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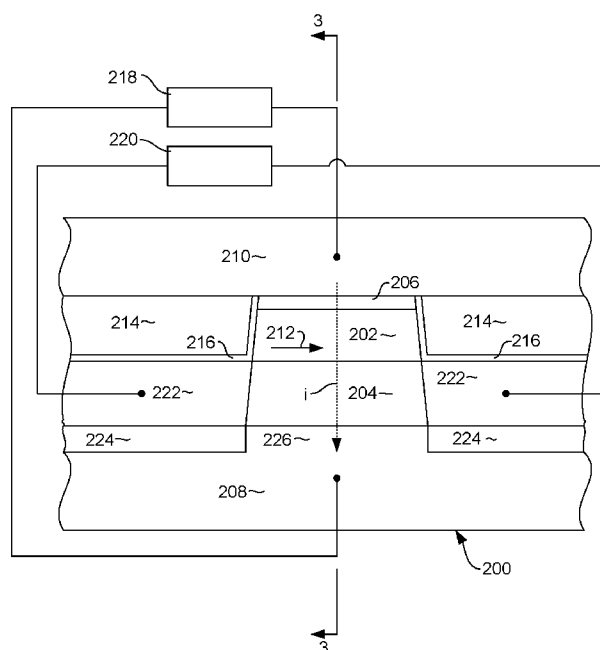


FIG. 2

(57) Abstract: A magnetic sensor that generates a signal based on inverse spin Hall effect. The sensor includes a magnetic free layer and a non-magnetic, electrically conductive spin Hall layer located adjacent to the magnetic free layer. Circuitry is configured to supply an electrical current that travels through the magnetic free layer and the spin Hall layer in a direction that is generally perpendicular to the plane of the layers or perpendicular to a plane defined by an interface between the magnetic free layer and the spin Hall layer. The inverse spin Hall effect causes an electrical voltage in the spin Hall layer as a result of the current, and the voltage changes relative to the orientation of magnetization of the magnetic free layer. Circuitry is provided for measuring the voltage in the spin Hall layer in a direction that is generally perpendicular to the direction of the electrical current.

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MAGNETIC SENSOR USING INVERSE SPIN HALL EFFECT

CROSS REFERENCE TO RELATED APPLICATION

[0001] The present invention claims priority to U.S. Application 15/385595, filed December 20, 2016, incorporated by reference in its entirety.

FIELD OF THE INVENTION

[0002] The present invention relates to magnetic data recording and more particularly to a magnetic read sensor that utilizes inverse spin Hall effect to detect the presence of a magnetic field.

BACKGROUND

[0003] At the heart of many computer systems is an assembly that is referred to as a magnetic disk drive. The magnetic disk drive includes a rotating magnetic disk, write and read heads that are suspended by a suspension arm adjacent to a surface of the rotating magnetic disk and an actuator that swings the suspension arm to place the read and write heads over selected tracks on the rotating disk. The read and write heads are directly located on a slider that has an air bearing surface (ABS). The suspension arm biases the slider into contact with the surface of the disk when the disk is not rotating, but when the disk rotates air is swirled by the rotating disk. When the slider rides on the air bearing, the write and read heads are employed for writing magnetic impressions to and reading magnetic impressions from the rotating disk. The read and write heads are connected to processing circuitry that operates according to a computer program to implement the reading and writing functions.

[0004] The write head includes at least one coil, a write pole and one or more return poles. When current flows through the coil, a resulting magnetic field causes a magnetic flux to flow through the write pole, which results in a magnetic write field emitting from the tip of the write pole. This magnetic field is sufficiently strong that it locally magnetizes a portion of the adjacent magnetic media, thereby recording a bit

of data. The write field then travels through a magnetically soft under-layer of the magnetic medium to return to the return pole of the write head.

[0005] Magnetoresistive sensors such as a Giant Magnetoresistive (GMR) sensors, Tunnel Junction Magnetoresistive (TMR) sensors or a scissor type magnetoresistive sensors have been employed to read a magnetic signal from the magnetic media. Such a magnetoresistive sensor has an electrical resistance that changes in response to an external magnetic field. This change in electrical resistance can be detected by processing circuitry in order to read magnetic data from the magnetic media. The sensor is located between first and second magnetic shields and the spacing between the shields effects data density. A smaller spacing between the shields results in an increase in data density by increasing the number of bits that can be recorded and detected on a given length of data track.

Summary

[0006] One embodiment of the present invention provides a magnetic sensor that includes a magnetic free layer and a spin Hall layer formed of an electrically conductive, non-magnetic material formed adjacent to the magnetic free layer. Circuitry is provided that is configured to cause an electrical current to flow through the magnetic free layer and spin Hall layer in a direction that is perpendicular to the plane of the layers. Circuitry is also provided for measuring a voltage across the spin Hall layer along the plane of the spin Hall layer and in a direction that is substantially perpendicular to the direction of the electrical current.

[0007] An embodiment of the invention can include a magnetic free layer, a non-magnetic, electrically conductive layer formed adjacent to the magnetic free layer and means for generating a voltage in the non-magnetic layer as a result of inverse spin Hall effect, with the voltage being affected by the direction of magnetization of the magnetic free layer. This can be provided by the circuitry described above, which provides a means for causing a current to flow through the magnetic free layer in a direction that is perpendicular to a plane defined by the magnetic free layer.

[0008] The electrical current flowing through the magnetic free layer becomes spin polarized and will inject a spin current into the spin Hall layer in a lateral direction due to spin-accumulation. The spin current will generate a charge current and hence an electrical voltage difference in the spin Hall layer as a result of inverse spin Hall effect. This voltage varies depending upon the spin polarization of spin current which is the same as the orientation of the magnetization of the magnetic free layer. Therefore, because the magnetization of the magnetic free layer can change in response to an external magnetic field, the external magnetic field can be detected by measuring this voltage across the spin Hall layer.

[0009] The spin Hall layer can be formed of a heavy metal with strong spin-orbital coupling and larger spin Hall efficiency. The spin Hall layer can be formed of one or more of Ta, W, Pt, Hf and Bi.

[0010] While the magnetic free layer can extend from the media facing surface to a first distance that defines a stripe height, the spin Hall layer can extend further to a second distance that is longer than the first distance. For example, the spin Hall layer can extend past the first distance to a second distance, and the difference between the first and second distances can be about equal to the spin diffusion length of the material of the spin diffusion layer. For example, the difference between the first and second distances can be equal to the spin diffusion length of the material of the spin diffusion layer plus or minus 10%.

[0011] The voltage can be measured across the spin Hall layer at a location that is just beyond the stripe height defined by the magnetic free layer. Alternatively, the voltage can be measured at a location that is adjacent to the magnetic free layer at a location that is between the media facing surface and the stripe height defined by the magnetic free layer.

[0012] The spin Hall layer can be in direct contact with the magnetic free layer thereby defining an interface between the spin diffusion layer and the magnetic free layer. The spin diffusion layer can have a thickness as measured perpendicular to the interface that is about equal to the spin diffusion length of the spin Hall layer or that is equal to the spin diffusion length plus or minus 10%.

[0013] The magnetic free layer can be a magnetic layer with a thickness that is greater than the spin-diffusion length of magnetic free layer. A material of high spin-polarization and shorter spin diffusion is preferred, such as a Heusler based alloy. The free layer can also be a structure that includes first and second magnetic layers that are anti-parallel coupled across a non-magnetic layer such as Ru located between the magnetic layers. Alternatively, the magnetic free layer can be a first magnetic layer located at a first side of the spin Hall layer and a second magnetic free layer can be located at an opposite side of the spin Hall layer.

