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IMPROVED ANTIPARALLEL-PINNED SPIN VALVE SENSOR

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates generally to spin valve magnetic transducers for reading information signals from a magnetic medium and, in particular, to an improved antiparallel-pinned spin valve sensor, and to magnetic recording 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.

In high capacity disk drives, magnetoresistive read sensors, commonly referred to as MR heads, are the prevailing read sensors because of their capability to read data from a surface of a disk

at greater 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 flow 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 separated by a layer of non-magnetic electrically conductive material are generally referred to as spin valve (SV) sensors manifesting the SV effect. In an SV sensor, one of the ferromagnetic layers, referred to as the pinned layer, has its magnetization typically pinned by exchange coupling with an antiferromagnetic (e.g., NiO or Fe-Mn) layer. The magnetization of the other ferromagnetic layer, referred to as the free layer, however, is not fixed and is free to rotate in response to the field from the recorded magnetic medium (the signal field). In SV sensors, the SV effect varies as the cosine of the angle between the magnetization of the pinned layer and the magnetization of the free layer. 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 free layer, which in turn causes a change in resistance of the SV sensor and a corresponding change in the sensed current or voltage.

Fig. 1 shows a prior art SV sensor 100 comprising end regions 104 and 106 separated by a central region 102. A free layer (free ferromagnetic layer) 110 is separated from a pinned layer (pinned ferromagnetic layer) 120 by a non-magnetic, electrically-conducting spacer 115. The magnetization of the

pinned layer **120** is fixed by an antiferromagnetic (AFM) layer **121**. Free layer **110**, spacer **115**, pinned layer **120** and the AFM layer **121** are all formed in the central region **102**. 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 over hard bias layers **130** and **135**, respectively, provide electrical connections for the flow of the sensing current I_s from a current source **160** to the MR sensor **100**. Sensing means **170** connected to leads **140** and **145** sense the change in the resistance due to changes induced in the free layer **110** by the external magnetic field (e.g., field generated by a data bit stored on a disk).

IBM's U.S. Patent No. 5,206,590 granted to Dieny et al., incorporated herein by reference, discloses an MR sensor operating on the basis of the SV effect.

Another type of spin valve sensor currently under development is an antiparallel (AP)-pinned spin valve sensor. Fig. 2 shows an AP-Pinned SV sensor disclosed in copending Application Serial No. 08/697,396 by Fontana et al., filed Aug. 23, 1996, and assigned to the assignee of the present invention. In the AP-pinned SV sensor **200** of Fig. 2, the pinned layer is a laminated structure of two ferromagnetic layers separated by a non-magnetic coupling layer such that the magnetizations of the

two ferromagnetic layers are strongly coupled together antiferromagnetically in an antiparallel orientation. The exchange coupling between the antiferromagnetic (AFM) layer and the laminated pinned layer of AP-pinned SV sensor of Fig. 2 is substantially stronger than the exchange coupling between the AFM layer and the single pinned layer of the SV sensor of Fig. 1. This improved exchange coupling increases the stability of the AP-pinned SV sensor at high temperatures which allows the use of corrosion resistant antiferromagnetic materials such as NiO for the AFM layer.

Referring again to Fig. 2, a free layer 210 is separated from a laminated AP-pinned layer 220 by a nonmagnetic, electrically-conducting spacer layer 215. The magnetization of the laminated AP-pinned layer 220 is fixed by an AFM layer 230 which is made of NiO. The laminated AP-pinned layer 220 includes a first ferromagnetic layer 222 (PF1) and a second ferromagnetic layer 226 (PF2) separated from each other by an antiparallel coupling (APC) layer 224 of nonmagnetic material. The two ferromagnetic layers 222, 226 in the laminated AP-pinned layer 220 are formed of Co and the APC layer 224 is formed of Ru. The AFM layer 230 is formed on a seed layer 240 deposited on the substrate 250. To complete the AP-pinned SV sensor, a capping layer 205 is formed on the free layer 210.

A key advantage of the AP-pinned SV sensor of Fig. 2, that allows the use of NiO material for the AFM layer, is the improvement of the exchange coupling field strength between the AFM layer **230** and AP-pinned layer **220**. This exchange coupling field is inversely proportional to the magnetic moment difference (net magnetic moment) between the two AP-pinned ferromagnetic layers.

However, experiments by the present inventor on fabrication of AP-pinned SV sensors of Fig. 2 (layered structure of NiO/Co/Ru/Co/Cu/Ni-Fe/Ta) have shown that the net moment of the laminated AP-pinned structure of Co/APC/Co is very difficult to control and reproduce because of interfacial diffusion and oxidation that takes place at the interface between the NiO AFM layer and the first ferromagnetic layer of Co. The interfacial diffusion and oxidation that takes place at the aforementioned interface causes a change in the moment of the first ferromagnetic Co layer even after the AP-pinned SV sensor of Fig. 2 has been completely built. The change in the moment of the first ferromagnetic layer causes the change in the net moment of the AP-pinned layer. These experiments have resulted in variations by factors of 2 to 3 in the net moments of the AP-pinned layers for successive fabrication runs. Variations in net moment of the AP-pinned structure results in large variations in

pinning fields which compromises the stability of the SV sensors. Furthermore, experiments conducted have shown that Co deposited on an NiO AFM layer has a very large coercivity, but low exchange pinning to the NiO AFM layer. The large coercivity of the Co layer makes it very difficult to reset the magnetization direction of the pinned layer if such a reset becomes necessary. Such a reset may become necessary if the magnetization direction of the pinned layer becomes disoriented, for example, in the disk drive due to a large unexpected magnetic field.

Therefore, there is a need for an AP-pinned SV sensor where the AP-pinned layer has a well controlled and reproducible net moment.

SUMMARY OF THE INVENTION

It is an object of the present invention to disclose an improved AP-Pinned SV sensor having a AP-pinned layer where the net moment and magnetic properties of the AP-pinned layer is well controlled.

It is another object of the present invention to disclose an AP-pinned SV sensor with the structure of substrate/seed layer/pinned layer/spacer/free layer where the pinned layer comprises a first and a second ferromagnetic pinned layer and where the first ferromagnetic pinned layer further comprises

first and second ferromagnetic sub-layers.

