

MAGNETORESISTIVE SENSOR WITH A THIN ANTIFERROMAGNETIC LAYER FOR PINNING ANTIPARALLEL COUPLED TABS

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates in general to spin valve magnetoresistive sensors for reading information signals from a magnetic medium, in particular, to a lead overlay spin valve sensor with a thin antiferromagnetic layer for pinning an antiparallel coupled lead/sensor overlap (tab) region.

2. Description of the 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.

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

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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 nonmagnetic layer (spacer) and the accompanying spin-dependent scattering which takes place at the interface of the magnetic and nonmagnetic layers and within the magnetic layers.

GMR sensors using only two layers of ferromagnetic material (e.g., Ni-Fe) separated by a layer of nonmagnetic 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 spin valve sensor is an antiparallel (AP) spin valve sensor. The AP-pinned valve sensor differs from the simple spin valve sensor in that an AP-pinned structure has multiple thin film layers instead of a single pinned layer. The AP-pinned structure has an antiparallel coupling (APC) layer sandwiched between first and second ferromagnetic pinned layers. The first pinned layer has its magnetization oriented in a first direction by exchange coupling to the antiferromagnetic pinning layer. The second pinned layer is immediately adjacent to the free layer and is antiparallel exchange coupled to the first pinned layer because of the minimal thickness (in the order of 8 Å) of the APC layer between the first and second pinned layers. Accordingly, the magnetization of the second pinned layer is oriented in a second direction that is antiparallel to the direction of the magnetization of the first pinned layer.

The AP-pinned structure is preferred over the single pinned layer because the magnetizations of the first and second pinned layers of the AP-pinned structure subtractively combine to provide a net magnetization that is less than the magnetization

of the single pinned layer. The direction of the net magnetization is determined by the thicker of the first and second pinned layers. A reduced net magnetization equates to a reduced demagnetization field from the AP-pinned structure. Since the antiferromagnetic exchange coupling is inversely proportional to the net pinning magnetization, this increases exchange coupling between the first pinned layer and the antiferromagnetic pinning layer. The AP-pinned spin valve sensor is described in commonly assigned U.S. Patent No. 5,465,185 to Heim and Parkin which is incorporated by reference herein.

A typical spin valve sensor has top and bottom surfaces and first and second side surfaces which intersect at an air bearing surface (ABS) where the ABS is an exposed surface of the sensor that faces the magnetic disk. Prior art read heads employ first and second hard bias layers and first and second lead layers that abut the first and second side surfaces for longitudinally biasing and stabilizing the free layer in the sensor and conducting a sense current transversely through the sensor. The track width of the head is measured between the centers of the side surfaces of the free layer. In an effort to reduce the track width to submicron levels it has been found that the hard bias layers make the free layer magnetically stiff so that its magnetic moment does not freely respond to field signals from a rotating magnetic disk. Accordingly, there is a strong-felt need to provide submicron track width spin valve sensors which are still sensitive to the signals from the rotating magnetic disk along with longitudinal biasing of the free layer transversely so that the free layer is kept in a single magnetic domain state.

Thus, a need clearly exists for a spin valve sensor with a highly stabilized free layer which is highly responsive to signals from a rotating magnetic disk.

SUMMARY OF THE INVENTION

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In accordance with the principles of the present invention, there is disclosed a spin valve (SV) sensor having first and second passive regions and a central track width region transversely disposed between said first and second passive regions, said SV sensor comprising:

a pinned layer;

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a ferromagnetic free layer;

a spacer layer sandwiched between said pinned layer and said free layer;

a ferromagnetic bias layer in said first and second passive regions;

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an antiparallel coupling layer sandwiched between said free layer and said ferromagnetic bias layer for providing strong antiparallel coupling between said bias layer and said free layer in the first and second passive regions; and

an antiferromagnetic (AFM) layer adjacent to said ferromagnetic bias layer, said AFM layer exchange coupled to the ferromagnetic bias layer to provide a pinning field to the bias layer;

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wherein said pinning field is directed in a canted direction intermediate between a direction parallel to an air bearing surface and a direction perpendicular to the air bearing surface.

