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MAGNETIC TUNNEL JUNCTION HEAD STRUCTURE WITH INSULATING ANTIFERROMAGNETIC LAYER

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates in general to magnetic tunnel junction transducers for reading information signals from a magnetic medium and, in particular, to a magnetic tunnel junction sensor with an electrically insulating antiferromagnetic layer, and to magnetic storage systems which incorporate such sensors.

2. Description of Related Art

Computers often include auxiliary memory storage devices having media on which data can be written and from which data can be read for later use. A direct access storage device (disk drive) incorporating rotating magnetic disks is commonly used for storing data in magnetic form on the disk surfaces. Data is recorded on concentric, radially spaced tracks on the disk surfaces. Magnetic heads including read sensors are then used to read data from the tracks on the disk surfaces.

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In high capacity disk drives, magnetoresistive (MR) read sensors, commonly referred to as MR sensors, are the prevailing read sensors because of their capability to read data from a surface of a disk at greater track and linear densities than thin film inductive heads. An MR sensor detects a magnetic field through the change in the resistance of its MR sensing layer (also referred to as an "MR element") as a function of the strength and direction of the magnetic flux being sensed by the MR layer.

The conventional MR sensor operates on the basis of the anisotropic magnetoresistive (AMR) effect in which an MR element resistance varies as the square of the cosine of the angle between the magnetization in the MR element and the direction of sense current flowing through the MR element. Recorded data can be read from a magnetic medium because the external magnetic field from the recorded magnetic medium (the signal field) causes a change in the direction of magnetization in the MR element, which in turn causes a change in resistance in the MR element and a corresponding change in the sensed current or voltage.

Another type of MR sensor is the giant magnetoresistance (GMR) sensor manifesting the GMR effect. In GMR sensors, the resistance of the MR sensing layer varies as a function of the

spin-dependent transmission of the conduction electrons between magnetic layers separated by a non-magnetic layer (spacer) and the accompanying spin-dependent scattering which takes place at the interface of the magnetic and non-magnetic layers and within the magnetic layers.

GMR sensors using only two layers of ferromagnetic material (e.g., Ni-Fe) separated by a layer of non-magnetic material (e.g., copper) are generally referred to as spin valve (SV) sensors manifesting the SV effect.

Fig. **1** shows a prior art SV sensor **100** comprising end regions **104** and **106** separated by a central region **102**. A first ferromagnetic layer, referred to as a pinned layer **120**, has its magnetization typically fixed (pinned) by exchange coupling with an antiferromagnetic (AFM) layer **125**. The magnetization of a second ferromagnetic layer, referred to as a free layer **110**, is not fixed and is free to rotate in response to the magnetic field from the recorded magnetic medium (the signal field). The free layer **110** is separated from the pinned layer **120** by a non-magnetic, electrically conducting spacer layer **115**. Hard bias layers **130** and **135** formed in the end regions **104** and **106**, respectively, provide longitudinal bias for the free layer **110**. Leads **140** and **145** formed on hard bias layers **130** and **135**,

respectively, provide electrical connections for sensing the resistance of SV sensor **100**. IBM's U.S. Patent No. 5,206,590 granted to Dieny et al., incorporated herein by reference, discloses a GMR sensor operating on the basis of the SV effect.

Another type of magnetic device currently under development is a magnetic tunnel junction (MTJ) device. The MTJ device has potential applications as a memory cell and as a magnetic field sensor. The MTJ device comprises two ferromagnetic layers separated by a thin, electrically insulating, tunnel barrier layer. The tunnel barrier layer is sufficiently thin that quantum-mechanical tunneling of charge carriers occurs between the ferromagnetic layers. The tunneling process is electron spin dependent, which means that the tunneling current across the junction depends on the spin-dependent electronic properties of the ferromagnetic materials and is a function of the relative orientation of the magnetic moments, or magnetization directions, of the two ferromagnetic layers. In the MTJ sensor, one ferromagnetic layer has its magnetic moment fixed, or pinned, and the other ferromagnetic layer has its magnetic moment free to rotate in response to an external magnetic field from the recording medium (the signal field). When an electric potential is applied between the two ferromagnetic layers, the sensor

resistance is a function of the tunneling current across the insulating layer between the ferromagnetic layers. Since the tunneling current that flows perpendicularly through the tunnel barrier layer depends on the relative magnetization directions of the two ferromagnetic layers, recorded data can be read from a magnetic medium because the signal field causes a change of direction of magnetization of the free layer, which in turn causes a change in resistance of the MTJ sensor and a corresponding change in the sensed current or voltage. IBM's U.S. Patent No. 5,650,958 granted to Gallagher et al., incorporated in its entirety herein by reference, discloses an MTJ sensor operating on the basis of the magnetic tunnel junction effect.