[0014] Such a magnetic sensor greatly reduces gap thickness by eliminating the need for a magnetic pinned layer or for a pinning layer such as an antiferromagnetic (AFM) layer, and even eliminates the need for a non-magnetic spacer or barrier layer. In addition, the sensor advantageously makes the electrical current (used to cause the inverse spin Hall effect) independent of the voltage measured across the spin Hall layer. This allows both the current and the voltage to be optimized as needed independently of one another.

[0015] These and other features and advantages of the invention will be apparent upon reading of the following detailed description of the embodiments taken in conjunction with the figures in which like reference numeral indicate like elements throughout.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] For a fuller understanding of the nature and advantages of this 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 which are not to scale.

[0017] FIG. 1 is a schematic illustration of a disk drive system in which the invention might be embodied;

[0018] FIG. 2 is a view of a magnetic sensor according to one embodiment as viewed from a media facing surface;

[0019] FIG. 3 is a side, cross sectional view of the sensor of FIG. 2 as taken from line 3-3 of Fig. 2;

[0020] FIG. 4 is a top down sectional view of a magnetic sensor according to one possible embodiment as seen from line 4-4 of Fig. 3;

[0021] FIG. 5 is a side, cross sectional view of a magnetic sensor according to another possible embodiment;

[0022] FIG. 6 is a top down sectional view of the sensor of FIG. 5 as seen from line 6-6 of FIG. 5;

[0023] FIG. 7 is a view of a magnetic sensor according to another embodiment as viewed from a media facing surface; and

[0024] FIG. 8 is a view of a magnetic sensor according to another embodiment as viewed from the media facing surface.

DETAILED DESCRIPTION

[0025] The following description is of the best embodiments presently contemplated for carrying out this invention. This description is made for the purpose of illustrating the general principles of this invention and is not meant to limit the inventive concepts claimed herein.

[0026] Referring now to FIG. 1, there is shown a disk drive / data storage system 100. The disk drive 100 includes a housing 101. At least one rotatable magnetic disk 112 is supported on a spindle 114 and rotated by a disk drive motor 118. The magnetic recording on each disk may be in the form of annular patterns of concentric data tracks (not shown) on the magnetic disk 112.

[0027] At least one slider **113** is positioned near the magnetic disk **112**, each slider **113** supporting one or more magnetic head assemblies **121**. As the magnetic disk rotates, slider **113** moves in and out over the disk surface **122** so that the magnetic head assembly **121** can access different tracks of the magnetic disk where desired data are written. Each slider **113** is attached to an actuator arm **119** by way of a suspension **115**. The suspension **115** provides a slight spring force which biases the slider **113** against the disk surface **122**. Each actuator arm **119** is attached to an actuator means **127**. The actuator means **127** as shown in Fig. **1** 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 the control unit **129**.

[0028] During operation of the disk storage system, the rotation of the magnetic disk **112** generates an air bearing between the slider **113** and the disk surface **122**, which exerts an upward force or lift on the slider. The air bearing thus counter-balances the slight spring force of the suspension **115** and supports the slider **113** off and slightly above the disk surface by a small, substantially constant spacing during normal operation.

[0029] The various components of the disk storage system are controlled in operation by control signals generated by control unit **129**, such as access control signals and internal clock signals. Typically, the control unit **129** comprises logic control circuits, and a microprocessor. The control unit **129** generates control signals to control various system operations such as drive motor control signals on line **123** and head position and seek control signals on line **128**. The control signals on line **128** provide the desired current profiles to optimally move and position the slider **113** to the desired data track on the media **112**. Write and read signals are communicated to and from write and read heads **121** by way of recording channel **125**.

[0030] Fig. **2** shows a magnetic sensor **200** according to one possible embodiment as viewed from a media facing surface. The sensor can include a magnetic free layer **202** and a non-magnetic spin Hall layer **204** formed adjacent to the magnetic free layer **202**. A capping layer **206** can be formed over the magnetic free layer **202**. The magnetic free layer **202**, spin Hall layer **204** and capping layer **206** can be located

between first and second magnetic shields **208**, **210**. The distance between the magnetic shields **208**, **210** defines the gap spacing. In order to maximize data density it is desirable to make the gap spacing as small as possible. This is because a smaller gap spacing allows the sensor to read a magnetic signal with small bit length along data tracks, thereby allowing the sensor to read more bits per inch of data track.

[0031] The magnetic free layer **202** can be constructed of a magnetic material such as one or more layers of Co-Fe, Co-Fe-B or a Heusler alloy. The thickness of magnetic free layer is preferably thicker than spin diffusion length of free layer in order to fully polarize current and increase spin current injection into spin Hall layer **204**. The spin Hall layer **204** can be constructed of a non-magnetic metal, which preferably has a large spin-orbital coupling. The spin diffusion layer **204** is preferably constructed of a heavy metal such as Ta, W, Pt, Hf, Bi or alloys thereof. The capping layer **206** can be formed of a material such as Ta and or Ru or Rh.

[0032] The magnetic free layer **202** has a magnetization that is generally oriented in a direction parallel with the media facing surface as indicated by arrow **212**, but which is free to move its orientation in response to an external magnetic field. Biasing for the free layer can be provided by permanent magnetic bias layers **214** that can be located at either side of the magnetic free layer **202** and that can be electrically separated from top shield layer **210** or by similarly located soft magnetic side shields which can be directly in contact with the top shield layer **210**. Each of the magnetic bias layers **214** can be separated from the magnetic free layer **202** and from the spin Hall layer **204** by a non-magnetic, electrically insulating layer **216**. Other biasing mechanisms are also possible, such as back edge bias structures, in plane bias structures, etc.

[0033] With continued reference to Fig. 2, circuitry **218** can be provided to supply an electrical current **i** through the sensor that is oriented in a direction that is perpendicular to the planes of the layers **204**, **202**, **206**. In other words, the circuitry applies the current **i** in a direction that is generally parallel with the direction of a data track to be read by the sensor. The circuitry **218** provides one example of a means for generating a voltage in the spin hall layer **204** as a result of inverse spin Hall effect, as will be explained in greater detail herein below.

[0034] Because of the magnetization of the free layer **202**, electrons traveling through the magnetic free layer **202** will become spin polarized. The orientation of spin polarization will be affected by the direction of the magnetization of the magnetic free layer **202**. Therefore, as the magnetization of the magnetic free layer **202** changes in response to a magnetic field, the orientation of the spin polarization will change as well.

[0035] When these spin polarized electrons travel through the interface between the free-layer **202** and the spin Hall layer **204**, due to spin accumulation at the interface, there will be a spin current induced and injected in to the spin Hall layer **204** as a result of spin accumulation at the interface between the free layer **202** and the spin Hall layer **204**. Such a spin current can generate a voltage inside spin Hall layer **204** as a result of inverse spin Hall effect. This voltage will be oriented parallel to the plane defined by the interface between the spin Hall layer **204** and the magnetic free layer **202**. This voltage can be oriented in a direction that is perpendicular to the direction of flow of the current i from top to the bottom or vice versa in Fig. 2 and also perpendicular to the spin polarization direction of magnetic free layer.