According to another aspect of the present invention there is provided a disk drive system comprising:

a magnetic recording disk;

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a magnetic read head for sensing magnetically recorded data on the magnetic recording disk, said magnetic read head comprising:

a spin valve (SV) sensor, the SV sensor being sandwiched between first and second read gap layers, the SV sensor having first and second passive regions and a central track width region transversely disposed between said first and second passive regions, said SV sensor comprising:

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a pinned layer;

a ferromagnetic free layer;

a spacer layer sandwiched between said pinned layer and said free layer;

a ferromagnetic bias layer in said first and second passive regions;

an antiparallel coupled layer sandwiched between said free layer and said ferromagnetic bias layer for providing strong antiparallel coupling between said bias layer and said free layer in the first and second passive regions;

an antiferromagnetic (AFM) layer adjacent to said ferromagnetic bias layer, said AFM layer exchange coupled to the ferromagnetic bias layer to provide a pinning field to the bias layer;

wherein said pinning field is directed in a canted direction intermediate between a direction parallel to an air bearing surface and a direction perpendicular to the air bearing surface; and

an actuator for moving said magnetic read head across the magnetic disk so that the read head may access different regions of the magnetic recording disk; and

a recording channel coupled electrically to the SV sensor of the read head for detecting changes in resistance of the SV sensor in response to magnetic fields from the magnetically recorded data.

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

BRIEF DESCRIPTION OF THE DRAWINGS

For a fuller understanding of the nature and advantages of the present invention, as well as of the preferred mode of use, 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. 2 is a simplified diagram of a magnetic recording disk drive system using the SV sensor of the present invention;

Fig. 3 is a vertical cross-section view, not to scale, of a "piggyback" read/write magnetic head;

Fig. 4 is a vertical cross-section view, not to scale, of a "merged" read/write magnetic head;

Fig. 5 is an air bearing surface view, not to scale, of an embodiment of a lead overlay SV sensor of the present invention;

Figs. 6a-6d are air bearing surface views, not to scale, of the SV sensor of Fig. 5 illustrating sequential steps of making the sensor by the method of the present invention;

Fig. 7 is an air bearing surface view, not to scale, of a second embodiment of a lead overlay sensor of the present invention;

Fig. 8 is a graphical representation of the strength of the AFM pinning field as a function of AFM layer thickness; and

Fig. 9 is plan view, not to scale, of a spin valve sensor indicating the orientation directions of longitudinal, transverse and canted bias fields relative to the air bearing surface.

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. 2, there is shown a disk drive 200 embodying the present invention. As shown in Fig. 2, at least one rotatable magnetic disk 212 is supported on a spindle 214 and rotated by a disk drive motor 218. The magnetic recording media on each disk is in the form of an annular pattern of concentric data tracks (not shown) on the disk 212.

At least one slider **213** is positioned on the disk **212**, each slider **213** supporting one or more magnetic read/write heads **221** where the head **221** incorporates the SV sensor of the present invention. As the disks rotate, the slider **213** is moved radially in and out over the disk surface **222** so that the heads **221** may access different portions of the disk where desired data is recorded. Each slider **213** is attached to an actuator arm **219** by means of a suspension **215**. The suspension **215** provides a slight spring force which biases the slider **213** against the disk surface **222**. Each actuator arm **219** is attached to an actuator **227**. The actuator as shown in Fig. **2** 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 **229**.

During operation of the disk storage system, the rotation of the disk **212** generates an air bearing between the slider **213** (the surface of the slider **213** which includes the head **321** and faces the surface of the disk **212** is referred to as an air bearing surface (ABS)) and the disk surface **222** which exerts an upward force or lift on the slider. The air bearing thus counter- balances the slight spring force of the suspension **215** and supports the slider **213** off and slightly above the disk surface by a small, substantially constant spacing during normal operation.

The various components of the disk storage system are controlled in operation by control signals generated by the control unit **229**, such as access control signals and internal clock signals. Typically, the control unit **229** comprises logic control circuits, storage chips and a microprocessor. The control unit **229** generates control signals to control various system operations such as drive motor control signals on line **223** and

head position and seek control signals on line 228. The control signals on line 228 provide the desired current profiles to optimally move and position the slider 213 to the desired data track on the disk 212. Read and write signals are communicated to and from the read/write heads 221 by means of the recording channel 225. Recording channel 225 may be a partial response maximum likelihood (PMRL) channel or a peak detect channel. The design and implementation of both channels are well known in the art and to persons skilled in the art. In the preferred embodiment, recording channel 225 is a PMRL channel.

