Description

This invention relates to a magnetoresistive read transducer assembly for reading information signals from a magnetic medium.

Magnetoresistive (MR) sensors or heads are known which are capable of reading data from a magnetic surface at great linear densities. An MR sensor detects magnetic field signals through the resistance changes of a read element made from a magnetoresistive material as a function of the amount and direction of magnetic flux being sensed by the MR element.

It is known that in order for an MR element to operate optimally, various bias fields should be provided. One bias field which is usually employed with MR elements is referred to in the art as the longitudinal bias field which extends parallel to the surface of the magnetic medium and parallel to the ngth of the MR element.

US-A-4,103,315 discloses the use of antiferromagnetic-ferromagnetic exchange coupling to produce a uniform longitudinal bias along the MR sensor. The exchange coupling occurs at the interface between an fcc (face-centred-cubic) FeMn antiferromagnetic layer and a NiFe ferromagnetic layer.

This invention seeks to provide a nagnetoresistive read transducer assembly with enhanced exchange bias.

EP-A-0216062, which is reflected in the preamble of claim 1, discloses a magnetoresistive read transducer assembly comprising: a thin magnetoresistive conductive layer; and a film of antiferromagnetic material in direct contact with said magnetoresistive layer whereby an exchange bias field is produced between them which is relatively high and remains stable during thermal cycling.

The present invention provides such a magnetoresistive read transducer assembly characterised in that the film of antiferromagnetic material has a thickness within the range of about 2.5 to 10 nm.

In a specific embodiment the antiferromagnetic material is FeMn, and a capping layer is provided over the antiferromagnetic layer. The capping layer is either a dielectric material such as Cr_2O_3, Al_2O_3 and SiO_2 or a metal oxide cermet film such as Cr - SiO, $Ni_{80}Cr_{20}$ - Cr_2O_3, Cr - Al_2O_3, and $Ni_{80}Cr_{20}$ - SiO_2.

In a further embodiment the antiferromagnetic layer is a ternary alloy Fe Mn - X where X is Rh, Ti or Cr.

How the invention can be carried out will now be described by way of example, with reference to the accompanying drawings, in which:-

Fig. 1 represents a section of one MR read transducer assembly embodying the invention;

Fig. 2 represents a section of another MR read transducer assembly embodying the invention;

Fig. 3 is an enlarged view of the laminated capping structure in the embodiment of Fig. 2;

Fig. 4 is a plot of exchange bias field and coercivity as a function of thickness of the FeMn layer in the MR read transducer assembly of Fig. 1;

Fig. 5 is a plot of exchange bias field and coercivity vs number of anneal cycles for the structure of Fig. 1 with 5 nm of FeMn;

Fig. 6 is a plot of exchange bias field and coercivity vs number of anneal cycles for the structure of Fig. 1 with 40 nm of FeMn.

Fig. 7 is a plot of exchange bias field and coercivity vs number of anneal cycles for the structure of Figs. 2 and 3 in which the capping layer is FeMn with either Al_2O_3, Cr_2O_3 or carbon.

With reference to Fig. 1, a magnetoresistive (MR) read transducer assembly 10 is shown which comprises a layer of soft magnetic material 12 on a suitable substrate 14. A non-magnetic spacer layer 16 separates the soft magnetic layer 12 from the layer of MR material 18 which is formed of ferromagnetic material such as nickel-iron (NiFe) The soft magnetic layer 12 provides a magnetic field oriented to bias the magnetic field in the MR layer 18 in a direction non-parallel to the recording medium. This bias field is normally referred to as the transverse bias field, and the transverse bias maintains the MR layer 18 in a linear response mode so that the signal detected across the MR layer is substantially a linear function of the resistance changes sensed in the MR layer due to changes in the magnetic field intercepted by the MR layer 16 from recorded data on the magnetic storage medium.

A second bias field, the longitudinal bias field, is produced by exchange coupling between the ferromagnetic MR layer 18 and an antiferromagnetic material deposited in a layer 20 intimately in contact with the layer 18 of MR material. The longitudinal bias creates a single domain state in MR layer 18, and the single domain state is essential to suppress Barkhausen noise which is associated with MR materials which exhibit multiple magnetic domain states.