Fig. **2a** shows a prior art MTJ sensor **200** comprising a first electrode **204**, a second electrode **202**, and a tunnel barrier layer **215**. The first electrode **204** comprises a pinned layer (pinned ferromagnetic layer) **220**, an antiferromagnetic (AFM) layer **230**, and a seed layer **240**. The magnetization of the pinned layer **220** is fixed through exchange coupling with the AFM layer **230**. The second electrode **202** comprises a free layer (free ferromagnetic layer) **210** and a cap layer **205**. The free layer **210** is separated from the pinned layer **220** by a non-magnetic, electrically

insulating tunnel barrier layer **215**. In the absence of an external magnetic field, the free layer **210** has its magnetization oriented in the direction shown by arrow **212**, that is, generally perpendicular to the magnetization direction of the pinned layer **220** shown by arrow **222** (tail of an arrow pointing into the plane of the paper). A first lead **260** and a second lead **265** formed in contact with first electrode **204** and second electrode **202**, respectively, provide electrical connections for the flow of sensing current I_s from a current source **270** to the MTJ sensor **200**. A signal detector **280**, typically including a recording channel such as a partial-response maximum-likelihood (PRML) channel, connected to the first and second leads **260** and **265** senses the change in resistance due to changes induced in the free layer **210** by the external magnetic field.

Fig. **2b** is a cross-sectional view perpendicular to the air bearing surface of the prior art MTJ sensor **200**. The MTJ sensor **200** comprises a sensor stripe **290** having a front edge **291** at the ABS and extending away from the ABS to a back edge **292** defined by the back edge of the tunnel barrier layer **215**. The leads **260**, **265** provide electrical connections for the flow of the sensing current I_s in a direction perpendicular to the tunnel barrier layer **215**. An electrical insulating layer **250** prevents shunting

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of the sensing current around the tunnel barrier layer at the back edge **292** of the sensor stripe **290**.

Since, in an MTJ sensor, the sensing current flows in a direction perpendicular to the tunnel barrier layer, a reasonably high electrical conductivity is needed for all the layers disposed between the lead layers except for the tunnel barrier layer. One of these layers is the AFM layer used to fix (pin) the magnetization direction of the ferromagnetic pinned layer. Mn-Fe is an antiferromagnet with good electrical conductivity that has been used in previous MTJ sensors. However, Mn-Fe has poor corrosion resistance which is a concern during the fabrication process and undesirable for long term stability of the MTJ sensor in a disk drive environment. Alternate AFM materials that have high corrosion resistance are NiO and α-Fe_2O_3/NiO bilayer, however these AFM materials are electrically insulating and therefore do not provide a path for the sensing current to flow between the leads in a direction perpendicular to the tunnel barrier layer with the usual MTJ sensor structure.

What is needed is a structure for an MTJ sensor which allows the use of electrically insulating AFM materials, such as NiO and α-Fe_2O_3/NiO with their high corrosion resistance, for the pinning

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layer used to fix the magnetization of the pinned layer and a process for fabrication of an MTJ sensor with this structure.

Summary of the Invention

It is an object of the present invention to disclose a magnetoresistive tunnel junction (MTJ) sensor having an electrically insulating AFM layer.

It is another object of the present invention to disclose an MTJ sensor having an AFM layer made of NiO.

It is yet another object of the present invention to disclose an MTJ sensor using an electrically insulating AFM layer and having a pinned layer structure in electrical contact to a magnetic shield, the shield also serving as an electrical lead.

In accordance with the principles of the present invention, there is disclosed an MTJ sensor comprising an MTJ sensor stripe having a generally rectangular shape and having two opposite side edges, a back edge and a front edge at the ABS surface. The sensor stripe includes a stack of layers including an AFM layer of NiO, an insulating antiferromagnetic material. A ferromagnetic pinned layer deposited on the AFM layer makes electrical contact with a ferromagnetic first shield behind the back edge of the MTJ sensor stripe (the edge opposite to the front edge of the stripe at the

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air bearing surface) to provide a path for the sensing current to bypass the electrically insulating AFM layer. The sensing current then flows from the pinning layer transversely through the tunnel barrier layer and the free layer of the MTJ sensor stripe to the ferromagnetic second shield which serves as a second electrical lead for the MTJ sensor.

