

SPIN VALVE SENSOR WITH LOW FERROMAGNETIC COUPLING

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a spin valve sensor with low ferromagnetic coupling (H_{FC}) between a pinned layer and a free layer, and a method of making such a spin valve sensor.

2. Description of the Related Art

A spin valve sensor is employed by a read head for sensing magnetic fields on moving magnetic media, such as magnetic disks or magnetic tapes. Such a sensor includes a nonmagnetic conductive layer, hereinafter referred to as a spacer layer, sandwiched between first and second ferromagnetic layers, hereinafter referred to as a pinned layer and a free layer. First and second leads are connected to the spin valve sensor for conducting a sense current therethrough. The magnetic field of the pinned layer is pinned at 90° with respect to the direction of the magnetic field of the free layer, and the magnetic field of the free layer is free to respond to external magnetic fields on the magnetic medium. The magnetic field of the pinned layer is typically pinned by antiferromagnetic exchange coupling between the pinned layer and an antiferromagnetic layer. The thickness of the spacer layer is chosen to be less than the mean free path of electron conduction through the sensor. With this arrangement, a portion of the conduction electrons are scattered by the interfaces of the spacer layer with the pinned and free layers. When the magnetic fields of the pinned and free layers are parallel with respect to one another, scattering is minimal; when these fields are antiparallel, scattering is maximized. Changes in scattering change the resistance of the spin valve sensor in proportion with $\sin \theta$, where θ is the angle between the magnetic fields of the pinned and free layers. A spin valve sensor has a significantly

higher magnetoresistive (MR) coefficient than an anisotropic magnetoresistive (AMR) sensor. For this reason it is sometimes referred to as a giant magnetoresistive (GMR) sensor.

A read head employing a spin valve sensor (hereinafter a "spin valve read head") may be combined with an inductive write head to form a combined head. The combined head may have the structure of either a merged head, or a piggyback head. In a merged head a single layer serves as a shield for the read head and as a first pole piece for the write head. A piggyback head has a separate layer which serves as the first pole piece for the write head. In a magnetic disk drive an air bearing surface (ABS) of a combined head is supported adjacent a rotating disk to write information on or read information from the disk. Information is written to the rotating disk by magnetic fields which fringe across a gap between the first and second pole pieces of the write head. In a read mode the resistance of the spin valve sensor changes proportionally to the magnitudes of the magnetic fields from the rotating disk. When sense current is conducted through the spin valve sensor, the resistance changes cause potential changes that are detected and processed as playback signals.

The transfer curve (readback signal of the spin valve head versus applied signal from the magnetic disk) for a spin valve is linear and is defined by $\sin \theta$, where θ is the angle between the directions of the magnetic moments of the free and pinned layers. The greater this angle, the greater the resistance of the spin valve to the sense current and the greater the readback signal (voltage sensed by the processing circuitry). With positive and negative magnetic fields from a moving magnetic disk (assumed to be equal in magnitude), it is important that positive and negative changes in the magnetoresistance (MR) of the spin valve read head be equal in order that the positive and negative magnitudes of readback signals be equal. When the direction of the magnetic moment of the free layer is parallel to the ABS, and the direction of the magnetic moment of the pinned layer is perpendicular to the ABS in a quiescent state (no magnetic field signals from the magnetic disk), the positive and negative readback signals will be equal when sensing positive and negative magnetic fields

from the magnetic disk. When the direction of the magnetic moment of the free layer is parallel to the ABS, the bias point on the transfer curve of the spin valve read head is zero and the readback signals will have symmetry about this bias point.

The bias point is influenced by four major forces on the free layer: a ferromagnetic coupling field (H_{FC}) between the pinned layer and the free layer, a demag field (H_{demag}) from the pinned layer, a sense current field (H_{SC}) from all conductive layers of the spin valve except the free layer, and the aforementioned influence of the AMR. The influence of the AMR on the bias point is the same as a magnetic influence thereon and can be defined in terms of magnitude and direction.

Reduction of the influences on the free layer makes it easier to establish a zero bias point from the spin valve sensor that will enable the sensor to produce read signal symmetry. In commonly assigned U.S. Patent No. 5,465,185, an antiparallel (AP) pinned spin valve is described that significantly reduces the influence of H_{demag} on the free layer. H_{FC} can be reduced by increasing the thickness of the spacer layer between the pinned and free layers. This is not a desirable adjustment, however, because it reduces the GMR effect of the sensor. H_{SC} can be controlled by direction and magnitude of the sense current, and it is employed for balancing the other influences to establish a zero bias point. There is a strong felt need to reduce the effect of the H_{FC} field by means other than increasing the thickness of the spacer layer so that when H_{FC} and H_{SC} are antiparallel, less sense current is required to counterbalance H_{FC} . Reduction of the sense current reduces heating of the spin valve sensor, and improves thermal stability. Further, reduction of counterbalancing leads to improved signal response, since the magnetic moment of the free layer is less stiff in its response to magnetic fields on storage media.