The previously mentioned US -A- 4,103,315 discusses exchange coupling between ferromagnetic and antiferromagnetic materials, and this prior document suggests NiFe as the ferromagnetic MR layer and a gamma phase (face-centred-cubic (FCC)) of manganese (Mn) alloy as the antiferromagnetic layer. Of the possible gamma Mn alloys mentioned, iron-manganese (FeMn) appears to exhibit the greatest ability to exchange couple with the NiFe layer.

It was unexpectedly discovered that ultrathin layers of the antiferromagnetic material produce a stronger exchange bias field with NiFe than structures that have been studied before. It was further discovered that the corrosion properties of the ultrathin antiferromagnetic layer can be substantially enhanced by providing a capping layer in contact with the antiferromagnetic layer.

In the embodiment shown in the drawings, there is provided an ultrathin layer 20 (2.5 to 20 nm) of a suitable antiferromagnetic material such as FeMn in direct contact with the MR layer 18. It was discovered that films as thin as 2.5 to 5 nm can exchange couple to NiFe and produce a large exchange bias field. The results are somewhat surprising since films in that thickness range may still be discontinuous.

A capping layer 22 is preferably provided in contact with the ultrathin layer 20 of antiferromagnetic material to protect the antiferromagnetic layer from corrosion damage and also to serve as a diffusion barrier since any interdiffusion into the layer of antiferromagnetic material will destroy the exchange coupling. The capping layer 22 is made of a stable dielectric material such as Cr_2O_3, Al_2O_3, and SiO_2 or a metal oxide cermet film such as Cr - Si O, $Ni_{80}Cr_{20}$ -Cr_2O_3, Cr - Al_2O_3, and $Ni_{80}Cr_{20}$ - SiO_2. The thickness of capping layer 22 is not critical, and capping layers within the range of about 20 to 40 nm have been found to be suitable.

In order to provide an improved antiferromagnetic layer in an MR sensor, various FeMn structures were prepared as thin films by RF sputter deposition in a uniform magnetic field of 10^{-2} tesla (100 Gauss). The power density, system pressure and substrate temperature were fixed at 2.6 w/cm^2, 3.3 Pa (25 millitorr) and 50°C respectively. The substrate was glass and the surface was sputter cleaned for five minutes prior to deposition. Films of nickel-iron ($Ni_{81}Fe_{19}$) were deposited on the substrate at a rate of about 0.1 nm per second to a thickness of about 40 nm. The nickel-iron film deposition was followed by the sputter deposition of $Fe_{50}Mn_{50}$ of variable thickness from 2.5 to 35 nm. The deposition of FeMn was at the rate of about 0.15 nm per second at the same pressure and power density as before. The thickness values were established by sputter power and time and were calibrated to step height measurements. The exchange structure was capped by a protective cermet film such as Cr - Si O about 30 nm thick. The capping layer provided a protective coating to prevent the exchange structure from oxidation during thermal cycling experiments.

The exchange bias field (H_{UA}) of the NiFe MR layer is illustrated in Fig. 4 as a function of thickness of the FeMn antiferromagnetic layer. Also shown in Fig. 4 is the exchange coercivity (H_{CE}) as a function of $Fe_{50}Mn_{50}$ thickness. These plots show that the coercivity was greater than the exchange bias when the FeMn thickness was 2.5 nm. However, the exchange bias increased to 0.31 amp/metre (25 oersteds (Oe)) for a 5 nm FeMn layer and the coercivity decreased to about 0.075 amp/metre (6 Oe). The maximum exchange bias field observed was for a 5 nm FeMn film and the exchange decreased linearly to 0.25 amp/metre (20 Oe) at 15 nm of FeMn and remained independent of thickness up to 35 nm.

Another experiment was conducted in which the capping layer was about 30 nm thick of FeMn laminated with Cr_2O_3, and in this case the exchange bias field peaked in the 2.5 to 5 nm range, decreased linearly to about 20 nm and remained independent of thickness up to 35 nm. The laminated capping layer structure will be described in greater detail below.

During the manufacturing process for a specific embodiment of a magnetic read/write transducer in which an MR read transducer is a part, a number of thermal cycles are used which have the effect of annealing the thin films comprising the magnetic head. It is desirable that neither the exchange bias field H_{UA}, nor the exchange coercivity H_{CE} change as a result of the thermal cycling. The thermal cycling properties of an MR read transducer, such as that depicted in Fig. 4, having an FeMn film thickness of 5 nm, is shown in Fig. 5. Neither the exchange bias field H_{UA} nor the exchange coercivity H_{CE} exhibit any significant change in properties after 9 cycles at 260 degree C. Each of these cycles comprises four hours at temperature and a 12-hour cool down to room temperature.