The above description of a typical magnetic disk storage system, and the accompanying illustration of Fig. 2 are for representation purposes only. It should be apparent that disk storage systems may contain a large number of disks and actuator arms, and each actuator arm may support a number of sliders.

Fig. 3 is a side cross-sectional elevation view of a "piggyback" magnetic read/write head 300, which includes a write head portion 302 and a read head portion 304, the read head portion employing a spin valve sensor 306 according to the present invention. The sensor 306 is sandwiched between nonmagnetic insulative first and second read gap layers 308 and 310, and the read gap layers are sandwiched between ferromagnetic first and second shield layers 312 and 314. In response to external magnetic fields, the resistance of the sensor 306 changes. A sense current I_s conducted through the sensor causes these resistance changes to be manifested as potential changes. These potential changes are then processed as readback signals by the processing circuitry of the data recording channel 246 shown in Fig. 2.

The write head portion **302** of the magnetic read/write head **300** includes a coil layer **316** sandwiched between first and second insulation layers **318** and **320**. A third insulation layer **322** may be employed for planarizing the head to eliminate ripples in the second insulation layer **320** caused by the coil layer **316**. The first, second and third insulation layers are referred to in the art as an insulation stack. The coil layer **316** and the first, second and third insulation layers **318**, **320** and **322** are sandwiched between first and second pole piece layers **324** and **326**. The first and second pole piece layers **324** and **326** are magnetically coupled at a back gap **328** and have first and second pole tips **330** and **332** which are separated by a write gap layer **334** at the ABS **340**. An insulation layer **336** is located between the second shield layer **314** and the first pole piece layer **324**. Since the second shield layer **314** and the first pole piece layer **324** are separate layers this read/write head is known as a "piggyback" head.

Fig. 4 is the same as Fig. 3 except the second shield layer **414** and the first pole piece layer **424** are a common layer. This type of read/write head is known as a "merged" head **400**. The insulation layer **336** of the piggyback head in Fig. 3 is omitted in the merged head **400** of Fig. 4.

First Example

Fig. 5 depicts an air bearing surface (ABS) view, not to scale, of a lead overlay spin valve sensor **500** according to a first embodiment of the present invention. The SV sensor **500** comprises end regions **502** and **504** separated from each other by a central region **506**. The substrate **508** can be any suitable substance including glass, semiconductor material, or a ceramic material such as alumina (Al_2O_3). The seed layer

509 is a layer or layers deposited to modify the crystallographic texture or grain size of the subsequent layers. An antiferromagnetic (AFM) layer **510** is deposited over the over the seed layer. An antiparallel (AP)-pinned layer **512**, a conductive spacer layer **514** and a free layer **516** are deposited sequentially over the AFM layer **510**. The AFM layer may have a thickness sufficient to provide the desired exchange properties to act as a pinning layer for the AP-pinned layer **512**. In the present embodiment, the AFM layer **510** is thinner than desirable for a pinning layer and is used to provide an additional seed layer to help promote improved properties of the subsequent layers of the sensor. The AP-pinned layer **512** comprises a first ferromagnetic (FM1) layer **517** and a second ferromagnetic (FM2) layer **519** separated by an antiparallel coupling (APC) layer **518** that allows the FM1 layer **517** and the FM2 layer **519** to be strongly AP-coupled as indicated by the antiparallel magnetizations **542** (represented by the tail of an arrow pointing into the paper) and **543** (represented by the head of an arrow pointing out of the paper), respectively. The AP-coupled layer **512** is designed to be a self-pinned layer as is known to the art. The free layer **516** comprises a ferromagnetic first free sublayer **520** of Co-Fe and a ferromagnetic second free sublayer **521** of Ni-Fe.

A bias layer **522** separated from the free layer **516** by an APC layer **523** comprises a ferromagnetic first bias sublayer **524** of Co-Fe deposited over the APC layer **523** and a ferromagnetic second bias sublayer **525** of Ni-Fe deposited over the first bias sublayer **524**. An antiferromagnetic layer **560** of Pt-Mn, or alternatively of In-Mn, Ni-Mn or other conducting antiferromagnetic material, is deposited over the second bias sublayer **525**. The APC layer **523** allows the bias layer **522** to be strongly AP-coupled to the free layer **516**. The AFM layer **560** is exchange coupled to the bias layer **522**

providing a weak pinning field to orient the direction of the magnetization **546** of the bias layer.