SUMMARY OF THE INVENTION

I have discovered that, when the deposition easy axis of the pinned layer is non-parallel to the deposition easy axis of the free layer, the ferromagnetic coupling (H_{FC}) therebetween is less than when the deposition easy axes are parallel with respect

to one another. I have further discovered that H_{FC} is maximized when the deposition axes are parallel with respect to one another, and is minimized when the deposition easy axis are perpendicular with respect to one another. In a preferred embodiment of my invention the deposition easy axis and the direction of the pinned layer moment are perpendicular to the ABS, and the deposition easy axis of the free layer is parallel to the ABS. In my experimentation, I found that the ferromagnetic coupling (H_{FC}) between the pinned and free layers was about 10 Oe when the deposition easy axes of these layers are parallel with respect to one another, and that the ferromagnetic coupling (H_{FC}) between these layers was less than 1 Oe when the deposition easy axes of these layers are perpendicular with respect to one another.

A method of making the thin film spin valve sensor includes depositing a first ferromagnetic layer on an antiferromagnetic layer. During deposition of the first ferromagnetic layer I subject the layer to a magnetic field in a first direction which establishes a deposition easy axis of the first ferromagnetic layer in said first direction. A non-magnetic, electrically conductive spacer layer is then deposited on the first ferromagnetic layer, and a second ferromagnetic layer is deposited on the spacer layer. During deposition of the second ferromagnetic layer I subject the layer to a magnetic field in a second direction, which establishes a deposition easy axis of the second ferromagnetic layer in said second direction. The first and second directions are preferably perpendicular with respect to one another so as to maximally reduce the magnitude of H_{FC} between the first and second ferromagnetic layers. The thin film layers are then annealed in a field which is in said first direction so as to pin a magnetic moment of the first ferromagnetic layer in said first direction, thereby to define the first ferromagnetic layer as a pinned layer. This permits a magnetic moment of the second ferromagnetic layer to rotate as a free layer relative to the direction of the magnetic moment of the pinned layer with less magnetic stiffness due to the decrease of the H_{FC} .

An object of the present invention is to provide a spin valve sensor which has minimal ferromagnetic coupling field H_{FC} between a pinned layer and a free layer.

Another object is to provide a spin valve sensor wherein the direction of a deposition easy axis and a direction of a magnetic moment of a pinned layer are perpendicular to an ABS and the direction of a deposition easy axis of a free layer is parallel to the ABS.

A further object is to provide a spin valve sensor which has improved read signal performance and symmetry as well as improved thermal stability.

Still another object is to provide a spin valve sensor wherein H_{FC} can be reduced without increasing a thickness of a spacer layer between pinned and free layers.

Still a further object is to provide a method of making a spin valve sensor which has minimal H_{FC} between the pinned and free layers.

Yet another object is to provide a spin valve sensor wherein a deposition easy axis and direction of the pinned magnetic moment of the pinned layer is perpendicular to the ABS and the deposition easy axis of the free layer is parallel to the ABS.

Other objects and attendant advantages of the invention will be appreciated upon reading the following description taken together with the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a planar view of an exemplary magnetic disk drive;

Fig. 2 is an end view of a slider with a magnetic head of the disk drive as seen in plane II-II;

Fig. 3 is an elevation view of the magnetic disk drive wherein multiple disks and magnetic heads are employed;

Fig. 4 is an isometric illustration of an exemplary suspension system for supporting the slider and magnetic head;

Fig. 5 is a partial elevation view of the slider and magnetic head as seen in plane V-V of Fig. 2;

Fig. 6 is a view taken along plane VI-VI of Fig. 5 with all material above the second pole piece removed;

Fig. 7 is a partial ABS view of the slider taken along plane VII-VII of Fig. 5 to show the read and write elements of the magnetic head;

Fig. 8 is a prior art spin valve sensor.

Fig. 9 is another prior art spin valve sensor.

Fig. 10 is a first embodiment of the present invention.

Fig. 11 is a second embodiment of the present invention.

Fig. 12 is a third embodiment of the present invention.

Fig. 13 is a first step in the construction of the first embodiment of the invention.

