One proposed solution to improve write-ability is the use of an exchange-coupled composite (ECC) medium consisting of a hard magnetic layer exchange-coupled with a soft magnetic layer in the magnetic recording medium. The ECC medium forms the magnetic recording layer of the magnetic recording medium. The hard magnetic layer comprises grains of magnetically hard regions with perpendicular anisotropy. The soft magnetic layer comprises grains of magnetically soft regions where the anisotropy may also point in the perpendicular direction provided it is small in magnitude. The ECC medium makes use of the exchange-coupling between the soft and hard magnetic layers to reduce switching fields of the recording medium. The effective switching field of the ECC medium may be much lower than that of a medium consisting of a hard magnetic layer alone. Therefore, medium material of high anisotropy

energy density K_u may be usefully employed as the hard magnetic layer of the ECC medium to further increase the areal density of the HDD product.

However, conventional ECC medium requires a thick soft magnetic layer with high saturation magnetization (M_S) and is greatly dependent on the exchange-coupling between the hard and soft magnetic layers. The thickness of the soft magnetic layer is comparable to or larger than that of the hard magnetic layer. A soft magnetic layer having a small thickness has less switching field reduction. In addition, a seed layer is one requirement in order to grow the hard magnetic layer with well controlled magnetic orientation. The soft magnetic layer is subsequently deposited on the hard magnetic layer in order to achieve a direct contact, thereby forming an exchange-coupling interface between the hard and soft magnetic layers.

The anisotropy energy density K_u value of the soft magnetic layer is significantly lower than that of the hard magnetic layer. Therefore, the thermal stability contribution from the soft magnetic layer is significantly lower and may be considered negligible. Further, remnant magnetization of the soft magnetic layer is not sufficiently high even though it is under the influence of the magnetostatic field from the adjacent hard magnetic layer. This causes a deterioration of the read-back performance of the magnetic recording medium.

There is also a conflict on the thickness requirement for the soft magnetic layer. The switching field reduction requires the layer to be thick but the read-back performance prefers it to be thin for optimal performance. Victora *et al* (*Proceedings of the IEEE*, vol. 96, No. 11, November 2008) disclose that the exchange-coupling strength between the soft and hard magnetic layers has to be very strong in order to achieve a significant switching field reduction. In this paper, when the ratio of soft magnetic layer thickness to hard magnetic layer thickness is set at 2, the exchange coupling energy J_{ex} has to be 9×10^6 erg/cc. But when the ratio is set at 1 (i.e. the value at which complete exchange-coupling switching is achieved), the exchange coupling energy J_{ex} has to be

14×10^6 erg/cc. The strength of the exchange-coupling depends on the layer material selected and the interface conditions, for example. It may be impractical due to the requirement of high exchange-coupling strength.

5 In reality, the thickness of the soft magnetic layer of the ECC medium cannot be too thick. Other than the deterioration of the read-back performance, the field strength of a writing head will also decrease due to an increment in spacing (or thickness) between the writing head and the soft magnetic under-layer, which under-layer is found below the seed layer of the hard magnetic layer. An
10 optimized ECC medium structure should ideally have thin soft magnetic layer and low hard-soft exchange-coupling strength that has the same amount of switching field reduction for the hard magnetic layer. However, the switching field reduction for a conventional ECC medium will require a strong interface exchange-coupling strength between the soft and hard magnetic layers, and a
15 thick soft magnetic layer with high magnetic moment. The strength of the exchange-coupling depends on the surface (interface) condition of soft and hard magnetic materials. There is a practical limit to the exchange-coupling strength and thickness of the soft magnetic layer. This places a constraint on the overall benefits of the convention ECC medium.

20 Thus, it is desirable to provide for an improved exchange-coupled composite medium that has sufficiently thin soft magnetic layer and low exchange-coupling strength, and reduces the switching field without comprising the thermal stability of the medium.

25 **SUMMARY OF THE INVENTION**

Throughout this document, unless otherwise indicated to the contrary, the terms "comprising", "consisting of", and the like, are to be construed as non-exhaustive, or in other words, as meaning "including, but not limited to".

30 In a first aspect of the present invention, there is provided an exchange-coupled composite medium comprising a multilayer structure having at least a first layer,

an intermediate layer, and a last layer, wherein the intermediate layer is on and in contact with the first layer, thereby forming a first exchange-coupling interface therebetween, and the last layer is on and in contact with the intermediate layer, thereby forming a second exchange-coupling interface therebetween.

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In a second aspect of the present invention, there is provided a magnetic recording medium comprising a substrate, a soft magnetic under-layer formed on the substrate, a seed layer formed on the soft magnetic under-layer to control magnetic orientation of an exchange-coupled composite medium of the first aspect formed on the seed layer. The exchange-coupled composite medium forms the magnetic recording layer of the magnetic recording medium.

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BRIEF DESCRIPTION OF THE DRAWINGS

In the figures, which illustrate, by way of example only, embodiments of the present invention,

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FIGURE 1 is an illustration of the present structure of an exchange-coupled composite medium whereby the medium comprises one intermediate hard magnetic layer sandwiched between two soft magnetic layers;

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FIGURE 2 is a graph of hysteresis loops of a conventional ECC medium (dash curve) and the present medium of **FIGURE 1** (solid line) at the same total volume of soft magnetic layer and at the same exchange-coupling strength between the hard and soft magnetic layers;

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FIGURE 3 is a graph showing the hard magnetic layer switching field reduction versus the strength of the exchange-coupling for a conventional ECC medium (circle mark) and the present medium of **FIGURE 1** (triangle mark) at the same total volume of the soft magnetic layer. The present medium is able to realize full reduction of switching field at a lower interface exchange-coupling than the conventional ECC medium;

30

FIGURE 4 is a graph showing the thermal stability to switching field ratio versus the strength of the exchange-coupling for a conventional ECC medium (circle mark) and the present medium of **FIGURE 1** (triangle mark) at the same total volume of the soft magnetic layer. The present medium is able to achieve a desired ratio at a lower interface exchange-coupling than the conventional ECC medium;

FIGURE 5 is an illustration of the medium structure and respective thickness of each layer of a single hard magnetic layer medium (**FIGURE 5a**), ECC medium (**FIGURE 5b**), and the present medium of **FIGURE 1** (**FIGURE 5c**); and

FIGURE 6 is a graph showing the switching field and energy barrier of corresponding embodiments presented in **FIGURE 5a-c**. The present medium reduces the switching field significantly without much influence on the energy barrier defined by the thermal stability of the medium.

