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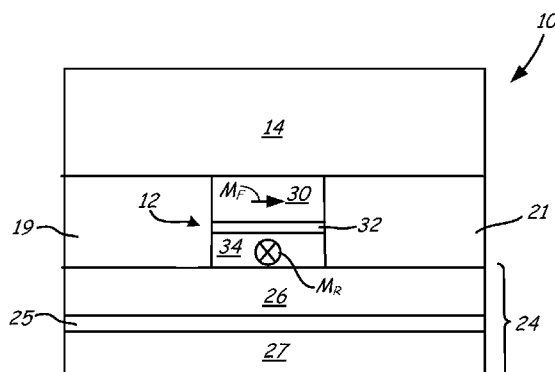


FIG. 1

(57) Abstract: A magneto-resistive reader includes a first magnetic shield element, a second magnetic shield element and a magneto-resistive sensor stack separating the first magnetic shield element from the second magnetic shield element. The first shield element includes two ferromagnetic anisotropic layers separated by a grain growth suppression layer.

MAGNETIC SENSOR WITH COMPOSITE MAGNETIC SHIELD

BACKGROUND

- [01] In an electronic data storage and retrieval system, a magnetic recording head can include a reader portion having a sensor for retrieving magnetically encoded information stored on a magnetic medium. Magnetic flux from the surface of the medium causes rotation of the magnetization vector of a sensing layer or layers of the sensor, which in turn causes a change in the electrical properties of the sensor. The sensing layers are often called free layers, since the magnetization vectors of the sensing layers are free to rotate in response to external magnetic flux. The change in the electrical properties of the sensor may be detected by passing a current through the sensor and measuring a voltage across the sensor. Depending on the geometry of the device, the sense current may be passed in the plane (CIP) of the layers of the device or perpendicular to the plane (CPP) of the layers of the device. External circuitry then converts the voltage information into an appropriate format and manipulates that information as necessary to recover information encoded on the disc.
- [02] A structure in contemporary magnetic read heads is a thin film multilayer structure containing ferromagnetic material that exhibits some type of magnetoresistance. One magnetoresistive sensor configuration includes a multilayered structure formed of a nonmagnetic layer (such as a thin insulating barrier layer or a nonmagnetic metal) positioned between a synthetic antiferromagnet (SAF) and a ferromagnetic free layer, or between two ferromagnetic free layers. The resistance of the magnetic sensor depends on the relative orientations of the magnetization of the magnetic layers.
- [03] Magnetic read sensors have magnetic shields that to increase the spatial resolution of the read sensor by shielding the read sensor from stray magnetic fields. It is important that the magnetic domain configuration of the magnetic shield and its response to small magnetic fields from recording media be stable against exposure to large and nonuniform magnetic fields in order to minimize unwanted noise registered in the read sensor. The magnetic domain configuration can be established by controlling the

magnetic anisotropy of the ferromagnetic shield material. However, processing of the read sensor can require that the shield be exposed to strong magnetic fields at elevated temperatures that can reorient (e.g., cause magnetic grain growth) the magnetic anisotropy of the magnetic shield in an unfavorable way.

BRIEF SUMMARY

- [04] The present disclosure relates to a magnetic sensor with a composite magnetic shield. The present disclosure can improve the areal density capabilities of various types of magneto resistive (MR) readers. The composite first magnetic shield provides stable anisotropy at elevated magnetic set and cross anneal temperatures.
- [05] In one particular embodiment, a magneto-resistive reader includes a first magnetic shield element, a second magnetic shield element and a tunneling magneto-resistive sensor stack separating the first magnetic shield element from the second magnetic shield element. The first shield element includes two ferromagnetic anisotropic layers separated by a grain growth suppression layer. The magneto-resistive reader can be a tunneling magneto-resistive reader with a TMR ratio of 100 % or greater.
- [06] These and various other features and advantages will be apparent from a reading of the following detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

- [07] The disclosure may be more completely understood in consideration of the following detailed description of various embodiments of the disclosure in connection with the accompanying drawings, in which:
- [08] **FIG. 1** is a front surface view of a reader including a free layer assembly having a perpendicular to the plane anisotropy and side shields;
- [09] **FIG. 2A** is layer schematic diagram of an illustrative composite shield;
- [10] **FIG. 2B** is a layer schematic diagram of another illustrative composite shield;

- [11] FIG. 3A-3C are layer schematic diagrams illustrating the method of forming an illustrative reader;
- [12] FIG. 4 is a flow diagram of an illustrative method of forming an illustrative reader;
- [13] FIG. 5A-5D are layer schematic diagrams illustrating the method of forming an illustrative shield element; and
- [14] FIG. 6 is a flow diagram of an illustrative method of forming an illustrative shield element.
- [15] The figures are not necessarily to scale. Like numbers used in the figures refer to like components. However, it will be understood that the use of a number to refer to a component in a given figure is not intended to limit the component in another figure labeled with the same number.