Fig. 14 is a second step in the construction of the first embodiment of the invention.

Fig. 15 is a third step in the construction of the first embodiment of the invention.

Fig. 16 is a first step in the construction of the second embodiment of the invention.

Fig. 17 is a second step in the construction of the second embodiment of the invention.

Fig. 18 is a third step in the construction of the second embodiment of the invention.

Fig. 19 is a graph illustrating a decrease in ferromagnetic coupling field H_{FC} upon an increase in thickness of a spacer layer between the pinned and free layers.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to the drawings wherein like reference numerals designate like or similar parts throughout the several views, there is illustrated in Figs. 1-3 a magnetic disk drive 30. The drive 30 includes a spindle 32 which supports and rotates a magnetic disk 34. The spindle 32 is rotated by a motor 36 which in turn is controlled by a motor controller 38. A horizontal combined magnetic head 40 for reading and recording is mounted on a slider 42 which, in turn, is supported by a

suspension 43 and actuator arm 44. A plurality of disks, sliders and suspensions may be employed in a large capacity direct access storage device (DASD) as shown in Fig. 3. The suspension 43 and actuator arm 44 position the slider 42 to place the magnetic head 40 in a transducing relationship with a surface of the magnetic disk 34. When the disk 34 is rotated by the motor 36 the slider is supported on a thin (typically, .05 μm) cushion of air (air bearing) by the air bearing surface (ABS) 46. The magnetic head 40 may then be employed for writing information to multiple circular tracks on the surface of the disk 44, as well as for reading information therefrom. Processing circuitry 48 exchanges signals representing such information with the head 40, provides motor drive signals, and also provides control signals for moving the slider to various tracks. In Fig. 4 the slider 42 is shown mounted to a head gimbal assembly (HGA) 50 which in turn is mounted to the suspension 43. The components, hereinabove, may be mounted on a base 49.

Fig. 5 is a side cross-sectional elevation view of the merged magnetoresistive (MR) head 40 which has a write head portion 50 and a read head portion 52, the read head portion employing an MR spin valve sensor 53 of the present invention. The MR sensor 53 is sandwiched between first and second gap layers 54 and 56 and the gap layers are sandwiched between first and second shield layers 58 and 60. In response to external magnetic fields, the resistance of the MR sensor 53 changes. A sense current conducted through the sensor causes these resistance changes to be manifested as potential changes. These potential changes are then processed by the processing circuitry 48 shown in Fig. 3.

The write head portion 50 of the prior art head includes a coil layer 64 which is sandwiched between first and second insulation layers 66 and 68. A third insulation layer 70 may be employed for planarizing the head to eliminate ripples in the second insulation layer caused by the coil layer 64. The first, second and third insulation layers are referred to in the art as an "insulation stack". The coil layer 64, and the first, second and third insulation layers 66, 68 and 70 are sandwiched between first and second pole piece layers 72 and 74. The first and second pole piece layers 72 and

74 are magnetically coupled at a back gap 76 and have first and second pole tips 78 and 80 which are separated by a gap layer 82 at the ABS. As shown in Fig. 2 first and second solder connections 84 and 86 connect leads (not shown) from the MR sensor 53 to leads 92 and 94 on the suspension 43 and third and fourth solder connections 96 and 98 connect leads 100 and 102 from the coil 64 (see Fig. 6) to leads 104 and 106 on the suspension.

In Figs. 8-18 the air bearing surface (ABS) is in the plane of the paper. Figs. 8 and 9 are exemplary prior art embodiments of spin valve sensors. Figs. 10, 11 and 12 are three embodiments of the present invention. Figs. 13-15 illustrate a method of making the embodiment shown Fig. 10 and Figs. 16-18 show steps in a method of making the embodiment shown in Fig. 11.

In Fig. 8 a prior art spin valve sensor 53a is shown which includes a spacer layer 120 sandwiched between pinned and free layers 122 and 124. Interfacially engaging the pinned layer 122 is an antiferromagnetic (AFM) layer 126 for pinning a magnetic moment 128 of the pinned layer 122 in a direction which is perpendicular to the ABS. If desired, a cobalt layer 130 may be sandwiched between the pinned and spacer layers 122 and 120, the cobalt layer 130 then becoming a portion of the pinned layer 122 and enhancing its pinning moment 128. A magnetic moment 132 of the free layer 124 is directed parallel to the ABS and is free to rotate from this position relative to the magnetic moment 128 of the pinned layer 122. When the spin valve sensor 53a senses a magnetic field at the ABS from a rotating magnetic disk, the magnetic moment 132 of the free layer rotates up and down with respect to the ABS which, because of its relative angle with respect to the magnetic moment 128, changes the resistance of the sensor 53a. A sense current source 134 provides a sense current I_s that is conducted through the sensor, permitting these resistance changes to be detected as voltage changes by the processing circuitry 48 shown in Fig. 3.

