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Non-localized spin valve reader hybridized with spin orbit torque layer

Abstract

The present disclosure generally relates to a magnetic recording head comprising a read head. The read head comprises a sensor disposed at a media facing surface (MFS) and a spin generator spaced from the sensor and recessed from the MFS. The sensor and spin generators are disposed on a non-magnetic layer. The sensor comprises a free layer and the spin generator comprises at least one spin orbit torque (SOT) layer. The SOT layer may comprise topological material such as BiSb. The sensor is configured to detect a read signal using a first voltage lead and a second voltage lead. The spin generator is configured to inject spin current through the non-magnetic layer to the sensor using a first current lead and a second current lead. The shape of the non-magnetic layer is a triangular or trapezoidal shape to further concentrate spin current.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS (1) This application claims benefit of U.S. provisional patent application Ser. No. 63/521,819, filed Jun. 19, 2023, which is herein incorporated by reference.

BACKGROUND OF THE DISCLOSURE
Field of the Disclosure
(1) Embodiments of the present disclosure generally relate to a magnetic recording head comprising a read head, such as a magnetic media drive or magnetic disk drive.
Description of the Related Art
(2) At the heart of a computer is a magnetic disk drive. Information is written to and read from a disk as the disk rotates past read and write heads that are positioned very closely to the magnetic surface of the disk. There have been various read head designs proposed to boost linear density based on different physical mechanisms such as a tunneling magneto-resistive (TMR) effect, a magneto-resistance (GMR) effect, an extraordinary magneto-Resistive (EMR) effect, a spin torque oscillator (STO) effect, and non-localize spin valve (NLSV).
(3) In NLSV design, the read head may include two spatially separated tunnel junction structures, with one tunnel junction structure being recessed from a media facing surface (MFS) and the other structure being disposed at the MFS. The recessed structure often comprises a pinned layer and a ferromagnetic layer having a fixed magnetization for spin injection. However, the reader signal output in such read heads is limited by the spin injection efficiency from the pinned layer, which has a spin polarization of less than 1. As such, the relatively low spin current injection results in poor signal output, negatively impacting the read head's ability to accurately read data.
(4) Therefore, there is a need in the art for improved read heads having high signal outputs for use in magnetic recording devices.
SUMMARY OF THE DISCLOSURE
(5) The present disclosure generally relates to a magnetic recording head comprising a read head. The read head comprises a sensor disposed at a media facing surface (MFS) and a spin generator spaced from the sensor and recessed from the MFS. The sensor and the spin generator are disposed on a non-magnetic layer. The sensor comprises a free layer and the spin generator comprises at least one spin orbit torque (SOT) layer. The SOT layer may comprise BiSb. The sensor is configured to detect a read signal using a first voltage lead and a second voltage lead. The spin generator is configured to inject spin current through the non-magnetic layer to the sensor using a first current lead and a second current lead. The shape of the non-magnetic layer is a triangular or trapezoidal shape to further concentrate spin current.
(6) In one embodiment, a read head comprises a first shield, a second shield, a non-magnetic layer disposed between the first shield and the second shield, a sensor disposed between the non-magnetic layer and the second shield at a media facing surface (MFS), the sensor comprising a free layer, and a spin generator disposed adjacent to the non-magnetic layer and recessed from the MFS

by a first distance, the spin generator being spaced from the sensor, wherein the spin generator comprises a spin orbit torque (SOT) layer and wherein the first distance is greater than a height of the free layer as measured from the MFS.
(7) In another embodiment, a magnetic recording device comprises a read head, the read head comprising: a first shield, the first shield comprising a shield notch, a second shield, a non-magnetic layer disposed between the shield notch and the second shield, a sensor disposed between the non-magnetic layer and the second shield at a media facing surface (MFS), the sensor comprising a free layer, and a spin generator recessed from the MFS, the spin generator being spaced from the sensor, wherein the spin generator comprises: a first spin orbit torque (SOT) layer disposed between the first shield and the non-magnetic layer, and a second SOT layer disposed between the non-magnetic layer and the second shield.
(8) In yet another embodiment, a magnetic recording device comprises a read head, the read head comprising: a first shield, a second shield, a non-magnetic layer disposed between the first shield and the second shield, a sensor disposed between the first shield and the second shield at a media facing surface (MFS), the sensor comprising a first free layer and a second free layer, and a spin generator recessed from the MFS, the spin generator being spaced from the sensor, wherein the spin generator comprises: a first spin orbit torque (SOT) layer disposed between the first shield and the non-magnetic layer, and a second SOT layer disposed between the non-magnetic layer and the second shield.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) So that the manner in which the above recited features of the present disclosure can be understood in detail, a more particular description of the disclosure, briefly summarized above, may be had by reference to embodiments, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only typical embodiments of this disclosure and are therefore not to be considered limiting of its scope, for the disclosure may admit to other equally effective embodiments.
(2) FIG. **1** illustrates a disk drive embodying this disclosure.
(3) FIG. **2** is a fragmented, cross-sectional side view through the center of a read/write head facing a magnetic media, according to one embodiment.
(4) FIG. **3** illustrates prior art of a read head based on NLSV.
(5) FIGS. **4**A-**4**B illustrate a read head, according to one embodiment.
(6) FIGS. **4**C-**4**D illustrate a read head, according to another embodiment.
(7) FIGS. **5**A-**5**B illustrate a read head of a magnetic recording head, according to one embodiment.
(8) FIGS. **5**C-**5**D illustrate a read head of a magnetic recording head, according to another embodiment.
(9) FIGS. **6**A-**6**B illustrate a read head of a magnetic recording head, according to yet another embodiment.
(10) FIGS. **6**C-**6**D illustrate a read head of a magnetic recording head, according to one embodiment.
(11) FIGS. **7**A-**7**B illustrate a read head of a magnetic recording head, according to another embodiment.
(12) FIGS. **7**C-**7**D illustrate a read head of a magnetic recording head, according to yet another embodiment.
(13) FIGS. **8**A-**8**B illustrate a read head of a magnetic recording head, according to another embodiment.
(14) FIGS. **8**C-**8**D illustrate a read head of a magnetic recording head, according to one

embodiment.
(15) FIGS. **9**A-**9**B illustrate a read head of a magnetic recording head, according to yet another embodiment.
(16) To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the figures. It is contemplated that elements disclosed in one embodiment may be beneficially utilized on other embodiments without specific recitation.
DETAILED DESCRIPTION
(17) In the following, reference is made to embodiments of the disclosure. However, it should be understood that the disclosure is not limited to specific described embodiments. Instead, any combination of the following features and elements, whether related to different embodiments or not, is contemplated to implement and practice the disclosure. Furthermore, although embodiments of the disclosure may achieve advantages over other possible solutions and/or over the prior art, whether or not a particular advantage is achieved by a given embodiment is not limiting of the disclosure. Thus, the following aspects, features, embodiments and advantages are merely illustrative and are not considered elements or limitations of the appended claims except where explicitly recited in a claim(s). Likewise, reference to "the disclosure" shall not be construed as a generalization of any inventive subject matter disclosed herein and shall not be considered to be an element or limitation of the appended claims except where explicitly recited in a claim(s).
(18) The present disclosure generally relates to a magnetic recording head comprising a read head. The read head comprises a sensor disposed at a media facing surface (MFS) and a spin generator spaced from the sensor and recessed from the MFS. The sensor and the spin generators are disposed on a non-magnetic layer. The sensor comprises a free layer and the spin generator comprises at least one spin orbit torque (SOT) layer. The SOT layer may comprise BiSb. The sensor is configured to detect a read signal using a first voltage lead and a second voltage lead. The spin generator is configured to inject spin current through the non-magnetic layer to the sensor using a first current lead and a second current lead. The shape of the non-magnetic layer is a triangular or trapezoidal shape to further concentrate spin current.
(19) FIG. **1** is a schematic illustration of a magnetic recording device **100**, according to one implementation. The magnetic recording device **100** includes a magnetic recording head, such as a write head. The magnetic recording device **100** is a magnetic media drive, such as a hard disk drive (HDD). Such magnetic media drives may be a single drive/device or include multiple drives/devices. For the ease of illustration, a single disk drive is shown as the magnetic recording device **100** in the implementation illustrated in FIG. **1**. The magnetic recording device **100** (e.g., a disk drive) includes at least one rotatable magnetic disk **112** supported on a spindle **114** and rotated by a drive motor **118**. The magnetic recording on each rotatable magnetic disk **112** is in the form of any suitable patterns of data tracks, such as annular patterns of concentric data tracks on the rotatable magnetic disk **112**.
(20) At least one slider **113** is positioned near the rotatable magnetic disk **112**. Each slider **113** supports a head assembly **121**. The head assembly **121** includes one or more magnetic recording heads (such as read/write heads), such as a write head including a spintronic device. As the rotatable magnetic disk **112** rotates, the slider **113** moves radially in and out over the disk surface **122** so that the head assembly **121** may access different tracks of the rotatable magnetic disk **112** 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** toward the disk surface **122**. Each actuator arm **119** is attached to an actuator **127**. The actuator **127** as shown in FIG. **1** may be a voice coil motor (VCM). The VCM includes a coil movable within a fixed magnetic field, the direction and speed of the coil movements being controlled by the motor current signals supplied by a control unit **129**.
(21) The head assembly **121**, such as a write head of the head assembly **121**, includes a media

