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Nibarger et al.

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(54) **METHOD FOR PROTECTING AGAINST CORROSION IN A GMR SENSOR BY PROVIDING A PROTECTIVE COATING OVER AN END OF A COPPER LAYER SPACED APART FROM A DETECTION SURFACE BY A SPECIFIED DIMENSION**

(58) **Field of Classification Search** 29/603.07, 29/603.13–603.16, 603.18; 216/62, 65, 66; 360/121, 122, 317; 427/127, 128; 451/5, 451/41
See application file for complete search history.

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 198 days.

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(57) **ABSTRACT**

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A method for providing a giant magneto-resistive (GMR) sensor for use in sensing magnetic flux is provided. The method comprises positioning a layer of Cu material between first and second layers of a specified ferromagnetic material. The respective end surfaces of the Cu layer and the first and second layers are initially located in a common plane and in a co-planar relationship with one another. The method further comprises removing an amount of material from the copper layer to form a new end surface thereof that is selectively spaced apart from the common plane and applying a protective coating to the new end surface of the Cu layer to inhibit corrosion of the Cu layer.

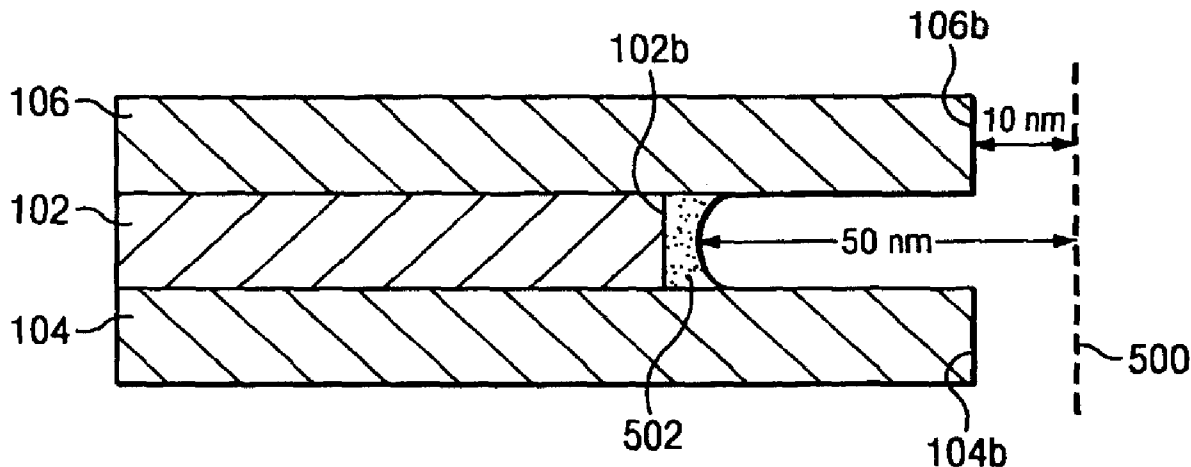
Related U.S. Application Data

(62) Division of application No. 11/177,606, filed on Jul. 8, 2005, now Pat. No. 7,403,359.

(51) **Int. Cl.**
G11B 5/127 (2006.01)
H04R 31/00 (2006.01)

(52) **U.S. Cl.** **29/603.16**; 29/603.07; 29/603.13; 29/603.15; 29/603.18; 216/62; 216/65; 216/66; 360/121; 360/122; 360/317; 451/5; 451/41