In accordance with the principles of the present invention, there is disclosed an AP-pinned SV sensor with the preferred structure of Substrate/Seed/NiO/Ni-Fe/Co/Ru/Co/Cu/Ni-Fe/Cap where the AP-pinned layer comprises a first and a second ferromagnetic pinned layer separated from each other by an anti-parallel coupling layer. The first ferromagnetic pinned layer comprises a first Ni-Fe sub-layer and a second Co sub-layer. The first Ni-Fe sub-layer is deposited over and in contact with the NiO AFM layer. The addition of the Ni-Fe sub-layer isolates the Co layer from the NiO AFM layer which results in improving the pinning field and magnetic moment control of the laminated AP-pinned layer structure as well as reducing the coercivity of the first pinned layer.

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, reference should be made to the following detailed description read in conjunction with the accompanying drawings.

Fig. 1 is a sectional view of a prior art SV sensor;

Fig. 2 is a sectional view of an AP-pinned SV sensor;

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

Fig. 4 is an air bearing surface view of the AP-pinned SV sensor according to the present invention;

Fig. 5 is an air bearing surface view of an alternate embodiment of the AP-pinned SV sensor of the present invention;

Fig. 6 is an air bearing surface view of a second alternate embodiment of the AP-pinned SV 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 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 MR sensor of the present invention. As the disks rotate, slider **313** is moved radially in and out over disk surface **322** so that 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 slider **313** against the disk surface **322**. Each actuator arm **319** is attached to an actuator means **327**. The actuator means 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 controller **329**.

During operation of the disk storage system, the rotation of disk **312** generates an air bearing between slider **313** (the surface of slider **313** which includes head **321** and faces the surface of disk **312** is referred to as an air bearing surface (ABS)) and disk surface **322** which exerts an upward force or lift on the slider. The air bearing thus counter-balances the slight spring force of suspension **315** and supports slider **313** 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 control unit **329**, such as access control signals and internal clock signals. Typically, control unit **329** comprises logic control circuits, storage means 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 slider **313** to the desired data track on disk **312**. Read and write signals are communicated to and from read/write heads **321** by means of 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. **4** shows an air bearing surface (ABS) view of the AP-pinned SV sensor **400** according to the preferred embodiment of the present invention. SV sensor **400** has end regions **404** and **406** separated from each other by a central region **402**. Substrate **450** can be any suitable substance, including glass, semiconductor material, or a ceramic material, such as alumina (Al_2O_3). Seed

layer **440** is any layer deposited on substrate **450** for the purpose of modifying the crystallographic texture or grain size of the subsequent layers deposited on the seed layer **440**. The seed layer **440** may not be needed depending on the type of substrate used. If used, the seed layer **440** may be formed of tantalum (Ta), zirconium (Zr), nickel-iron (Ni-Fe), or Al_2O_3. In the preferred embodiment, seed layer **440** is made of Ta. Subsequent to the deposition of the seed layer **440**, antiferromagnetic (AFM) layer **430** of NiO material is formed over the seed layer. The NiO AFM layer **430** is formed over the seed layer **440** by ion beam sputtering a Ni target in the presence of an oxygen-containing gas to the thickness at which the desired exchange properties are achieved, typically 200-500Å. A laminated AP-pinned layer **420** is subsequently formed over the AFM layer **430**. AP-pinned layer **420** comprises first and second pinned ferromagnetic layers **425** and **426**, respectively. The first pinned ferromagnectic layer **425** is a composite layer comprising first and second pinned ferromagnetic sub-layers **435** and **422**, respectively. In the preferred embodiment, first sub-layer **435** is a thin layer of Ni-Fe deposited on and in contact with the AFM layer **430** and the second sub-layer **422** is a layer of Co deposited over first sub-layer **435**. The second ferromagnetic layer **426**, also formed of Co, has equal or nearly equal magnetic moment to Co layer **422**.

First and second ferromagnetic pinned layers **425** and **426** are separated from each other by an antiparallel coupling (APC) layer **424** of nonmagnetic material that allows pinned layers **425** and **426** to be strongly coupled together antiferromagnetically. Pinned layers **425** and **426** in the laminated AP-pinned layer structure **420** have their magnetization directions oriented antiparallel, as indicated by the tails of the arrows **421** and **423** and the head of the arrow **427**. The antiparallel alignment of the magnetizations of the pinned layers **425** and **426** is due to an antiferromagnetic exchange coupling through the anti-parallel coupling layer **424**. Because of this antiferromagnetic coupling, and because the two Co films **422** and **426** have substantially the same thickness, the magnetic moments of each of the films nearly cancel each other so that the net magnetic moment in the laminated AP-pinned layer **420** structure is mainly due to the magnetic moment of the Ni-Fe sub-layer **435**, typically in the range of 2 to 30 Å in thickness. The small net magnetic moment of the laminated AP-pinned layer **420** results in an amplification of the exchange field above that which would be present if only layer **422** were used as a single pinned layer pinned by AFM layer **430**.

To complete the SV sensor **400**, a metallic spacer layer **415** is formed on the second pinned layer **426**, a free layer **410** is formed on the spacer layer **415**, and a capping layer **405** is formed

on the free layer **410**. In the absence of an applied field, the free layer **410** has its magnetization axis oriented in the direction shown by arrow **412**, i.e., generally perpendicular to the magnetization axes **421**, **423**, **427** of the pinned layers **435**, **422**, **426**.

Referring again to Fig. **4**, SV sensor **400** further includes hard bias layers **470** and **475**, formed in end regions **404** and **405**, respectively, for longitudinally biasing the free layer **410**. Electrical leads **460**, **465** are also formed over hard bias layers **470** and **475**, respectively to form a circuit path between the SV sensor **400** and a current source **490** and a sensing means **480**. In the preferred embodiment, a magnetic signal in the medium is sensed by the sensing means **480** detecting the change in resistance, deltaR, as the magnetization of the free layer **410** rotates in response to the applied magnetic signal from the recorded medium.