facing surface (MFS) such as an air bearing surface (ABS) that faces the disk surface **122**. During operation of the magnetic recording device **100**, the rotation of the rotatable magnetic disk **112** generates an air or gas bearing between the slider **113** and the disk surface **122** which exerts an upward force or lift on the slider **113**. The air or gas bearing thus counter-balances the slight spring force of suspension **115** and supports the slider **113** off and slightly above the disk surface **122** by a small, substantially constant spacing during operation.

(22) The various components of the magnetic recording device **100** are controlled in operation by control signals generated by control unit **129**, such as access control signals and internal clock signals. The control unit **129** includes logic control circuits, storage means and a microprocessor. The control unit **129** generates control signals to control various system operations such as drive motor control signals on a line **123** and head position and seek control signals on a line **128**. The control signals on line **128** provide the desired current profiles to optimally move and position slider **113** to the desired data track on rotatable magnetic disk **112**. Write and read signals are communicated to and from the head assembly **121** by way of recording channel **125**. In one embodiment, which can be combined with other embodiments, the magnetic recording device **100** may further include a plurality of media, or disks, a plurality of actuators, and/or a plurality number of sliders.

(23) FIG. **2** is a schematic illustration of a cross sectional side view of a head assembly **200** facing the rotatable magnetic disk **112** shown in FIG. **1** or other magnetic storage medium, according to one implementation. The head assembly **200** may correspond to the head assembly **121** described in FIG. **1**. The head assembly **200** includes a MFS **212**, such as an ABS, facing the rotatable magnetic disk **112**. As shown in FIG. **2**, the rotatable magnetic disk **112** relatively moves in the direction indicated by the arrow **232** and the head assembly **200** relatively moves in the direction indicated by the arrow **234**.

(24) In one embodiment, which can be combined with other embodiments, the head assembly **200** includes a magnetic read head **211**. The magnetic read head **211** may include a sensing element **204** disposed between shields S1 and S2. The sensing element **204** and related structures will be further described with respect to various embodiments shown in the disclosure. The magnetic fields of magnetized regions in the rotatable magnetic disk **112**, such as perpendicular recorded bits or longitudinal recorded bits, are detectable by the sensing element **204** as the recorded bits.

(25) The head assembly **200** includes a write head **210**. In one embodiment, which can be combined with other embodiments, the write head **210** includes a main pole **220**, a leading shield **206**, a trailing shield (TS) **240**, and an optional spintronic device (not shown) disposed between the main pole **220** and the TS **240**. Each of the main pole **220**, the spintronic device, the leading shield **206**, and the TS **240** has a front portion at the MFS.

(26) The main pole **220** includes a magnetic material, such as CoFe, CoFeNi, NiFe or FeNiRe, other suitable magnetic materials. In one embodiment, which can be combined with other embodiments, the main pole **220** includes small grains of magnetic materials in a random texture, such as body-centered cubic (BCC) materials formed in a random texture. In one example, a random texture of the main pole **220** is formed by electrodeposition. The write head **210** includes a coil **218** around the main pole **220** that excites the main pole **220** to produce a writing magnetic field for affecting a magnetic recording medium of the rotatable magnetic disk **112**. The coil **218** may be a helical structure or one or more sets of pancake structures.

(27) In one embodiment, which can be combined with other embodiments, the main pole **220** includes a trailing taper **242** and a leading taper **244**. The trailing taper **242** extends from a location recessed from the MFS **212** to the MFS **212**. The leading taper **244** extends from a location recessed from the MFS **212** to the MFS **212**. The trailing taper **242** and the leading taper **244** may have the same degree or different degree of taper with respect to a longitudinal axis **260** of the main pole **220**. In one embodiment, which can be combined with other embodiments, the main pole **220** does not include the trailing taper **242** and the leading taper **244**. In such an embodiment, the main

pole **220** includes a trailing side and a leading side in which the trailing side and the leading side are substantially parallel.
(28) The TS **240** includes a magnetic material, such as FeNi, or other suitable magnetic materials, serving as a second electrode and return pole for the main pole **220**. The leading shield **206** may provide electromagnetic shielding and is separated from the main pole **220** by a leading gap **254**.
(29) FIG. **3** illustrates a read head **300** based on prior art using NLSV. The read head **300** comprises a read sensor **340** disposed at the MFS adjacent to a media **301** and a spin generator **350** recessed from the MFS. The read sensor **340** and the spin generator **350** are each individually disposed between a first shield (not shown) and the second shield (not shown), and are separate, with the read sensor **340** being exposed to MFS and the spin generator **350** been recessed from MFS. The read sensor **340** and the spin generator **350** are also spaced from each other by some finite distance. A non-magnetic layer **306** is disposed adjacent to each of the sensor **340** and spin generator **350**. The non-magnetic layer **306** may comprise Al, for example.
(30) The read sensor **340** comprises a first free layer **344** and a first tunnel barrier layer **342** disposed between the first free layer **344** and the non-magnetic layer **306**. Voltage leads are connected to the non-magnetic layer **306** and the first free layer **344** for read signal detection through the read sensor **340**.
(31) The spin generator **350** comprises a reference layer **336**, a cap layer **332** disposed on the reference layer **336**, and a second magnetic layer (FM) layer **334** disposed between the non-magnetic layer **306** and second the tunnel barrier layer **332**. The spin generator **350** is spaced a distance of about up to a spin diffusion length of the non-magnetic layer **306** from the read sensor **340**. For instance, if the non-magnetic layer **306** is made of Cu, the distance can be up to about 100 nm to about 300 nm. Current leads are connected to the non-magnetic layer **306** and the reference layer **336** for spin current generator. During operation, when an electrical current is applied and applied through the spin generator **350**, a spin current travels from the spin generator **350** down through the non-magnetic layer **306** to the read sensor **340**. The spin injection allows the spin current to flow to the read sensor **340**, enabling the signal detection from the first free layer **344**'s magnetization changes when reading data.
(32) However, since the spin generator **350** comprises a reference layer **336** having a fixed magnetization direction, the spin injection efficiency is limited by the spin polarization of the reference layer **336** which less than about 1. As such, the reader signal output of the read head **300** is limited.
(33) FIGS. **4**A-**4**B illustrate a read head **400**, according to one embodiment. FIG. **4**A illustrates a cross-sectional view of the read head **400** and FIG. **4**B illustrates a top view of the read head **400**. The read head **400** may be within the read head **211** of FIG. **2**. The read head **400** may be a part of the magnetic recording device **100** of FIG. **1**. In the top view of FIG. **4**B, the first shield (S1) **402** and the second shield (S2) **404** are not shown for clarity purposes. The first shield **402** may be the S1 of FIG. **2**, and the second shield **404** may be the S2 of FIG. **2**.
(34) The read head **400** comprises a read sensor **440** disposed at the MFS and a spin generator **450** recessed from the MFS. The read sensor **440** is disposed between the first shield **402** and the second shield **404**. A non-magnetic spin transport layer **406** is disposed between the second shield **404** and between the read sensor **440** and the spin generator **450**. The non-magnetic layer **406** extends from the MFS to a back edge of the spin generator **450**, and may have same height from the MFS as the first and second shields **402**, **404**.
(35) In some embodiments, the non-magnetic layer **406** may have a greater height than the first and second shields **402**, **404**, or a smaller height than the first and second shields **402**, **404** (the configuration shown in FIG. **4**A). The non-magnetic layer **406** has a height **452** of less than, or closer to, the spin diffusion length of the non-magnetic layer **406**, generally of about 100 nm to about 300 nm, depending on material used in the non-magnetic layer **406**. The non-magnetic layer **406** may comprise a material having a long spin diffusion length, such as Cu, Al, or some other 2D

materials, such as graphene, and other van der Waals material, like MoS.sub.2, HfS.sub.2, etc. The read sensor **440** is spaced a distance **444** of about 100 nm to about 300 nm from the spin generator **450**. In addition, the first and second shields **402** and **404** may have different dimensions (different heights from MFS).