DETAILED DESCRIPTION

The invention relates to an improved exchange-coupled composite medium for use in magnetic recording media. The invention also relates to a method for fabricating a magnetic recording medium comprising the improved exchange-coupled composite medium.

In accordance with a first aspect of the invention, there is provided an exchange-coupled composite medium comprising a multilayer structure having at least a first layer, an intermediate layer, and a last layer, wherein the intermediate layer is on and in contact with the first layer, thereby forming a first exchange-coupling interface therebetween, and the last layer is on and in contact with the intermediate layer, thereby forming a second exchange-coupling interface therebetween.

FIGURE 1 illustrates a first embodiment of an improved exchange-coupled composite medium **100** in accordance with the first aspect of the present

invention. The improved exchange-coupled composite medium **100** comprises a tri-layer structure consisting of a first layer **10**, a second layer **20**, and a third layer **30**. The second layer **20** is positioned intermediate between the first layer **10** and the third layer **30**, thereby separating the two layers. The first layer **10** is positioned closer to a substrate of a magnetic recording medium when the medium **100** is in use (to be described later). The third layer **30** is positioned further away from the substrate of the magnetic recording medium when the medium **100** is in use (to be described later).

The second layer **20** is on and in contact with the first layer **10**, thereby forming a first exchange-coupling interface therebetween. The third layer **30** is on and in contact with the second layer **20**, thereby forming a second exchange-coupling interface therebetween. It is to be appreciated that each of the contact between the second layer **20** and the first layer **10**, and between the third layer **30** and the second layer **20** is a direct contact between the respective layers. Such an arrangement dispenses with the need for a separate exchange-coupling control layer between the respective layers.

The first layer **10** consists of grains of magnetically soft regions where the anisotropy can point in any direction provided it is small in magnitude, and the layer is commonly termed as a soft magnetic layer. In a preferred embodiment, the anisotropy of the soft magnetic layer points in the perpendicular direction to the plane of the layer. Similarly, the third layer **30** is also a soft magnetic layer. On the other hand, the second layer **20** consists of grains of magnetically hard regions with perpendicular anisotropy, and the layer is commonly termed as a hard magnetic layer.

The resulting exchange-coupled composite medium in this embodiment comprises a hard magnetic layer being sandwiched between two soft magnetic layers on opposing surfaces of the second layer **20**. The soft magnetic layer in each of the first layer **10** and the third layer **30** may have the same or different magnetic properties and thicknesses. The larger the total thickness of the first

layer and the third layer, the more reduction in the switching field is achieved. However, a thicker first layer may change the desired texture of the seed layer (the seed layer will be described in subsequent paragraphs) and affect the magnetic orientation of the hard magnetic layer formed on the first layer. On the other hand, a thicker third layer may deteriorate the read-back performance of the exchange-coupled composite medium. These considerations place a constraint on the thicknesses of the first layer and the third layer. In a preferred and convenient embodiment, the two soft magnetic layers are selected to have the same magnetic properties and same thickness. More preferably, the total thickness of the first layer and the third layer is less than the thickness of the second layer. The resultant composite medium **100** is hereinafter termed as a double exchange-coupled composite medium (or DECC for short) because it comprises two separate exchange-coupling interfaces formed between different layers. The conventional exchange-coupled composite medium (or ECC for short) comprises only one exchange-coupling interface. To facilitate the distinction between the two composite media in this application, the terms "DECC" and "ECC" are used as appropriate, including in the figures.

Key parameters of the soft magnetic first layer **10** are defined as the saturation magnetization M_{s1} , the anisotropy field H_{ks1} , and the volume V_{s1} . Key parameters of the soft magnetic third layer **30** are defined as the saturation magnetization M_{s2} , the anisotropy field H_{ks2} , and the volume V_{s2} . Key parameters of the hard magnetic second layer **20** are defined as the saturation magnetization M_h , the anisotropy field H_{kh} , and the volume V_h . The exchange-coupling strength of the two interfaces is denoted as J_{hs} . The exchange-coupling strengths of the two interfaces are the same if the magnetic properties and thicknesses of the first layer **10** and the third layer **30** are the same. It is to be appreciated that the exchange-coupling strengths may also be different.

To compare the performance between DECC and ECC media, the thickness and the magnetic properties (M_h , H_h , and V_h) of the hard magnetic layer are deliberately fixed to be the same. The magnetic properties of the soft magnetic

layers are also fixed to be the same. The numerical values of soft and hard magnetic layers are set as follows: $M_h = 550$ emu/cc, $H_h = 73$ KOe, $M_{s1} = M_{s2} = 150$ emu/cc, $H_{ks1} = H_{ks2} = 1.33$ KOe, $V_h/(V_{s1}+V_{s2}) = 1$, $V_{s1} = V_{s2}$, $J_{hs} = 10^7$ erg/cc. For the DECC medium, the two soft magnetic layers (i.e. first layer **10** and third layer **30**) are each fixed to be half the thickness of the soft magnetic layer of the ECC medium such that the total thickness of the soft magnetic layers of the DECC medium equals the thickness of the ECC medium.