The AP-pinned SV sensor **400** was fabricated in the following manner. The NiO AFM layer **430** of approximately **425** Å thick was deposited on the aluminum oxide substrate layer **450** by ion beam sputtering from a Ni target in the presence of oxygen. No seed layer was used on the aluminum oxide substrate. Next, the laminated AP-pinned layer **420**, spacer **415**, free layer **410** and cap layer **405** were deposited by ion beam sputtering while the sample

was in an applied transverse magnetic field of about 20 Oe. Ni-Fe layer **435** had a thickness of about 10 Å, Cobalt layer **422** had a thickness of about 24 Å, spacer layer **424** had a thickness of about 5 Å, cobalt layer **426** had a thickness of about 24 Å, spacer **415** had a thickness of about 22 Å, free layer **410** had a thickness of about 72 Å and the Ta cap layer **405** had a thickness of about 50 Å.

After all the layers of SV sensor **400** have been deposited, the AFM layer **430** will likely not be in a single antiferromagnetic domain state, and as a result the Ni-Fe/Co/Ru/Co laminated AP-pinned layer **420** may not be in a single ferromagnetic domain state, resulting in reduced magnetoresistance amplitude. Therefore, after all the layers of the SV sensor **400** have been deposited, the SV sensor **400** was heated to above the NiO antiferromagnetic blocking temperature (about 180 deg C) in a field of 15 kOe. This large field is sufficient to rotate the magnetization of the ferromagnetic layers in the AP-pinned layer **420** against the effect of the anti-parallel coupling layer **424**, so that the magnetizations of both pinned ferromagnetic layers **425** and **426** are parallel to the applied magnetic field, and both pinned ferromagnetic layers are in a single domain state. The sample was then cooled with the applied field still present, so that the single domain state of

the NiO/Ni-Fe/Co portion of the laminated AP-pinned layer **420** was maintained. After cooling to room temperature the applied field is removed, and the magnetization of the second pinned ferromagnetic layer **426** rotates to be antiparallel to that of the first pinned ferromagnetic layer **425** due to the influence of the anti-parallel coupling layer **424**. This aligns the direction of the exchange anisotropy and places the laminated AP-pinned layer **420** in an essentially single domain state, yielding the largest magnetoresistance.

Referring again to Fig. **4**, if the thickness of the two ferromagnetic Co layers **422** and **426** are identical, then in theory the net moment of the laminated AP-pinned layer **420** would be the moment of the thin Ni-Fe layer **435**. Without Ni-Fe layer **435**, net moment control would depend on precise control of the Co layers thicknesses and on the stability of the Co layer at the NiO/Co interface which is extremely difficult to control. Introduction of Ni-Fe layer **435** between the NiO AFM layer **430** and the first Co layer **422** dramatically improves control of the magnetic moment of the first Co layer **422**. With this improved structure, moment control of the two Co films **422**, **426** is reduced essentially to thickness control of the Ni-Fe deposited layer. With equal thicknesses of Co layers **422**, **426**, the net moment of the laminated AP-pinned layer **420** is equal to the moment of Ni-Fe

layer **435**. A thin Ni-Fe layer **435** ensures a small, well-controlled net moment which ensures that the magnetization of the laminated AP-pinned layer **420** is stable in the presence of magnetic fields so that the direction of magnetization is predictable.

While the best embodiment of this invention described herein has used equal thicknesses of the two Co layers **422, 426**, it will be obvious to those skilled in the art that other combinations of the thicknesses of Co layer **422** and Ni-Fe layer **435** can result in the same small net moment for the laminated AP-pinned layer structure. If Co layer **422** is made thinner, then Ni-Fe layer **435** must be increased in thickness to achieve the desired net moment, and if Co layer **422** is made thicker a correspondingly thinner Ni-Fe layer **435** is required.

The AP-pinned SV sensors fabricated according to the best embodiment of this invention have significantly improved characteristics and batch-to-batch reproducibility. The pinning field H_p (magnetic field at which the pinned layer begins to rotate) is approximately 1100 Oe ensuring no rotation of the AP-pinned layer under SV sensor operating conditions. The ferromagnetic coupling field between the pinned and free layers is only about 4 Oe indicative of high sensitivity of the free layer to rotate in response to external signal fields. The

magnetoresistive coefficient (deltaR/R) is about 4.3% and the batch-to-batch variation (variation of properties of SV sensors processed in one fabrication run to those processed in a different run) was less than +/-4 percent for more than 20 batches.

Fig. 5 shows an ABS view of an alternate embodiment of an AP-pinned SV sensor **500** having end regions **504** and **506** separated from each other by a central region **502**. SV sensor **500** is similar to SV sensor **400** but wherein the free layer **510** is a multi-layer structure. In the preferred embodiment, the SV sensor **500** has a structure according to the following: Substrate/seed/NiO/Ni-Fe/Co/Ru/Co/Cu/Co/Ni-Fe/Cap. A seed layer **540**, if used, is deposited on a substrate **550**. The NiO AFM layer **530** is deposited on seed layer **540** by ion beam sputtering a Ni target in the presence of an oxygen. The laminated AP-pinned layer **520** is formed on the AFM layer **530**. The first ferromagnetic pinned layer **525** is a composite layer comprising a thin Ni-Fe layer **535** deposited on and in contact with the AFM layer **530** and a Co layer **522** deposited on the Ni-Fe layer **535**. The second ferromagnetic pinned layer **526**, also formed of Co, has a magnetic moment which is equal or nearly equal to the magnetic moment of the Co layer **522**. The two Co layers **522**, **526** are separated by an anti-parallel coupling layer **524** of nonmagnetic

material that allows the pinned layers 525 and 526 to be strongly coupled together antiferromagnetically. A metallic spacer layer 515 is formed on the second ferromagnetic pinned layer 526. In this embodiment, the free layer 510 is a multilayer structure comprising a thin Co layer 514 and a Ni-Fe layer 513. Co layer 514 is formed on and in contact with the spacer layer 515 and Ni-Fe layer 513 is formed on and in contact with the Co layer 514. To complete the SV sensor 500, a capping layer 505 is formed on the Ni-Fe layer 513. In the absence of an applied field, the free layer 510 has its magnetization axis oriented in the direction shown by arrow 512, i.e., generally perpendicular to the magnetization axes 521, 523, 527 of the pinned layers 535, 522, 526.