The pinned layer 122 has a deposition easy axis 136 and the free layer 124 has a deposition easy axis 138. The deposition easy axes 136 and 138 are formed during deposition of these layers which will be described in more detail hereinafter. In the

prior art spin valve sensor 53a the deposition easy axes 136 and 138 are parallel with respect to one another which results in a maximum ferromagnetic coupling H_{FC} between the pinned and free layers 122 and 124. In the prior art embodiment 53a, shown in Fig. 8, the deposition easy axes 136 and 138 are oriented parallel to the ABS while in another prior art spin valve sensor 53b, shown in Fig. 9, the deposition easy axes 148 and 150 of the pinned and free layers 122 and 124 are both perpendicular to the ABS. In both embodiments the ferromagnetic coupling field H_{FC} between the pinned and free layers is at a maximum. As will be discussed in more detail, the H_{FC} between the pinned and free layers 122 and 124 of the prior art embodiments 53a and 53b is approximately 7 to 10 Oe and the $\Delta r/R$ is 5.5% to 5.9%. As discussed hereinabove, the ferromagnetic coupling field H_{FC} affects the biasing of the free layer, the thermal stability of the sensor and the amplitude response of the sensor.

A first embodiment 53c of the present invention is shown in Fig. 10. In this embodiment the pinned layer 122 has a deposition easy axis 160 and the free layer 124 has a deposition easy axis 162. The deposition easy axes 160 and 162 are preferably perpendicular with respect to one another with the deposition easy axis 160 being perpendicular to the ABS and the deposition easy axis 162 being parallel to the ABS. Because of the perpendicular relationship between the easy axes 160 and 162 the ferromagnetic coupling field H_{FC} is at a minimum. In my experimentation, I have shown that the ferromagnetic coupling field H_{FC} is less than 1 Oe and that the $\Delta r/R$ was 5.38%. This proved to be a significant drop in the ferromagnetic coupling field H_{FC} with only a slight decrease in the $\Delta r/R$.

Another embodiment 53d of the present invention is shown in Fig. 11. In this embodiment the pinned layer 122 has a deposition easy axis 164 and the free layer 124 has a deposition easy axis 166. The easy axes 164 and 166 are perpendicular with respect to one another which again results in minimizing the ferromagnetic coupling H_{FC} . The embodiment 53d differs from the embodiment 53c in that the

deposition easy axis 164 is parallel to the ABS and the deposition easy axis 166 is perpendicular to the ABS.

Still another embodiment 53e of the present invention is shown in Fig. 12. The embodiment 53e is the same as the embodiment 53c in Fig. 10 except the embodiment 53e has a cobalt layer 168 sandwiched between the spacer layer 120 and the free layer 124. The cobalt layer 168 is considered part of the free layer 124 and enhances its capability. However, the cobalt layer increases the ferromagnetic coupling field H_{FC} to a greater extent than that produced by the embodiments 53c and 53d in Figs. 10 and 11. Accordingly, in the embodiment 53e it becomes even more important to take steps to reduce the ferromagnetic coupling field H_{FC} according to the present invention.

The steps in constructing the embodiment 53c, shown in Fig. 10, are shown in Figs. 13-15. In Fig. 13 the antiferromagnetic layer 126, the pinned layer 122 and the cobalt layer 130 are ion beam sputtered while subjected to a magnetic field 170 perpendicular to the ABS, either directed toward the ABS, as shown in Fig. 13, or away therefrom. This magnetically establishes the deposition easy axis 160 of the pinned layer perpendicular to the ABS, as shown in Fig. 13. While it is important that the field 170 be present during the deposition of the pinned layer 122 and the cobalt layer 130, it can optionally be turned on during the deposition of the antiferromagnetic layer 126. The cobalt layer 130 is considered as part of the pinned layer 122 and will have a deposition easy axis the same as the deposition easy axis 160. The next step is to ion beam sputter the spacer layer 120 and the free layer 124 while subjected to a magnetic field 172 which is magnetically parallel to the ABS, directed either to the right, as shown in Fig. 14, or to the left. This magnetically establishes the deposition easy axis 162 of the free layer parallel to the ABS and perpendicular to the deposition easy axis 160 of the pinned layer. Again, it is only necessary that the field 172 be applied to the layers during the sputter deposition of the free layer 124, however, it may optionally be turned on during the deposition of the spacer layer 120. In the last step, as shown in Fig. 15, the sensor 53c is annealed