(36) Depending on (1) the respective heights of the first shield **402** and the second shield **404**, and (2) the spin diffusion characteristics of the non-magnetic layer **406** (which influences the recess spacing of the spin generator **450**), the spin generator **450** may or may not be between the two shields. While FIGS. **4**A-**9**B show one or more spin generator between the shields and the shields are relatively similar or the same in dimensions, the disclosure is not so limited and there are other embodiments where the spin generator **450** may not be between the two shields. In those embodiments, a portion of the non-magnetic layer **406** that overlaps with the sensor could be between the two shields, but another portion of the non-magnetic layer **406** that overlaps with the spin generator **450** may not be.

(37) The read sensor **440** comprises a free layer **418** disposed adjacent to the first shield **402** and a tunnel barrier layer **442** disposed between the free layer **418** and the non-magnetic layer **406**. The free layer **418** may comprise a magnetic material such as one or more layers of Co—Fe, Co—Fe—B, Pt, or a Heusler alloy. The tunnel barrier layer **442** may comprise MgO or AlOx, for example, where x is a numeral greater than 1. Voltage leads are connected to the first and second shields **402**, **404** for read signal detection through the read sensor **440**.

(38) The spin generator **450** is a multilayer structure. The spin generator **450**, or the recessed read sensor **450**, may be any of the read sensors **500-900** discussed below in FIGS. **5**A-**9**B. Electrical current leads are connected to the spin generator **450** for spin injection. During operation, when a current is applied to the read head **400** inside of the spin generator **450** plane, due to a spin Hall effect, there will be a spin current generated that flows across the spin generator **450** into the non-magnetic layer **406**. This spin current travels from the spin generator **450** down through the non-magnetic layer **406** to the read sensor **440**. This spin current flowing through the read sensor **440** enables an electrical signal generation across the sensor **440** when the free layer **418** rotates its magnetization directions when reading data.

(39) As shown in FIG. **4**B, the non-magnetic layer **406** may have a triangular or trapezoidal shape such that the non-magnetic layer **406** is wider further away from the MFS and narrows as the non-magnetic layer **406** gets closer to the MFS. In such embodiments, the wider portion of the non-magnetic layer **406** has a width **454** of less than or equal to about 100 nm, and the narrower portion of the non-magnetic layer **406** has a width **456** of about 10 nm to about 20 nm, which is closer to a track width (TW) of the read sensor **440**. The free layer **418** of the sensor **440** may have a same width **456** as the narrower portion of the non-magnetic layer **406**. The spin generator **450** is disposed on a wider part of the non-magnetic layer **406** when the non-magnetic layer **406** varies in width. Side shields **448** are disposed on either side the read sensor **440** at the MFS for the proper biasing of the free layer **418**.

(40) FIGS. **4**C-**4**D illustrate a read head **401**, according to one embodiment. FIG. **4**C illustrates a cross-sectional view of the read head **401** and FIG. **4**D illustrates a top view of the read head **401**. The read head **401** may be within the read head **211** of FIG. **2**. The read head **401** may be a part of the magnetic recording device **100** of FIG. **1**. In the top view of FIG. **4**D, the first shield (S1) **402** and the second shield (S2) **404** are not shown for clarity purposes.

(41) The read head **401** of FIGS. **4**C-**4**D is similar to the read head **400** of FIGS. **4**A-**4**B; however, the spin generator **450** serves the function of spin detection, and will be referred to herein as a spin detector **450** or spin detector layer **450**, and the current and voltage leads are reversed, resulting in the direction the generated spin current flows through the non-magnetic layer **406** being reversed. In the read head **401**, input current leads (I) are connected to the first shield **402** and to the second shield **404**, and voltage leads (V) are connected to the spin detector **450**. During operation, when a current is applied to read head **401**, a spin current (I.sub.s) from the FL **418** is generated and flows

across the read sensor **440** into the non-magnetic layer **406**. The spin current travels from the read sensor **440** up through the non-magnetic layer **406** to the spin detector **450**. The vertical spin current flowing through the spin detector **450** enables an electrical signal/voltage generation across the side (cross-track direction) of the spin detector **450** due to the inverse spin Hall effect. When the free layer **418** rotates its magnetization directions when reading data, spin polarization of the spin current (I.sub.s) will change, resulting in an output voltage (Vout) across the spin detector **450** reflecting the magnetic bit information on the recording track.

(42) Furthermore, when the current leads (I) are connected to the first shield **402** and to the second shield **404**, and voltage leads (V) are connected to the spin detector **450**, the non-magnetic layer **406** has a rectangular shape. In such embodiments, the non-magnetic layer **406** has a consistent narrow width **456** of about 10 nm to about 20 nm, which is closer to a track width (TW) of the read sensor **440**.

(43) FIGS. **5**A-**9**B illustrate various embodiments of read heads **500**, **501**, **600**, **601**, **700**, **701**, **800**, **801**, **900**, respectively, according to various embodiments. Each read head **500**, **600**, **700**, **800**, **900** may individually be the read head **400** of FIGS. **4**A-**4**B. Each read head **501**, **601**, **701**, **801** may individually be the read head **401** of FIGS. **4**C-**4**D. Each read head **500**, **501**, **600**, **601**, **700**, **701**, **800**, **801**, **900** may individually be within the read head **211** of FIG. **2**. Each read head **500**, **501**, **600**, **601**, **700**, **701**, **800**, **801**, **900** may individually be a part of the magnetic recording device **100** of FIG. **1**. Aspects of FIGS. **5**A-**9**B may not be shown to scale, such as the height of the first and second shields **402**, **404** in the x-direction. Furthermore, aspects of each read head **500**, **501**, **600**, **601**, **700**, **701**, **800**, **801**, **900** may be used in combination with one another and/or with the read head **400** of FIGS. **4**A-**4**B and/or the read head **401** of FIGS. **4**C-**4**D. As such, various layers and/or aspects of the read heads **400**, **401**, **500**, **501**, **600**, **601**, **700**, **701**, **800**, **801**, **900** may have consistent reference numerals.

(44) FIGS. **5**A-**5**B illustrate a read head **500** of a magnetic recording head, according to one embodiment. FIG. **5**A illustrates a cross-sectional view of the read head **500** and FIG. **5**B illustrates a MFS view of the read head **500**.

(45) The read head **500** comprises the first shield **402**, the second shield **404**, the non-magnetic layer **406**, a read sensor **540** disposed at the MFS, and a spin generator or spin generation structure **550** recessed from the MFS. A notch **516** is disposed between the first shield **402** and the non-magnetic layer **406** recessed from the MFS. The notch **516** can be recessed a distance of about 0 nm to about 20 nm from the MFS. The notch **516** has a thickness in the y-direction of about 5 nm to about 20 nm and a height in the x-direction of about 5 nm to about 20 nm. A dielectric layer **515** is disposed in front of the notch **516** at the MFS and behind the notch **516** recessed from the MFS. The dielectric layer **515** spaces the first shield **402** from the non-magnetic layer **406**. The dielectric layer **515** may comprise SiN, SiO.sub.2, MgO, AlO, AlN, or combinations thereof. The read sensor **540** comprises a first tunnel barrier layer **520** disposed on the non-magnetic layer **406**, a free layer **418** disposed on the first tunnel barrier layer **520**, and a cap layer **522**, which may comprise a conductive material, disposed on the free layer **418** and in contact with the second shield **404**. As shown in FIG. **5**B, a spin orbit torque (SOT) layer **510** has a greater overall size than the free layer **418** along the X and Z directions. A magnetization (M) direction of the free layer **418** is in the −z-direction during operation, which is in the same direction of magnetization of soft bias (SB) side shield **526**.