DETAILED DESCRIPTION

- [16] In the following description, reference is made to the accompanying set of drawings that form a part hereof and in which are shown by way of illustration several specific embodiments. It is to be understood that other embodiments are contemplated and may be made without departing from the scope or spirit of the present disclosure. The following detailed description, therefore, is not to be taken in a limiting sense. The definitions provided herein are to facilitate understanding of certain terms used frequently herein and are not meant to limit the scope of the present disclosure.
- [17] Unless otherwise indicated, all numbers expressing feature sizes, amounts, and physical properties used in the specification and claims are to be understood as being modified in all instances by the term “about.” Accordingly, unless indicated to the contrary, the numerical parameters set forth in the foregoing specification and attached claims are approximations that can vary depending upon the desired properties sought to be obtained by those skilled in the art utilizing the teachings disclosed herein.

- [18] The recitation of numerical ranges by endpoints includes all numbers subsumed within that range (e.g. 1 to 5 includes 1, 1.5, 2, 2.75, 3, 3.80, 4, and 5) and any range within that range.
- [19] As used in this specification and the appended claims, the singular forms “a”, “an”, and “the” encompass embodiments having plural referents, unless the content clearly dictates otherwise. As used in this specification and the appended claims, the term “or” is generally employed in its sense including “and/or” unless the content clearly dictates otherwise.
- [20] It is noted that terms such as “top”, “bottom”, “above”, “below”, etc. may be used in this disclosure. These terms should not be construed as limiting the position or orientation of a structure, but should be used as providing spatial relationship between the structures. Other layers, such as seed or capping layers, are not depicted for clarity but could be included as technical need arises.
- [21] The present disclosure relates to a magnetic sensor with a composite magnetic shield. The composite magnetic shield provides stable anisotropy at elevated magnetic set anneal and cross temperatures. The composite magnetic shield includes two ferromagnetic layers separated by a grain growth suppression layer. The grain growth suppression layer inhibits structural changes in the ferromagnetic layers and stabilizes the anisotropic magnetic domain structure of the shield during a high temperature anneal. While the present disclosure is not so limited, an appreciation of various aspects of the disclosure will be gained through a discussion of the examples provided below.
- [22] **FIG. 1** is a front surface view of a magneto-resistive (MR) reader **10** including a composite first shield **24** in some embodiments the magneto-resistive (MR) reader is a tunneling magneto-resistive (TMR) reader. The tunneling magneto-resistive (TMR) reader **10** includes a sensor stack **12** separating a second magnetic shield **14** from a first composite magnetic shield **24**. The sensor stack **12** includes a reference magnetic element **34** having a reference magnetization orientation \mathbf{M}_R direction a free magnetic element **30** having a free magnetization orientation \mathbf{M}_F direction substantially perpendicular (and in-plane) to the reference magnetization orientation \mathbf{M}_R direction,

and a non-magnetic spacer **32** layer separating the reference magnetic element **34** from the free magnetic element **30**. While **FIG. 1** illustrates a free magnetic element **30** having magnetization orientation \mathbf{M}_F direction substantially perpendicular to the reference magnetization orientation \mathbf{M}_R direction, it is understood that the free magnetization orientation \mathbf{M}_F direction can be substantially parallel or anti-parallel to the reference magnetization orientation \mathbf{M}_R direction. Electrically insulating layer **19**, **21** electrically insulates the second magnetic shield **14** from a first composite magnetic shield **24**.