at a temperature of approximately 200°C while subjected to the magnetic field 170, which sets the spin orientation in the antiferromagnetic layer 126 to pin the magnetic moment 128 of the pinned layer perpendicular to the ABS in a direction either toward the ABS, as shown in Fig. 15, or away therefrom. The magnetic field 170 for pinning the magnetic moment 128 of the pinned layer in Fig. 15 is in the same direction as the field 170 employed for setting the deposition easy axis 160 of the pinned layer, as shown in Fig. 13.

The method of constructing the embodiment 53d of Fig. 11 is shown in Figs. 16-18. In Fig. 16 the pinned layers 122 and 130 are ion beam sputtered in the presence of a field which is directed parallel to the ABS either to the right, as shown in Fig. 16, or to the left. This establishes the pinned layer 122 and the cobalt layer 130 with a deposition easy axis 164 which is parallel to the ABS. The next step in the method is shown in Fig. 17 wherein, after deposition of the spacer layer 120, the free layer 124 is ion beam sputtered while subjected to a magnetic field 182 which is perpendicular to the ABS, directed either toward the ABS or away therefrom. This magnetically establishes the free layer 124 with the deposition easy axis 166. The next step is shown in Fig. 18 wherein the sensor 53d is annealed at a temperature of approximately 200°C while subjected to the field 182, which orients the spins of the antiferromagnetic layer 126 to pin the pinned layer 122 and the cobalt layer 130 with a magnetic moment 128 which is perpendicular to the ABS either toward the ABS, as shown in the figure, or away therefrom depending upon the direction of the magnetic field 182.

In each of the prior art embodiments 53a and 53b in Figs. 8 and 9 the deposition easy axes of the pinned and free layers were sputter deposited in a unidirectional field. In the present embodiment 53c, 53d and 53e in Figs. 10-11 of the present invention the deposition easy axes were deposited in fields which were perpendicular with respect to one another. The prior art embodiment 53a, shown in Fig. 8, and the embodiment 53c, shown in Fig. 10, of the present invention were constructed for comparison purposes. Each structure was composed of the

following from the bottom to the top layer NiO/NiFe/Co/Cu/NiFe/Ta (400Å/18Å/10Å/21Å/72Å/35Å). The prior art sensor 53a had a ferromagnetic coupling field H_{FC} between 7 to 8 Oe with a $\Delta r/R$ of 5.5% to 5.9%. The embodiment 53c of the present invention had a ferromagnetic coupling field H_{FC} of 0.8984 Oe with a $\Delta r/R$ of 5.38%. With a similar $\Delta r/R$ the embodiment 53c of the present invention had a significant reduction in the ferromagnetic coupling field H_{FC} as compared to the prior art embodiment 53a.

One scheme of reducing the ferromagnetic coupling H_{FC} in a spin valve sensor is to reduce the thickness of the copper spacer layer, as shown in Fig. 19. Fig. 19 shows that when the thickness of the spacer layer is increased the ferromagnetic coupling field decreases. Unfortunately, however, an increase in the copper spacer layer results in less $\Delta r/R$ and less sensitivity of the spin valve sensor to information field signals from the rotating magnetic disk.

It should be understood that the directions of the magnetic moments 128 and 132 in each of the embodiments 53c, 53d and 53e shown in Figs. 10-12 could be reversed in their directions without departing from the spirit of the invention. Typically the magnetic moment 128 of the pinned layer is perpendicular to the ABS in either direction and the magnetic moment 132 of the free layer 124 is parallel to the ABS in either direction. Further, the cobalt layer 130 may be omitted as desired. Still further, other materials may be substituted for the various layers without departing from the spirit of the invention.

Clearly, other embodiments and modifications of this invention will occur readily to those of ordinary skill in the art in view of these teachings. Therefore, this invention is to be limited only by the following claims, which include all such embodiments and modifications when viewed in conjunction with the above specification and accompanying drawings.