(46) As shown in FIG. **5**A, an insulating layer **514** is disposed behind the sensor **540** recessed from the MFS. The spin generator **550** is disposed adjacent to the insulating layer **514**. The spin generator **550** comprises a seed layer **508** disposed on the non-magnetic layer **406**, the SOT layer **510** (which may be referred to herein as a BiSb layer **510** in certain embodiments where the SOT layer comprises BiSb) disposed on the seed layer **508**, and a cap layer **512** disposed on the SOT layer **510**. The cap layer **512** may comprise a non-magnetic, high resistivity material, such as Ru, NiFeG, or some oxide materials, for example. In some embodiments, the insulating layer **514**

extends over the cap layer **512** and behind the spin generator **550**, like shown in FIG. **5**A. The insulating layer **514** may comprise SiN, SiO.sub.2, MgO, AIO, AIN, or combinations thereof. As discussed above, a first voltage lead (V−) is connected to the first shield **402**, and a second voltage lead (V+) is connected to the second shield **404** for read signal detection across the first read sensor **540**. The first shield **402**, the second shield **404**, and the notch **516** may each individually comprise a magnetic material similar to the soft bias material, such as NiFe, NiFe/CoFe laminates, NiFe/NiFeCr laminates, or NiFe/W laminates, for example ("/" as used here denotes separate layers in a multi-layer stack).
(47) As shown in the MFS view of FIG. **5**B, the read head **500** further comprises a first soft bias (SB) side shield **524** and a second SB shield **526** each adjacent to the sensor **540**. The first and second SB side shields **524**, **526** may each individually comprise NiFe, CoFe, and other magnetic materials for proper free layer biasing across track (i.e., the z-direction in FIG. **5**B). A first current lead (I+) and a second current lead (I−) are connected to the SOT layer **510** for spin injection. From FIG. **5**A, the electrical current flows through the SOT layer **510** into the page, or the z-direction. During operation, when this in-plane (in plane of the SOT layer **510**) current is applied to the read head **500**, a spin accumulation will occur, and hence a spin current is generated in the non-magnetic layer **406** due to a spin Hall effect. This spin current travels from the spin generator **550** down through the non-magnetic layer **406** to the read sensor **540**. This spin current flowing to the read sensor **540** enables an electrical signal generation across the sensor **540** when the free layer **418** rotates its magnetization directions when reading data.
(48) The SOT layer **510** comprises a heavy metal with strong spin orbital coupling, such as Ta, Pt, W, Hf, etc. The SOT layer **510** can comprise a topological insulator material, such as BiSe, WTe, YBiOPt, or BiSb. The SOT layer **510** may comprise BiSb in a (012) orientation. The SOT layer **510** may comprise undoped BiSb or doped BiSbX, where the dopant is less than about at. 10%, and where X is extracted from elements which don't readily interact with Bi, such as B, N, Al, Si, Ti, V, Cr, Fe, Ni, Cu, Ge, Y, Zr, Ru, Mo, Ag, Hf, Ta, W, or Ir, or in alloy combinations with one or more of aforementioned elements, like CuAg, CuNi, RuGe, etc. More generally, some of the listed dopants may be used with other topological insulator materials other than BiSb. The SOT layer **510** has a thickness **558** in the y-direction (e.g., a down-track direction) of about 5 nm to about 20, a height **560** in the x-direction (e.g., a stripe height) of about 100 nm to about 1 μm, and a width **562** (e.g., a cross-track direction) in the z-direction of less than about 100 nm.
(49) Numerous materials may be utilized as seed layer **508** to provide a textured SOT layer **510** (012) growth using either textures (100) or as amorphous seed layers. One group of materials, Group A, includes body centered cubic (BCC) such as V, V.sub.3Al, Mn.sub.3Al, Nb, Mo, W, Ta, WTi50, NiAl, RhAl, or in alloy combinations of these materials with similar lattice parameters, or a BCC material used in combination with (100) textured layers such as Cr (heated at about 250° C. or larger), RuAl, IrAl, CoAl, B2 phases, NiAl—B2 phase, CrMo (Mo of about 20-50 at. %)-A2, or B2 phase, A2 CrX (X is about at. 10%, heated at about 250° C. or larger, and is selected from Ru, Ti, W, and Mo).
(50) The Group A materials provide texturing for subsequent layers and may be referred to as a MgO (100) texturing layer stack. Generally speaking, depositing a high boron affinity elements or alloys such as alloys of tantalum, tungsten, or titanium and then depositing a magnetic layer containing boron, an amorphous magnetic layer material such as cobalt iron boron or cobalt boron is formed, but the boron would be pulled out leaving a magnetic cobalt iron or cobalt layer behind. On top of that layer, MgO could be formed with a (100) texture. Other manners to make MgO (100) can include depositing heated chromium or ruthenium aluminum grow in a textured fashion. MgO (100) texturing layer stacks can also be made by depositing thin MgO on a magnetic bilayer of Co, or CoFe on a magnetic boron alloy of CoFeB or CoB deposited on a thin high B gettering alloy seed layers of Hf, Ta, W, Ti, or alloys containing these elements.
(51) Another group of materials, Group B, includes face centered cubic (FCC) oxide materials

including FeO, CoO, NiO, ZrO, MgO, TiO, MgTiO, and MnO. Another group of materials, Group C, includes FCC nitrides and carbides including ScN, TiN, NbN, ZrN, HfN, TaN, VN, CrN, ScC, TiC, NbC, ZrC, HfC, TaC, WC, VC, and W.sub.0.8Zr.sub.0.2C. Group C materials can be deposited as amorphous to nanocrystalline thin films depending upon deposition conditions. Resistivities of Group C materials are >100-200 micro ohm-cm.

(52) Another groups of materials, Group D, includes nonmagnetic Heusler materials including Fe.sub.2VAl, Cr.sub.2CoAl, CoTiSb, Mn.sub.2VSi, V.sub.2Al, [Mn.sub.0.5Co.sub.0.5].sub.2VAl, [Mn.sub.0.75Co.sub.0.25].sub.2VSi, CoMnNbAl, CoZrFeAl, and Ti.sub.2MnAl. Another group of materials, Group E, are crystalline high polarization layers using magnetic alloys or Heusler alloys that have large spin polarizations and do not readily mix with a spin Hall layer including: Co.sub.2MnSb, CoFeX, NiFeX, (where X is one or more of Si, Al, Mn, and Ge) CoFe, NiFe, Co.sub.2MnGe, CoMnSb, NiMnSb, Co.sub.2FeGe, Co.sub.2MnSn, and Co.sub.2MnFeGe. Another group of materials, Group F, includes amorphous nonmagnetic high resistive electrical shunt block layers that do not promote strong (012) BiSbX texture or growth. They include SiO.sub.2, Al.sub.2O.sub.3, SiN, AlN, SiC, SiCrOx, NiX, FeX, and CoX, where X can be one or more of these elements including Fe, Co, Ni, Ta, Hf, W, Ir, Pt, Ti, Zr, N, Ru, Ge and/or B.

(53) Another group of materials, Group G, includes any metal amorphous or ceramic amorphous material with the nearest neighbor x-ray diffraction peak in the 2.19 Å to 2.02 Å d-spacing range. Such materials include nonmagnetic and magnetic materials from Group A, D, or E which are laminated or alloyed with one or more elements of: Cu, Ag, Ge, Al, Mg, Si, Mn, Ni, Co, Mo, Zr, Y, Bi, Hf, Ta, W, Ir, Pt, Ti, or B. They form effectively nonmagnetic amorphous layers which produce amorphous materials or start with amorphous materials like a-Ge, and a-NiPX alloys (where X is one of Ru, Rh, Y, Zr, Mo, Hf, Ta, W, Re, Pt, or Ir), etc. Group G also may include amorphous/nanocrystalline alloys with a-Ge, a-NiP and one or more elements of: Cu, Ag, Ge, Al, Mg, Si, Mn, Ni, Co, Mo, Zr, Y, Bi, Hf, Ta, W, Ir, Pt, Ti, or B to promote a strong (012) BiSb texture.