Setting the same interface exchange-coupling strength for both the DECC and ECC media, **FIGURE 2** shows the hysteresis loops of a DECC medium (solid line) and an ECC medium (dash line). The exchange-coupling strength was set at a low level and the ECC medium shows a two-phase switching, in which the soft magnetic layer starts to switch at a lower magnetic field while the hard magnetic layer needs a much higher magnetic field to switch. The exchange-coupling strength was not sufficiently high to fulfill the concept of ECC switching. With the same exchange-coupling strength and the same total soft layers thickness, although the magnetic switching field of the DECC medium is slightly higher than the switching field of the soft layer of the ECC medium, the DECC medium demonstrated a classic type of magnetic switching in a single phase. This clearly demonstrates the advantages of the DECC structure over the ECC structure.

FIGURE 3 is a graph showing switching field versus exchange-coupling strength for both ECC (circle mark) and DECC (triangle mark) media. At an exchange-coupling constant of 8×10^6 erg/cc, it is sufficient for the DECC medium to fulfill exchange-coupled switching entirely. But the ECC medium needs an exchange-coupling constant of 14×10^6 erg/cc in order to achieve complete exchange-coupling switching. This shows that the DECC medium requires a significant lower value of exchange-coupling strength to attain comparable results.

With the same soft layer volume and magnetic properties, the thermal stability of both ECC and DECC media is the same and can be expressed mathematically as:

$$\Delta E = K_h V_h + K_s V_s \approx K_h V_h \quad (1)$$

5 Where ΔE is the energy barrier to thermal fluctuations, K is the anisotropy energy density, V is the volume of each magnetic grain. The subscripts s and h refer to soft and hard layers, respectively.

10 The figure of merit (ξ) which is defined as the ratio of energy barrier to switching energy needed, is mathematically expressed as:

$$\xi = \frac{2\Delta E}{H_{sw} M_s V_s} \quad (2)$$

The higher the ξ value, the more effective is the exchange-coupling switching.

15 From **FIGURE 4**, it can be seen that the ECC medium (circle mark) is relatively ineffective in utilizing the exchange-coupling effect due to a low ξ value. On the other hand, the DECC medium (triangle mark) provides an increase of more than double in the ξ value. The DECC medium therefore exhibits a better exchange-coupling assisted switching over a wide range of exchange-coupling constants.

20 The following paragraphs will now describe the DECC medium when the same is used in a magnetic recording medium.

25 In accordance with a second aspect of the invention, there is provided a magnetic recording medium comprising a substrate, a soft magnetic under-layer formed on the substrate, a seed layer formed on the soft magnetic under-layer to control magnetic orientation of an exchange-coupled composite medium of the first aspect formed on the seed layer. The exchange-coupled composite medium forms the magnetic recording layer of the magnetic recording medium.

In a preferred embodiment, the exchange-coupled composite medium comprises the DECC medium described in previous paragraphs, whereby a hard magnetic layer is sandwiched between two soft magnetic layers. In this general illustration, a first thickness of a soft magnetic layer is first deposited at a low temperature on a seed layer. Then, a second thickness of a hard magnetic layer is deposited at a high temperature on the first soft magnetic layer. Subsequently, a third thickness of a soft magnetic layer is deposited at a low temperature on the hard magnetic layer. The magnetic material used for each of the hard and soft magnetic layers of the DECC medium may be the same or different. Preferably, the magnetic material is one selected from the group consisting of FePt, CoPt, CoCrPt, CoCrTa, CoCr, CoSm, CoPd, FePd, and a mixture thereof. Conveniently, the same magnetic material is used for each of the hard and soft magnetic layers. More preferably, the magnetic material is FePt.

FIGURES 5a-c show the fabrication conditions and structures for different magnetic recording media samples for comparison. Sample I and Sample II are prior art magnetic recording media structure. Sample III is one embodiment of the present magnetic recording medium.

For Sample I shown in **FIGURE 5a**, $(\text{Fe}_{50}\text{Pt}_{50})_{80}(\text{TiO}_2)_{20}$ nano-composite thin films with TiO_2 volume fraction of 20% were fabricated and used as a hard magnetic layer in the recording layer. The recording medium comprises the film structure of glass (Microcover glass)/ $\text{Cr}_{90}\text{Ru}_{10}$ (100 nm)/ MgO (2 nm)/ $(\text{Fe}_{50}\text{Pt}_{50})_{80}(\text{TiO}_2)_{20}$ (10 nm) fabricated by a custom-designed four targets ultrahigh vacuum magnetron sputtering system. The sputtering system was vented to atmosphere with 99.99% purity nitrogen gas and then pumped down to a base pressure of about 8×10^{-8} Torr. 99.999% purity Ar gas was used as the working gas. The CrRu under-layer was deposited at a pressure of 3 mTorr and at a substrate temperature of 250 °C. After that, the substrate temperature was cooled down to 80 °C and a 2 nm MgO seed layer was deposited onto the CrRu

under-layer at a pressure of 10 mTorr. The substrate was subsequently re-heated to 350 °C. A $(\text{Fe}_{50}\text{Pt}_{50})_{80}(\text{TiO}_2)_{20}$ layer was subsequently deposited by co-sputtering $\text{Fe}_{50}\text{Pt}_{50}$ and TiO_2 at a fixed temperature of 350 °C, at a fixed pressure of 10 mTorr and at a fixed sputter power and duration for $\text{Fe}_{50}\text{Pt}_{50}$. The same fabrication conditions are used in Samples I, II, and III for forming the structure consisting of the substrate, under-layer, and seed layer. The same fabrication conditions are used in Samples I, II, and III for forming the hard and soft magnetic layers, except for the deposition temperatures mentioned below.