[0036] Circuitry **220** can be provided for measuring this voltage. The voltage generated by the Inverse Spin Hall Effect will change based on the relative orientation of the magnetization **212** of the magnetic free layer **202** across the track width direction. By detecting a change in the voltage, the circuitry **220** can, thereby, detect the presence of an external magnetic field such as from an adjacent magnetic media. The circuitry **220** can be connected with leads **222** formed at either side of the spin Hall layer **204**. The leads **222**, which will be discussed in greater detail herein below, can be integral with the spin Hall layer **204** (being formed of the same material and even in the same patterning process) or could also be separate structures formed of an electrically conductive material that is different from the material of the spin Hall layer **204**.

[0037] As shown in Fig. 2, electrically insulating layers **224** can be provided between the leads **222** and the adjacent shield **208**, leaving the shield **208** electrically connected with the spin Hall layer **204** in the sensor area so as to prevent the current i from being shunted from the leads **222** to the shield **208**. This can be accomplished

by forming an upwardly extending, electrically conductive portion **226** at the top of the shield **208** between the electrically insulating layers **224**. This portion **226** can be formed of the shield material **208**, or can be a separately formed feature and can be self aligned with the layer **204** in a common masking and ion milling process.

[0038] Fig. **3** is a side cross-sectional view as seen from line **3-3** of Fig. **2**, and Fig. **4** is a top-down sectional view as seen from line **4-4** of Fig. **3**. With reference to Fig. **3**, it can be seen that the magnetic free layer **202** extends from the media facing surface **MFS** to a distance **SH**, which defines the stripe height of the sensor. On the other hand, the spin Hall layer **204** can extend further from the media facing surface to a second distance **LSHL**. Preferably, the distance between **LSHL** and **SH** is about equal to the spin diffusion length of the material of the spin Hall layer **204**. For example, the spin Hall layer **204** can extend beyond the stripe height distance **SH** by a distance that is equal to the spin diffusion length of the spin Hall layer **204** plus or minus 10%. The voltage measurement (designated by dot **V** in Fig. **3**) can be measured across the spin Hall layer at a location that is at a distance **LV** as measured from the media facing surface **MFS**. The distance **LV** can be slightly larger than the stripe height **SH**, so that the voltage can be measured at a location that is just slightly beyond the back edge of the magnetic free layer **202**.

[0039] This can be seen more clearly with reference to Fig. **4**, which shows a top down sectional view of the magnetic free layer **202** and the spin Hall layer **204**. In Fig. **4** it can be seen that the leads **222** can be formed at either side of the spin Hall layer **204** and can be located at a location that is just beyond the back edge of the magnetic free layer **202**. As discussed above, the leads **222** can be formed of the same material as the spin Hall layer **204** and can be formed in the same patterning step as the spin Hall layer. Or, alternatively, the leads **222** can be formed of a different electrically conductive material such as Cu or Au. At or near the end of each of the leads **222**, vias **302** can be formed to allow electrical connection between the circuitry **220** and the leads **222**. The space beyond the back of the free layer **202** and spin Hall layer **204** can be filled with an electrically insulating fill layer such as alumina, MgO, SiN or Ta₂O₅ **304**.

[0040] Placing the electrical leads **222** slightly behind the back edge of the magnetic free layers facilitates electrical connection with the leads **222** while avoiding interference with the magnetic bias structures **214** (Fig. 2). However, moving the leads **222** further from the magnetic free layer **202** decreases performance of the sensor **200**. The further the leads **222** are from the free layer **202**, the more the performance of the sensor will suffer. In one embodiment, we can put the electrical leads **222** directly underneath magnetic free layer **202** as will be described further herein below. It should also be pointed out that, while Figs. 2, 3 and 4 show the magnetic free layer **202** being above the spin Hall layer **204**, this by way of example. The magnetic free layer **202** could also be beneath the spin Hall layer **204**.

[0041] The space between the magnetic shields **208**, **210** defines the read gap, and reducing the read gap is desirable for increasing data density along data track in a magnetic data recording system. The above described magnetic sensor **200** greatly decreases the read gap by eliminating the need for a magnetic pinned layer and also eliminating the need for a pinning structure such as a layer of antiferromagnetic material (AFM layer) and also eliminating the need for a spacer or barrier layer between such a free layer and pinned layer structure. In more traditional magnetic sensor designs, the pinned layer is pinned by a layer of antiferromagnetic material and this layer must be significantly thick to perform its function as a pinning mechanism. Therefore, in a traditional magnetic sensor these layers (pinning layer, pinned layer and spacer or barrier layer) require a great deal of thickness to function properly and, therefore, greatly limit the amount by which the read gap can be reduced. The sensor **200** described above provides a novel approach for generating a magnetic signal, which allows for greatly reduced gap spacing as compared with other more conventional sensors such as giant magnetoresistive sensors or tunnel junction sensors, both of which require thick pinned magnetic layer structures, magnetic pinning structures (such as a thick antiferromagnetic layer) and spacer or barrier layer structures.

[0042] With reference to Figs. 5 and 6, in a sensor **500** according to another possible embodiment, the voltage can be measured at a location (designated as **V** in Fig. 5) that is directly in the region of the magnetic free layer **202**. This can be

accomplished by locating the leads **222** in a region that is between the media facing surface **MFS** and the stripe height **SH** as shown. In this case, **LV** can be smaller than or equal to **SH**. This configuration may maximize the performance of the sensor so long as care is taken not to interfere with the presence of the magnetic bias layers **214** and insulation layer **216** (Fig. 2). For example an in stack bias structure (not shown) could be used to bias the magnetic free layer **202**, or a back edge bias structure (also not shown) could be used to bias the magnetic free layer **202**. Again, it should be pointed out that, while the magnetic free layer **202** is shown as being above the spin Hall layer **204** in Figs. 5 and 6, this is by way of example only. The magnetic free layer **202** could also be beneath the spin Hall layer **204**.

[0043] Fig. 7 shows a view of a magnetic sensor according to another possible embodiment. The sensor **700** includes an anti-parallel coupled free layer structure **702** that includes first and second magnetic layers **704**, **706** that are anti-parallel coupled with one another by a thin, non-magnetic antiparallel coupling layer such as Ru **708** located between the magnetic layers **704**, **706**. The thickness of the anti-parallel coupling layer **708** is chosen so as to cause the magnetizations of the first and second magnetic layers **704**, **706** to orient themselves in directions that are generally opposite (anti-parallel) to one another. This sensor functions as a differential sensor to detect magnetic fields in the bit transition region, and as with the previously described embodiment the response is via in plane voltage induced from Inverse Spin Hall Effect. As with the above described embodiments, the magnetic layers **704**, **706** could be constructed of various magnetic materials such as one or more of Co-Fe, Ni-Fe and/or a Heusler alloy. Again it should be pointed out that, while the magnetic free layer structure **702** is shown being above the spin Hall layer, this is by way of example. The magnetic free layer structure **702** could also be beneath the spin Hall layer **204**.

[0044] Fig. 8 shows a magnetic sensor **800** according to yet another possible embodiment. The sensor **800** can have first and second magnetic free layer structures **802**, **804** located at opposite sides of the spin Hall layer **204**. In other words, the spin Hall layer **204** can be located directly between the first and second magnetic free layers **802**, **804**. This results in a first interface **803** between the free layer **802** and

the spin Hall layer **204** and a second interface **805** between the second magnetic free layer **804** and the spin Hall layer **204**. This configuration essentially doubles the spin current and therefore doubles output voltage. However, as can be seen, increase in signal output may come at a cost of increasing the read gap as a result of the space occupied by the second magnetic free layer. Each of the magnetic free layers **802**, **804** can be biased by magnetic bias structure **214**. The biasing provided by the bias structures **214** can be such that the magnetic free layers **802**, **804** have their magnetizations biased in opposite directions parallel with the media facing surface as indicated by arrows **806**, **808**. This will cause the direct spin injection into spin Hall layer through transmission at first interface **803** and reflection at second interface **805** to have the same direction of polarizations for maximum signal output. Again, the magnetic free layers **802**, **804** can be constructed of one or more magnetic materials such as one or more of Co-Fe, Ni-Fe or a Heusler alloy.