(54) Yet another group of materials, Group H, are high perpendicular magnetic anisotropy (PMA) materials that can be amorphous or crystalline materials. Amorphous rare-earth transition metals (RE-TM) that have high PMA like TbFeCo, TbFeB, Nd, Pr, Sm(Fe,Co)B or heavy metals like CoZrTaB can be used. This multilayer polycrystalline stacks of Co/Pt, Co/Pd, CoFe/Pt, Co/Tb, or CoFe/Tb ("/" denoting layer separation), or single layer PMA materials like CoPt, CoPtCr, CoFePt, and FePt with high Ku can be used with an amorphous high polarizing layer next to the spin Hall layer for (012) texture growth.

(55) FIGS. **5**C-**5**D illustrate a read head **501** of a magnetic recording head, according to one embodiment. FIG. **5**C illustrates a cross-sectional view of the read head **501** and FIG. **5**D illustrates a MFS view of the read head **501**. In the read head **501**, the non-magnetic layer **406** may be rectangular in shape, like shown and discussed above in FIGS. **4**A-**4**D.

(56) The read head **501** is similar to the read head **500** of FIGS. **5**A-**5**B, however, the current and voltage leads are reversed. In the read head **501**, a first current lead (I+) is connected to the second shield **404** and a second current lead (I−) is connected to the first shield **402** for spin injection. A first voltage lead (V−) and a second voltage lead (V+) are connected to the SOT layer **510** for read signal detection through the spin detector **550**.

(57) From FIG. **5**C, the electrical current flows through the read sensor **540** and the non-magnetic layer **406** in the x-direction. During operation, when the current is applied to the read head **501**, a spin accumulation will occur, and hence a spin current is generated from the free layer **418** which flows into and along the non-magnetic layer **406**. The spin current travels across the read sensor **540** through the non-magnetic layer **406** to the spin detector **550**, where the spin current flows out-of-plane (i.e., in the y-direction) through the SOT layer **510**. The spin current flowing to the spin detector **550** enables an electrical signal generation across the SOT layer **510** along the z-direction when the free layer **418** rotates its magnetization directions when reading data.

(58) FIGS. **6**A-**6**B illustrate a read head **600** of a magnetic recording head, according to another embodiment. FIG. **6**A illustrates a cross-sectional view of the read head **600** and FIG. **6**B illustrates a MFS view of the read head **600**.
(59) The read head **600** is similar to the read head **500** of FIGS. **5**A-**5**B; however, the read head **600** does not comprise the notch **516**. Rather, the dielectric layer **515** extends between the first shield **402** and the non-magnetic layer **406**. Additionally, the first voltage lead (V−) is connected to the back of non-magnetic layer **406** instead of the first shield **402**.
(60) FIGS. **6**C-**6**D illustrate a read head **601** of a magnetic recording head, according to one embodiment. FIG. **6**C illustrates a cross-sectional view of the read head **601** and FIG. **6**D illustrates a MFS view of the read head **601**. In the read head **601**, the non-magnetic layer **406** may be rectangular in shape, like shown and discussed above in FIGS. **4**A-**4**D.
(61) The read head **601** is similar to the read head **600** of FIGS. **6**A-**6**B; however, the current and voltage leads are reversed. In the read head **601**, a first current lead (I+) is connected to the second shield **404** and a second current lead (I−) is connected to the non-magnetic layer **406** for spin injection. A first voltage lead (V−) and a second voltage lead (V+) are connected to the SOT layer **510** for read signal detection through the spin detector **650**.
(62) During operation, when the current is applied to the read head **601**, a spin accumulation will occur, and hence a spin current is generated and flows from the sensor **640** into the non-magnetic layer **406**. The spin current travels across the read sensor **640** through the non-magnetic layer **406** to the spin detector **650**, where the spin current flows out-of-plane (i.e., in the y-direction) through the SOT layer **510**. The spin current flowing to the spin detector **650** enables an electrical signal generation across the SOT layer **510** due to the inverse spin Hall effect when the free layer **418** rotates its magnetization directions when reading data.
(63) FIGS. **7**A-**7**B illustrate a read head **700** of a magnetic recording head, according to yet another embodiment. FIG. **7**A illustrates a cross-sectional view of the read head **700** and FIG. **7**B illustrates a MFS view of the read head **700**. The read head **700** is similar to the read head **500** of FIGS. **5**A-**5**B, however, the sensor **740** and the spin generator **750** of the read head **700** are unaligned in both the x-direction and the y-direction.
(64) In the read head **700**, the spin generator **750** is disposed over the first shield **402**. The spin generator **750** is recessed from the MFS by a shield notch **702**. The shield notch **702** may be considered a part of the first shield **402**. The shield notch **702** may comprise the same material as the first shield **402** and/or the notch **516**. A first insulating layer **715** is disposed between the shield notch **702** and the spin generator **750**. The first insulating layer **715** may extend between the first shield **402** and the seed layer **508** as well. The notch **516** is disposed on the shield notch **702**. The non-magnetic layer **406** is disposed over the notch **516**, the spin generator **750**, and the first insulating layer **715**. The sensor **740** is disposed on the non-magnetic layer **406** at the MFS. A second insulating layer **714** is disposed on the non-magnetic layer **406** behind the sensor **740**. Portions of the first and second insulating layers **715**, **714** may be exposed at the MFS, like shown in FIG. **7**B, and may each individually comprise the same materials as the insulating layer **514**. The first SB side shield **524** and the second SB side shield **526** are disposed adjacent to the sensor **740** at the MFS.
(65) A negative voltage lead (V−) is connected to the first shield **402**, and a positive voltage lead (V+) is connected to the second shield **404**. A negative current lead (I−) and a positive current lead (I+) are connected to the SOT layer **510** for spin injection. The electrical current flows through the SOT layer **510** into the page (with respect to FIG. **5**A), or the z-direction. During operation, when this in-plane (in plane of the SOT layer **510**) current is applied to the read head **700**, a spin accumulation will occur, and hence a spin current is generated in the non-magnetic layer **406** due to a spin Hall effect. This spin current travels from the spin generator **750** down through the non-magnetic layer **406** to the read sensor **740**. This spin current flowing to the read sensor **740** enables an electrical signal generation across the sensor **740** when the free layer **418** rotates its

magnetization directions when reading data.

(66) FIGS. **7**C-**7**D illustrate a read head **701** of a magnetic recording head, according to one embodiment. FIG. **7**C illustrates a cross-sectional view of the read head **701** and FIG. **7**D illustrates a MFS view of the read head **701**. In the read head **701**, the non-magnetic layer **406** may be rectangular in shape, like shown and discussed above in FIGS. **4**A-**4**D.

(67) The read head **701** is similar to the read head **700** of FIGS. **7**A-**7**B, however, the current and voltage leads are reversed. In the read head **701**, a first current lead (I+) is connected to the second shield **404** and a second current lead (I−) is connected to the first shield **402** for spin injection. A first voltage lead (V−) and a second voltage lead (V+) are connected to the SOT layer **510** for read signal detection through the spin detector **750**.

(68) During operation, when the current is applied to the read head **701**, a spin accumulation will occur, and hence a spin current is generated from the sensor **740** and flows into the non-magnetic layer **406**. The spin current travels across the read sensor **740** through the non-magnetic layer **406** to the spin detector **750**, where the spin current flows out-of-plane (i.e., in the y-direction) through the SOT layer **510**. The spin current flowing to the spin detector **750** enables an electrical signal generation across the SOT layer **510** due to the inverse spin Hall effect when the free layer **418** rotates its magnetization directions when reading data.

(69) FIGS. **8**A-**8**B illustrate a read head **800** of a magnetic recording head, according to another embodiment. FIG. **8**A illustrates a cross-sectional view of the read head **800** and FIG. **8**B illustrates a MFS view of the read head **800**. The read head **800** is similar to the read head **500** of FIGS. **5**A-**5**B; however, the read head **800** comprises a second seed layer **808**, a second SOT layer **810**, and a second cap layer **812**.