14 Claims, 4 Drawing Sheets



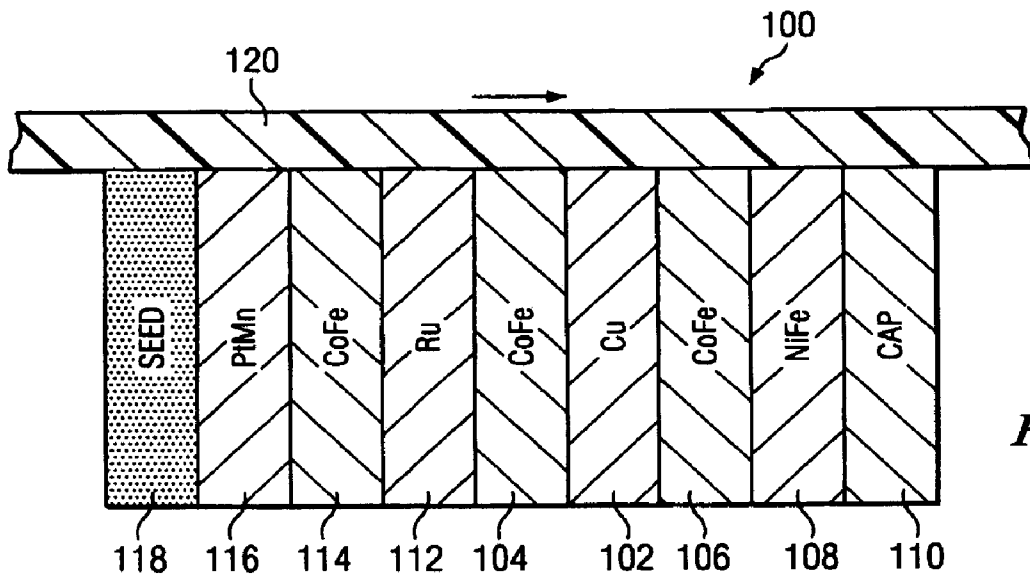


FIG. 1

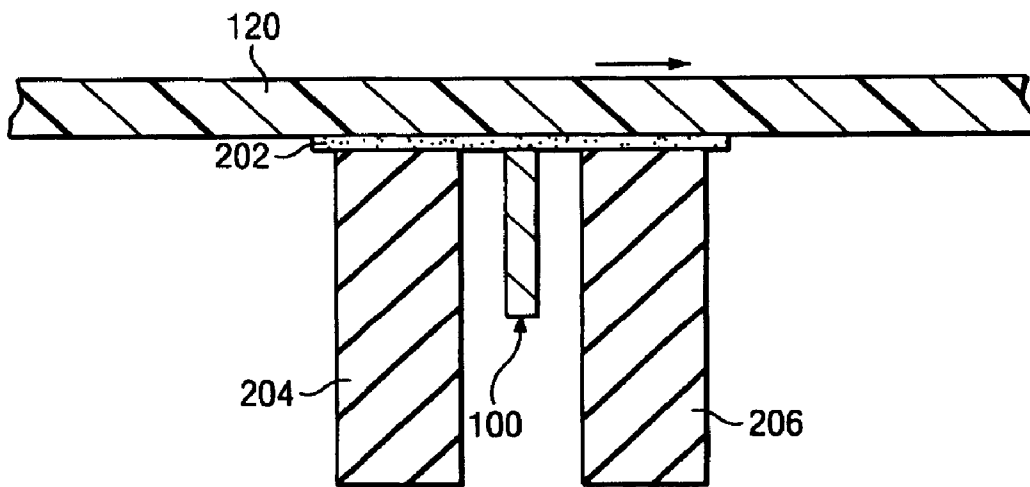


FIG. 2
(PRIOR ART)

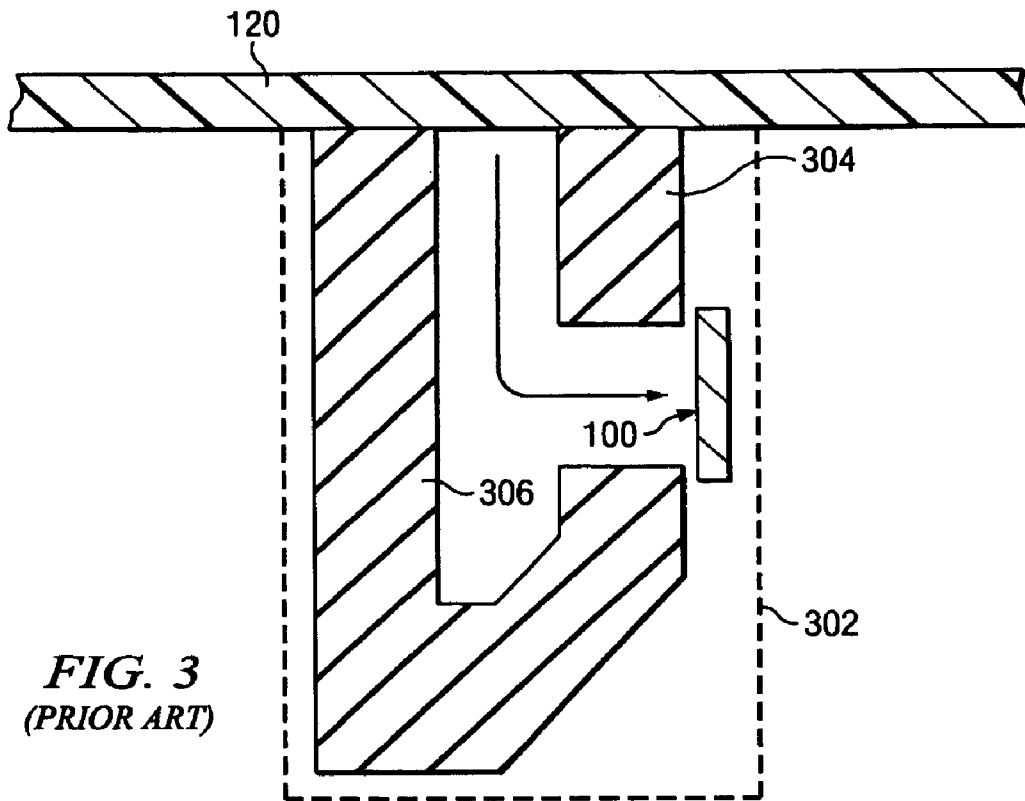


FIG. 3
(PRIOR ART)