For Sample II shown in **FIGURE 5b**, a 3 nm magnetically soft $(\text{Fe}_{50}\text{Pt}_{50})_{80}(\text{TiO}_2)_{20}$ layer was further deposited at room temperature onto the hard magnetic layer of Sample I to form a conventional ECC medium structure.

For Sample III shown in **FIGURE 5c**, a 1.5 nm magnetically soft $(\text{Fe}_{50}\text{Pt}_{50})_{80}(\text{TiO}_2)_{20}$ layer was first deposited at room temperature on top of the MgO seed layer, followed by the 10 nm hard magnetic layer being deposited at 350 °C. On top of the hard magnetic layer, another 1.5 nm magnetically soft $(\text{Fe}_{50}\text{Pt}_{50})_{80}(\text{TiO}_2)_{20}$ layer was deposited at room temperature. It is to be appreciated that the deposition temperature for the hard magnetic layer may be higher than 350 °C and the deposition temperature for the soft magnetic layer may range from room temperature to 200 °C.

FIGURE 6 is a graph showing the remanent coercivity (H_{cr}) and energy barrier versus Samples I, II, and III as presented in **FIGURE 5a-c**. From **FIGURE 6**, it is clearly shown that while the energy barrier levels are rather similar, the switching field of Sample III is the lowest among Samples I, II, and III. As such, it has been demonstrated that the DECC medium of the present invention provides a clear switching field reduction better than the conventional ECC medium.

The afore-described improved exchange-coupled composite medium provides several advantages. The present medium alleviates the needs for a thick and

high saturation magnetization (M_s) soft-layer, and also a high exchange-coupling strength. In practice, the present medium effectively “doubles” the exchange-coupling effects by providing at least two exchange-coupling interfaces and achieves a better switching field reduction than conventional exchange-coupled composite medium.

Although the previous paragraphs provide for a tri-layer structure of the present medium, it is to be understood and appreciated that the present medium is not confined to only such structure. For example, the hard magnetic layer may comprise at least two hard magnetic sub-layers instead of a uniform single hard magnetic layer. The magnetic properties of each of the sub-layer may be the same or different. Regardless the number of layers provided in the exchange-coupled composite medium, the present medium will still work so long as there are at least two exchange-coupling interfaces between respective alternate soft and hard magnetic layers.

Although the foregoing invention has been described in some detail by way of illustration and example, and with regard to one or more embodiments, for the purposes of clarity of understanding, it is readily apparent to those of ordinary skill in the art in light of the teachings of this invention that certain changes, variations and modifications may be made thereto without departing from the spirit or scope of the invention as described in the appended claims.

WE CLAIM:

1. An exchange-coupled composite medium comprising a multilayer structure having at least a first layer, an intermediate layer, and a last layer, wherein the intermediate layer is on and in contact with the first layer, thereby
5 forming a first exchange-coupling interface therebetween, and the last layer is on and in contact with the intermediate layer, thereby forming a second exchange-coupling interface therebetween.
2. The composite medium of claim 1, wherein the intermediate layer further
10 comprises a plurality of sub-layers.
3. The composite medium of claim 1 or 2, wherein the first layer comprises a soft magnetic layer, the intermediate layer comprises a hard magnetic layer, and the last layer comprises a soft magnetic layer.
15
4. The composite medium of claim 3, wherein the anisotropy of each of the first layer, the intermediate layer, and the last layer points perpendicularly to the plane of the respective layer.
- 20 5. The composite medium of any one of the preceding claims, wherein each of the first layer, the intermediate layer, and the last layer is formed of a material selected from the group consisting of FePt, CoPt, CoCrPt, CoCrTa, CoCr, CoSm, CoPd, FePd, and a mixture thereof.
- 25 6. The composite medium of claim 5, wherein each of the first layer, the intermediate layer, and the last layer is formed of FePt.
7. The composite medium of any one of the preceding claims, wherein the thickness of each of the first layer and the last layer is substantially the
30 same.

8. The composite medium of claim 7, wherein the total thickness of the first layer and the last layer is less than the thickness of the intermediate layer.

9. A magnetic recording medium comprising:

- 5 - a substrate;
- a soft magnetic under-layer formed on the substrate;
- a seed layer formed on the soft magnetic under-layer; and
- a magnetic recording layer formed on the seed layer

 wherein the magnetic recording layer comprises an exchange-coupled
10 composite medium comprising a multilayer structure having at least a first
 layer, an intermediate layer, and a last layer, wherein the intermediate
 layer is on and in contact with the first layer, thereby forming a first
 exchange-coupling interface therebetween, and the last layer is on and in
 contact with the intermediate layer, thereby forming a second exchange-
15 coupling interface therebetween, and the first layer is on and in contact
 with the seed layer.

10. The recording medium of claim 9, wherein the intermediate layer further
 comprises a plurality of sub-layers.

20 11. The recording medium of claim 9 or 10, wherein the first layer comprises a
 soft magnetic layer, the intermediate layer comprises a hard magnetic layer,
 and the last layer comprises a soft magnetic layer.

25 12. The recording medium of claim 11, wherein the anisotropy of each of the
 first layer, the intermediate layer, and the last layer points perpendicularly to
 the plane of the respective layer.

30 13. The recording medium of any one of claims 9 to 12, wherein each of the
 first layer, the intermediate layer, and the last layer is formed of a material
 selected from the group consisting of FePt, CoPt, CoCrPt, CoCrTa, CoCr,
 CoSm, CoPd, FePd, and a mixture thereof.

14. The recording medium of claim 13, wherein each of the first layer, the intermediate layer, and the last layer is formed of FePt.