[0045] As can be seen, all of the above described embodiments provide the ability to greatly reduce read gap thickness and thereby improve resolution by eliminating the need for a pinned layer structure, pinning structure such as a layer of antiferromagnetic material, and spacer or barrier layer. In addition, a reader sensor based on the inverse spin Hall effect such as described above with regard to the various possible embodiments provides an additional advantage in that the current used to generate the inverse spin Hall effect is perpendicular to the voltage used to read the signal. By contrast, in a more conventional sensor such as a tunnel junction sensor, a sense current is supplied through the sensor layers, for example between the upper and lower shields, and the voltage is measured across the same path between the shields. By contrast, in sensors such as those described above, the current and voltage are along different paths, independent of one another. The voltage can then be measured independently of the current in a direction that is not affected by this current.

[0046] While various embodiments have been described above, it should be understood that they have been presented by way of example only and not limitation. Other embodiments falling within the scope of the invention may also become apparent to those skilled in the art. Thus, the breadth and scope of the inventions

should not be limited by any of the above-described exemplary embodiments, but should be defined only in accordance with the following claims and their equivalents.

What is claimed is:

1. A magnetic sensor, comprising:

a magnetic free layer;

a spin Hall layer formed of an electrically conductive, non-magnetic material formed adjacent to the magnetic free layer;

circuitry configured to cause an electrical current to flow through the magnetic free layer and the spin Hall layer in a direction that is perpendicular to the plane of the layers; and

circuitry for measuring a voltage across the spin Hall layer in a direction that is substantially perpendicular to the direction of the electrical current.
2. The magnetic sensor as in claim 1, wherein the electrical current flowing through the magnetic free layer and the spin Hall layer results in an electrical voltage in the spin Hall layer as a result of inverse spin Hall effect.
3. The magnetic sensor as in claim 1, wherein the spin Hall layer is constructed of a heavy metal.
4. The magnetic sensor as in claim 1, wherein the spin Hall layer comprises one or more of: Ta, W, Pt, Hf and Bi.
5. The magnetic sensor as in claim 1, wherein the magnetic free layer extends from a media facing surface to a first distance that defines a stripe height, and the spin Hall layer extends from the media facing surface to a second distance that is greater than the first distance.

6. The magnetic sensor as in claim 5, wherein the spin Hall layer is formed of a material having a spin diffusion length, and wherein the difference between the first and second distances is substantially equal to the spin diffusion length of spin Hall layer.
7. The magnetic sensor as in claim 5, wherein the spin Hall layer is formed of a material having a spin diffusion length and wherein the difference between the first and second distances is equal to the spin diffusion length plus or minus 10%.
8. The magnetic sensor as in claim 1, wherein the spin Hall layer is in direct contact with the magnetic free layer.
9. The magnetic sensor as in claim 1, wherein:

the spin Hall layer is in direct contact with the magnetic free layer, defining an interface between the spin Hall layer and the magnetic free layer;

the spin Hall layer comprises a material having a spin diffusion length; and

the spin Hall layer has a thickness measured perpendicular to the interface that is substantially equal to the spin diffusion length.
10. The magnetic sensor as in claim 1, wherein:

the spin Hall layer is in direct contact with the magnetic free layer, defining an interface between the spin Hall layer and the magnetic free layer;

the spin Hall layer comprises a material having a spin diffusion length; and

the spin Hall layer has a thickness measured perpendicular to the interface that is equal to the spin diffusion length plus or minus 10%.

11. The magnetic sensor as in claim 5, wherein the voltage is measured in a region beyond the stripe height.
12. The magnetic sensor as in claim 5, wherein the voltage is measured in a region that is just slightly beyond the stripe height.
13. The magnetic sensor as in claim 5, wherein the voltage is measured in a region that is between the media facing surface and the stripe height.
14. The magnetic sensor as in claim 1, wherein the magnetic free layer is a single magnetic layer.
15. The magnetic sensor as in claim 1, wherein the magnetic free layer is a structure that includes first and second magnetic layers that are antiparallel coupled by a non-magnetic layer located between the first and second magnetic layers.
16. The magnetic sensor as in claim 1, wherein the magnetic free layer is a first magnetic free layer located at a first side of the spin Hall layer, the sensor

further comprising a second magnetic free layer located at a second side of the spin Hall layer that is opposite to the first side of the spin Hall layer.

17. The magnetic sensor as in claim 1, wherein the spin Hall layer comprises a material having a strong spin orbit coupling effect.
18. A magnetic data recording system, comprising:
 - a housing;
 - a magnetic media mounted within the housing;
 - an actuator;
 - a slider connected with the actuator for movement adjacent to the magnetic media; and
 - a magnetic sensor formed on the slider, the magnetic sensor comprising a magnetic free layer, and a spin Hall layer formed of an electrically conductive, non-magnetic material formed adjacent to the magnetic free layer;
 - circuitry configured to cause an electrical current to flow through the magnetic free layer and the spin Hall layer in a direction that is perpendicular to the plane of the layers; and
 - circuitry for measuring a voltage across the spin Hall layer in a direction that is substantially perpendicular to the direction of the electrical current.
19. The magnetic data recording system as in claim 18, wherein the electrical current flowing through the magnetic free layer and the spin Hall layer results

in an electrical voltage in the spin Hall layer as a result of inverse spin Hall effect.

20. The magnetic data recording system as in claim 18, wherein the spin Hall layer comprises one or more of: Ta, W, Pt, Hf and Bi.
21. A magnetic sensor, comprising:

a magnetic free layer;

a non-magnetic, electrically conductive layer formed adjacent to magnetic free layer; and