Referring again to Fig. 5, SV sensor 500 further includes hard bias layers 570 and 575, formed in the end regions 504 and 506, respectively, for longitudinally biasing the free layer 510. Electrical leads 560 and 565 are also formed over hard bias layers 570 and 575, respectively, to form a circuit path between the SV sensor 500 and a current source 590 and a sensing means 580.

In this embodiment, the Co free layer 514 has a thickness of about 16 Å and the Ni-Fe free layer 513 has a thickness of about 29 Å thick. The magnetoresistive coefficient deltaR/R for this

embodiment has a value of 7.5%. The improvement of deltaR/R over that obtained with the preferred embodiment shown in Fig. 4 is due to the better interface properties between the composite free layer 514 and the spacer 515. However, the use of a composite free layer adds to the complexity of the fabrication process for this SV sensor.

Fig. 6 shows an air bearing surface view of a second alternative embodiment of an AP-pinned SV sensor 600 similar to that of Fig. 4 but wherein the free layer 610 is on the bottom (near substrate 650) of the SV sensor and the AP-pinned layer 620, having first and second pinned layers 625 and 626, is formed on the top of the spacer 615. After deposition of free layer 610, spacer layer 615 is deposited followed by Co layer 626, Ru APC layer 624, Co layer 622, and Ni-Fe layer 635. The AFM layer 630 is then deposited on Ni-Fe layer 635 followed by depositing the cap layer 605. The AFM layer 630 is preferably made of NiO material although it may also be made of other anitiferromagnetic material such as NiMN. Hard bias layers 670 and 675 longitudinally bias the free layer 610. Electrical leads 660, 665, formed on the hard bias layers 670 and 675, respectively, are provided to form a circuit path between the SV sensor 600, a current source 690, and a sensing means 680.

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.

CLAIMS

What is claimed is:

1. A spin valve magnetoresistive sensor, comprising:

a free ferromagnetic layer;

an antiparallel (AP)-pinned layer including:

an antiferromagnetically coupling layer;

first and second ferromagnetic layers separated from each other by said antiferromagnetically coupling layer, said first ferromagnetic layer further comprising first and second ferromagnetic sub-layers;

antiferromagnetic (AFM) layer in contact with said first ferromagnetic sub-layer for pinning the magnetizations of said first ferromagnetic layer; and

a spacer layer disposed between said free ferromagnetic layer and said AP-pinned layer.

2. The spin valve magnetoresistive sensor as in claim 1 wherein said second ferromagnetic layer is made of cobalt.

3. The spin valve magnetoresistive sensor as in claim 2 wherein said first sub-layer is made of Ni-Fe and said second sub layer is made of Co.

4. The spin valve magnetoresistive sensor as in claim 3 wherein the Ni-Fe composition of said first sub-layer is approximately 81% Ni and 19% Fe.

5. The spin valve magnetoresistive sensor as in claim 4 wherein the Ni-Fe thickness of said first ferromagnetic sub-layer is in the range of approximately 2-30 Angstroms.

6. The spin valve magnetoresistive sensor as in claim 1 wherein the thickness of first ferromagnetic layer is larger than the thickness of the second ferromagnetic layer.

7. The spin valve magnetoresistive sensor as in claim 1 wherein the thickness of first ferromagnetic layer is smaller than the thickness of the second ferromagnetic layer.

* C L M S *

8. A disk drive system, comprising::

a magnetic recording disk;

a spin valve magnetoresistive sensor for sensing magnetically recorded data on the disk, the spin valve sensor comprising:

a free ferromagnetic layer;

an antiparallel pinned layer including:

an antiferromagnetically coupling layer;

first and second ferromagnetic layers antiferromagnetically coupled to one another by said antiferromagnetically coupling layer, said first ferromagnetic film further comprising first and second sub-layers;

an antiferromagnetic (AFM) layer for pinning the magnetizations of said first and second ferromagnetic sub-layers, said first-sub-layer being in direct contact with said AFM layer; and

a spacer layer disposed between said free ferromagnetic layer and said AP-pinned layer;

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

* C L M S *

means electrically coupled to the spin valve sensor for detecting changes in resistance of the sensor caused by rotation of the magnetization axis of the free ferromagnetic layer relative to the fixed magnetizations of the antiparallel coupled first and second ferromagnetic layers in the laminated antiparallel pinned layer in response to magnetic fields from the magnetically recorded data.

9. The disk drive system of claim 8 wherein said second ferromagnetic layer is made of cobalt.

10. The disk drive system of claim 8 wherein said first sub layer is made of Ni-Fe and said second sub layer is made of Co.

11. The disk drive system of claim 10 wherein the Ni-Fe composition of said first sub-layer is approximately 81% Ni and 19% Fe.

12. The disk drive system of claim 10 wherein the Ni-Fe thickness of said first sub-layer is in the range of approximately 2-30 Angstoms.

13. The spin valve magnetoresistive sensor as in claim 8

* C L M S *

wherein the thickness of first ferromagnetic layer is larger than the thickness of the second ferromagnetic layer.

* C L M S *

14. The spin valve magnetoresistive sensor as in claim 8 wherein the thickness of first ferromagnetic layer is smaller than the thickness of the second ferromagnetic layer.

IMPROVED ANTIPARALLEL-PINNED SPIN VALVE SENSOR

ABSTRACT

An AP-Pinned SV sensor (400) with the preferred structure of NiO/Ni-Fe/Co/Ru/Co/Cu/Ni-Fe/Cap where the pinned layer comprises first and second ferromagnetic pinned layers (425,426) separated from each other by an anti-parallel coupling layer (424). The first ferromagnetic pinned layer (425) further comprises a first pinned sub-layer of Ni-Fe and a second pinned sub-layer of Co where the first pinned sub-layer (435) of Ni-Fe is formed over and in direct contact with the NiO antiferromagnetic (AFM) layer (430). Addition of the first pinned sub-layer (435) of Ni-Fe isolates the second pinned sub-layer (422) of Co from the NiO AFM layer (430) resulting in dramatic improvement in the pinning field and magnetic moment control of the laminated AP-pinned layer (420).