15. The recording medium of any one of the claims 9 to 14, wherein the thickness of each of the first layer and the last layer is substantially the same.

16. The recording medium of claim 15, wherein the total thickness of the first layer and the last layer is less than the thickness of the intermediate layer.

17. A method for fabricating a magnetic recording medium, comprising the steps of:

- forming a soft magnetic under-layer on a substrate;
- forming a seed layer on the soft magnetic under-layer; and
- forming a magnetic recording layer on the seed layer

wherein the magnetic recording layer comprises an exchange-coupled composite medium comprising a multilayer structure formed by depositing at least an intermediate layer on and in contact with a first layer, thereby forming a first exchange-coupling interface therebetween, and depositing a last layer on and in contact with the intermediate layer, thereby forming a second exchange-coupling interface therebetween, and the first layer is formed on and in contact with the seed layer.

18. The method of claim 17, wherein the first layer is deposited on the seed layer at a temperature below 200 °C to form a soft magnetic layer.

19. The method of claim 18, wherein the first layer is deposited on the seed layer at room temperature.

20. The method of any one of claims 17 to 19, wherein the intermediate layer is deposited on the first layer at a temperature above 350 °C to form a hard magnetic layer.
- 5 21. The method of claim 20, wherein the intermediate layer is deposited on the first layer at temperature 350 °C.
22. The method of any one of claims 17 to 21, wherein the last layer is deposited on the intermediate layer at a temperature below 200 °C to form
10 a soft magnetic layer.
23. The method of claim 22, wherein the last layer is deposited on the intermediate layer at room temperature.

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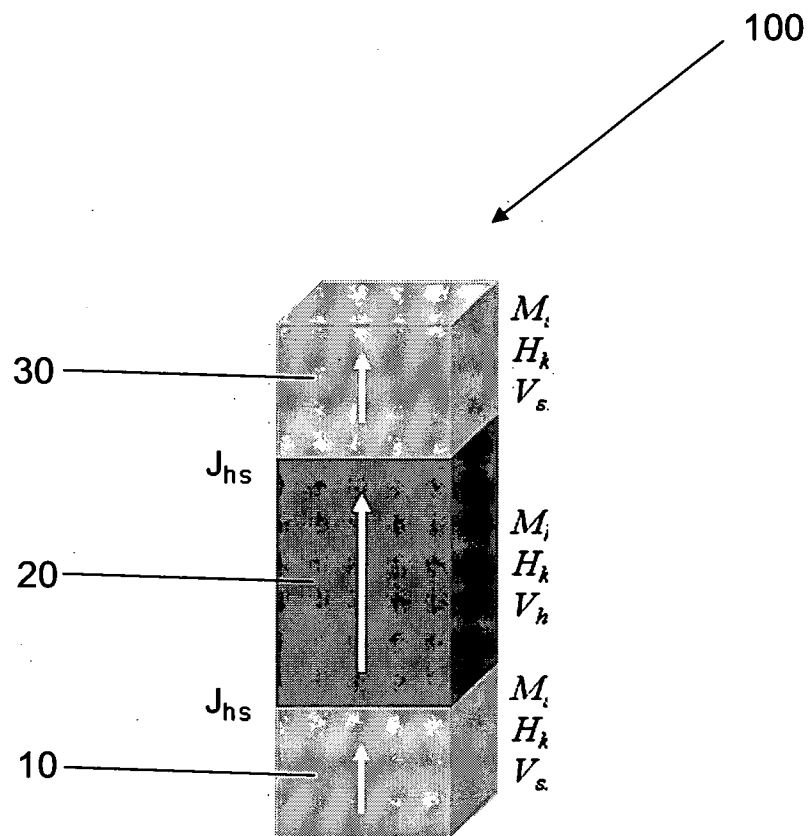


FIGURE 1

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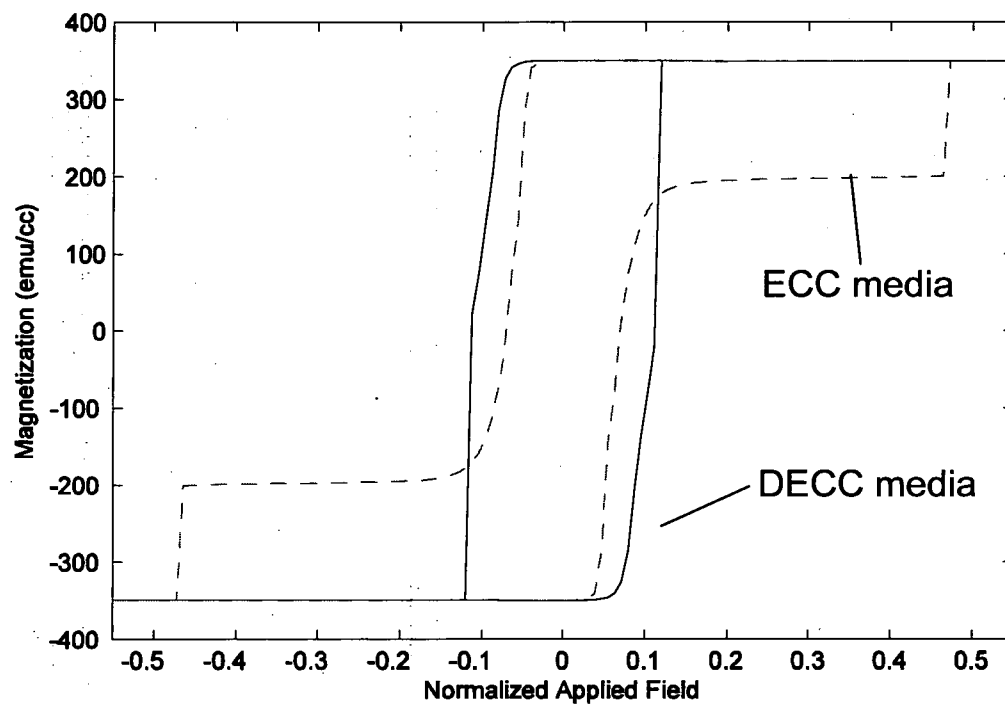