The AFM layer **560** is formed of a layer having a thickness less than needed to provide a maximum (saturated) pinning field. Fig. 8 is a graphical representation of the variation of pinning field strength as a function of layer thickness for a typical AFM material. The pinning field increases with AFM layer thickness as the exchange coupling strength increases until a saturated or maximum pinning field is reached at a layer thickness, t_{SAT} . For an AFM layer formed of Pt-Mn, a thickness (t_{SAT}) of about 150 Å is needed to provide the maximum pinning. For an AFM layer formed of Ir-Mn, t_{SAT} is approximately 80 Å while for an AFM layer formed of Ni-Mn, t_{SAT} is approximately 250 Å. As the AFM layer thickness is decreased, its exchange coupling strength decreases due to the decreased grain size of the thinner layer. In order to achieve the desired weaker exchange coupling to the bias layer required for pinning the AP-tabs while maintaining high sensitivity for the SV sensor, the AFM layer **560** is formed of Pt-Mn having a thickness in the range of 30-100 Å. Alternatively, the AFM layer may be formed of Ir-Mn, Ni-Mn or other electrically conductive antiferromagnetic materials. The weak pinning field due to the thin AFM layer is particularly effective at the interfaces of the track width region and the first and second passive regions where the bias layer ends. At this discontinuity of the bias layers, demagnetization fields can result in destabilization of the free layer magnetization in the absence of a pinning field. A weak pinning field removes this instability without significant stiffening of the free layer magnetization **544** in the track field region. After the thin AFM layer has been deposited, a first cap layer **526** is formed on the AFM layer **560**.

First and second leads L1 528 and L2 530 are formed over the cap layer 526 in the passive regions 532 and 534 and over the end regions 502 and 504 overlapping the central region 506 of the sensor in the first and second passive regions. A space between L1 528 and L2 530 in the central region 506 of the sensor defines the track width region 536 which defines the track width of the read head and which can have submicron dimensions. The first cap layer 536 in the track width region 536 between L1 and L2 is removed by a sputter etch and reactive ion etch (RIE) process followed by a sputter etch and oxidation process to convert the AFM material 560 and the ferromagnetic materials of bias layer 522 into a nonmagnetic oxide layer 538 in the track width region 536. A second cap layer 540 is formed over the leads L1 528 and L2 530 in the end regions 502, 504 and the passive regions 532, 534 and over the nonmagnetic oxide layer 538 in the track width region 536.

The AP-pinned layer 512 has the magnetizations of the FM1 layer 517 and the FM2 layer 519 pinned in directions perpendicular to the ABS as indicated by arrow tail 542 and arrow head 543 pointing into and out of the plane of the paper, respectively. In the track width region 536, the magnetization of the free layer 516 indicated by the arrow 544 is the net magnetization of the ferromagnetically coupled first and second free sublayers 520 and 521 and is free to rotate in the presence of an external (signal) magnetic field. The magnetization 544 is preferably oriented parallel to the ABS in the absence of an external magnetic field. In the first and second passive regions 532 and 534, the free layer 516 is strongly AP-coupled to the bias layer 522.

The magnetization 546 of the bias layer 522 in the first and second passive regions 532 and 534 is the net magnetization of the ferromagnetically coupled first and

second bias sublayers **524** and **525**. Due to the presence of the APC layer **523** which allows the free layer **516** to be strongly AP-coupled to the bias layer **522** in the passive regions, the magnetization **546** of the bias layer is oriented antiparallel to the magnetization **545** of the free layer. The effect of this AP-coupling is stabilization of the free layer **516** in the passive regions **532** and **534** since the magnetization **545** does not rotate in response to external fields thus inhibiting undesirable side reading on the rotating magnetic disk. The weak pinning field from AFM layer **560** provides additional stabilization of the free layer **521** in the first and second passive regions **532** and **534** especially at the transition between the passive regions and the track field region **536**.