Fig 4

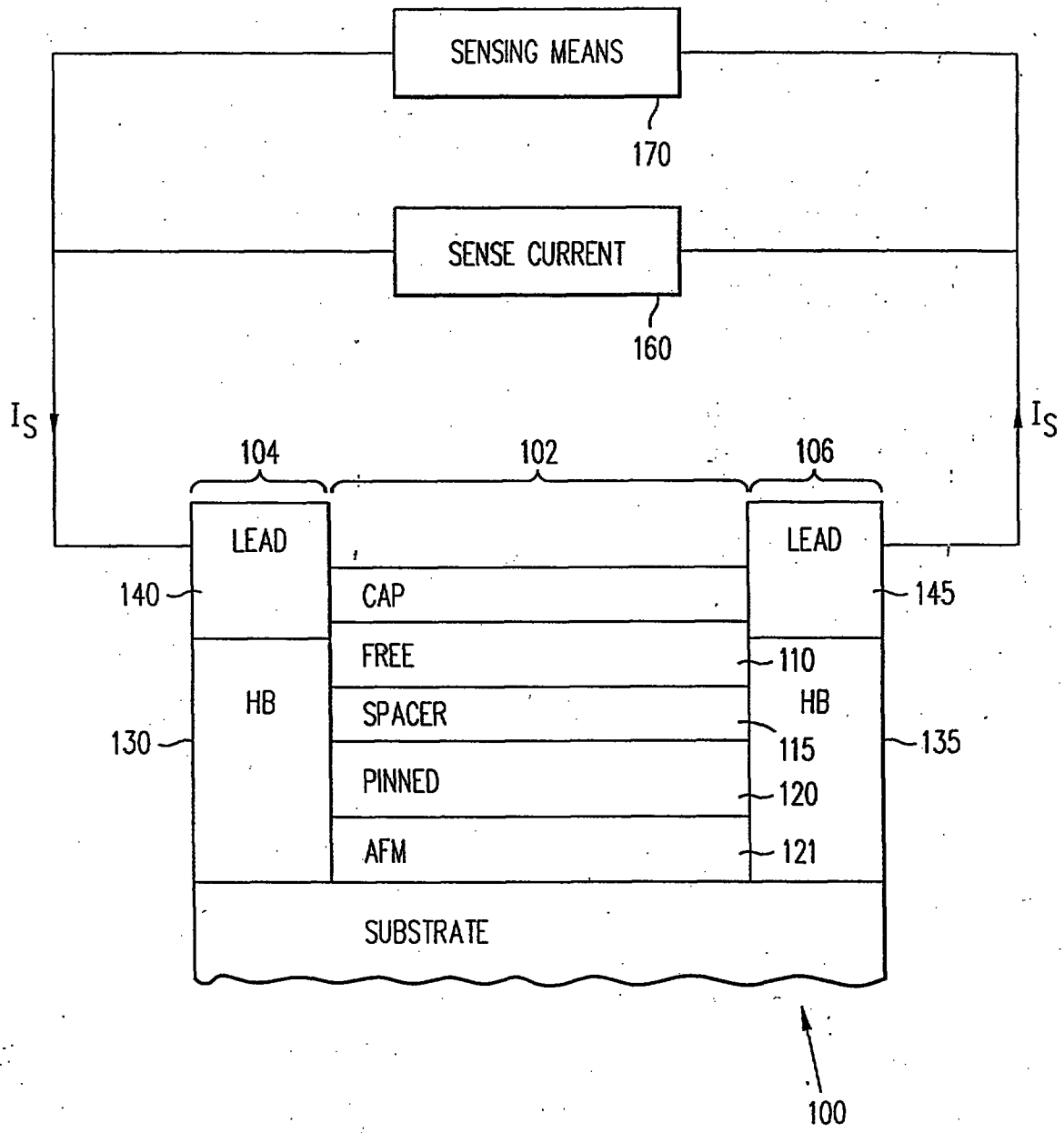


FIG. 1

Prior Art

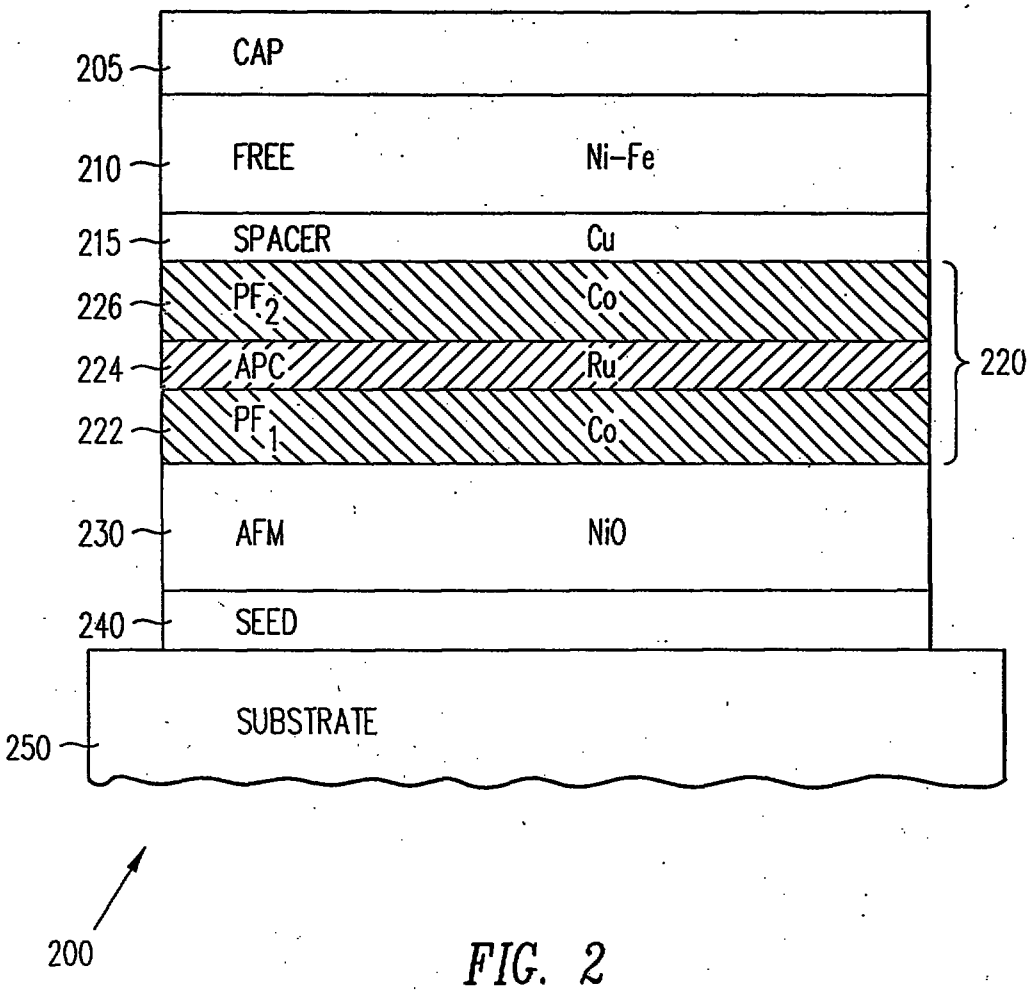

205
CAP
210
FREE
Ni-Fe
215
SPACER
Cu
226
PF2
Co
224
APC
Ru
222
PF1
Co
220
230
AFM
NiO
240
SEED
250