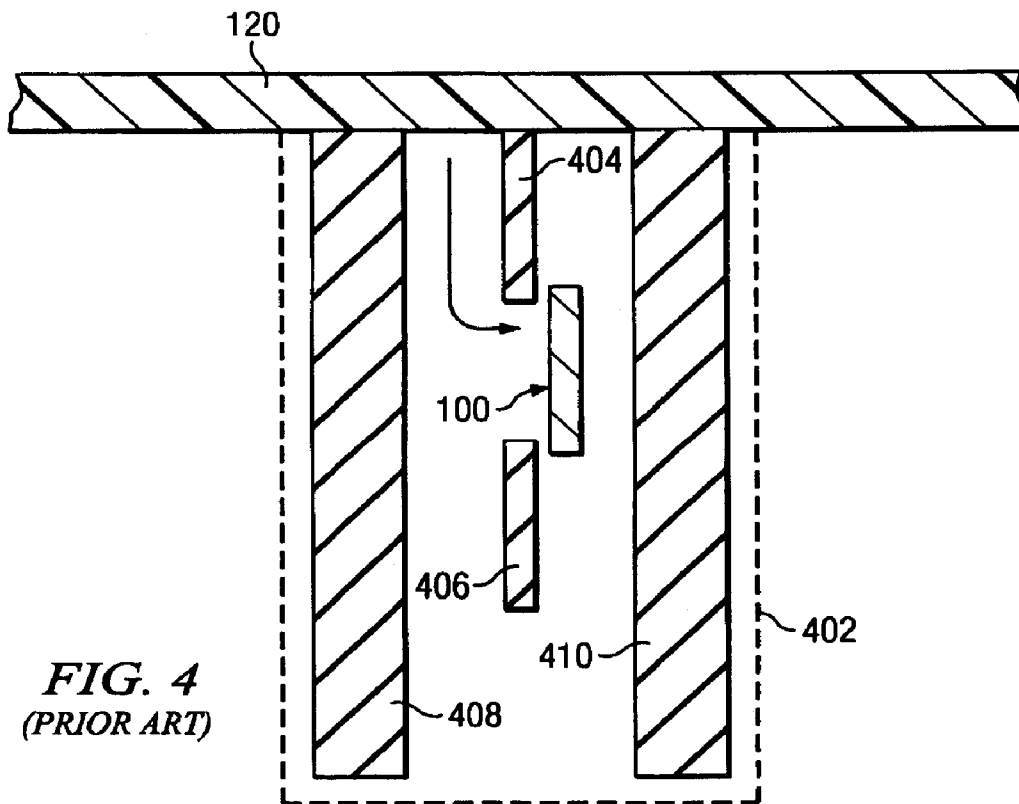


FIG. 4
(PRIOR ART)