End region layers **548** and **550** abutting the spin valve layers may be formed of electrically insulating material such as alumina, or alternatively, may be formed of a suitable hard bias material in order to provide a longitudinal bias field to the free layer **516** to ensure a single magnetic domain state in the free layer. An advantage of having the hard bias material forming the end region layers **548** and **550** is that these layers are remote from the track width region **536** so that they do not magnetically stiffen the magnetization **544** of the free layer in this region, which stiffening makes the free layer insensitive to field signals from the rotating magnetic disk.

Leads L1 **528** and L2 **530** deposited in the end regions **502** and **504**, respectively, provide electrical connections for the flow of a sensing current I_s from a current source to the SV sensor **500**. A signal detector which is electrically connected to the leads senses the change of resistance due to changes induced in the free layer **516** by the external magnetic field (e.g., field generated by a data bit stored on a rotating magnetic disk). The external field acts to rotate the direction of the magnetization **544** of the free layer **516**

relative to the direction of the magnetization **543** of the pinned layer **519** which is preferably pinned perpendicular to the ABS.

The fabrication of SV **500** is described with reference to Figs. **5** and **6a-d**. The SV sensor **500** is fabricated in a magnetron sputtering or an ion beam sputtering system to sequentially deposit the multilayer structure shown in Fig. **5**. The sputter deposition process is carried out in the presence of a longitudinal magnetic field of about 40 Oe. The seed layer **509** is formed on the substrate **508** by sequentially depositing a layer of alumina (Al_2O_3) having a thickness of about 30 Å, a layer of Ni-Fe-Cr having a thickness of about 20 Å and a layer of Ni-Fe having a thickness of about 8 Å. The AFM layer **510** of Pt-Mn, having a thickness in the range of 4-150 Å, is deposited over the seed layer **509**. The AP-pinned layer **512** is formed over the AFM layer by sequentially depositing the FM1 layer **517** of Co-Fe having a thickness of about 10 Å, the APC layer **518** of ruthenium (Ru) having a thickness of about 8 Å and the FM2 layer **519** of Co-Fe having a thickness of about 19 Å. The spacer layer **514** of copper (Cu) having a thickness of about 20 Å is deposited over the FM2 layer **519** and the free layer **516** is deposited over the spacer layer **514** by first depositing the first free sublayer **520** of Co-Fe having a thickness of about 10 Å followed by the second free sublayer **521** of Ni-Fe having a thickness of about 15 Å. The APC layer **523** of Ru having a thickness of about 8 Å is deposited over the second free sublayer **521**. The bias layer **522** is deposited over the APC layer **523** by first depositing the first bias sublayer **524** of Co-Fe having a thickness of about 10 Å followed by the second bias sublayer **525** of Ni-Fe having a thickness of about 20 Å. The AFM layer **560** of Pt-Mn having a thickness in the range of 30-100 Å is deposited over the second bias sublayer **525**. A first cap layer **526** deposited over the

bias layer **522** comprises a first sublayer of tantalum (Ta) having a thickness of about 20 Å and a second sublayer of ruthenium (Ru) having a thickness of about 20 Å over the first sublayer. Alternatively, the first cap layer may be formed of a single layer of tantalum (Ta) having a thickness of 40 Å.

After the deposition of the central region **506** is completed, photoresist **602** is applied and exposed in a photolithography tool to mask SV sensor **500** in the central region **506** and then developed in a solvent to expose end regions **502** and **504**. The layers in the unmasked end regions **502** and **504** are removed by ion milling and end region layers **548** and **550** of alumina (Al_2O_3) are deposited in the end regions. Alternatively, longitudinal hard bias layers may be formed in the end regions **502** and **504** in order to provide a longitudinal bias field to the free layer **516** to ensure a single magnetic domain state in the free layer.