SUBSTRATE
200

FIG. 2

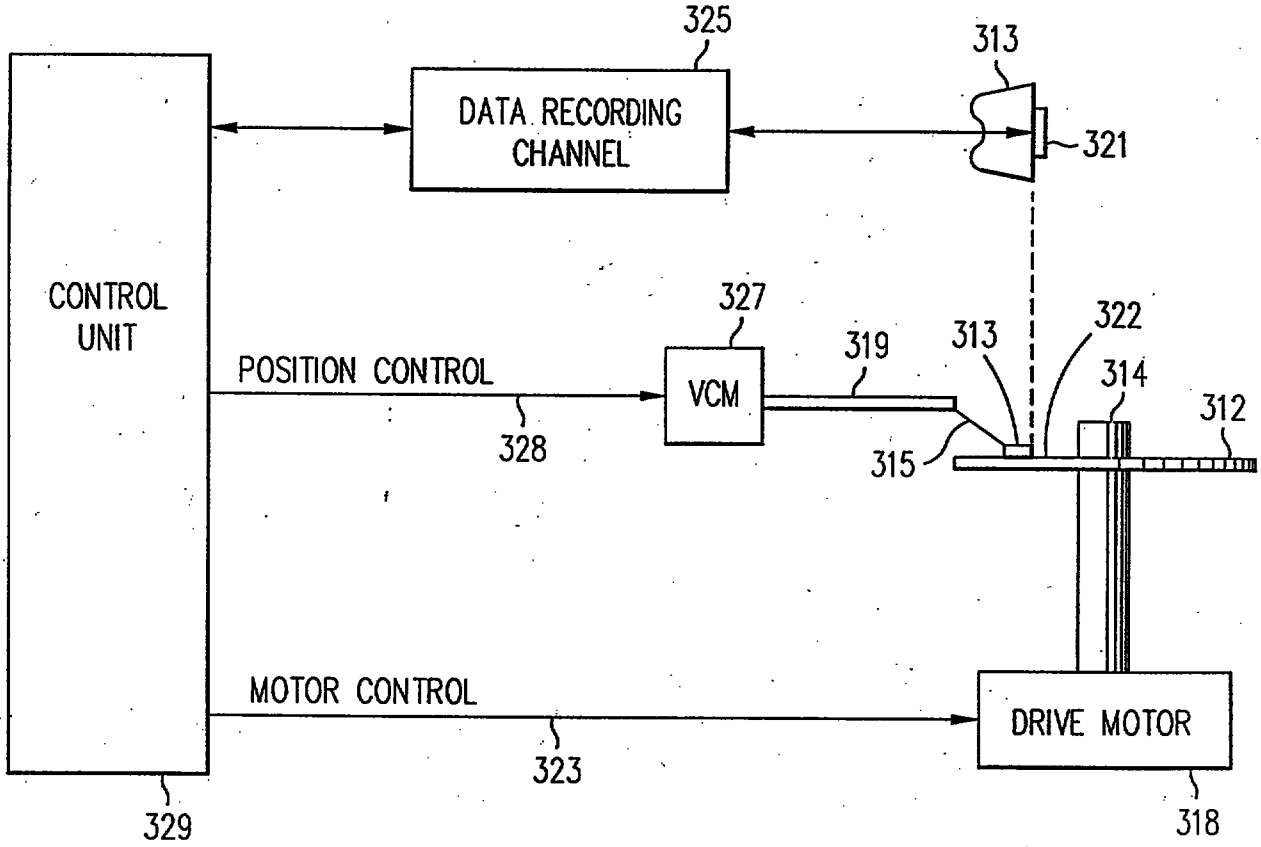

325
313
DATA RECORDING CHANNEL
321
CONTROL UNIT
327
319
313
322
314
312
POSITION CONTROL
VCM
328
315
MOTOR CONTROL
DRIVE MOTOR
323
329
318
300