The MTJ sensor comprises a seed layer, an AFM layer, a pinned ferromagnetic layer, a tunnel barrier layer, a free ferromagnetic layer and a cap layer sequentially deposited on the first shield. After deposition of the seed layer and the AFM layer, the AFM layer is defined by photolithography to have an AFM back edge extending beyond the back edge of the sensor stripe. The pinned ferromagnetic layer is deposited on the AFM layer, over the AFM back edge and on the first shield making electrical contact with the first shield. The tunnel barrier layer, free layer and cap layer are then deposited sequentially and patterned by photolithography to form the MTJ sensor stripe. An electrically insulating layer is then deposited over the entire MTJ sensor area. The photoresist covering the MTJ sensor stripe is then removed and the second shield of ferromagnetic material is deposited over the MTJ sensor making direct

electrical contact with the second electrode of the MTJ sensor stripe.

In the MTJ sensor structure of the present invention, the ferromagnetic first and second shield layers provide magnetic shielding from stray magnetic fields as is known to the art and also provide the electrical leads to supply sensing current to the first and second electrodes, respectively, of the MTJ stack. Because the AFM layer used in this embodiment is electrically insulating, direct contact between the first shield and the pinned layer beyond the back edge of the sensor stripe provides the sensing current path to the first electrode of the MTJ sensor. The electrically insulating layer of material at the end regions of the MTJ sensor and at the back edge of the sensor stripe prevent sensing current flow from being shunted around the tunnel barrier layer between the first and second shields.

The above, as well as additional objects, features, and advantages of the present invention will become apparent in the following detailed written description.

BRIEF DESCRIPTION OF THE DRAWINGS

For a fuller understanding of the nature and advantages of the present invention, as well as the preferred mode of use,

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reference should be made to the following detailed description read in conjunction with the accompanying drawings. In the following drawings, like reference numerals designate like or similar parts throughout the drawings.

Fig. **1** is an air bearing surface view, not to scale, of a prior art SV sensor;

Fig. **2a** is an air bearing surface view, not to scale, of a prior art magnetic tunnel junction sensor;

Fig. **2b** is a cross-section, not to scale, perpendicular to the air bearing surface of a prior art magnetic tunnel junction sensor;

Fig. **3a** is a simplified drawing of a magnetic recording disk drive system;

Fig. **3b** is a vertical cross-section view, not to scale, of an inductive write/MTJ read head with the MTJ read head located between the shields and adjacent to the inductive write head;

Fig. **4a** is an air bearing surface view, not to scale, of an embodiment of the magnetic tunnel junction sensor of the present invention;

Fig. **4b** is a cross-section, not to scale, perpendicular to the air bearing surface of the magnetic tunnel junction sensor of the present invention;

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Fig. **5a** is an air bearing surface view, not to scale, of another embodiment of the magnetic tunnel junction sensor of the present invention; and

Fig. **5b** is a cross-section, not to scale, perpendicular to the air bearing surface of yet another embodiment of the magnetic tunnel junction sensor of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The following description is the best embodiment presently contemplated for carrying out the present invention. This description is made for the purpose of illustrating the general principles of the present invention and is not meant to limit the inventive concepts claimed herein.

Referring now to Fig. **3**, there is shown a disk drive **300** embodying the present invention. As shown in Fig. **3**, at least one rotatable magnetic disk **312** is supported on a spindle **314** and rotated by a disk drive motor **318**. The magnetic recording media on each disk is in the form of an annular pattern of concentric data tracks (not shown) on the disk **312**.

At least one slider **313** is positioned on the disk **312**, each slider **313** supporting one or more magnetic read/write heads **321** where the head **321** incorporates the MTJ sensor of the present

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invention. As the disks rotate, the slider **313** is moved radially in and out over the disk surface **322** so that the heads **321** may access different portions of the disk where desired data is recorded. Each slider **313** is attached to an actuator arm **319** by means of a suspension **315**. The suspension **315** provides a slight spring force which biases the slider **313** against the disk surface **322**. Each actuator arm **319** is attached to an actuator **327**. The actuator as shown in Fig. **3** may be a voice coil motor (VCM). The VCM comprises a coil movable within a fixed magnetic field, the direction and speed of the coil movements being controlled by the motor current signals supplied by a controller **329**.

During operation of the disk storage system, the rotation of the disk **312** generates an air bearing between the slider **313** (the surface of the slider **313** which includes the head **321** and faces the surface of the disk **312** is referred to as an air bearing surface (ABS)) and the disk surface **322** which exerts an upward force or lift on the slider. The air bearing thus counter-balances the slight spring force of the suspension **315** and supports the slider **313** off and slightly above the disk surface by a small, substantially constant spacing during normal operation.