FIGURE 2

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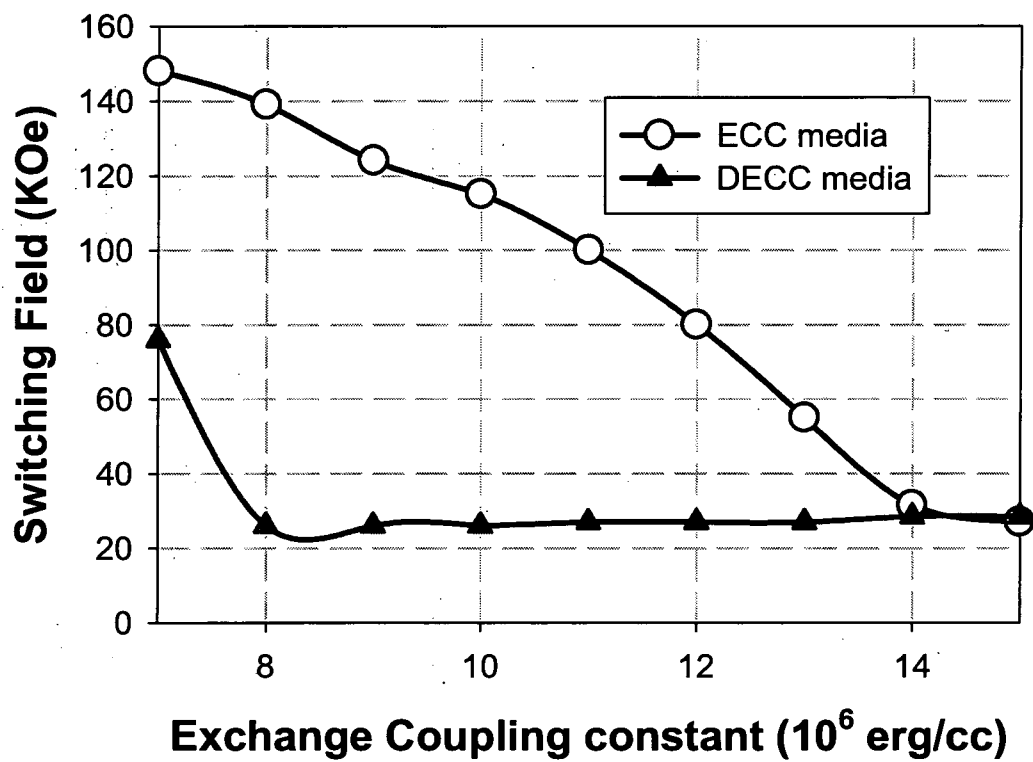


FIGURE 3

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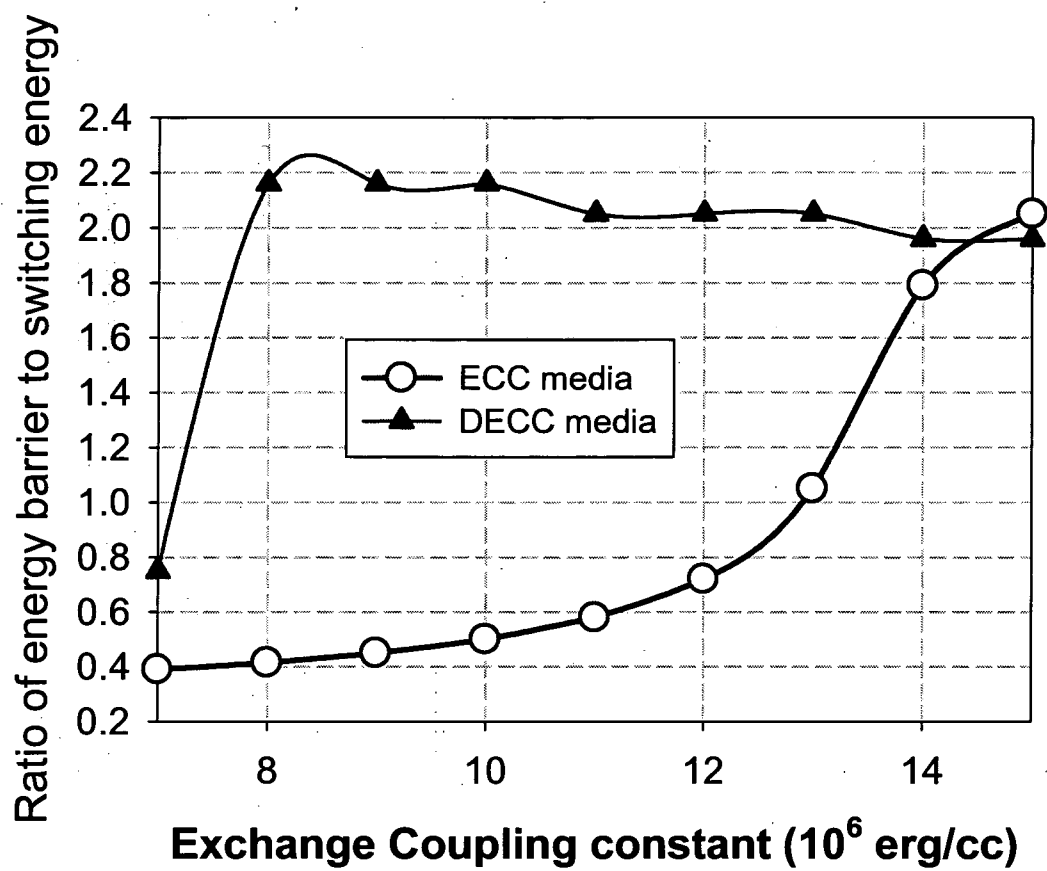