The stability of the ultrathin FeMn film and the exchange properties are somewhat surprising considering the thickness involved in the exchange interface. In contrast, Fig. 6 shows the thermal cycling properties of a similar structure which has a FeMn film thickness of 40 nm. Note that in this case both the exchange bias field and the exchange coercivity change substantially with thermal cycling.

Electron diffraction experiments have shown that the dependence of exchange coupling on FeMn thickness is related to the FeMn phase stability. When the FeMn thickness is in the about 2.5 to 20 nm range (on Ni Fe), the FeMn phase is for the most part single phase fcc. However, when the FeMn thickness exceeds a critical thickness (~15-20 nm, then the FeMn is composed of both the fcc (γ phase) and a bcc (body-centred-cubic) α Mn phase which is not antiferromagnetic at room temperature. When the FeMn is thin and single phase fcc it is believed to be more stable during thermal processing than when the FeMn is composed of both the fcc (γ phase) and the bcc (α Mn) phase

(See Figs. 5 and 6).

Another embodiment of the invention is shown in Fig. 2 in which similar components of the MR read transducer assembly are given the same reference numerals as the embodiment shown in Fig. 1. Note however that the capping layer 24 is constructed in a different manner although the function of the capping layer is the same. In this embodiment, the capping layer 24 comprises a laminated structure FeMn - Lx where Lx comprises stable oxides, carbides, nitrides or carbon. The basic concept is that the exchange coupling depends only on the ultrathin layer 20 of FeMn and the capping layer 24 comprises MnFe laminated with high resistivity (or insulating) layers which are inert to many corrosive environments, and the materials of the capping layer can actually improve the mechanical integrity of the FeMn layer. Since the oxide phases such as Al_2O_3, Cr_2O_3, SiO_2, etc. exhibit low diffusivity, they are very stable at 200-300 degrees C and provide excellent diffusion barriers near the exchange interface.

The capping layer 24 is shown in expanded form in Fig. 3. The capping layer comprises alternating layers 26 of FeMn with layers 28 of the high resistivity material such as Cr_2O_3, Al_2O_3, SiO_2 and carbon, for example. The capping layer 24 is produced by co-sputtering FeMn and the high resistivity material with both sources ON simultaneously while rotating at a speed of 10 to 40 rpm. The thickness of the individual laminations is dependent on the rotating speed and did not appear to be critical. The capping layer 24 is formed of n laminations to a total thickness in the range of 30 nm which also did not appear to be critical.

Fig. 7 shows thermal cycling data for a laminated capping layer on a FeMn film 5 nm thick in which three different laminating materials, Al_2O_3, SiO_2 and carbon are used. Both the exchange bias field H_{UA} and the exchange coercivity H_{CE} are substantially stable with thermal cycling with SiO_2 showing the highest exchange, while the carbon structure showed the lowest exchange as well as the greatest change in coercivity with thermal cycling.

While the experimental data shows that a capping layer having a laminated structure of FeMn with Cr_2O_3, Al_2O_3 and SiO_2 produces a high exchange field that is stable with thermal cycling, it is possible to conclude that HfO_2, ZrO_2 and Ta_2O_5 may also produce acceptable device performance when included in a laminated capping layer structure with FeMn.

There is evidence that the addition of small amounts of a third element to FeMn to produce ternary alloys can result in improved characteristics. In particular, small amounts of titanium (Ti), rhodium (Rh) or chromium (Cr) lead to ternary alloys having improved characteristics. For this reason the layer 20 of antiferromagnetic material in either Fig. 1 or Fig. 2 may comprise Mn Fe-X where X is Ti, Rh or Cr.

The dependence of exchange coupling on FeMn thickness seems to be a basic materials property rather than depending on processing systems since essentially the same thickness dependence was noted in sputtering systems with higher base pressures, in the 1.3×10^{-5} Pa (10^{-7} torr) range, for example.

Claims

1. A magnetoresistive read transducer assembly comprising:

   a thin magnetoresistive conductive layer (18); and

   a film of antiferromagnetic material (20) in direct contact with said magnetoresistive layer whereby an exchange bias field is produced between them which is relatively high and remains stable during thermal cycling, characterised in that said film of antiferromagnetic material has a thickness within the range of about 2.5 to 10 nm.