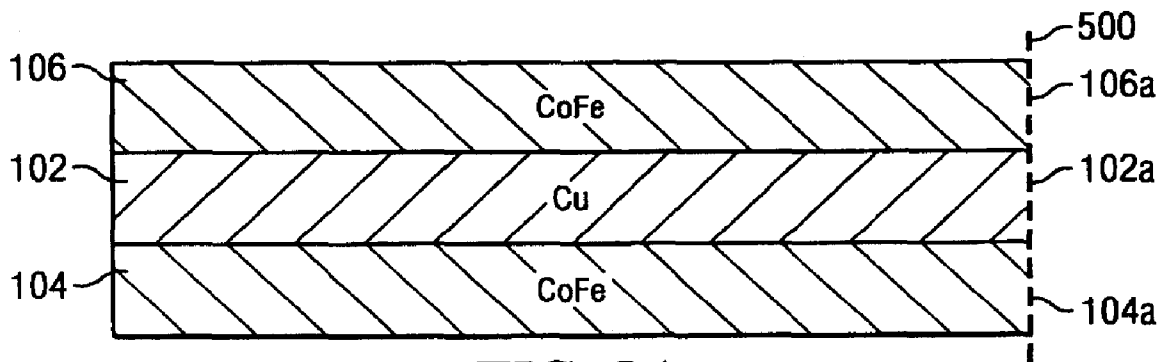


FIG. 5A

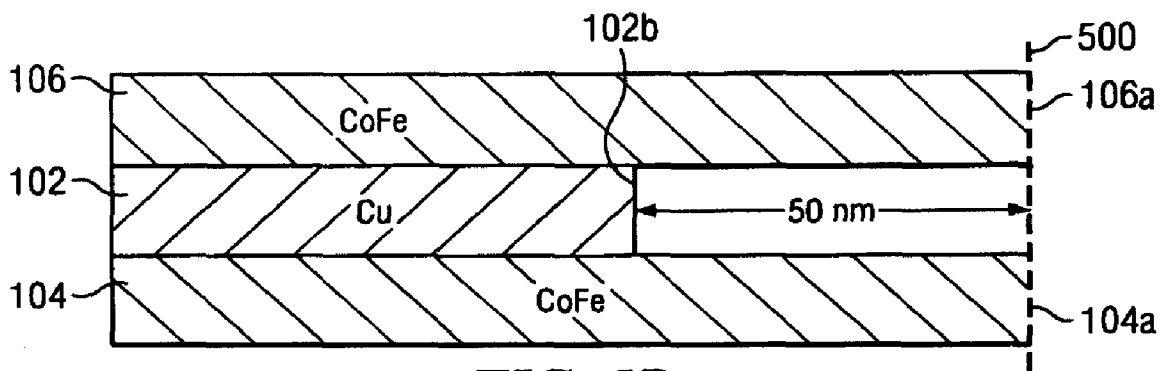


FIG. 5B

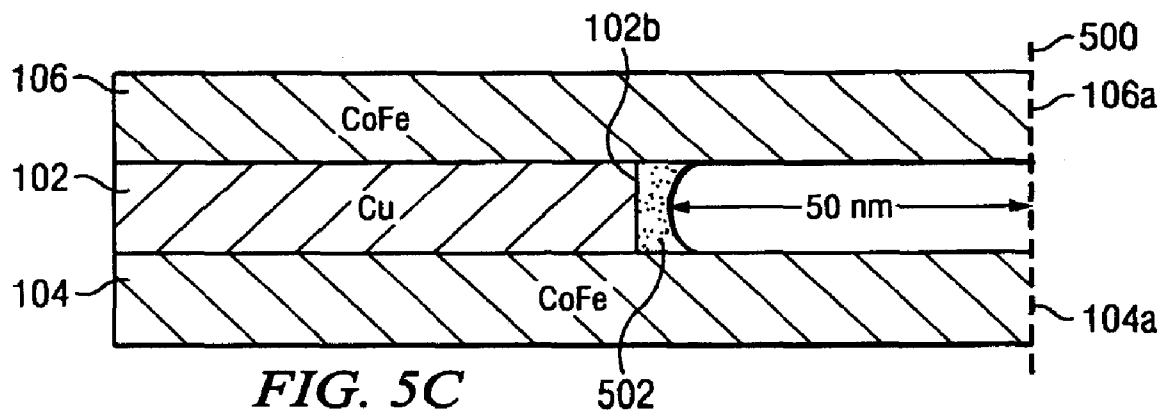
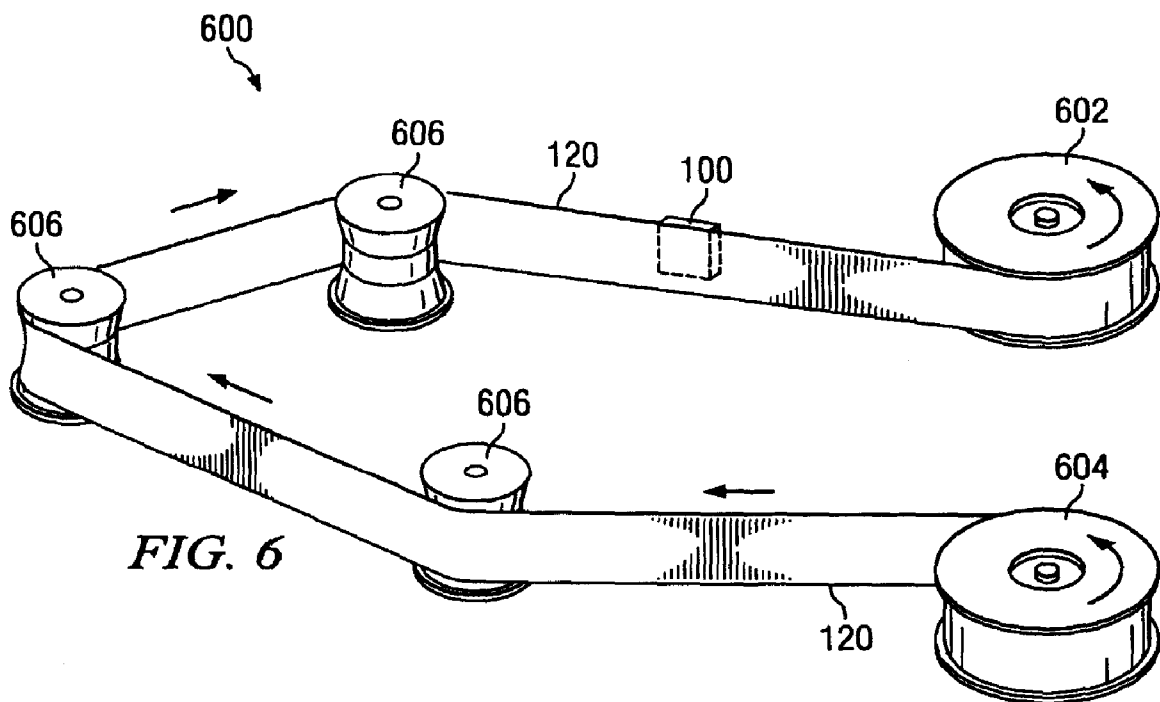
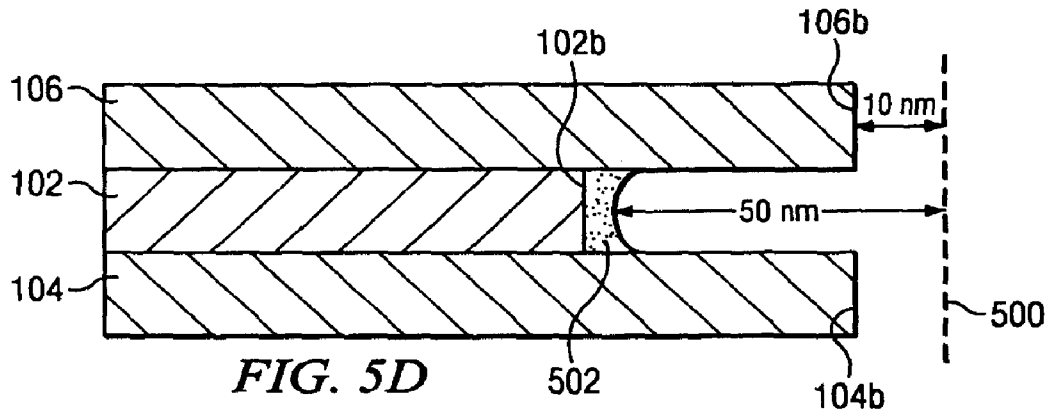


FIG. 5C



**METHOD FOR PROTECTING AGAINST
CORROSION IN A GMR SENSOR BY
PROVIDING A PROTECTIVE COATING
OVER AN END OF A COPPER LAYER
SPACED APART FROM A DETECTION
SURFACE BY A SPECIFIED DIMENSION**

CROSS-REFERENCE TO RELATED
APPLICATIONS

This application is a divisional of U.S. application Ser. No. 11/177,606 filed Jul. 8, 2005, now U.S. Pat. No. 7,403,359 B1.