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The various components of the disk storage system are controlled in operation by control signals generated by the control unit **329**, such as access control signals and internal clock signals. Typically, the control unit **329** comprises logic control circuits, storage chips and a microprocessor. The control unit **329** generates control signals to control various system operations such as drive motor control signals on line **323** and head position and seek control signals on line **328**. The control signals on line **328** provide the desired current profiles to optimally move and position the slider **313** to the desired data track on the disk **312**. Read and write signals are communicated to and from the read/write heads **321** by means of the recording channel **325**.

The above description of a typical magnetic disk storage system, and the accompanying illustration of Fig. **3** are for representation purposes only. It should be apparent that disk storage systems may contain a large number of disks and actuators, and each actuator may support a number of sliders.

Fig. **3b** shows a cross-sectional schematic view of the read/write head **321** embodying the present invention which includes an MTJ read head portion and an inductive write head portion. The head **321** is lapped to form an ABS. The read head

includes an MTJ sensor **340** disposed between first and second shield layers S1 and S2. An insulating gap layer G1 is disposed between the first and second shield layers S1 and S2 in the region away from the MTJ sensor. The write head includes a coil layer C and an insulation layer IN2 which are disposed between insulation layers IN1 and IN3 which are, in turn, disposed between first and second pole pieces P1 and P2. A gap layer G2 is disposed between the first and second pole pieces P1, P2 for providing a magnetic write gap at their pole tips adjacent to the ABS. The combined read/write head **321** shown in Fig. **3b** is a "merged" head in which the second shield layer S2 of the read head is employed as a first pole piece P1 for the write head.

Fig. **4a** shows an air bearing surface (ABS) view of an MTJ sensor **400** according to the preferred embodiment of the present invention. The MTJ sensor **400** comprises end regions **464** and **466** separated from each other by a central region **462**. The active region of the MTJ sensor **400** is an MTJ sensor stripe **403** formed in the central region **462**. The MTJ sensor stripe **403** has a generally rectangular shape with two opposite side edges **407**, **408** and a back edge (not shown) opposite to a front edge **491** at the ABS. The MTJ sensor stripe **403** comprises a first electrode **404**, a second electrode **402** and a tunnel barrier layer **415** disposed

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between the first electrode **404** and the second electrode **402**. The first electrode **404** comprises a pinned layer **420**, an AFM layer **430**, and a seed layer **440**, where the pinned layer **420** is disposed between the tunnel barrier layer **415** and the AFM layer **430** and the AFM layer **430** is disposed between the pinned layer **420** and the seed layer **440**. The second electrode **402** comprises a free layer **410** and a cap layer **405**, where the free layer **410** is disposed between the tunnel barrier layer **415** and the cap layer **405**.

The AFM layer **430** is exchange coupled to the pinned layer **420** providing an exchange field to pin the magnetization direction of the pinned layer **420** perpendicular to the ABS. The magnetization of the free layer **410** is oriented parallel to the ABS and is free to rotate in the presence of a signal magnetic field.

In the preferred embodiment of the present invention, the MTJ sensor stripe **403** is formed in the central region **462** over a first shield (S1) **460**. The first shield **460** is a layer of soft ferromagnetic material such as Ni-Fe (permalloy), or alternatively Al-Fe-Si (Sendust), deposited on a substrate **401** and extending over the central region **462** and the end regions **464** and **466** to provide magnetic shielding of the MTJ sensor from

stray magnetic fields. An insulator layer **450** of electrically insulating material such as Al_2O_3 is formed in the end regions **464** and **466** and behind the back edge of the MTJ sensor stripe **403**. A second shield (S2) **461** of soft ferromagnetic material such as Ni-Fe, or alternatively Al-Fe-Si, is formed on the insulator layer **450** in the end regions **464** and **466** and over the MTJ sensor stripe **403** in the central region **462**.

Fig. **4b** shows the cross-section of the MTJ sensor **400** perpendicular to the ABS. The MTJ sensor stripe **403** has a front edge **491** at the ABS and extending away from the ABS to a back edge **492** defined by the back edges of the tunnel barrier layer **415**. Because the AFM layer in the MTJ sensor of the present invention is formed of electrically insulating material, it is necessary to provide a path for the sensing current to bypass the AFM layer **430** and to flow perpendicular to the tunnel barrier layer **415**. The path for sensing current flow is formed by patterning the AFM layer **430** to define an AFM back edge **494** significantly further away from the ABS than the MTJ sensor stripe back edge **492** and then depositing the pinned ferromagnetic layer **420** over the AFM layer **430** and over the exposed region of the first shield **460** further away from the ABS than the AFM back edge **494**. The AFM back edge **494** may be patterned to be in the

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range of 10-50 micrometers away from the ABS while the MTJ sensor stripe back edge **492** is only about 0.5 micrometers away from the ABS. This structure provides a path for the flow of the sensing current I_s from the first shield **460**, into and along the plane of the pinned layer **420**, and transversely through the tunnel barrier layer **415** and the free layer **410** to the second shield **461**. The insulating layer **450** deposited over the pinned layer **420** beyond the MTJ sensor stripe back edge **492** provides electrical isolation between the first and second shields **460** and **461** and prevents the sensing current from shunting around the MTJ sensor stripe **403**. Since the sensing current flows in the plane of the pinned layer **420**, its magnetic field may be used to achieve a stable magnetic state in the free layer **410**.