2. An assembly as claimed in claim 1, wherein said antiferromagnetic material is FeMn.

3. An assembly as claimed in claim 1, wherein said antiferrogmagnetic material is FeMn - X where X is Rh, Ti or Cr.

4. An assembly as claimed in any preceding claim, including a capping layer (22) comprising a high resistivity material in contact with said film of antiferrogmagnetic material to protect said film of antiferromagnetic material from damage due to adverse environments.

5. An assembly as claimed in claim 4, wherein said high resistivity material is a dielectric material.

6. An assembly as claimed in claim 5, wherein said dielectric material is taken from the group consisting of Cr_2O_3, Al_2O_3, and SiO_2.

7. An assembly as claimed in claim 4, wherein said high resistivity material is a metal oxide cermet material.

8. An assembly as claimed in claim 7, wherein said metal oxide cermet material is taken from the group consisting of cr - Si O, $Ni_{80}Cr_{20}$ - Cr_2O_3, and $Ni_{80}Cr_{20}$ - SiO_2.

(See Figs. 5 and 6).

Another embodiment of the invention is shown in Fig. 2 in which similar components of the MR read transducer assembly are given the same reference numerals as the embodiment shown in Fig. 1. Note however that the capping layer 24 is constructed in a different manner although the function of the capping layer is the same. In this embodiment, the capping layer 24 comprises a laminated structure FeMn - Lx where Lx comprises stable oxides, carbides, nitrides or carbon. The basic concept is that the exchange coupling depends only on the ultrathin layer 20 of FeMn and the capping layer 24 comprises MnFe laminated with high resistivity (or insulating) layers which are inert to many corrosive environments, and the materials of the capping layer can actually improve the mechanical integrity of the FeMn layer. Since the oxide phases such as Al_2O_3, Cr_2O_3, SiO_2, etc. exhibit low diffusivity, they are very stable at 200-300 degrees C and provide excellent diffusion barriers near the exchange interface.

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Fig. 7 shows thermal cycling data for a laminated capping layer on a FeMn film 5 nm thick in which three different laminating materials, Al_2O_3, SiO_2 and carbon are used. Both the exchange bias field H_{UA} and the exchange coercivity H_{CE} are substantially stable with thermal cycling with SiO_2 showing the highest exchange, while the carbon structure showed the lowest exchange as well as the greatest change in coercivity with thermal cycling.

While the experimental data shows that a capping layer having a laminated structure of FeMn with Cr_2O_3, Al_2O_3 and SiO_2 produces a high exchange field that is stable with thermal cycling, it is possible to conclude that HfO_2, ZrO_2 and Ta_2O_5 may also produce acceptable device performance when included in a laminated capping layer structure with FeMn.

There is evidence that the addition of small amounts of a third element to FeMn to produce ternary alloys can result in improved characteristics. In particular, small amounts of titanium (Ti), rhodium (Rh) or chromium (Cr) lead to ternary alloys having improved characteristics. For this reason the layer 20 of antiferromagnetic material in either Fig. 1 or Fig. 2 may comprise Mn Fe-X where X is Ti, Rh or Cr.

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2. An assembly as claimed in claim 1, wherein said antiferromagnetic material is FeMn.

3. An assembly as claimed in claim 1, wherein said antiferrogmagnetic material is FeMn - X where X is Rh, Ti or Cr.

4. An assembly as claimed in any preceding claim, including a capping layer (22) comprising a high resistivity material in contact with said film of antiferrogmagnetic material to protect said film of antiferromagnetic material from damage due to adverse environments.

5. An assembly as claimed in claim 4, wherein said high resistivity material is a dielectric material.

6. An assembly as claimed in claim 5, wherein said dielectric material is taken from the group consisting of Cr_2O_3, Al_2O_3, and SiO_2.

7. An assembly as claimed in claim 4, wherein said high resistivity material is a metal oxide cermet material.

8. An assembly as claimed in claim 7, wherein said metal oxide cermet material is taken from the group consisting of cr - Si O, $Ni_{80}Cr_{20}$ - Cr_2O_3, and $Ni_{80}Cr_{20}$ - SiO_2.

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9. An assembly as claimed in claim 4, wherein said capping layer comprises a laminated structure comprising alternating thin films of FeMn and a dielectric material.