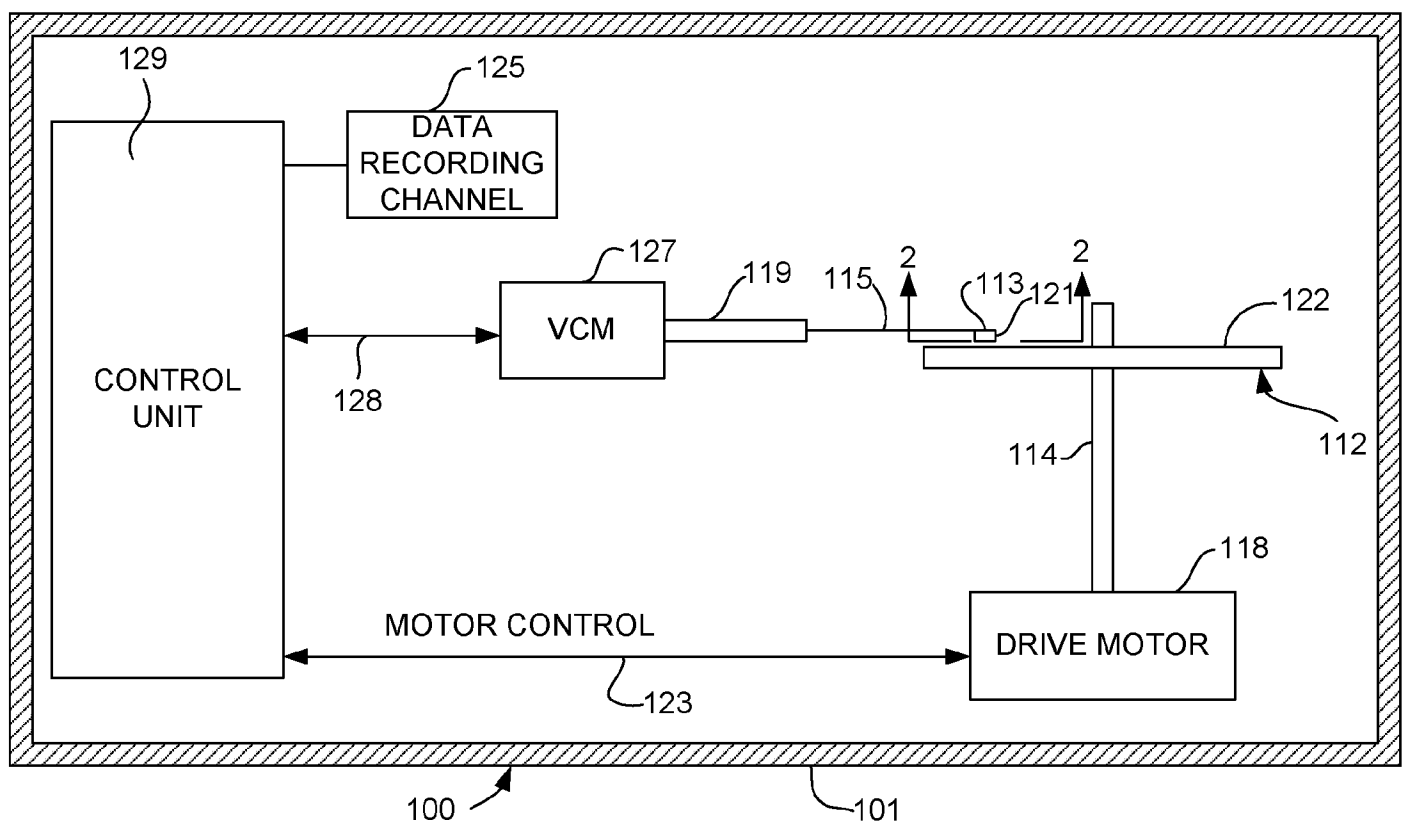
means for generating a voltage in the non-magnetic layer as a result of inverse spin Hall effect, the voltage being effected by a direction magnetization of the magnetic free layer.
22. The magnetic sensor as in claim 21, further comprising means for causing a current to flow through the magnetic free layer in a direction that is perpendicular to a plane defined by the magnetic free layer.
23. The magnetic sensor as in claim 22, further comprising means for detecting the electrical voltage in the non-magnetic, electrically conductive layer.
24. The magnetic sensor as in claim 22, wherein the voltage is measured in a direction that is perpendicular to the direction of current flow.

25. The magnetic sensor as in claim 21, wherein the non-magnetic, electrically conductive layer is a heavy metal.
26. The magnetic sensor as in claim 21, wherein the non-magnetic, electrically conductive layer comprises one or more of Ta, W, Pt, Hf and Bi.
27. The magnetic sensor as in claim 21, wherein the magnetic free layer extends from a media facing surface to a first distance and the non-magnetic, electrically conductive layer extends from the media facing surface to a second distance that is greater than the first distance.
28. The magnetic sensor as in claim 27, wherein the non-magnetic, electrically conductive layer has a spin diffusion length and wherein the second distance is greater than the second distance by an amount that is about equal to the spin diffusion length of the non-magnetic, electrically conductive layer.
29. The magnetic sensor as in claim 27, wherein the non-magnetic, electrically conductive layer has a spin diffusion length and wherein the second distance is greater than the second distance by an amount that is equal to the spin diffusion length of the non-magnetic, electrically conductive layer plus or minus 10%.
30. The magnetic sensor as in claim 21, wherein

the magnetic free layer is in contact with the non-magnetic, electrically conductive layer thereby defining an interface between the magnetic free layer and the non-magnetic, electrically conductive layer;

the non-magnetic, electrically conductive layer comprises a material having a spin diffusion length; and

the non-magnetic, electrically conductive layer has a thickness measured perpendicular to the interface that is equal to the spin diffusion length of the non-magnetic, electrically conductive layer plus or minus 10%.