Referring again to Fig. **4a**, the first and second shields **460** and **461** provide electrical connections for the flow of the sensing current I_s from a current source **470** to the MTJ sensor stripe **403**. A signal detector **480** which is electrically connected to shields **460** and **461** senses the change in the resistance due to changes induced in the free layer **410** by the external magnetic field (e.g., field generated by a data bit stored on a disk). The external magnetic field acts to rotate the direction of magnetization of the free layer **410** relative to

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the direction of magnetization of the pinned layer **420** which is preferably pinned perpendicular to the ABS. The signal detector **480** preferably includes a digital recording channel such as a partial response maximum-likelihood (PRML) channel as is known to those skilled in the art or other types of well known recording channels such as peak detect or maximum likelihood channels. The signal detector **480** also includes other supporting circuitries such as a preamplifier (electrically placed between the sensor and the channel) for conditioning the sensed resistance changes as is known to those skilled in the art.

The MTJ sensor **400** may be fabricated in a magnetron sputtering or an ion beam sputtering system to deposit sequentially the multilayer structure shown in Figs. **4a** and **4b**. The first shield (S1) **460** of Ni-Fe (permalloy) having a thickness in the range of about 5000-10000 Å is deposited on the substrate **401**. The seed layer **440**, the AFM layer **430**, the pinned layer **420**, the tunnel barrier layer **415**, the free layer **410**, and the cap layer **405** are sequentially deposited over the first shield **460** in the presence of a longitudinal or transverse magnetic field of about 40 Oe to orient the easy axis of all of the ferromagnetic layers. The seed layer **440** is a layer deposited to modify the crystallographic texture or grain size of the

subsequent layers, and may not be needed depending on the material of the subsequent layer. If used, the seed layer may be formed of tantalum (Ta), zirconium (Zr), nickel-iron (Ni-Fe), or Al_2O_3 having a thickness of about 30-50 Å. The AFM layer **430** formed of NiO having a thickness of about 100-400 Å is deposited on the seed layer **440** by sputtering a nickel target in the presence of a reactive gas that includes oxygen. The AFM layer **430** is patterned by photolithography to define the AFM back edge **494**. The ferromagnetic pinned layer **420** is deposited on the AFM layer **430** and on the area of the first shield **460** exposed by the patterning of the AFM back edge **494**. The pinned layer **420** may be formed of Ni-Fe having a thickness in the range of about 20-50 Å, or alternatively, may be formed of a sub-layer of Ni-Fe having a thickness in the range of 20-50 Å and an interface layer of Co having a thickness of about 5 Å deposited on the Ni-Fe sublayer. The tunnel barrier layer **415** is formed of Al_2O_3 by depositing and then plasma oxidizing an 8-20 Å aluminum (Al) layer on the pinned layer **420**. The ferromagnetic free layer **410** may be formed of Ni-Fe having a thickness in the range of about 20-50 Å, or alternatively, may be formed of an interface layer of Co having a thickness of about 5 Å deposited on the tunnel barrier layer **415** and a sub-layer of Ni-Fe having a thickness of

about 20-50 Å deposited on the Co interface layer. The cap layer **405** formed of Ta having a thickness of about 50 Å is deposited on the free layer **410**. A photoresist layer is deposited on the cap layer **405** and photolithography and ion milling processes well known in the art may be used to define the back edge **492** and the central region **462** of the MTJ sensor stripe **403**.

The insulator layer **450** can now be deposited on the exposed portion of the pinned layer **420** in the area behind the MTJ stripe back edge **492** and on the first shield (S1) **460** in the end regions **464, 466**. The insulator layer **450** is formed of Al_2O_3 by depositing and then plasma oxidizing an aluminum (Al) layer having a thickness approximately equal to the total thickness of the MTJ sensor active layers in the central region **462**. The photoresist protecting the MTJ sensor stripe **403** is then removed and the second shield **461** of Ni-Fe (permalloy) having a thickness in the range of about 5000-10000 Å is deposited on the exposed MTJ sensor stripe **403** and on the insulator layer **450**.

The second shield **461** makes electrical contact to the second electrode **402**. The free ferromagnetic layer **410** is separated from the second shield **461** by the thin cap layer **405** to break

magnetic coupling between the free layer **410** and the second shield **461**.