FIG. 3

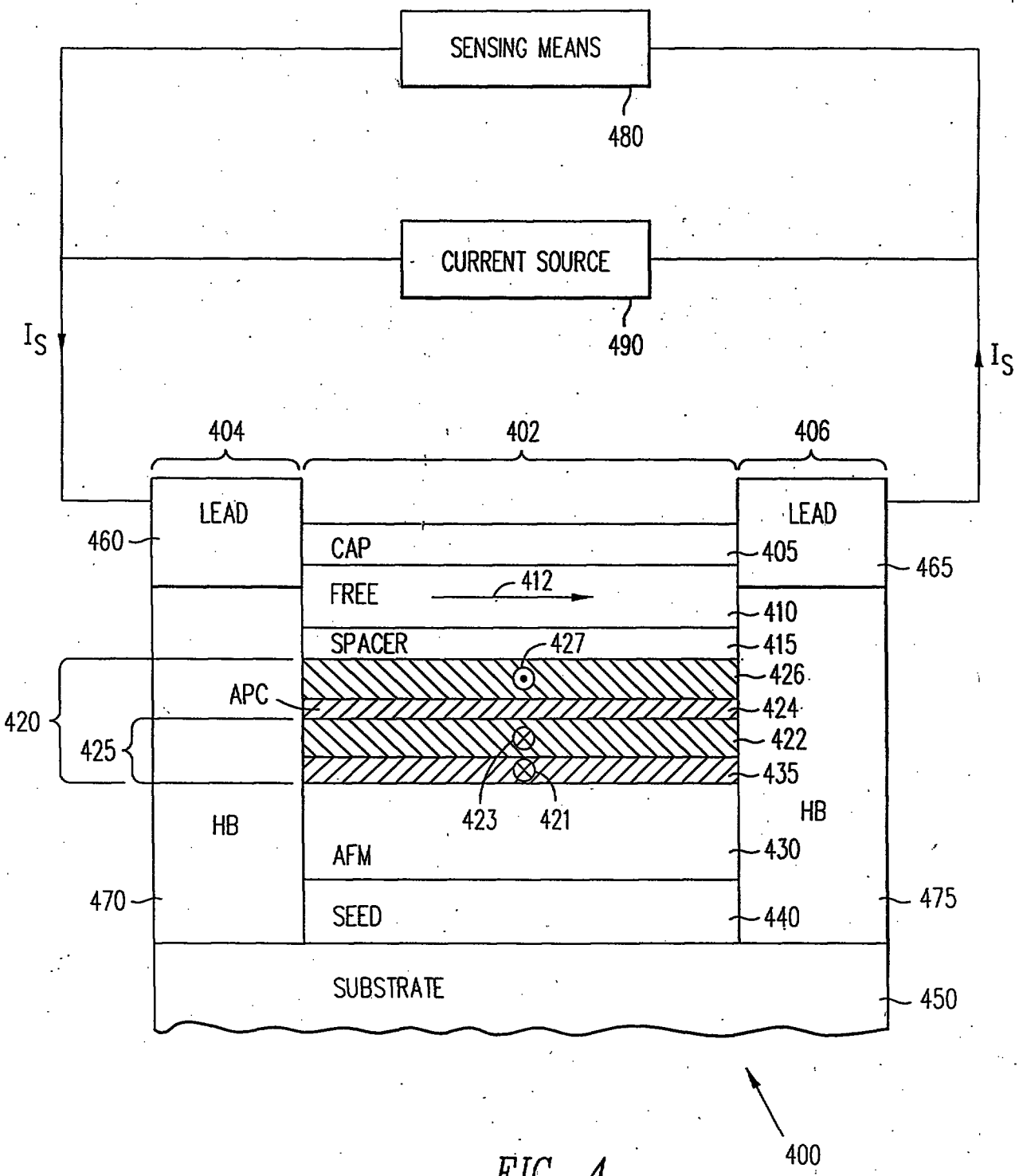

SENSING MEANS
480
CURRENT SOURCE
490
I_S
I_S
404
402
406
LEAD
LEAD
460
CAP
405
465
FREE
412
410
SPACER
427
415
APC
426
424
420
425
422
435
423
421
HB
HB
AFM
430
470
SEED
440
475
SUBSTRATE
450
400