Photoresist **604** and photolithography processes are used to define the track width region **536** in the central region **506** of the SV sensor **500**. First and second leads L1 **528** and L2 **530** of rhodium (Rh) having a thickness in the range 200-600 Å are deposited over the end regions **502** and **504** and over the unmasked first cap layer **526** and in the first and second passive regions **532** and **534** which provide the desired lead/sensor overlap. After removal of the photoresist mask **604** in the track width region **536**, the leads L1 **528** and L2 **530** are used as masks for a sputter etch and reactive ion etch (RIE) process to remove the first cap layer **526** in the track width region **536**. After removal of the first cap layer, the exposed portions of the AFM layer **560** and the bias layer **522** in the track width region **536** are sputter etched with an oxygen containing gas to convert the AFM layer and ferromagnetic bias layers materials into a nonmagnetic oxide layer

538. The second cap layer **540** of rhodium (Rh), or alternatively ruthenium (Ru), having a thickness of about 40 Å is deposited over the leads L1 **528** and L2 **530** in the end regions **502** and **504** and the passive regions **532** and **534** and over the nonmagnetic oxide layer **538** in the track field region **536**. After fabrication of the structure of the SV sensor **500** is completed, the AFM layer **560** is set so that the bias layer **522** is pinned in a longitudinal direction. To set the AFM layer **560**, the SV sensor **500** is heated to about 265° C in the presence of a magnetic field of about 13 kOe oriented in the longitudinal direction (that is, in the plane of the layers and parallel to the ABS) and held for about 5 hours. With the magnetic field still applied, the sensor is cooled before removing the magnetic field.

An alternative process for defining the AP-coupled antiparallel tabs in the passive regions may be used to replace the process of sputter etching with an oxygen containing gas to oxidize the AFM layer and ferromagnetic bias layer materials in the track width region. In the alternative process, the step of using a sputter etch and reactive ion etch (RIE) process to remove the first cap layer **526** in the track width region **536** is continued to also remove the AFM layer **560** and the bias layer **522** in the track width region. To protect the free layer **516** from the sputter etch and RIE process a secondary ion mass spectrometer (SIMS) installed in the vacuum chamber of the sputtering system is used to provide endpoint detection for the ruthenium (Ru) forming the spacer layer **523**. The second cap layer **540** of rhodium (Rh), or alternatively ruthenium (Ru), having a thickness of about 40 Å is deposited over the leads L1 **528** and L2 **530** in the end regions **502** and **504** and the passive regions **532** and **534** and over the spacer layer **523** in the track field region **536**.

Second Example

Fig. 7 depicts an air bearing surface (ABS) view, not to scale, of a lead overlay SV sensor 700 according to an alternative embodiment of the present invention. The SV sensor 700 differs from the SV sensor 500 of the first example in having the AFM layer 560 set so that the bias layer 522 is pinned in a transverse direction, or alternatively, in a canted direction oriented at an intermediate angle between the longitudinal and transverse directions. The layer structure and the method of making the SV sensor 700 is the same as described herein above with respect to the SV sensor 500 of the first example. Only the process of setting the AFM layer 560 so that the bias layer 522 is pinned in a transverse direction or a canted direction is different for the SV sensor 700.

Fig. 9 is plan view, not to scale, of a spin valve sensor 902 indicating the orientations of longitudinal, transverse and canted bias fields relative to an air bearing surface (ABS) 904. The SV sensor has an approximately rectangular shape with front edge 906, a back edge 908, and two side edges 910. The front edge is defined by the lapped ABS 904 which forms a plane perpendicular to the plane of the SV sensor layers. The back edge 908 is spaced away from the front edge 906 by a distance that defines the stripe height of the SV sensor. A longitudinal bias field has an orientation in the plane of the SV sensor layers and directed parallel to the ABS 904 and to the front edge 906 as indicated by the arrow 912 pointing to the right, or alternatively, in an opposite direction as indicated by the arrow 913 pointing to the left. A transverse bias field has an orientation in the plane of the SV sensor layers and directed perpendicular to the ABS 904 and to the front edge 906 as indicated by the arrow 914 pointing upward (away from

the ABS), or alternatively, in an opposite direction as indicated by the arrow **915** pointing downward (toward the ABS). A canted bias field has an orientation in the plane of the SV sensor layers and directed at some angle φ to the plane of the ABS **904** intermediate between the directions of the longitudinal and transverse bias fields as indicated by the arrow **916**, or alternatively, in an opposite direction as indicated by arrow **917**. The angle φ may have any value between 0° and 180° .

After fabrication of the structure of the SV sensor **700** is completed, the AFM layer **560** is set so that the bias layer **522** is pinned in a transverse direction, or alternatively in a canted direction. To set the AFM layer **560**, the SV sensor **700** is heated to about 265°C in the presence of a magnetic field of about 13 kOe oriented in the transverse direction (that is, in the plane of the layers and perpendicular to the ABS), or alternatively in a canted direction (that is, in the plane of the layers and at an angle φ with respect to the ABS) and held for about 5 hours. With the magnetic field still applied, the sensor is cooled before removing the magnetic field.