Fig. **5a** shows an ABS view of an MTJ sensor **500** according to another embodiment of the present invention. This embodiment only differs from the embodiment shown in Figs. **4a** and **4b** in having the seed layer **440** and the AFM layer **430** extend over the first shield (S1) **460** in the end regions **464** and **466** as well as in the central region **462**. Since the AFM layer **430** is made of an electrically insulating AFM material, such as NiO, the AFM layer **430** in the end regions **464, 466** provides electrical insulation between the first shield (S1) **460** and the second shield (S2) **461** which together with the insulating layer **450** prevents electrical shorting between S1 and S2. The structure at the back edge of the MTJ sensor and the method of making electrical contact of the pinned layer **420** to the first shield (S1) **460** to provide a sensing current path may be the same as shown in Fig. **4b** for the preferred embodiment or, alternatively, may have the structure and method of making electrical contact shown in Fig. **5b**.

Fig. **5b** shows the cross-section of an MTJ sensor **510** perpendicular to the ABS according to yet another embodiment of the present invention. In this embodiment, the seed layer **440** and the AFM layer **430** deposited on the first shield (S1) extend

away from the ABS over the first shield (S1). Since the AFM layer **430** is formed of electrically insulating material, it is necessary to provide a path for the sensing current I_s to bypass the AFM layer **430** and to flow in a direction perpendicular to the tunnel barrier layer **415**. The path for the sensing current flow is made by forming an opening (via) **496** through the AFM layer **430** prior to the deposition of the pinned layer **420** over the AFM layer **430**. The via **496** is formed in the region of the AFM layer **430** further away from the ABS than the MTJ sensor stripe back edge **492** using methods well known to the art. The pinned layer **420** is deposited on the AFM layer **430** and on the area of the first shield (S1) **460** exposed by the via **496** through the AFM layer **430**. The pinned layer **420** makes electrical contact to the first shield (S1) **460** through the via **496** providing a path for the flow of the sensing current I_s from the first shield (S1) **460**, into and along the plane of the pinned layer, and transversely through the tunnel barrier layer **415** and the free layer **410** to the second shield (S2) **461**. The insulating layer **450** deposited over the pinned layer **420** beyond the MTJ stripe back edge **492** provides electrical isolation between the first and second shields **460** and **461** and prevents the sensing current from shunting around the MTJ sensor stripe **403**.

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Alternatively, AFM layer **430** may be made of an α-Fe_2O_3/NiO bilayer to fabricate the MTJ sensor **400** according to the present invention.

While the present invention has been particularly shown and described with reference to the preferred embodiments, it will be understood by those skilled in the art that various changes in form and detail may be made without departing from the spirit, scope and teaching of the invention. Accordingly, the disclosed invention is to be considered merely as illustrative and limited in scope only as specified in the appended claims.

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We claim:

1. A magnetic tunnel junction (MTJ) sensor, comprising:

a substrate;

a first shield (S1) of ferromagnetic material formed on the substrate;

a magnetic tunnel junction (MTJ) sensor stripe formed on said first shield, the MTJ sensor stripe having a generally rectangular shape and having two opposite side edges, a back edge and a front edge, said MTJ sensor stripe comprising:

an antiferromagnetic (AFM) layer of electrically insulating antiferromagnetic material;

a pinned layer of ferromagnetic material in contact with said AFM layer, said pinned layer making electrical contact with said first shield;

a free layer of ferromagnetic material;

a tunnel junction layer of electrically insulating material disposed between said pinned and free layers;

a second shield (S2) of ferromagnetic material formed on and in contact with said MTJ sensor stripe; and

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an insulator layer formed on the first shield on opposite sides of said MTJ sensor stripe and on said pinned layer beyond the back edge of said MTJ sensor stripe, said insulator layer separating said first shield and said pinned layer from said second shield.

2. The MTJ sensor as recited in claim 1, wherein said AFM layer is made of NiO.

3. The MTJ sensor as recited in claim 1, wherein said insulator layer is made of Al_2O_3.

4. The MTJ sensor as recited in claim 1, wherein said first shield is made of Ni-Fe.

5. The MTJ sensor as recited in claim 1, wherein said second shield is made of Ni-Fe.

6. The MTJ sensor as recited in claim 1, further comprising:

a signal detector;

a current source for providing a sensing current;

a first electrical connection for connecting said first shield to the current source and to the signal detector; and

a second electrical connection for connecting said second shield to the current source and to the signal detector;

said first and second shields providing electrical leads for sensing the electrical resistance to the sensing current flowing perpendicularly through the tunnel barrier layer and the free layer, said sensing current flow prevented from shunting around said MTJ sensor stripe by said insulator layer.