Patentansprüche

1. Eine magnetoresistive Lesewandlerbaugruppe, die folgendes umfaßt: eine dünne, magnetoresistive Schicht aus einem leitendem Werkstoff (18), und einen Film eines Antiferromagnetikums (20), der in direktem Kontakt mit der magnetoresistiven Schicht steht, wodurch ein Austauschvormagnetisierungsfeld zwischen diesen Schichten erzeugt wird, das relativ stark ist und sich bei Temperaturvechselbeanspruchungen stabil verhält, dadurch gekennzeichnet, daß der Film des Antiferromagnetikums eine Stärke im Bereich von etwa 2,5 bis 10 nm aufweist.

2. Eine Baugruppe gemäß Anspruch 1, bei der als Antiferromagnetikum FeMn verwendet wird.

3. Eine Baugruppe gemäß Anspruch 1, bei der die antiferromagnetische Schicht aus FeMn - X besteht, wobei X einer der Werkstoffe Rh, Ti oder Cr ist.

4. Eine Baugruppe gemäß einem beliebigen der vorstehenden Ansprüche, die eine Abdeckschicht (22) mit einem hoch resistiven Werkstoff umfaßt, der in Kontakt mit dem Film des Antiferromagnetikums steht, um diesen Film des Antiferromagnetikums vor Schäden aufgrund ungünstiger Umgebungsbedingungen zu schützen.

5. Eine Baugruppe gemäß Anspruch 4, bei welcher der hoch resistive Werkstoff ein dielektrischer Werkstoff ist.

6. Eine Baugruppe gemäß Anspruch 5, bei welcher der dielektrische Werkstoff aus der Gruppe stammt, die Cr_2O_3, Al_2O_3 und SiO_2 beinhaltet.

7. Eine Baugruppe gemäß Anspruch 4, bei welcher der hoch resistive Werkstoff ein metallkeramischer Werkstoff aus Metalloxid ist.

8. Eine Baugruppe gemäß Anspruch 7, bei welcher der metallkeramische Werkstoff aus Metalloxid der Gruppe entstammt, die Cr - SiO, $Ni_{80}Cr_{20}$ - Cr_2O_3 und $Ni_{80}Cr_{20}$ - SiO_2 enthält.

9. Eine Baugruppe gemäß Anspruch 4, bei welcher die Abdeckschicht eine laminierte Struktur umfaßt, die abwechselnd dünne Filme aus FeMn und aus einem dielektrischen Werkstoff enthält.

Revendications

1. Assemblage de transducteur de lecture magnétorésistif comprenant une couche conductrice magnétorésistive mince (18), et un film de matériau antiferromagnétique (20) en contact direct avec ladite couche magnétorésistive de sorte qu'un champ de polarisation par échange est produit entre la couche et le film, qui est relativement élevé et reste stable durant le cycle thermique, caractérisé en ce que ledit film de matériau antiferromagnétique a une épaisseur dans la gamme d'environ 2,5 à 10 nm.

2. Assemblage tel que revendiqué dans la revendication 1, dans lequel ledit matériau antiferromagnétique est FeMn.

3. Assemblage tel que revendiqué dans la revendication 1, dans lequel ledit matériau antiferromagnétique est FeMn-X où X est Rh, Ti ou Cr.

4. Assemblage tel que revendiqué dans une quelconque des revendications précédentes, comprenant une couche de recouvrement (22) comprenant un matériau de grande résistivité en contact avec ledit film de matériau antiferromagnétique pour protéger ledit film de matériau antiferromagnétique contre les dommages causés par les environnements hostiles.

5. Assemblage tel que revendiqué dans la revendication 4, dans lequel ledit matériau de grande résistivité est un matériau diélectrique.

6. Assemblage tel que revendiqué dans la revendication 5, dans lequel ledit matériau diélectrique est choisi dans le groupe consistant en Cr_2O_3, Al_2O_3 et SiO_2

7. Assemblage tel que revendiqué dans la revendication 4, dans lequel ledit matériau de grande résistivité est un mélange céramique-métal.

8. Assemblage tel que revendiqué dans la revendication 7, dans lequel ledit mélange céramique-métal est choisi dans le groupe consistant en Cr-SiO_2, $Ni_{80}Cr_{20}$-Cr_2O_3, et $Ni_{80}Cr_{20}$-SiO_2.

9. Assemblage tel que revendiqué dans la revendication 4, dans lequel ladite couche de recouvrement comprend une structure laminée com-

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portant des films minces alternés de FeMn et un matériau diélectrique.