It should be understood that the antiparallel coupled tabs with AFM pinning in the lead/sensor overlap regions (passive regions **532** and **534**) of the present invention may be used with any bottom spin valve sensor (SV) (sensor having the pinned layers located near the bottom of the stacked layers). In the bottom spin valve structure, the free layer can be easily AP-coupled to a bias layer and oxidation of the ferromagnetic bias layer to form a nonmagnetic oxide in the track width region can be easily accomplished. In particular, the antiparallel coupled tabs with AFM pinning bias in the lead/sensor overlap

regions may be used with AFM pinning simple pinned or AP-pinned SV sensors and with self-pinned SV sensors.

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 only as specified in the appended claims.

CLAIMS

1. A spin valve (SV) sensor having first and second passive regions and a central track width region transversely disposed between said first and second passive regions, said SV sensor comprising:

a pinned layer;

a ferromagnetic free layer;

a spacer layer sandwiched between said pinned layer and said free layer;

a ferromagnetic bias layer in said first and second passive regions;

an antiparallel coupling layer sandwiched between said free layer and said ferromagnetic bias layer for providing strong antiparallel coupling between said bias layer and said free layer in the first and second passive regions; and

an antiferromagnetic (AFM) layer adjacent to said ferromagnetic bias layer, said AFM layer exchange coupled to the ferromagnetic bias layer to provide a pinning field to the bias layer;

wherein said pinning field is directed in a canted direction intermediate between a direction parallel to an air bearing surface and a direction perpendicular to the air bearing surface.

2. The SV sensor as recited in claim 1 wherein said AFM layer is made of Pt-Mn, said AFM layer having a thickness in the range of 30-100 Å.

3. The SV sensor as recited in claim 1 wherein said AFM layer is chosen from a group of materials consisting of Pt-Mn, Ir-Mn and Ni-Mn.

4. The SV sensor as recited in claim 1 wherein said AFM layer has a thickness greater than zero but less than the thickness needed to provide a saturation value of said pinning field to the bias layer.

5. The SV sensor as recited in claim 1 wherein said bias layer has a thickness greater than the thickness of said free layer.

6. A disk drive system comprising:
a magnetic recording disk;

a magnetic read head for sensing magnetically recorded data on the magnetic recording disk, said magnetic read head comprising:

a spin valve (SV) sensor, the SV sensor being sandwiched between first and second read gap layers, the SV sensor having first and second passive regions and a central track width region transversely disposed between said first and second passive regions, said SV sensor comprising:

a pinned layer;

a ferromagnetic free layer;

a spacer layer sandwiched between said pinned layer and said free layer;

a ferromagnetic bias layer in said first and second passive regions;

an antiparallel coupled layer sandwiched between said free layer and said ferromagnetic bias layer for providing strong antiparallel coupling between said bias layer and said free layer in the first and second passive regions;

an antiferromagnetic (AFM) layer adjacent to said ferromagnetic bias layer, said AFM layer exchange coupled to the ferromagnetic bias layer to provide a pinning field to the bias layer;

wherein said pinning field is directed in a canted direction intermediate between a direction parallel to an air bearing surface and a direction perpendicular to the air bearing surface; and

an actuator for moving said magnetic read head across the magnetic disk so that the read head may access different regions of the magnetic recording disk; and

a recording channel coupled electrically to the SV sensor of the read head for detecting changes in resistance of the SV sensor in response to magnetic fields from the magnetically recorded data.

7. The disk drive system as recited in claim 6 wherein said AFM layer is made of Pt-Mn, said AFM layer having a thickness in the range of 30-100 Å.

8. The disk drive system as recited in claim 6 wherein said AFM layer is chosen from a group of materials consisting of Pt-Mn, Ir-Mn and Ni-Mn.

9. The disk drive system as recited in claim 6 wherein said AFM layer has a thickness greater than zero but less than the thickness needed to provide a saturation value of said pinning field to the bias layer.

10. The disk drive system as recited in claim 6 wherein said bias layer has a thickness greater than the thickness of said free layer.