FIGURE 4

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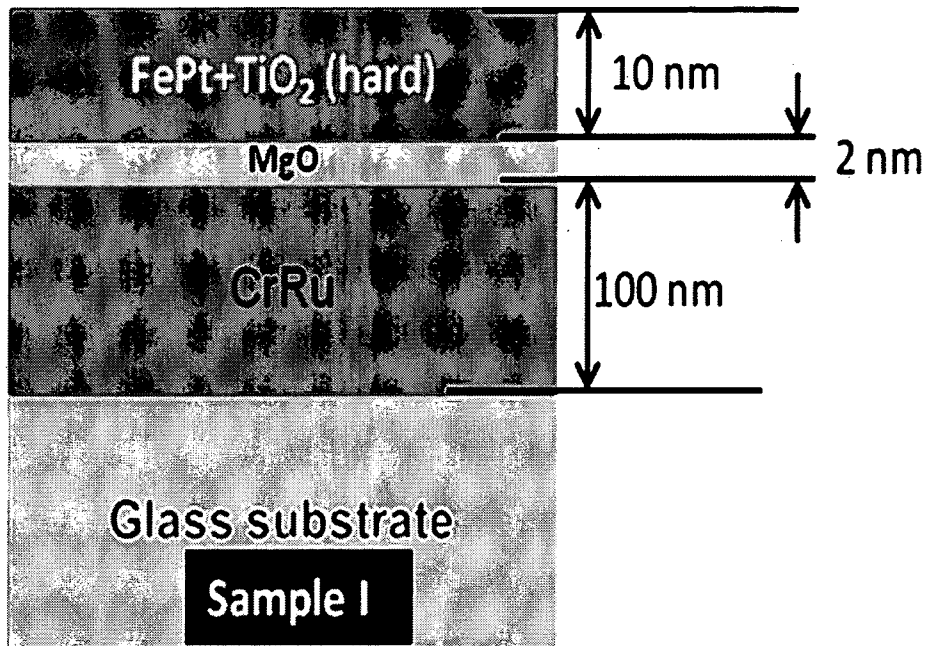


FIGURE 5a

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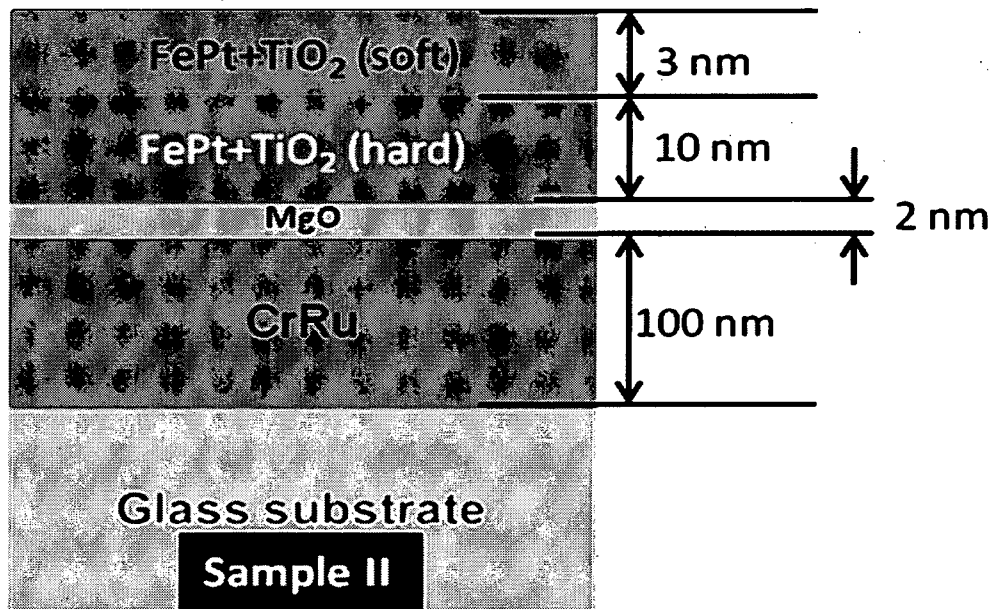


FIGURE 5b

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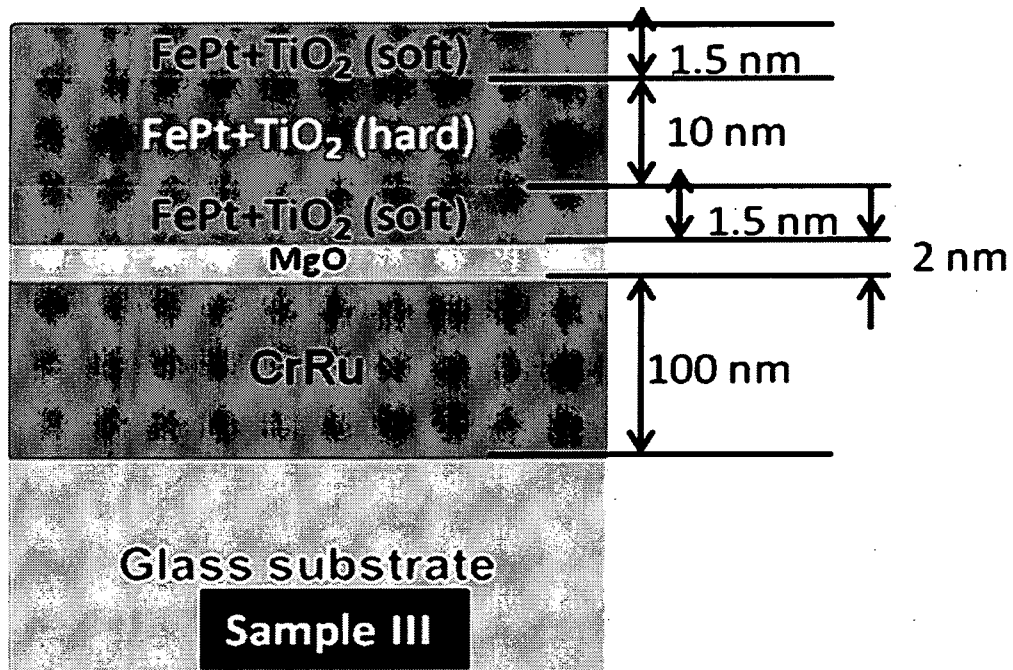