BACKGROUND

1. Technical Field

The invention disclosed and claimed herein generally pertains to a method for applying a protective coating to at least one layer of a giant magneto-resistive (GMR) sensor, to inhibit corrosion. More particularly, the invention pertains to a method of the above type wherein a protective coating is applied to a layer of copper or copper alloy sandwiched between other layers of material, such as an alloy of cobalt and iron. Even more particularly, the invention pertains to a method of the above type wherein the copper and cobalt-iron layers are included in a stack of layers comprising a sensor for a read head of a magnetic media data storage system.

2. Description of the Related Art

The continuing requirement to increase storage densities of magnetic media data storage systems, such as magnetic tape drive systems, is increasing the need for more sensitive magneto-resistive sensors. Currently, anisotropic magneto-resistive (AMR) sensors are being employed in the read heads of such systems. In AMR sensors, corrosion generally has not been a significant issue associated with their use. In these sensors corrosion has been mitigated through the use of half-power storage, which keeps the sensor material warm when not in use. This, in turn, reduces the amount of corrosive gases that are adsorbed onto the sensor material. However, the maximum change in sensor resistance ($\Delta R/R$) for an AMR sensor is only 2%. As is known by those of skill in the art, $\Delta R/R$ is a metric of total signal available from the sensor, and thus indicates the sensitivity of the sensor.

In the effort to increase data storage density in magnetic media, it has been recognized that the $\Delta R/R$ of a read sensor may be significantly increased by using a device known as a giant magneto-resistive (GMR) sensor. The $\Delta R/R$ for a GMR sensor is 10-20%. However, a major drawback associated with this type of sensor has been its increased susceptibility to corrosion. A GMR sensor generally comprises a stack of layers, wherein a central layer is formed of copper or a copper alloy. Hereinafter, for convenience, the term "Cu" is used to mean or refer to the copper or copper alloy material forming such central layer. Other layers are formed of materials such as alloys of platinum-manganese (PtMn), cobalt-iron (CoFe), nickel-iron (NiFe), ruthenium (Ru) and tantalum (Ta). The most susceptible layer to corrosion is the crucial Cu layer. The Cu layer carries substantial electric current, and the GMR effect occurs at the interface of the copper and adjoining layers, which usually are comprised of a cobalt-ferrite alloy (CoFe).

Several solutions to the Cu corrosion problem are available in the prior art. One such solution is to place a protective layer on top of the stack of sensor layers, to prevent corrosion of any of the layers. However, at least two problems exist with this solution: the protective layer can be worn off by the moving

magnetic tape or other media, and the protective layer, when present, introduces spacing loss which can reduce the sensor signal and resolution to unacceptable levels.

A second prior art solution is to bury the GMR sensor within the read head of the tape drive system. This is commonly done in either a yoke structure or in a flux guide structure. However, a number of problems also arise with these solutions. Signal strength is reduced, since yoke and flux guide designs have a maximum efficiency of only 50%, with efficiency usually being closer to 20-30%. Also, the manufacture of the yoke structure tends to involve substantial complexity.

The above prior art solutions to corrosion of the Cu layer in a GMR sensor are further described hereinafter, in connection with FIGS. 3-5. It would clearly be of great benefit to provide a process for protecting the vulnerable Cu layer of a GMR sensor that did not introduce additional spacing losses between the media and the active layer of the sensor.

SUMMARY

In at least one embodiment, a method for providing a giant magneto-resistive (GMR) sensor for use in sensing magnetic flux is provided. The method comprises positioning a layer of Cu material between first and second layers of a specified ferromagnetic material. The respective end surfaces of the Cu layer and the first and second layers are initially located in a common plane and in a co-planar relationship with one another. The method further comprises removing an amount of material from the copper layer to form a new end surface thereof that is selectively spaced apart from the common plane and applying a protective coating to the new end surface of the Cu layer to inhibit corrosion of the Cu layer.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic view showing a GMR sensor for processing to inhibit corrosion, in accordance with an embodiment of the invention;

FIGS. 2-4 are schematic views showing respective prior art approaches for reducing corrosion in a GMR sensor;

FIGS. 5A-D are views illustrating successive process steps applied to the GMR sensor of FIG. 1, in implementing an embodiment of the invention; and

FIG. 6 is a perspective view showing a magnetic tape drive system having a GMR sensor processed as shown by FIGS. 5A-D.

DETAILED DESCRIPTION OF THE PREFERRED
EMBODIMENT(S)

Referring to FIG. 1, there is shown a giant magneto-resistive (GMR) sensor 100, comprising a number of layers that are stacked together. Respective layers are formed of different ferromagnetic, antiferromagnetic, and non-magnetic materials, as described hereinafter. Of particular importance is non-magnetic Cu layer 102, formed of copper or a copper alloy such as CuAg or CuAu. The Cu layer 102 is sandwiched between ferromagnetic CoFe layers 104 and 106. Layers 104 and 106 may comprise, for example, a cobalt-iron alloy such as $\text{Co}_{50}\text{Fe}_{50}$.