CLAIMS

I Claim:

1. A spin valve sensor with an air bearing surface (ABS), comprising:
a ferromagnetic free layer, a ferromagnetic pinned layer and a non-magnetic electrically conductive spacer layer;
the spacer layer being sandwiched between the free and pinned layers;
the pinned layer having a magnetic moment which is pinned in a first direction;
the free layer having a magnetic moment which is free to rotate from a second direction and relative to said first direction of the magnetic moment of the pinned layer;
a ferromagnetic coupling H_{FC} between the free and pinned layers;
each of the free and pinned layers having a respective deposition easy axis which is established during deposition of the respective layer; and
an angular spacing θ between the deposition easy axes of the free and pinned layers being greater than 0 to 90° with respect to one another so as to reduce said ferromagnetic coupling H_{FC} .
2. A spin valve sensor as claimed in claim 1 wherein θ is substantially 90° for maximum reduction of said ferromagnetic coupling H_{FC} .
3. A spin valve sensor as claimed in claim 2 wherein said first direction and the deposition easy axis of the pinned layer is substantially perpendicular to the ABS and said second direction and the deposition easy axis of the free layer is substantially parallel to said ABS.



4. A spin valve sensor as claimed in claim 3 wherein an antiferromagnetic layer interfacially engages the pinned layer for pinning the magnetic moment of the pinned layer in said first direction.

5. A spin valve sensor as claimed in claim 4 comprising:
a cobalt layer; and
the cobalt layer being sandwiched between the spacer and free layers.

6. A spin valve read head, comprising:
a spin valve sensor, first and second gap layers and first and second shield layers;

the spin valve sensor being sandwiched between the first and second gap layers and the first and second gap layers being sandwiched between the first and second shield layers; and

a sense current source for applying a sense current to the sensor;
the spin valve sensor including:

a ferromagnetic free layer, a ferromagnetic pinned layer and a non-magnetic electrically conductive spacer layer;

the spacer layer being sandwiched between the free and pinned layers:

the pinned layer having a magnetic moment which is pinned in a first direction;

the free layer having a magnetic moment which is free to rotate from a second direction and relative to said first direction of the magnetic moment of the pinned layer;

a ferromagnetic coupling H_{FC} between the free and pinned layers;

each of the free and pinned layers having a respective deposition easy axis which is an easy axis during deposition of the respective layer; and



an angular spacing θ between the deposition easy axes of the free and pinned layers being greater than 0 but less than 180 degrees with respect to one another so as to reduce said ferromagnetic coupling H_{FC} .

7. A spin valve read head as claimed in claim 6 wherein θ is substantially 90° for maximum reduction of said ferromagnetic coupling H_{FC} .

8. A spin valve read head as claimed in claim 7 wherein said first direction and the deposition easy axis of the pinned layer is substantially perpendicular to the ABS and said second direction and the deposition easy axis of the free layer is substantially parallel to said ABS.

9. A spin valve read head as claimed in claim 8 wherein an antiferromagnetic layer interfacially engages the pinned layer for pinning the magnetic moment of the pinned layer in said first direction.

10. A spin valve read head as claimed in claim 9 comprising:
a cobalt layer; and
the cobalt layer being sandwiched between the spacer and free layers.

11. A magnetic head, comprising:
a write head, including:
at least one coil layer and an insulation stack;
the coil layer being embedded in the insulation stack;
first and second pole pieces connected at a back gap and having pole tips with edges forming a portion of an air bearing surface (ABS);
the insulation stack being sandwiched between the first and second pole pieces;



a write gap layer sandwiched between the pole tips of the first and second pole pieces and forming a portion of the ABS;
a read head including:

a spin valve sensor, first and second gap layers and first and second shield layers;

the spin valve sensor being sandwiched between the first and second gap layers and the first and second gap layers being sandwiched between the first and second shield layers; and

means for conducting a sense current through the sensor;
the spin valve sensor including:

a ferromagnetic free layer, a ferromagnetic pinned layer and a non-magnetic electrically conductive spacer layer;

the spacer layer being sandwiched between the free and pinned layers;
the pinned layer having a magnetic moment which is pinned in a first direction;

the free layer having a magnetic moment which is free to rotate from a second direction and relative to said first direction of the magnetic moment of the pinned layer;

a ferromagnetic coupling H_{FC} between the free and pinned layers;
each of the free and pinned layers having a respective deposition easy axis which is established during deposition of the respective layer; and

an angular spacing θ between the deposition easy axes of the free and pinned layers being greater than 0 to 90° with respect to one another so as to reduce said ferromagnetic coupling H_{FC} .

12. A magnetic head as claimed in claim 11 wherein θ is substantially 90° for maximum reduction of said ferromagnetic coupling H_{FC} .



13. A magnetic head as claimed in claim 12 wherein said first direction and the deposition easy axis of the pinned layer is substantially perpendicular to the ABS and said second direction and the deposition easy axis of the free layer is substantially parallel to said ABS.