(70) In the read head **800**, the first shield **402** further comprises a shield notch **802** disposed at the MFS between the first shield **402** and the notch **516**. The shield notch **802** may comprise the same material as the first shield **402**. A second cap layer **812** is disposed over the first shield **402** behind the shield notch **802**, a second SOT layer **810** is disposed on the second cap layer **812**, and a second seed layer **808** is disposed on the second SOT layer **810**. The second cap layer **812** may comprise the same material as the cap layer **512**. The non-magnetic layer **406** is disposed on the second seed layer **808**. A second insulating layer **814** is disposed between the shield notch **802** and the second cap layer **812**, the second SOT layer **810**, and the second seed layer **808**. The second insulating layer **814** may be disposed between the first shield **402** and the second cap layer **812**, as well as behind the second cap layer **812**, the second SOT layer **810**, and the second seed layer **808**, similar to the insulating layer **514**. The second insulating layer **814** may comprise the same material as the first insulating layer **514**. The second SOT layer **810** has the same dimensions as the first SOT layer **510** (i.e., the same dimensions as the SOT layer **510** of FIGS. **5**A-**7**B).

(71) The first seed layer **508** is disposed on the non-magnetic layer **406**, a first SOT layer **510** is disposed on the first seed layer **508**, and a first cap layer **512** is disposed on the first SOT layer **510**. The second shield **404** is disposed over the first cap layer **512**. The first cap layer **512** may comprise the same material as the second cap layer **812**, the first SOT layer **510** may comprise the same material as the second SOT layer **810**, and the first seed layer **508** may comprise the same material as the second seed layer **808**. The first cap layer **512**, the first SOT layer **510**, the first seed layer **508**, a portion of the non-magnetic layer **406** disposed in contact with the first seed layer **508**, the second seed layer **808**, the second SOT layer **810**, and the second cap layer **812** collectively form the spin generator **850**.

(72) The first signal voltage lead (V−) is connected to the shield notch **802**, and the second signal voltage lead (V+) is connected to the second shield **404**. A first negative current lead (I.sub.1−) and a first positive current lead (I.sub.1+) are connected to the second SOT layer **810**, and a second negative current lead (I.sub.2−) and a second positive current lead (I.sub.2+) are connected to the first SOT layer **510**. The first negative current lead (I.sub.1−) is disposed adjacent to the second positive current lead (I.sub.2+), and the first positive current lead (I.sub.1+) is disposed adjacent to

the second negative current lead (I.sub.2−). During operating, a first electrical current (I.sub.1) flows through the second SOT layer **810** out of the page (with respect to FIG. **8**A), or in the z-direction, and a second electrical current (I.sub.2) flows through the first SOT layer **510** into the page (with respect to FIG. **8**A), or in the −z-direction. By including two SOT layers on both sides of the non-magnetic **406**, the amount of spin current generated from the spin generator **850**, and hence the spin flow into the non-magnetic layer **406**, is doubled.

(73) FIGS. **8**C-**8**D illustrate a read head **801** of a magnetic recording head, according to one embodiment. FIG. **8**C illustrates a cross-sectional view of the read head **801** and FIG. **8**D illustrates a MFS view of the read head **801**. In the read head **801**, the non-magnetic layer **406** may be rectangular in shape, like shown and discussed above in FIGS. **4**A-**4**D.

(74) The read head **801** is similar to the read head **800** of FIGS. **8**A-**8**B, however, the current and voltage leads are reversed. In the read head **801**, a first input current lead (I+) is connected to the second shield **404** and a second input current lead (I−) is connected to the shield notch **802** for spin injection. A first negative voltage lead (V.sub.1−) and a first positive voltage lead (V.sub.1+) are connected to the second SOT layer **810**, and a second negative voltage lead (V.sub.2−) and a second positive voltage lead (V.sub.2+) are connected to the first SOT layer **510** for read signal detection through the spin detector **850**. The first positive voltage lead (V.sub.1+) is disposed adjacent to the second negative voltage lead (V.sub.2−), and the first negative voltage lead (V.sub.1−) is disposed adjacent to the second positive voltage lead (V.sub.2+). The first positive voltage lead (V.sub.1+) and the second negative voltage lead (V.sub.2−) are connected together such that the final signal read out occurs at the first negative voltage lead (V.sub.1−) and the second positive voltage lead (V.sub.2+).

(75) During operation, when the input current is applied to the read head **801**, a spin accumulation will occur, and hence a spin current is generated from the sensor **840** and flows into the non-magnetic layer **406**. The spin current travels across the read sensor **840** through the non-magnetic layer **406** to the spin detector **850**. The spin current then splits such that half of the spin current flows down through the second SOT layer **810** and half of the spin current flows up through the first SOT layer **510** (as shown by the arrows labeled Is), where the spin current flows out-of-plane (i.e., in the y-direction) through each SOT layer **510**, **810**. The vertical spin current flowing into the SOT layers **510**, **810** enables an electrical signal generation across the SOT layers **510**, **810** via the inverse spin Hall effect when the free layer **418** rotates its magnetization directions when reading data. Because the two split spin currents flow opposite in the y-direction, the generated signal polarity will be opposite as well, as shown by the voltage leads V.sub.2+N.sub.2− and V.sub.1+N.sub.1− in FIG. **8**D. The first positive voltage lead (V.sub.1+) and the second negative voltage lead (V.sub.2−) are connected together such that the final signal read out occurs at the first negative voltage lead (V.sub.1−) and the second positive voltage lead (V.sub.2+).

(76) FIGS. **9**A-**9**B illustrate a read head **900** of a magnetic recording head, according to yet another embodiment. FIG. **9**A illustrates a cross-sectional view of the read head **900** and FIG. **9**B illustrates a MFS view of the read head **900**. The read head **900** is similar to the read head **800** of FIGS. **8**A-**8**B, however, rather than comprising the shield notch **802**, the sensor **940** comprises a first free layer **418** and a second free layer **918** for a dual free layer (DFL) configuration. Furthermore, similar to the read heads **600** and **700** of FIGS. **6**A-**7**B, the read head **900** does not comprise the notch **516**.

(77) In the read head **900**, the sensor **940** comprises a seed layer **920** disposed over the first shield **402**, a second free layer **918** disposed on the seed layer **920**, a second tunnel barrier layer **922** disposed on the second free layer **918**, the first tunnel barrier layer **520** disposed on the non-magnetic layer **406**, a first free layer **418** disposed on the first tunnel barrier layer **520**, and the cap layer **522** disposed on the first free layer **418**. A portion of the non-magnetic layer **406** disposed in contact with the second tunnel barrier layer **922** and the first tunnel barrier layer **520** may be considered a part of the sensor **940** as well. The second free layer **918** may comprise the same

material as the first free layer **418**.

(78) A second insulating layer **914** is disposed between the sensor **940** and the spin generator **950** below the non-magnetic layer **406**. The second insulating layer **914** may be disposed between the second cap layer **812** and the first shield **402**, as well as behind the second cap layer **812**, the second SOT layer **810**, and the second seed layer **808**. The second insulating layer **914** may comprise the same material as the insulating layer **514**. The first and second tunnel barrier layers **520**, **922** may each comprise the same material. The seed layer **920** and the cap layer **522** may comprise the same material.

(79) The first and second SB side shields **524**, **526** are disposed adjacent to the first free layer **418** at the MFS. A third SB side shield **924** and a fourth SB side shield **926** are disposed adjacent to the second free layer **918** at the MFS. The first, second, third, and fourth SB side shields **524**, **526**, **924**, **926** may all comprise the same material. The first SB side shield **524** is disposed over the third SB side shield **924**, and the second SB side shield **526** is disposed over the fourth SB side shield **926**. A first Ru layer **925** is disposed between the first SB side shield **524** and the third SB side shield **924**, and a second Ru layer **927** is disposed between the second SB side shield **526** and the fourth SB side shield **926**. The first Ru layer **925** is adjusted such that it allows for antiferromagnetic coupling of the first and third SB side shields **524**, **924**, and the second Ru layer **927** is adjusted such that it allows for antiferromagnetic coupling of the second and fourth SB side shields **526**, **926**. The magnetization of the third and fourth SB side shields **924**, **926** to that of the first and second SB side shields **524**, **526** is opposite such that first free layer **418** and the second free layer **918** have an opposite magnetization orientation in the cross-track direction (along the z-direction).