FIGURE 5c

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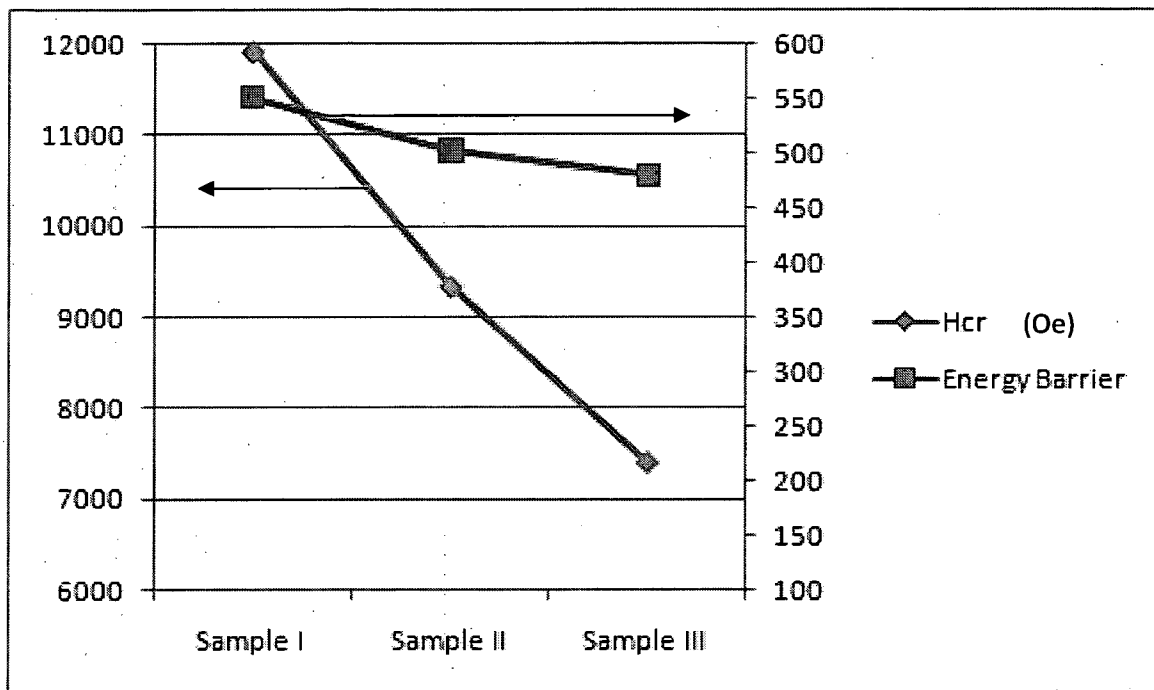


FIGURE 6

INTERNATIONAL SEARCH REPORT

International application No.

PCT/SG2010/000325

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl.

G11B 5/673 (2006.01)

G11B 5/66 (2006.01)

G11B 5/667 (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI,EPDOC: IPC G11B 5/-, Key words: Exchange coupled, perpendicular, composite, multiple, two and similar words

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2007/0072011 A1 (LI et al) 29 March 2007 paragraphs 0063, 0066, 0067, 0069, 0073, 0075, 0076, figs 1, 3, 5	1-5,7-13,15-17-23
X	US 2007/0292720 A1 (SUESS) 20 December 2007 paragraphs 0024, 0030, 0032,0035,0048, figs 1, 2	1,2,5,6,9,10,13,14,17-23
X	US2010/0209736 A1 (HASHIMOTO) 19 August 2010 [Earlier Family Member WO2009031630 A1 (SHOWA DENKO K K) 12 March 2009] abstract, paragraphs 0046, 0069, 0074, 0078, 0079, fig 1	1,9,17
X	US 2008/0199735 A1 (BERGER et al) 21 August 2008 abstract, paragraphs 0021, 0022, figs 3A, 4	1,9,17



Further documents are listed in the continuation of Box C



See patent family annex

* "A"	Special categories of cited documents: document defining the general state of the art which is not considered to be of particular relevance	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"E"	earlier application or patent but published on or after the international filing date	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O"	document referring to an oral disclosure, use, exhibition or other means	"&"	document member of the same patent family
"P"	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search
19 November 2010

Date of mailing of the international search report
24 NOV 2010

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/SG2010/000325

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	INABA et al, 'Preliminary Study on (CoPtCr/NiFe)-SiO ₂ Hard/Soft-Stacked Perpendicular Recording Media' IEEE TRANSACTIONS ON MAGNETICS, Vol 41, No 10, October 2005 pages 3136-3138	

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/SG2010/000325

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member			
US	2007072011	NONE			
US	2007292720	US	2010062286		
US	2010209736	CN	101796580	JP	2009064520 WO 2009031630
US	2008199735	CN	101246698	US	7572526
Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.					
END OF ANNEX					