14. A magnetic head as claimed in claim 13 wherein an antiferromagnetic layer interfacially engages the pinned layer for pinning the magnetic moment of the pinned layer in said first direction.

15. A magnetic head as claimed in claim 14 comprising:
a cobalt layer; and
the cobalt layer being sandwiched between the spacer and free layers.

16. A magnetic disk drive, comprising:
a write head, including:
at least one coil layer and an insulation stack;
the coil layer being embedded in the insulation stack;
first and second pole pieces connected at a back gap and having pole tips with edges forming a portion of an air bearing surface (ABS);
the insulation stack being sandwiched between the first and second pole pieces;
a write gap layer sandwiched between the pole tips of the first and second pole pieces and forming a portion of the ABS;
a read head, including:
a spin valve sensor, first and second gap layers and first and second shield layers;
the spin valve sensor being sandwiched between the first and second gap layers and the first and second gap layers being sandwiched between the first and second shield layers; and



a sense current source for applying a sense current to the sensor;
the spin valve sensor including:

a ferromagnetic free layer, a ferromagnetic pinned layer and a non-magnetic electrically conductive spacer layer;

the spacer layer being sandwiched between the free and pinned layers:

the pinned layer having a magnetic moment which is pinned in a first direction;

the free layer having a magnetic moment which is free to rotate from a second direction and relative to said first direction of the magnetic moment of the pinned layer;

a ferromagnetic coupling H_{FC} between the free and pinned layers;

each of the free and pinned layers having a respective deposition easy axis which is established during deposition of the respective layer; and

an angular spacing θ between the deposition easy axes of the free and pinned layers being greater than 0 to 90° with respect to one another so as to reduce said ferromagnetic coupling H_{FC} ;

the write and read heads being adjacent one another to form a combined magnetic head;

a frame;

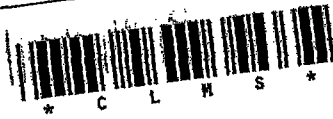
a magnetic disk rotatably supported on the frame;

a support mounted on the frame for supporting the combined magnetic head in a transducing relationship with the magnetic disk;

means for rotating the magnetic disk;

positioning means connected to the support for moving the combined magnetic head to multiple positions with respect to said magnetic disk; and

means connected to the combined magnetic head, to the means for rotating the magnetic disk and to the positioning means for exchanging signals with the combined magnetic head, for controlling movement of the magnetic disk and for controlling the position of the combined magnetic head.



17. A magnetic disk drive as claimed in claim 16 wherein θ is substantially 90° for maximum reduction of said ferromagnetic coupling H_{FC} .

18. A magnetic disk drive as claimed in claim 17 wherein said first direction and the deposition easy axis of the pinned layer is substantially perpendicular to the ABS and said second direction and the deposition easy axis of the free layer is substantially parallel to said ABS.

19. A magnetic disk drive as claimed in claim 18 wherein an antiferromagnetic layer interfacially engages the pinned layer for pinning the magnetic moment of the pinned layer in said first direction.

20. A magnetic disk drive as claimed in claim 19 comprising:
a cobalt layer; and
the cobalt layer being sandwiched between the spacer and free layers.

21. A method of making a thin film spin valve sensor comprising the steps of:

- depositing a thin film antiferromagnetic layer;
- depositing a thin film first ferromagnetic layer on the antiferromagnetic layer;
- during deposition of the first ferromagnetic layer magnetically establishing a deposition easy axis of the first ferromagnetic layer in a first direction;
- depositing a non-magnetic electrically conductive thin film spacer layer on the first ferromagnetic layer;
- depositing a thin film second ferromagnetic layer on the spacer layer;
- during deposition of the second ferromagnetic layer magnetically establishing a deposition easy axis of the second ferromagnetic layer in a second direction;
- the first and second directions being nonparallel with respect to one another;



annealing the thin film layers in a field which is in said first direction so as to pin a magnetic moment of the first ferromagnetic layer in said first direction and define the first ferromagnetic layer as a pinned layer.

22. A method as claimed in claim 21 wherein the spin valve sensor can be provided with an air bearing surface (ABS) which extends substantially perpendicular to the layers, the method comprising the step of:

the first direction being nonparallel to the ABS and the second direction being parallel to the ABS.

23. A method as claimed in claim 22 wherein the first direction is perpendicular to the ABS.

24. A method as claimed in claim 21 wherein the depositing steps are by sputter deposition.

25. A method as claimed in claim 24 wherein between the steps of depositing the thin film spacer layer and depositing the thin film second ferromagnetic layer a thin film cobalt layer is deposited on the thin film spacer layer.