FIG. 4

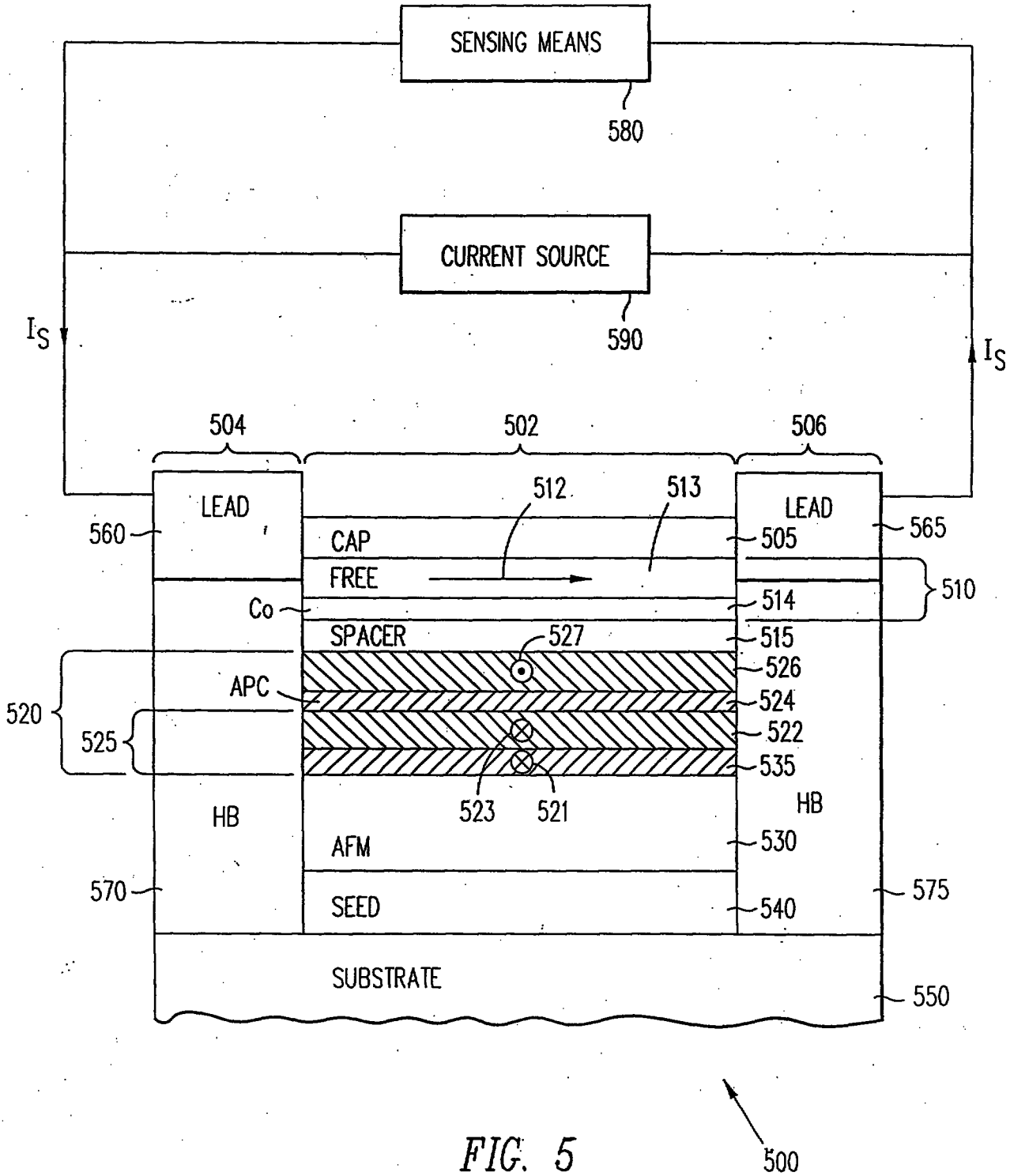

SENSING MEANS
580
CURRENT SOURCE
590
I_S
I_S
504
502
506
LEAD
560
512
513
LEAD
565
CAP
505
FREE
510
Co
514
SPACER
527
515
APC
526
520
524
525
522
535
523
521
HB
HB
AFM
530
570
SEED
540
575
SUBSTRATE
550
500

FIG. 5

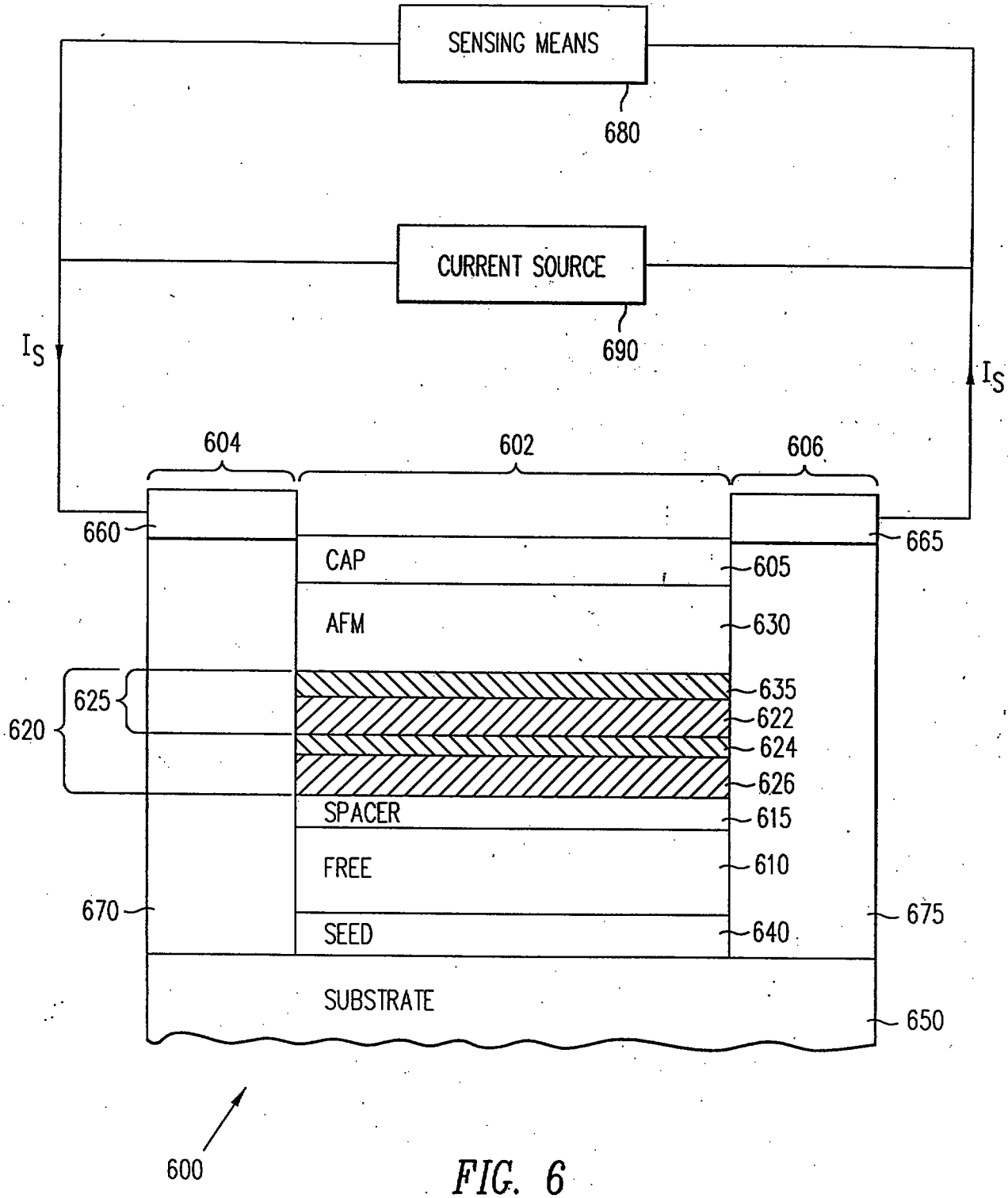

SENSING MEANS
680
CURRENT SOURCE
690
I_S
I_S
604
602
606
660
665
CAP
605
AFM
630
625
620
635
622
624
626
SPACER
615
FREE
610
670
675
SEED
640
SUBSTRATE
650
600

FIG. 6