(80) The first signal voltage lead (V−) is connected to the first shield **402**, and the second signal voltage lead (V+) is connected to the second shield **404**. A first negative current lead (I.sub.1−) and a first positive current lead (I.sub.1+) are connected to the second SOT layer **810**, and a second negative current lead (I.sub.2−) and a second positive current lead (I.sub.2+) are connected to the first SOT layer **510**. The first negative current lead (I.sub.1−) is disposed adjacent to the second positive current lead (I.sub.2+), and the first positive current lead (I.sub.1+) is disposed adjacent to the second negative current lead (I.sub.2−).

(81) During operating, a first electrical current (I.sub.1) flows through the second SOT layer **810** out of the page (with respect to FIG. **9**A), or in the z-direction, and a second electrical current (I.sub.2) flows through the first SOT layer **510** into the page (with respect to FIG. **9**A), or in the −z-direction. A magnetization direction of the second free layer **918** is in the z-direction, and a magnetization direction of the first free layer **418** is in the −z-direction. As such, the first free layer **418** and the second free layer **918** have anti-parallel magnetization directions. By including two SOT layers in the spin generator **950**, the induced spin current is doubled. The signal coming from each free layer **418**, **918** is decided by the relative angle between the free layer magnetization to spin polarization (P) in the non-magnetic layer **406**. By including two free layers **418**, **918** in the sensor **940**, the signal produced is doubled.

(82) By including at least one SOT layer in a read sensor recessed from the MFS, the read heads discussed above are able to achieve a higher spin current injection/polarization, such that by making effective polarization significantly larger than 1. Furthermore, due to the trapezoidal shape of the non-magnetic transport layer, the spin current is more concentrated and the signal output is increased at the read sensor disposed at the MFS.

(83) In one embodiment, a read head comprises a first shield, a second shield, a non-magnetic layer disposed between the first shield and the second shield, a sensor disposed between the non-magnetic layer and the second shield at a media facing surface (MFS), the sensor comprising a free layer, and a spin generator disposed adjacent to the non-magnetic layer and recessed from the MFS by a first distance, the spin generator being spaced from the sensor, wherein the spin generator comprises a spin orbit torque (SOT) layer and wherein the first distance is greater than a height of the free layer as measured from the MFS.

(84) The spin generator is disposed between the non-magnetic layer and the second shield. The read head further comprises a negative voltage lead connected to the first shield, a positive voltage lead connected to the second shield, a positive current lead connected to the SOT layer, and a negative current lead connected to the SOT layer, wherein the positive and negative current leads are aligned to provide a current path through the SOT layer in a cross-track direction. The read head further comprises a negative voltage lead connected to the non-magnetic layer, a positive voltage lead connected to the second shield, a positive current lead connected to the SOT layer, and a negative current lead connected to the SOT layer, wherein the positive and negative current leads are aligned to provide a current path through the SOT layer in a cross-track direction.
(85) The read head further comprises a negative current lead connected to the first shield, a positive current lead connected to the second shield, a positive voltage lead connected to the SOT layer, and a negative voltage lead connected to the SOT layer. The read head further comprises a negative current lead connected to the non-magnetic layer, a positive current lead connected to the second shield, a positive voltage lead connected to the SOT layer, and a negative voltage lead connected to the SOT layer. The SOT layer comprises a topological insulating material. The topological insulator material is BiSb. The non-magnetic layer comprises a first portion and a second portion, the first portion have a greater width than the second portion, wherein the first portion is disposed adjacent to the spin generator and the second portion is disposed adjacent to the sensor. The spin generator further comprises a seed layer disposed on the non-magnetic layer and a cap layer disposed on the SOT layer, and wherein the sensor further comprises a first tunnel barrier layer disposed on the non-magnetic layer and a cap layer disposed on the free layer. The spin generator is disposed between the non-magnetic layer and the first shield. A magnetic recording head comprises the read head. A magnetic recording device comprises the magnetic recording head.
(86) In another embodiment, a magnetic recording device comprises a read head, the read head comprising: a first shield, the first shield comprising a shield notch, a second shield, a non-magnetic layer disposed between the shield notch and the second shield, a sensor disposed between the non-magnetic layer and the second shield at a media facing surface (MFS), the sensor comprising a free layer, and a spin generator recessed from the MFS, the spin generator being spaced from the sensor, wherein the spin generator comprises: a first spin orbit torque (SOT) layer disposed between the first shield and the non-magnetic layer, and a second SOT layer disposed between the non-magnetic layer and the second shield.
(87) The first SOT layer is disposed adjacent to the shield notch, and wherein the second SOT layer is disposed adjacent to the free layer. The non-magnetic layer extends between the sensor and the spin generator, and wherein the non-magnetic layer has a height of about 100 nm to about 300 nm. The read head further comprises: a first negative current lead connected to the first SOT layer, a first positive current lead connected to the first SOT layer, a second positive current lead connected to the second SOT layer, the second positive current lead being disposed adjacent to the first negative current lead, and a second negative current lead connected to the second SOT layer, the second negative current lead being disposed adjacent to the first positive current lead.
(88) The read head further comprises: a first negative voltage lead connected to the first SOT layer, a first positive voltage lead connected to the first SOT layer, a second positive voltage lead connected to the second SOT layer, the second positive voltage lead being disposed adjacent to the first negative voltage lead, and a second negative voltage lead connected to the second SOT layer, the second negative voltage lead being disposed adjacent to the first positive voltage lead. The read head further comprises a non-magnetic notch disposed between the shield notch and the non-magnetic layer. The spin generator is disposed between the first shield and the second shield. A magnetic recording device comprises the magnetic recording head.
(89) In yet another embodiment, a magnetic recording device comprises a read head, the read head comprising: a first shield, a second shield, a non-magnetic layer disposed between the first shield and the second shield, a sensor disposed between the first shield and the second shield at a media

facing surface (MFS), the sensor comprising a first free layer and a second free layer, and a spin generator recessed from the MFS, the spin generator being spaced from the sensor, wherein the spin generator comprises: a first spin orbit torque (SOT) layer disposed between the first shield and the non-magnetic layer, and a second SOT layer disposed between the non-magnetic layer and the second shield.

(90) The read head further comprises: a first negative current lead connected to the first SOT layer, a first positive current lead connected to the first SOT layer, a second positive current lead connected to the second SOT layer, the second positive current lead being disposed adjacent to the first negative current lead, and a second negative current lead connected to the second SOT layer, the second negative current lead being disposed adjacent to the first positive current lead. The read head further comprises: a first negative voltage lead connected to the first SOT layer, a first positive voltage lead connected to the first SOT layer, a second positive voltage lead connected to the second SOT layer, the second positive voltage lead being disposed adjacent to the first negative voltage lead, and a second negative voltage lead connected to the second SOT layer, the second negative voltage lead being disposed adjacent to the first positive voltage lead.

(91) The first free layer is disposed between the first shield and the non-magnetic layer, and wherein the second free layer is disposed between the non-magnetic layer and the second shield. The read head further comprises: a first soft bias side shield disposed adjacent to the first free layer at the MFS, a second soft bias side shield disposed adjacent to the first free layer at the MFS, a third soft bias side shield disposed adjacent to the second free layer at the MFS, a fourth soft bias side shield disposed adjacent to the second free layer at the MFS, a first Ru layer disposed between the first soft bias side shield and the third soft bias side shield, and a second Ru layer disposed between the second soft bias side shield and the fourth soft bias side shield. The first free layer is spaced from the first SOT layer by a first insulating layer, and wherein the second free layer is spaced from the second SOT layer by a second insulating layer. The first SOT layer and the second SOT layer each individually have a thickness of about 5 nm to about 20 nm, a height of about 100 nm to about 1 μm, and a width of less than about 100 nm. The non-magnetic layer extends between the sensor and the spin generator, and wherein the non-magnetic layer has a height of about 100 nm to about 300 nm, and wherein the non-magnetic comprises a first portion and a second portion, the first portion have a greater width than the second portion, wherein the first portion is disposed adjacent to the spin generator and the second portion is disposed adjacent to the sensor. The spin generator is disposed between the first shield and the second shield. A magnetic recording device comprises the magnetic recording head.