26. A method of making a spin valve magnetoresistive (MR) read head comprising the steps of:

depositing a thin film first shield layer;

depositing a thin film first gap layer on the first shield layer;

forming a spin valve sensor on the first gap layer which includes the steps of:

depositing a thin film antiferromagnetic layer on the first gap layer;

depositing a thin film first ferromagnetic layer on the antiferromagnetic layer;



during deposition of the first ferromagnetic layer magnetically establishing a deposition easy axis of the first ferromagnetic layer in a first direction;

depositing a thin film non-magnetic electrically conductive spacer layer on the first ferromagnetic layer;

depositing a thin film second ferromagnetic layer on the spacer layer;

during deposition of the second ferromagnetic layer magnetically establishing a deposition easy axis of the second ferromagnetic layer in a second direction;

the first and second directions being nonparallel with respect to one another; and

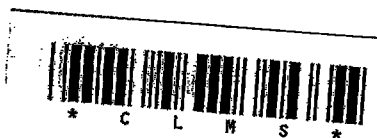
annealing the thin film layers in a field which is in said first direction so as to pin a magnetic moment of the first ferromagnetic layer in said first direction and define the first ferromagnetic layer as a pinned layer and permit a magnetic moment of the second ferromagnetic layer to rotate relative to the direction of the magnetic moment of the pinned layer so as to define the second ferromagnetic layer as a free layer.

27. A method as claimed in claim 26 wherein the spin valve sensor can be provided with an air bearing surface (ABS) which extends substantially perpendicular to the layers, the method comprising the step of:

the first direction being nonparallel to the ABS and the second direction being parallel to the ABS.

28. A method as claimed in claim 27 wherein the first direction is perpendicular to the ABS.

29. A method as claimed in claim 28 wherein the depositing steps are by sputter deposition.



30. A method as claimed in claim 29 wherein between the steps of depositing the thin film spacer layer and depositing the thin film second ferromagnetic layer a thin film cobalt layer is deposited on the thin film spacer layer.

31. A method of making a merged magnetoresistive (MR) spin valve magnetic head comprising the steps of:

forming an MR spin valve read head which includes the steps of:

depositing a thin film first shield layer;

depositing a thin film first gap layer on the first shield layer;

depositing a thin film antiferromagnetic layer on the first gap layer;

depositing a thin film first ferromagnetic layer on the antiferromagnetic layer;

during deposition of the first ferromagnetic layer magnetically establishing a deposition easy axis of the first ferromagnetic layer in a first direction;

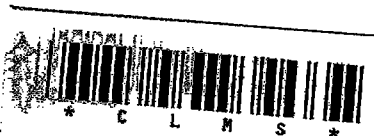
depositing a thin film non-magnetic electrically conductive spacer layer on the first ferromagnetic layer;

depositing a thin film second ferromagnetic layer on the spacer layer;

during deposition of the second ferromagnetic layer magnetically establishing a deposition easy axis of the second ferromagnetic layer in a second direction;

the first and second directions being nonparallel with respect to one another; and

annealing the thin film layers in a field which is in said first direction so as to pin a magnetic moment of the first ferromagnetic layer in said first direction and define the first ferromagnetic layer as a pinned layer and permit a magnetic moment of the second ferromagnetic layer to rotate relative to the direction of the magnetic moment of the pinned layer so as to define the second ferromagnetic layer as a free layer;



depositing a thin film second gap layer on the second ferromagnetic layer; and

depositing a thin film second shield layer on the second gap layer; forming a write head on the read head including the steps of:

said step of forming a thin film second shield layer on the thin film second gap layer also forming a thin film first pole piece layer;

depositing a thin film write gap layer on the second shield layer;

depositing a first insulation layer on the second shield layer;

depositing at least one thin film coil layer on the first insulation layer;

depositing at least a second insulation layer on said at least one thin film coil layer; and

depositing a second thin film pole piece layer on the write gap layer and the second insulation layer.

32. A method as claimed in claim 31 wherein the spin valve sensor can be provided with an air bearing surface (ABS) which extends substantially perpendicular to the layers, the method comprising the step of:

the first direction being nonparallel to the ABS and the second direction being parallel to the ABS.

33. A method as claimed in claim 32 wherein the first direction is perpendicular to the ABS.

34. A method as claimed in claim 33 wherein the depositing steps are by sputter deposition.

35. A method as claimed in claim 33 wherein between the steps of depositing the thin film spacer layer and depositing the thin film second ferromagnetic layer a thin film cobalt layer is deposited on the thin film spacer layer.