7. The MTJ sensor as recited in claim 1, wherein said AFM layer is made of α-Fe_2O_3/NiO.

8. A disk drive system, comprising:

a magnetic recording disk;

a magnetic tunnel junction (MTJ) sensor for sensing magnetically recorded data on said magnetic recording disk, said MTJ sensor comprising:

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a substrate;

a first shield (S1) of ferromagnetic material formed on the substrate;

a magnetic tunnel junction (MTJ) sensor stripe formed on the first shield, the MTJ sensor stripe having a generally rectangular shape and having two opposite side edges, a rear edge and a front edge, said MTJ sensor stripe comprising:

an antiferromagnetic (AFM) layer of electrically insulating antiferromagnetic material;

a pinned layer of ferromagnetic material in contact with said AFM layer, said pinned layer making electrical contact with said first shield;

a free layer of ferromagnetic material; and

a tunnel junction layer of electrically insulating material disposed between said pinned and free layers;

a second shield (S2) of ferromagnetic material formed on and in contact with said MTJ sensor stripe; and

an insulator layer formed on the first shield on opposite sides of said MTJ sensor stripe and on said pinned layer beyond the back edge of said MTJ sensor stripe, said

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insulator layer separating said first shield and said pinned layer from said second shield;

an actuator for moving said MTJ sensor across the magnetic recording disk so the MTJ sensor may access different regions of magnetically recorded data on the magnetic recording disk; and

a recording channel coupled electrically to the MTJ sensor for detecting changes in resistance of the MTJ sensor caused by rotation of the magnetization axis of the free ferromagnetic layer relative to the fixed magnetization of the pinned layer in response to magnetic fields from the magnetically recorded data.

9. The disk drive system as recited in claim 8, wherein said AFM layer is made of NiO.

10. The disk drive system as recited in claim 8, wherein said insulator layer is made of Al_2O_3.

11. The disk drive system as recited in claim 8, wherein said first shield is made of Ni-Fe.

12. The disk drive system as recited in claim 8, wherein said second shield is made of Ni-Fe.

13. The disk drive system as recited in claim 8, further comprising:

a signal detector;

a current source for providing a sensing current;

a first electrical connection for connecting said first shield to the current source and to the signal detector; and

a second electrical connection for connecting said second shield to the current source and to the signal detector;

said first and second shields providing electrical leads for sensing the electrical resistance to the sensing current flowing perpendicularly through the tunnel barrier layer and the free layer, said sensing current flow prevented from shunting around said MTJ sensor stripe by said insulator layer.

14. The MTJ sensor as recited in claim 8, wherein said AFM layer is made of α-Fe_2O_3/NiO.

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15. A magnetic tunnel junction (MTJ) sensor, comprising:

a substrate;

a first shield (S1) of ferromagnetic material formed on the substrate;

a magnetic tunnel junction (MTJ) sensor stripe formed on said first shield, the MTJ sensor stripe having a generally rectangular shape and having two opposite side edges, a back edge and a front edge, said front edge located at an air bearing surface, said MTJ sensor stripe comprising:

an antiferromagnetic (AFM) layer of electrically insulating antiferromagnetic material;

a pinned layer of ferromagnetic material in contact with said AFM layer, said pinned layer making electrical contact with said first shield;

a free layer of ferromagnetic material;

a tunnel junction layer of electrically insulating material disposed between said pinned and free layers;

a second shield (S2) of ferromagnetic material formed on and in contact with said MTJ sensor stripe; and

an insulator layer formed on the first shield on opposite sides of said MTJ sensor stripe and on said pinned layer beyond the back edge of said MTJ sensor stripe, said insulator layer separating said first shield and said pinned layer from said second shield.

16. The MTJ sensor as recited in claim 15, wherein said AFM layer is made of NiO.

17. The MTJ sensor as recited in claim 15, wherein said insulator layer is made of Al_2O_3.

18. The MTJ sensor as recited in claim 15, wherein said first shield is made of Ni—Fe.

19. The MTJ sensor as recited in claim 15, wherein said second shield is made of Ni—Fe.

20. The MTJ sensor as recited in claim 15, further comprising:

a signal detector;

a current source for providing a sensing current;

a first electrical connection for connecting said first shield to the current source and to the signal detector; and

a second electrical connection for connecting said second shield to the current source and to the signal detector;

said first and second shields providing electrical leads for sensing the electrical resistance to the sensing current flowing perpendicularly through the tunnel barrier layer and the free layer, said sensing current flow prevented from shunting around said MTJ sensor stripe by said insulator layer.