(92) While the foregoing is directed to embodiments of the present disclosure, other and further embodiments of the disclosure may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

Claims

1. A read head, comprising: a first shield; a second shield; a non-magnetic layer disposed between the first shield and the second shield; a sensor disposed between the non-magnetic layer and the second shield at a media facing surface (MFS), the sensor comprising a free layer, a first tunnel barrier layer, and a first cap layer, wherein the first tunnel barrier layer is disposed on the non-magnetic layer and the first cap layer is disposed on the free layer; and a spin generator disposed adjacent to the non-magnetic layer and recessed from the MFS by a first distance, the spin generator being spaced from the sensor, wherein the spin generator comprises a spin orbit torque (SOT) layer, a seed layer, and a second cap layer disposed on the SOT layer, wherein the first distance is greater than a height of the free layer as measured from the MFS, and wherein the seed layer is disposed on non-magnetic layer.

2. The read head of claim 1, wherein the spin generator is disposed between the non-magnetic layer

and the second shield.
3. The read head of claim 1, further comprising: a negative voltage lead connected to the non-magnetic layer; a positive voltage lead connected to the second shield; a positive current lead connected to the SOT layer; and a negative current lead connected to the SOT layer, wherein the positive and negative current leads are aligned to provide a current path through the SOT layer in a cross-track direction.
4. The read head of claim 1, further comprising: a negative current lead connected to the first shield; a positive current lead connected to the second shield; a positive voltage lead connected to the SOT layer; and a negative voltage lead connected to the SOT layer.
5. The read head of claim 1, further comprising: a negative current lead connected to the non-magnetic layer; a positive current lead connected to the second shield; a positive voltage lead connected to the SOT layer; and a negative voltage lead connected to the SOT layer.
6. The read head of claim 1, wherein the SOT layer comprises a topological insulating material.
7. The read head of claim 6, wherein the topological insulating material is BiSb.
8. The read head of claim 1, wherein the non-magnetic layer comprises a first portion and a second portion, the first portion have a greater width than the second portion, wherein the first portion is disposed adjacent to the spin generator and the second portion is disposed adjacent to the sensor.
9. The read head of claim 1, wherein the spin generator is disposed between the non-magnetic layer and the first shield.
10. A magnetic recording head comprising the read head of claim 1.
11. A magnetic recording device comprising the magnetic recording head of claim 10.
12. A read head, comprising: a first shield; a second shield; a non-magnetic layer disposed between the first shield and the second shield; a sensor disposed between the non-magnetic layer and the second shield at a media facing surface (MFS), the sensor comprising a free layer, a first tunnel barrier layer and a first cap layer; a spin generator disposed adjacent to the non-magnetic layer and recessed from the MFS by a first distance, the spin generator being spaced from the sensor, wherein the spin generator comprises a spin orbit torque (SOT) layer and a seed layer, and wherein the first distance is greater than a height of the free layer as measured from the MFS; a negative voltage lead connected to the first shield; a positive voltage lead connected to the second shield; a positive current lead connected to the SOT layer; and a negative current lead connected to the SOT layer, wherein the positive and negative current leads are aligned to provide a current path through the SOT layer in a cross-track direction.
13. A magnetic recording device, comprising: a read head, the read head comprising: a first shield, the first shield comprising a shield notch; a second shield; a non-magnetic layer disposed between the shield notch and the second shield; a sensor disposed between the non-magnetic layer and the second shield at a media facing surface (MFS), the sensor comprising a free layer; and a spin generator disposed recessed from the MFS, the spin generator being spaced from the sensor, wherein the spin generator comprises: a first spin orbit torque (SOT) layer disposed between the first shield and the non-magnetic layer; and a second SOT layer disposed between the non-magnetic layer and the second shield.
14. The magnetic recording device of claim 13, wherein the first SOT layer is disposed adjacent to the shield notch, and wherein the second SOT layer is disposed adjacent to the free layer.
15. The magnetic recording device of claim 13, wherein the non-magnetic layer extends between the sensor and the spin generator, and wherein the non-magnetic layer has a height of about 100 nm to about 300 nm.
16. The magnetic recording device of claim 13, wherein the read head further comprises: a first negative current lead connected to the first SOT layer; a first positive current lead connected to the first SOT layer; a second positive current lead connected to the second SOT layer, the second positive current lead being disposed adjacent to the first negative current lead; and a second negative current lead connected to the second SOT layer, the second negative current lead being

disposed adjacent to the first positive current lead.

17. The magnetic recording device of claim 13, wherein the read head further comprises: a first negative voltage lead connected to the first SOT layer; a first positive voltage lead connected to the first SOT layer; a second positive voltage lead connected to the second SOT layer, the second positive voltage lead being disposed adjacent to the first negative voltage lead; and a second negative voltage lead connected to the second SOT layer, the second negative voltage lead being disposed adjacent to the first positive voltage lead.

18. The magnetic recording device of claim 13, wherein the read head further comprises a non-magnetic notch disposed between the shield notch and the non-magnetic layer.

19. The magnetic recording device of claim 13, wherein the spin generator is disposed between the first shield and the second shield.

20. A magnetic recording device, comprising: a read head, the read head comprising: a first shield; a second shield; a non-magnetic layer disposed between the first shield and the second shield; a sensor disposed between the first shield and the second shield at a media facing surface (MFS), the sensor comprising a first free layer; and a spin generator disposed recessed from the MFS, the spin generator being spaced from the sensor, wherein the spin generator comprises: a first spin orbit torque (SOT) layer disposed between the first shield and the non-magnetic layer; and a second SOT layer disposed between the non-magnetic layer and the second shield.

21. The magnetic recording device of claim 20, wherein the read head further comprises: a first negative current lead connected to the first SOT layer; a first positive current lead connected to the first SOT layer; a second positive current lead connected to the second SOT layer, the second positive current lead being disposed adjacent to the first negative current lead; and a second negative current lead connected to the second SOT layer, the second negative current lead being disposed adjacent to the first positive current lead.

22. The magnetic recording device of claim 20, wherein the read head further comprises: a first negative voltage lead connected to the first SOT layer; a first positive voltage lead connected to the first SOT layer; a second positive voltage lead connected to the second SOT layer, the second positive voltage lead being disposed adjacent to the first negative voltage lead; and a second negative voltage lead connected to the second SOT layer, the second negative voltage lead being disposed adjacent to the first positive voltage lead.

23. The magnetic recording device of claim 20, wherein the sensor further comprises a second free layer, wherein the first free layer is disposed between the first shield and the non-magnetic layer, and wherein the second free layer is disposed between the non-magnetic layer and the second shield.

24. The magnetic recording device of claim 23, wherein the read head further comprises: a first soft bias side shield disposed adjacent to the first free layer at the MFS; a second soft bias side shield disposed adjacent to the first free layer at the MFS; a third soft bias side shield disposed adjacent to the second free layer at the MFS; a fourth soft bias side shield disposed adjacent to the second free layer at the MFS; a first Ru layer disposed between the first soft bias side shield and the third soft bias side shield; and a second Ru layer disposed between the second soft bias side shield and the fourth soft bias side shield.

25. The magnetic recording device of claim 23, wherein the first free layer is spaced from the first SOT layer by a first insulating layer, and wherein the second free layer is spaced from the second SOT layer by a second insulating layer.

26. The magnetic recording device of claim 20, wherein the first SOT layer and the second SOT layer each individually have a thickness of about 5 nm to about 20, a height of about 100 nm to about 1 μm, and a width of less than about 100 nm.

27. The magnetic recording device of claim 20, wherein the non-magnetic layer extends between the sensor and the spin generator, and wherein the non-magnetic layer has a height of about 100 nm to about 300 nm, wherein the non-magnetic layer comprises a first portion and a second portion,

the first portion have a greater width than the second portion, and wherein the first portion is disposed adjacent to the spin generator and the second portion is disposed adjacent to the sensor.

28. The magnetic recording device of claim 20, wherein the spin generator is disposed between the first shield and the second shield.