Referring further to FIG. 1, there is shown sensor 100 referred to as a spin valve. The spin valve is comprised of a stack of ferromagnetic, antiferromagnetic, and non-magnetic materials. A PtMn layer 116 with the appropriate seed 118 provides antiferromagnetic exchange coupling of the pinned layer. A pinned layer is comprised of a CoFe pinned layer 114,

a Ru spacer layer **112**, and a CoFe reference layer **104**. The thickness of the Ru spacer layer is chosen so that antiferromagnetic coupling occurs between the pinned **114** and reference **104** CoFe layers. This structure is referred to as a synthetic antiferromagnet. The next layer is the crucial Cu non-magnetic spacing layer **102**. The next two layers, $\text{Co}_{90}\text{Fe}_{10}$ **106** and $\text{Ni}_{80}\text{Fe}_{20}$ **108** compromise the free layer. Finally a protective capping layer **110** is used to protect the films during further photolithography and processing steps.

It will, of course, be appreciated that other embodiments of the invention may comprise stacked layers of other materials than those shown, and in other combinations, as will occur to those of skill in the art. Sensor **100** comprises a device known as a spin valve, which achieves a large resistance change depending on the relative orientation of two ferromagnetic layers; the pinned CoFe reference layer **104** and the CoFe free layer **106**. In order for the ferromagnetic layers to have independent magnetizations, they must be magnetically decoupled by a non-magnetic spacer layer, such as Cu layer **102**. The non-magnetic spacer layer must have the appropriate band structure to allow spin dependent scattering at the reference and free layer interfaces. Cu, Au, and Ag as well as Cu alloys have been shown to provide this property.

FIG. **1** further shows magnetic data storage tape **120** positioned to travel along GMR sensor **100**, in close proximity thereto. As is known by those of skill in the art, the resistance of a device such as GMR sensor **100** changes when it experiences or is exposed to a magnetic field. Thus, by passing an electric current through the GMR sensor **100**, the sensor can be used to read information that is magnetically stored on the tape **120**. As the tape moves past sensor **100**, a pattern of magnetic flux is applied to sensor **100** by the tape **120**. This flux pattern continually changes, in accordance with the information stored on the tape. Accordingly, the resistance of the GMR sensor varies in corresponding relationship with the changes in flux. It follows that these variations represent the stored data, and can be readily detected by monitoring the current that flows through the sensor. In a very useful arrangement, data is stored on the magnetic tape in the form of successive digital bits. Different transition patterns of flux emitted from the tape represent digital 1's and 0's, respectively.

When tape data storage density is increased, each individual stored data bit is allocated a smaller amount of the tape or other storage media. As a result, the media provides less flux for each bit, for use by a sensor in detecting flux transitions. Accordingly, the higher $\Delta R/R$ ratio available with GMR sensors has caused such sensors to have great appeal, for use in read heads for magnetic data storage media. However, as stated above, GMR sensors, and particularly the crucial Cu layer thereof, tend to be very susceptible to corrosion. The Cu layer carries approximately half of the current, and the GMR effect occurs at the interface of the Cu layer **102** and CoFe layers **104** and **106**.

FIG. **2** shows one of the prior art approaches for reducing corrosion in a GMR sensor, wherein a protective layer **202** is placed on top of the stacked layers that collectively form GMR sensor **100**. FIG. **2** shows the same view of sensor **100** as shown in FIG. **1**, but without differentiating the respective layers. However, as previously stated, the moving storage tape **120** may eventually wear away the protective layer **202**. Moreover, the protective layer **202** necessarily spaces the sensor **100** away from the magnetic tape **120**. Thus, a spacing loss is introduced, which can reduce the amount of flux that is detectable at sensor **100** and also the resolution of sensor **100**, to unacceptable levels.

FIG. **2** further shows magnetic field shields **204** and **206**, positioned to prevent GMR sensor **100** from being affected by stray magnetic fields.

Referring to FIG. **3**, there is shown an alternative prior art approach to reducing corrosion in a GMR sensor **100**. In the arrangement of FIG. **3**, the sensor is placed well within the tape read head **302**, and can thus be protected from a surrounding corrosive environment. A yoke structure, comprising components **304** and **306**, is provided in read head **302** to direct flux from the magnetic storage tape **120** to sensor **100**. The yoke structure provides a magnetic flux path from the tape **120** through yoke **304**, through sensor **110**, through yoke **306**, and returning to tape **120**. However, prior art yoke designs generally have a maximum efficiency of 50%, and efficiency is typically closer to 20-30%. Accordingly, signal strength is substantially reduced at the GMR sensor. Moreover, the yoke structure involves significant manufacturing complexity.

FIG. **4** is a further prior art approach, similar to the yoke structure approach of FIG. **3**. FIG. **4** shows the sensor **100** again placed within a tape head **402**. Components **404** and **406** are flux guide components, positioned to direct magnetic flux from storage tape **120** to sensor **100**. However, as with the yoke structure, signal strength at sensor **100** is significantly reduced, since efficiency is no greater than 50% and is usually on the order of 20-30%. FIG. **4** shows the sensor **100** and flux guide components **404** and **406** positioned between magnetic field shields **408** and **410**.