**FIG. 1**

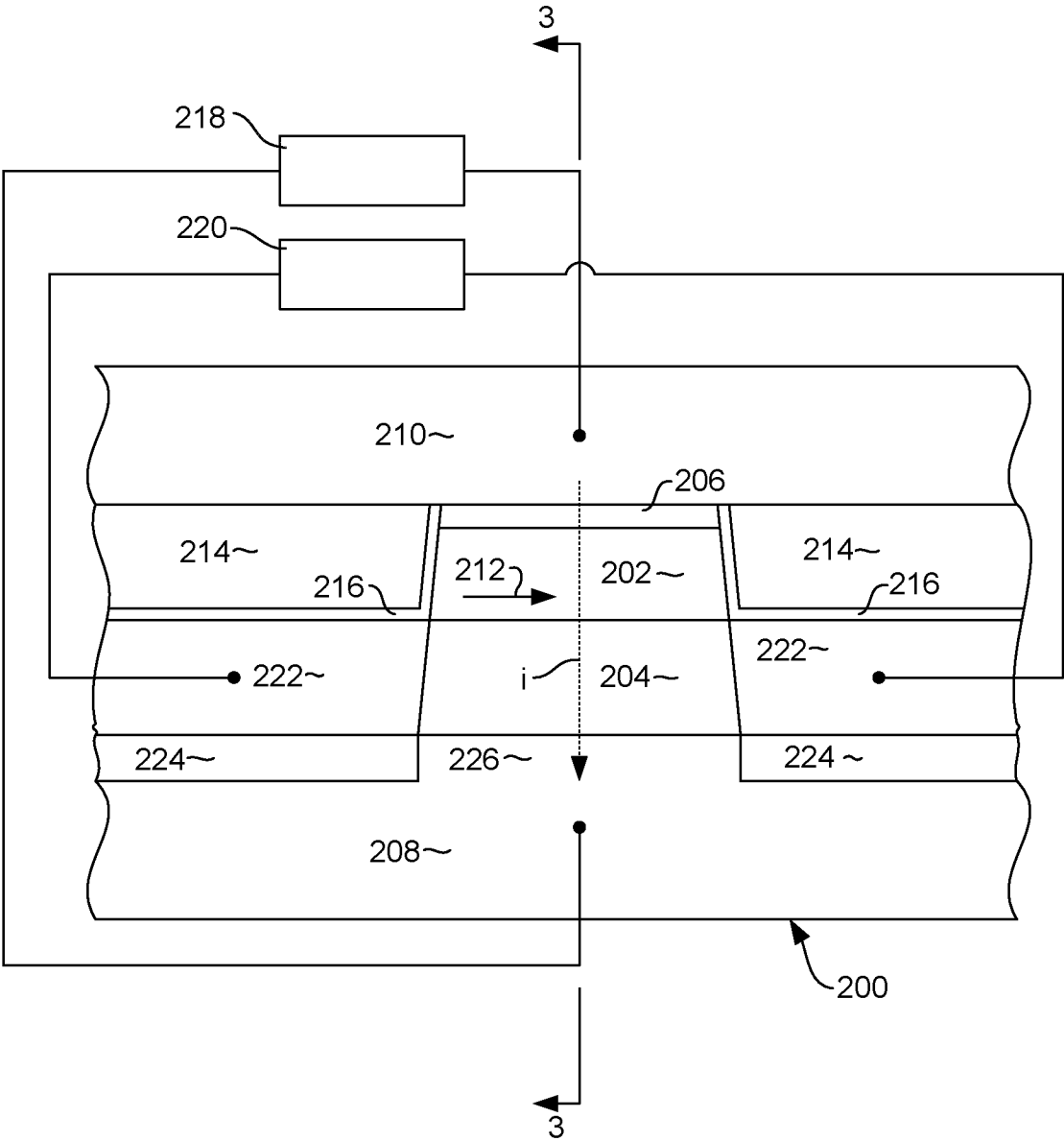


FIG. 2

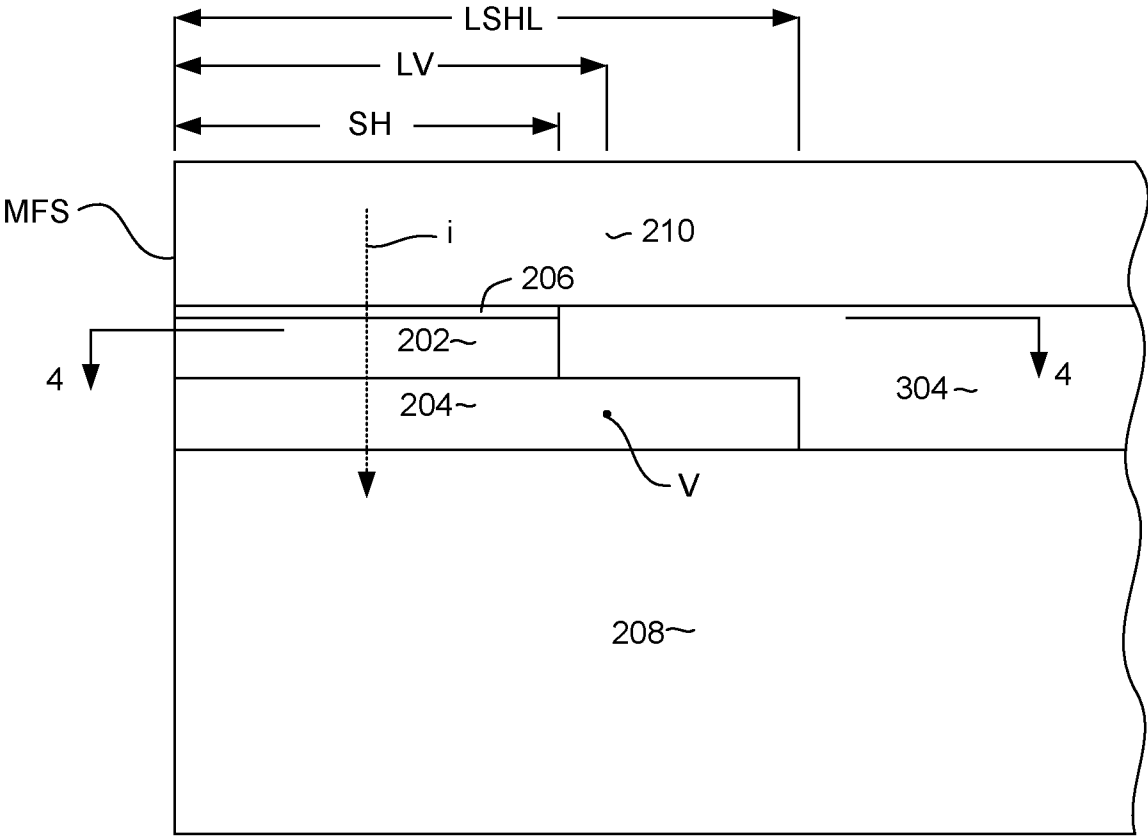


FIG. 3

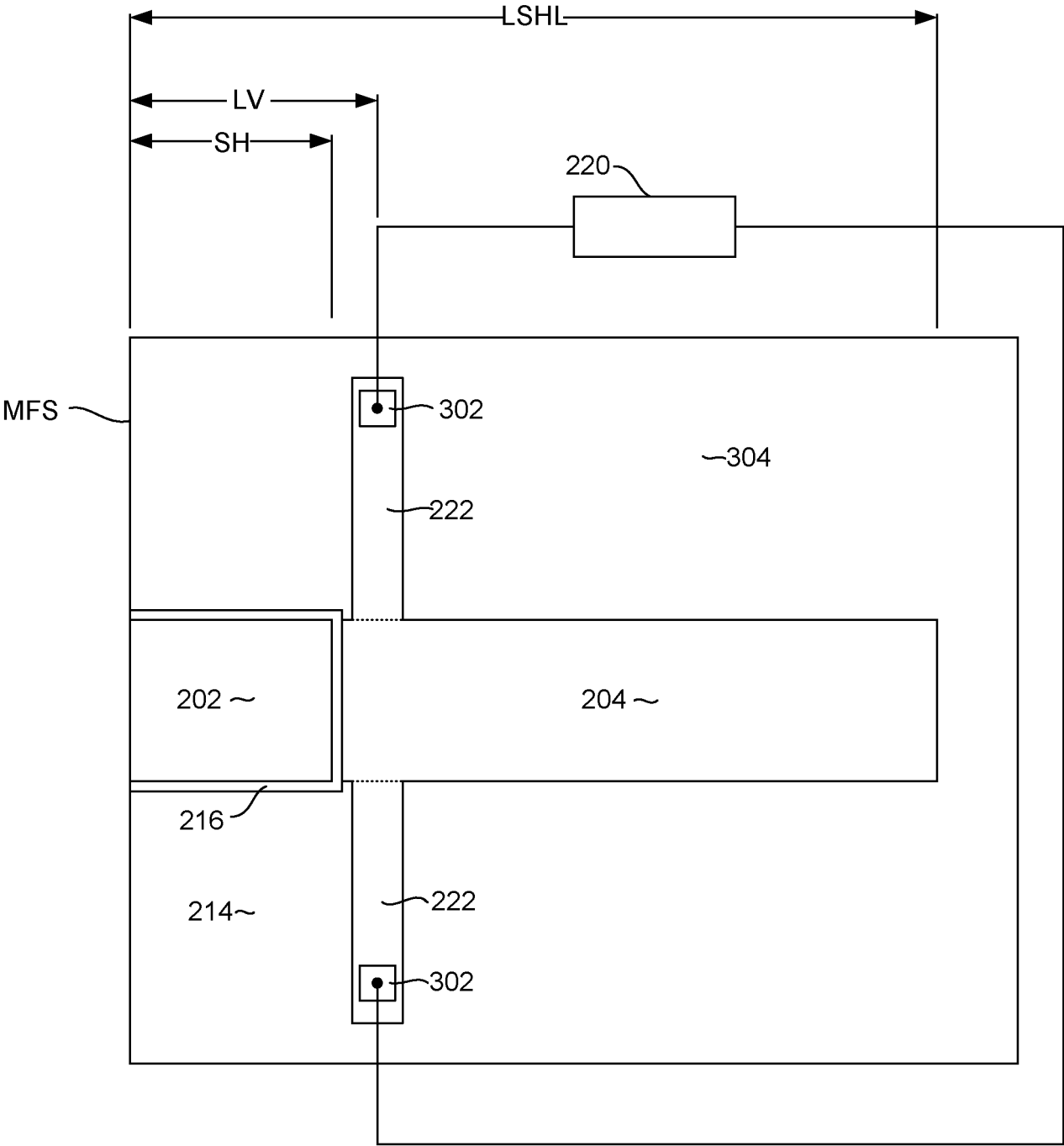


FIG. 4

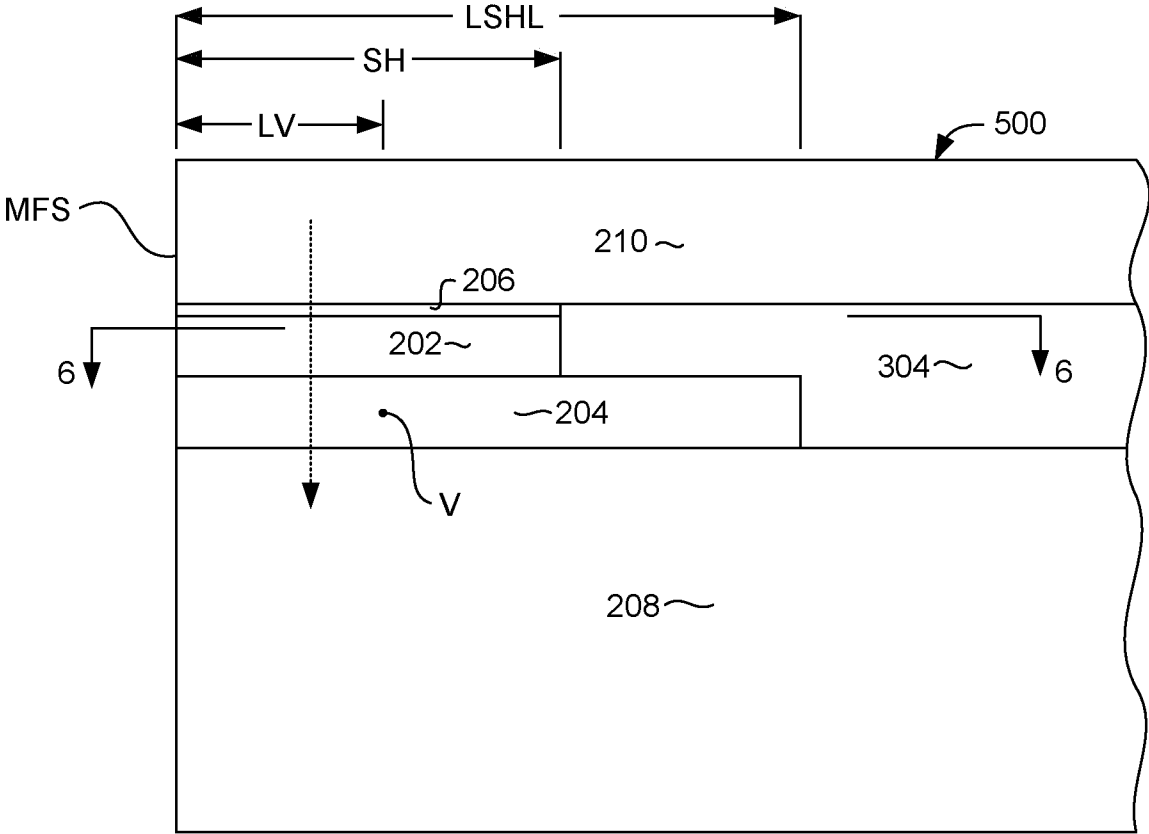


FIG. 5

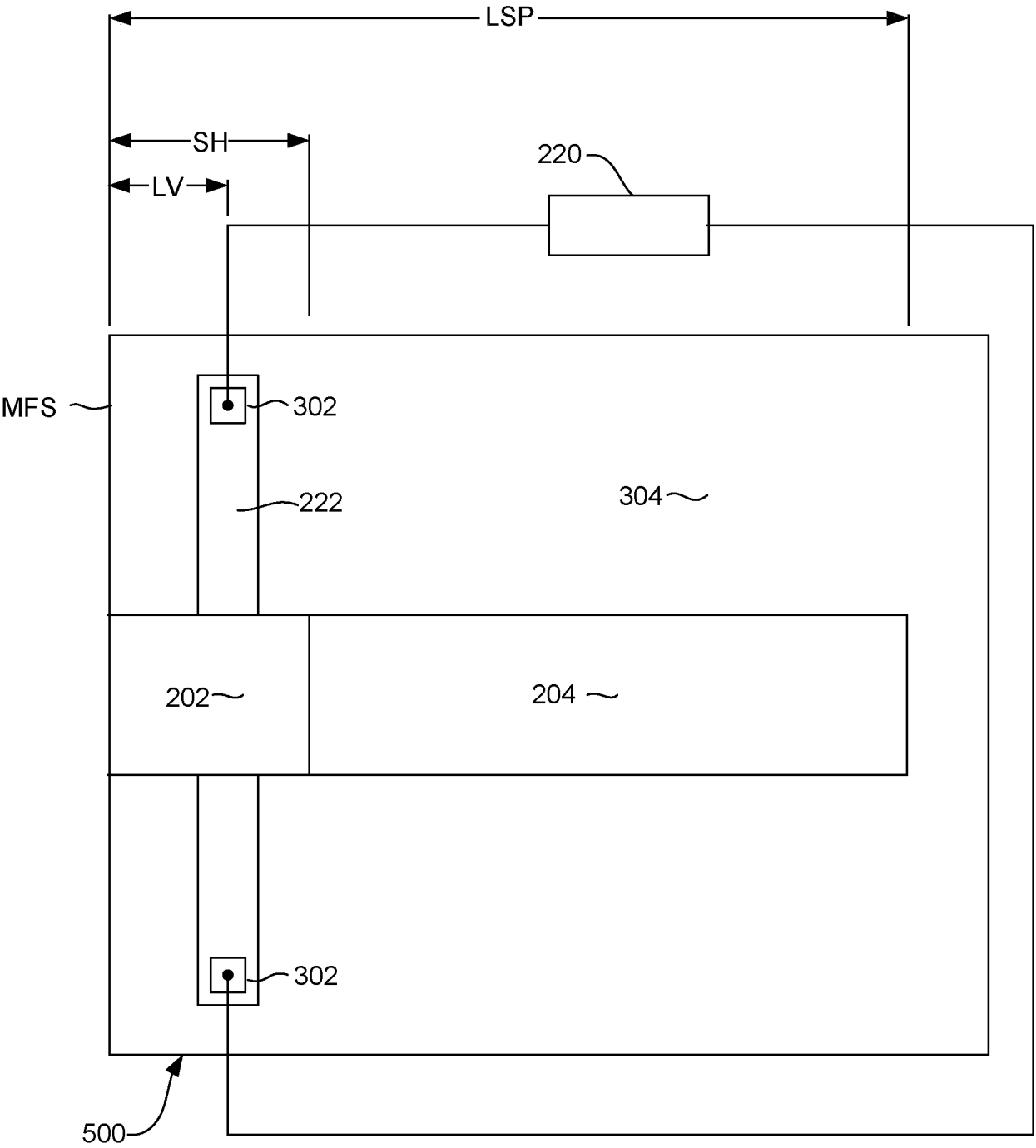


FIG. 6

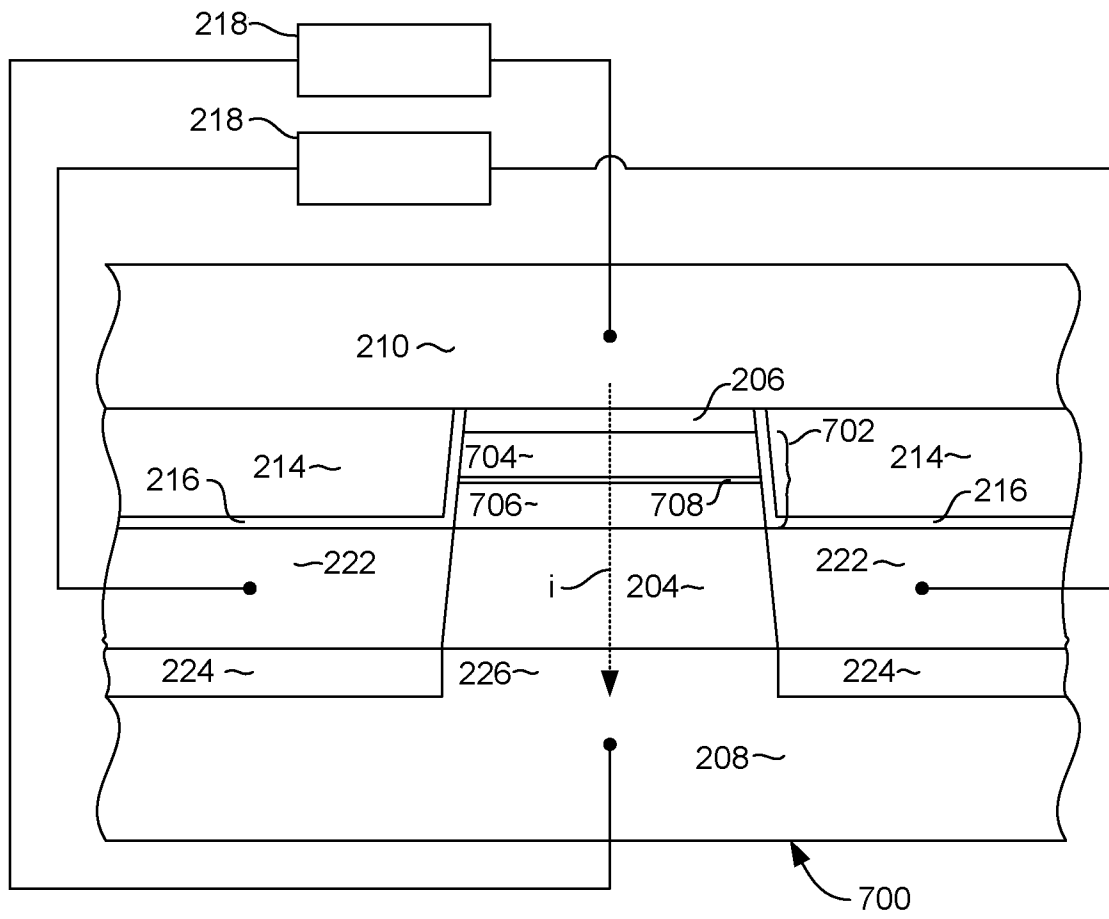


FIG. 7

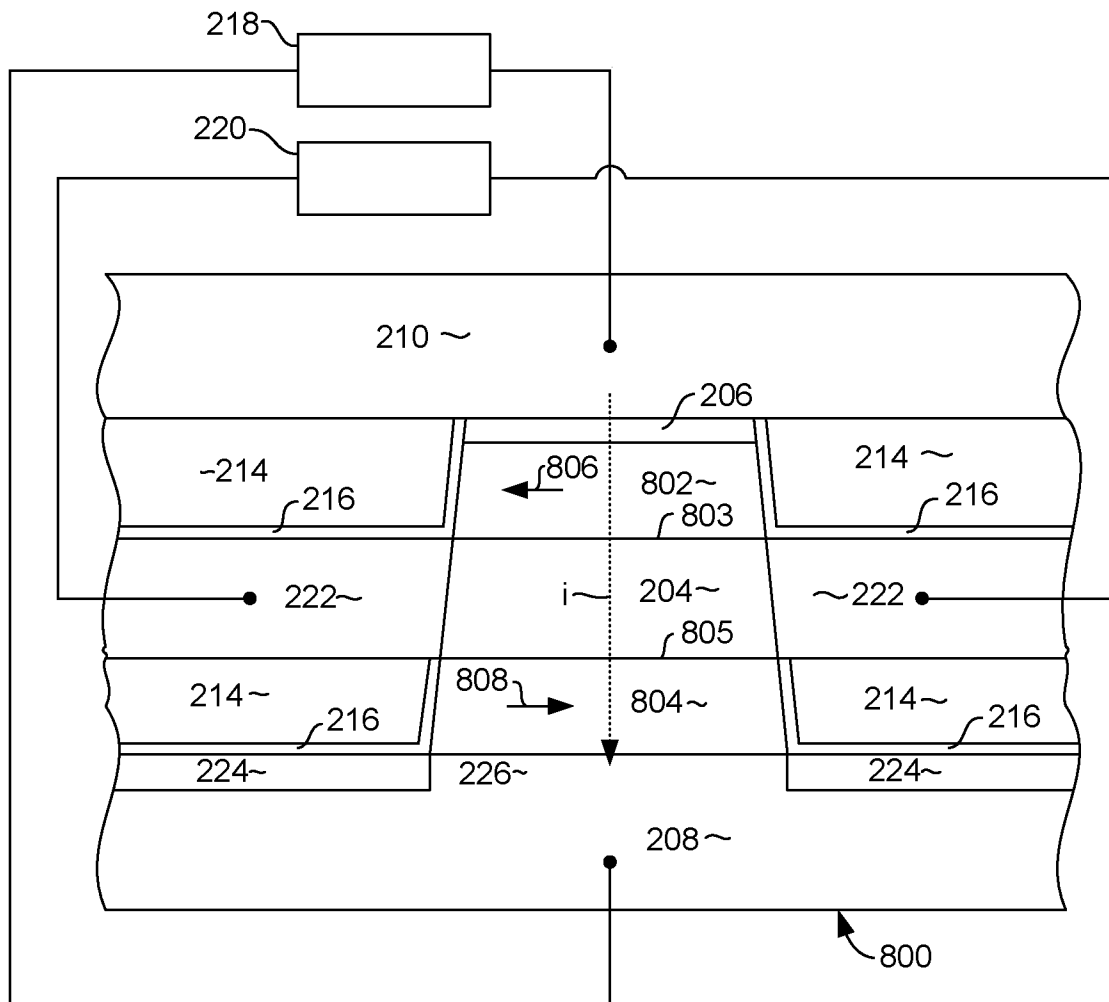


FIG. 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2017/051521

A. CLASSIFICATION OF SUBJECT MATTER

INV. G01R33/07 H01J43/06 G11B5/33 G11B5/37
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G01R H01J G11B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EP0-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2013/154633 A1 (FUJIWARA KOHEI [JP] ET AL) 20 June 2013 (2013-06-20) paragraphs [0043] - [0068], [0081] - [0092]; figure 7 -----	1-30
A	US 2007/019340 A1 (GILL HARDAYAL S [US]) 25 January 2007 (2007-01-25) the whole document -----	1-30
A	US 2015/287426 A1 (MIHAJLOVIC GORAN [US] ET AL) 8 October 2015 (2015-10-08) abstract; figures 1-3e -----	1-30

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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Date of the actual completion of the international search

8 December 2017

Date of mailing of the international search report

20/12/2017

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2017/051521

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		WO 2012026168 A1	01-03-2012

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