21. The MTJ sensor as recited in claim 15, wherein said AFM layer is made of α-Fe_2O_3 /NiO.

22. A magnetic tunnel junction (MTJ) sensor, comprising:

a substrate;

a first shield (S1) of ferromagnetic material formed on the substrate;

a magnetic tunnel junction (MTJ) sensor stripe formed on said first shield, the MTJ sensor stripe having a generally rectangular shape and having two opposite side edges, a back

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edge and a front edge, said front edge located at an air bearing surface (ABS), said MTJ sensor stripe comprising:

an antiferromagnetic (AFM) layer of electrically insulating antiferromagnetic material, said AFM layer having a front edge at the ABS and a back edge further from the ABS than said back edge of the MTJ sensor stripe;

a pinned layer of ferromagnetic material in contact with said AFM layer, said pinned layer extending further from the ABS than said back edge of the AFM layer, said pinned layer making electrical contact with said first shield in a region further from the ABS than said back edge of the AFM layer;

a free layer of ferromagnetic material;

a tunnel junction layer of electrically insulating material disposed between said pinned and free layers;

a second shield (S2) of ferromagnetic material formed on and in contact with said MTJ sensor stripe; and

an insulator layer formed on the first shield on opposite sides of said MTJ sensor stripe and on said pinned layer beyond the back edge of said MTJ sensor stripe, said insulator layer separating said first shield and said pinned layer from said second shield.

23. The MTJ sensor as recited in claim 22, wherein said AFM layer is made of NiO.

24. The MTJ sensor as recited in claim 22, wherein said insulator layer is made of Al_2O_3.

25. The MTJ sensor as recited in claim 22, wherein said first shield is made of Ni—Fe.

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26. The MTJ sensor as recited in claim 22, wherein said second shield is made of Ni—Fe.

27. The MTJ sensor as recited in claim 22, further comprising:

a signal detector;

a current source for providing a sensing current;

a first electrical connection for connecting said first shield to the current source and to the signal detector; and

a second electrical connection for connecting said second shield to the current source and to the signal detector;

said first and second shields providing electrical leads for sensing the electrical resistance to the sensing current flowing perpendicularly through the tunnel barrier layer and the free layer, said sensing current flow prevented from shunting around said MTJ sensor stripe by said insulator layer.

28. The MTJ sensor as recited in claim 22, wherein said AFM layer is made of α-Fe_2O_3 /NiO.

29. A magnetic tunnel junction (MTJ) sensor, comprising:

a substrate;

a first shield (S1) of ferromagnetic material formed on the substrate;

a magnetic tunnel junction (MTJ) sensor stripe formed on said first shield, the MTJ sensor stripe having a generally rectangular shape and having two opposite side edges, a back edge and a front edge, said front edge located at an air bearing surface (ABS), said MTJ sensor stripe comprising:

an antiferromagnetic (AFM) layer of electrically insulating antiferromagnetic material, said AFM layer having a front edge at the ABS and said AFM layer extending away from the ABS over said first shield, said AFM layer having an opening (via) through the AFM layer in a region further from the ABS than said back edge of the MTJ sensor stripe;

a pinned layer of ferromagnetic material in contact with said AFM layer, said pinned layer making electrical contact with said first shield through said opening (via) through the AFM layer;

a free layer of ferromagnetic material;

a tunnel junction layer of electrically insulating material disposed between said pinned and free layers;

a second shield (S2) of ferromagnetic material formed on and in contact with said MTJ sensor stripe; and

an insulator layer formed on the first shield on opposite sides of said MTJ sensor stripe and on said pinned layer beyond the back edge of said MTJ sensor stripe, said insulator layer separating said first shield and said pinned layer from said second shield.

30. The MTJ sensor as recited in claim 29, wherein said AFM layer is made of NiO.

31. The MTJ sensor as recited in claim 29, wherein said insulator layer is made of Al_2O_3.

32. The MTJ sensor as recited in claim 29, wherein said first shield is made of Ni—Fe.

33. The MTJ sensor as recited in claim 29, wherein said second shield is made of Ni—Fe.

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34. The MTJ sensor as recited in claim 29, further comprising:

a signal detector;

a current source for providing a sensing current;

a first electrical connection for connecting said first shield to the current source and to the signal detector; and

a second electrical connection for connecting said second shield to the current source and to the signal detector;

said first and second shields providing electrical leads for sensing the electrical resistance to the sensing current flowing perpendicularly through the tunnel barrier layer and the free layer, said sensing current flow prevented from shunting around said MTJ sensor stripe by said insulator layer.

35. The MTJ sensor as recited in claim 29, wherein said AFM layer is made of α-Fe_2O_3 /NiO.