Referring to FIG. **5A**, there is shown Cu layer **102** of sensor **100** initially positioned between CoFe layers **104** and **106**, as described above. Moreover, the layers are respectively positioned so that an end surface **102a** of Cu layer **102** is in co-planar relationship with end surfaces **104a** and **106a**, of CoFe layers **104** and **106**, respectively. More particularly, each of the ends **102a**, **104a**, and **106a** lies in a common plane **500**. This plane is the plane of the bearing surface for storage tape **120**, as tape **120** moves over sensor **100**. As shown by FIG. **1**, this bearing surface is provided by the support collectively furnished by the ends of respective layers of sensor **100**. Cu layer **102** usefully has a thickness of 30 Angstroms, and CoFe layers **104** and **106** each have a thickness of 40 Angstroms.

For ease and simplicity of illustration, FIG. **5A**, as well as FIGS. **5B-D**, do not show the layers **108-118** of sensor **100**. Such layers are affected only by the lapping step described hereinafter in FIG. **5D**.

Referring to FIG. **5B**, there is shown Cu layer **102**, wherein layer **102** has been specifically etched to remove 50 nanometers (nm) of material therefrom. Accordingly, layer **102** is provided with a new end surface **102b**, which is spaced apart from the plane **500** by 50 nm, and will thus be spaced 50 nm from tape **120** when the tape moves over the sensor **100**. In other embodiments of the invention, this spacing could be other values selected from a range between 30 nm and 100 nm.

A number of Cu specific etchants are currently available for use in removing the Cu material. These etchants include, for example, sodium persulfate, dilute hydrochloric acid and dilute nitric acid. A Cu specific etchant will, of course, act to remove material only from the Cu layer, and not from adjacent layers of sensor **100** that are formed of other materials.

Referring to FIG. **5C**, there is shown a layer of protective material **502** that is bonded specifically to surface **102b** of Cu layer **102**. The Cu layer is thereby sealed from air of the surrounding environment and protected from corrosion. A number of different materials could be used to form protective coating **502**, depending at least partly on the technique

selected to apply the protective coating. Several alternative techniques that would be particularly useful would be (1) mechanical entrainment; (2) electroplating; and (3) electroless plating.

In mechanical entrainment, it is simply necessary to provide material to cover over end surface **102b**, in the space between CoFe layers **104** and **106**. The material **502** may come from two sources during lapping. It could come from the removed material during lapping or be an additional material added during lapping.

Electrolytic plating may usefully be employed to apply protective coating **502**, since approximately 50% of the electric current passing through the sensor **100** is in the Cu layer **102**. The Cu layer would thus be used as an electrode in an electrolytic plating process, and an appropriate material having an affinity for copper, such as gold, could be plated onto Cu end surface **102b**. If plating were to occur in an undesirable location, tape lapping, may be required to remove the unwanted material.

Electroless plating is a comparatively straightforward method, whereby a chemical coating is applied to end surface **102b**, to provide protective coating **502**. This could be either through a catalytic or immersion process. The protective coating could comprise one of a number of copper specific complexing compounds, such as benzotriazole (BTA), and chromate conversion coatings of a type generally used for corrosion protection. A BTA molecule is a planar molecule having a diameter on the order of 5 Angstroms. Accordingly, it is considered feasible to fit the BTA molecules onto the Cu layer **102**, since such layer has a thickness on the order of 30 Angstroms.

Referring to FIG. 5D, there is shown a tape lap performed on CoFe layers **104** and **106**. The tape lap is a process whereby small amounts of material are removed from the ends of layers **104** and **106**, to form new end surfaces **104b** and **106b**, respectively. Usefully, the tape lap provides spacing on the order of 10 nanometers between end surfaces **104b** and **106b** and the plane **500** of the tape bearing surface. The tape lap of layers **104** and **106** set the contour for the tape bearing surface provided by sensor **100**.

The tape lap of CoFe layers **104** and **106** also creates a pole tip recession of 10 nanometers. As is known by those of skill in the art, the CoFe material of layers **104** and **106** tends to be removed by passage of tape **120**, whereby the ends of layers **104** and **106** gradually become spaced farther and farther from the tape. Accordingly, the signal level sensed by layers **104** and **106** tends to diminish over time, and periodic adjustment in signal reception capability is necessary. However, by providing the 10 nanometer spacing of layers **104** and **106** initially, the signal reception adjustment can likewise be made initially, and thus will not become a concern later on.

In another embodiment of the invention, the steps shown in FIGS. 5B and 5C could be applied to other sensitive layers as well. For example, the steric acid in the magnetic tape lubricant may electrochemically deplete cobalt at a faster rate than other materials used in the GMR sensor **100**. Accordingly, a cobalt specific etchant could be used to remove a portion of material from CoFe layers **104** and **106**. A protective coating could then be applied to such layers, in like manner with Cu layer **102**. In fact, applying protective coatings to both Cu layer **102** and CoFe layers **104** and **106** would make the introduction of the magnetic tape to the Cu and CoFe surfaces easier, since the combined area thereof would be proportionally larger.

In a modification of the embodiment illustrated by FIGS. 5A-D, there could be an initial tape lap of Cu layer **102**, before

the Cu layer etch step. The etch step may or may not be followed by a final tape lap of the Cu layer.

Referring to FIG. 6, there is shown a tape drive system **600** disposed to move magnetic tape **120** past a tape read head comprising or including GMR sensor **100**. Tape drive system **600** may be used for data storage in a computer system or the like. FIG. 6 shows system **100** having tape reels **602** and **604**, driven by a motor or motors (not shown) to move tape media **120** along its path of travel or movement. Tape guides **606** are located at different positions along the path of travel, to accomplish respective direction changes.

The description of the present invention has been presented for purposes of illustration and description, and is not intended to be exhaustive or limited to the invention in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art. The embodiment was chosen and described in order to best explain the principles of the invention, the practical application, and to enable others of ordinary skill in the art to understand the invention for various embodiments with various modifications as are suited to the particular use contemplated.

While embodiments of the invention have been illustrated and described, it is not intended that these embodiments illustrate and describe all possible forms of the invention. Rather, the words used in the specification are words of description rather than limitation, and it is understood that various changes may be made without departing from the spirit and scope of the invention.

What is claimed is:

1. A method for providing a giant magneto-resistive (GMR) sensor for use in sensing magnetic flux, the method comprising:

positioning a layer of Cu material between first and second layers of a specified ferromagnetic material, wherein respective end surfaces of the Cu layer and the first and second layers are initially located in a common plane, in co-planar relationship with one another;

removing an amount of material from the Cu layer to form a new end surface of the Cu layer that is selectively spaced apart from the common plane; and

applying a protective coating to the new end surface of the Cu layer, to inhibit corrosion of the Cu layer,

wherein the first and second layers each comprises metallic ferromagnetic layers and/or alloys containing Ni, Fe, Co, or combinations thereof, selectively,

wherein the Cu layer and the first and second layers are placed between a selected number of other layers to form a stack, the other layers comprising one or more materials selected from a group comprising metallic ferromagnetic layers containing Ni, Fe, Co, or combinations thereof and manganese based antiferromagnetic alloys, ruthenium and tantalum, the layers of the stack collectively comprising a spin valve device, and

wherein the protective coating is applied to the new end surface of the Cu layer by entrainment of material removed from other layers of the stack.

2. The method of claim 1, wherein removing an amount of material from the Cu layer further comprises selectively etching the Cu layer with a Cu specific etchant.

3. The method of claim 2, wherein a tape lap of the Cu layer is carried out before the etching step.

4. The method of claim 1, wherein the new end surface formed in the Cu layer is spaced apart from the common plane by a spacing amount of between 30 nm and 100 nm.

5. The method of claim 1, wherein material is removed from the first and second layers to create a pole tip recession,

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whereby new end surfaces are respectively formed therein that are each spaced apart from the common plane by on the order of 10 nm.

6. The method of claim 1, wherein a cobalt specific etchant is used to provide a spacing between the ends of the first and second layers, and a protective coating is then applied to the first and second layers.

7. A method for providing a giant magneto-resistive (GMR) sensor for use in sensing magnetic flux, the method comprising:

positioning a layer of Cu material between first and second layers of a specified ferromagnetic material, wherein respective end surfaces of the Cu layer and the first and second layers are initially located in a common plane, in co-planar relationship with one another;

removing an amount of material from the Cu layer to form a new end surface of the Cu layer that is selectively spaced apart from the common plane; and

applying a protective coating to the new end surface of the Cu layer, to inhibit corrosion of the Cu layer,

wherein the first and second layers each comprises metallic ferromagnetic layers and/or alloys containing Ni, Fe, Co, or combinations thereof, selectively,

wherein the Cu layer and the first and second layers are placed between a selected number of other layers to form a stack, the other layers comprising one or more materials selected from a group comprising metallic ferromagnetic layers containing Ni, Fe, Co, or combinations thereof and manganese based antiferromagnetic alloys, ruthenium and tantalum, the layers of the stack collectively comprising a spin valve device,

wherein removing an amount of material from the Cu layer further comprises selectively etching the Cu layer with a Cu specific etchant, and

wherein a tape lap of the Cu layer is carried out before the etching step.

8. The method of claim 7, wherein the protective coating is applied to the new end surface of the Cu layer by entrainment of material removed from other layers of the stack.

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9. The method of claim 7, wherein the protective coating is applied to the new end surface of the Cu layer by electrolytic plating, using material having an affinity for copper.

10. The method of claim 7, wherein the protective coating is applied to the new end surface of the Cu layer by electroless plating.

11. The method of claim 10, wherein the protective coating comprises benzotriazole (BTA).

12. The method of claim 7, wherein material is removed from the first and second layers to create a pole tip recession, whereby new end surfaces are respectively formed therein that are each spaced apart from the common plane by a predetermined amount.

13. A method for providing a giant magneto-resistive (GMR) sensor for use in sensing magnetic flux, the method comprising:

positioning a layer of Cu material between first and second layers of a specified ferromagnetic material, wherein respective end surfaces of the Cu layer and the first and second layers are initially located in a common plane, in co-planar relationship with one another;

removing an amount of material from the Cu layer to form a first new end surface of the Cu layer that is selectively spaced apart from the common plane; and

removing material from the first and second layers to create a pole tip recession such that second and third new ends are respectively formed therein,

selectively spacing apart the second and third new ends from the common plane by the predetermined amount; and

performing an initial signal reception adjustment after the second, and third new ends are formed for avoiding periodic signal reception adjustments.

14. The method of claim 13 wherein the predetermined amount is on the order of 10 nm.

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