- [23] In the embodiment shown, free magnetic element **30** is on the top of sensor stack **12** and reference magnetic element **34** is on the bottom of sensor stack **12**. It will be appreciated that sensor stack **12** may alternatively include reference magnetic element **34** on the top of sensor stack **12** and free magnetic element **30** on the bottom of sensor stack **12**.
- [24] Free magnetic element **30** is a single or a composite or multiple layer structure having a magnetization \mathbf{M}_F that rotates in response to an external magnetic field. In many embodiments, the sensor stack **12** senses magnetic flux from a magnetic media. In tunneling magneto-resistive (TMR) reader embodiments, the sensor stack **12** is a tunneling magneto resistive type (TMR) sensor where the reference magnetic element **34** and the free magnetic element **30** are ferromagnetic layers separated by an insulating spacer layer **32** that is thin enough (e.g., 1 to 5 nanometers thick) to allow electrons to tunnel from one ferromagnetic layer to the other ferromagnetic layer.
- [25] Spacer layer **32** is a nonmagnetic insulting layer disposed between free magnetic element **30** and reference magnetic element **34**. In many embodiments, spacer layer **32** is a non-magnetic, insulative or semi-conductive material, such as oxides formed of Mg, Al, Hf, or Ti. In some embodiments the spacer layer **32** is MgO.
- [26] Reference magnetic element **34** has a fixed magnetization direction \mathbf{M}_R that is in-plane with the layer or layers of magnetic element **34**. Magnetization direction \mathbf{M}_F of free magnetic element **30** is either perpendicular to fixed magnetization direction \mathbf{M}_R in a quiescent state or parallel or anti-parallel to fixed magnetization direction \mathbf{M}_R in a quiescent state. Reference magnetic element **34** may be a single ferromagnetic layer

having an anisotropically defined magnetization direction. Reference magnetic element **34** may also include various combinations of layers to provide magnetization \mathbf{M}_R having a fixed direction, such as a ferromagnetic pinned layer with an antiferromagnetic pinning layer, a synthetic ferromagnetic pinned layer (i.e., two ferromagnetic layers coupled by a nonmagnetic metal, such as Ru), or a synthetic ferromagnetic pinned layer coupled to an antiferromagnetic pinning layer. Ferromagnetic layers of reference layer assembly **34** may be made of a ferromagnetic alloy, such as CoFe, NiFe, or NiFeCo, and the antiferromagnetic layer may be made of PtMn, IrMn, NiMn, or FeMn.

- [27] In operation, a sense current is passed through sensor stack **12** via shields **14** and **24** (which can also function as electronic leads in some embodiments) such that the sense current passes perpendicular to the plane of the layer or layers of sensor stack **12**. As magnetization \mathbf{M}_F rotates in response to external magnetic fields, the resistance of sensor stack **12** changes as a function of the angle between magnetizations \mathbf{M}_F and \mathbf{M}_R . The voltage across sensor stack **12** is measured between leads/shields **14** and **24** by external circuitry (not shown) to detect changes in resistance of sensor stack **12**.
- [28] Portions of the sensor stack **12** require annealing to set a magnetization direction therein. Tunneling magneto resistive type sensor stack **12** design has shown that higher annealing temperatures such as, 300 degrees centigrade or greater, or 340 degrees centigrade or greater, or 390 degrees centigrade or greater, for example, improves the TMR ratio % of the sensor stack **12**. The high temperature anneals can produce a tunneling magneto resistive type sensor stack **12** having a TMR ratio of 100% or greater, or 200% or greater, or 300% or greater. The TMR (tunneling magneto-resistive) ratio % is derived from the following equation (1):

$$\text{TMR ratio (\%)} = (\text{Rmax} - \text{Rmin}) / \text{Rmax} \times 100 \quad (1)$$

Where Rmax and Rmin are the resistance values obtained when applying a current through the sensor stack in a parallel (low resistance state) and anti-parallel (high resistance state). Increasing the TMR ratio improves the sensor stack sensitivity and reliability.

- [29] Since the tunneling magneto resistive type sensor stack **12** is deposited on the composite first shield **24**, the composite first shield **24** has to provide stable anisotropy at the higher anneal temperatures that are needed to provide the sensor stack **12** that possess a higher TMR ratio percentage. The composite first shield **24** described herein provides stable anisotropy at the higher anneal temperatures.
- [30] The composite first shield **24** includes two ferromagnetic anisotropic layers **26**, **27** separated by a grain growth suppression layer **25**. The grain growth suppression layer **25** inhibits diffusion, defect mobility, and grain crystallization during magnetic annealing of the magneto-resistive reader **10**. The grain growth suppression layer **25** has a thickness of less than 100 Angstroms or 50 Angstroms or less, or a thickness in a range from 5 to 50 Angstroms. In many embodiments, the overall thickness of the composite first shield **24** is about one micrometer and in many embodiments the thickness of each of the two ferromagnetic anisotropic layers **26**, **27** is about equal.
- [31] In some embodiments the grain growth suppression layer **25** is non-magnetic. In some embodiments the grain growth suppression layer **25** is magnetic. In illustrative embodiments, the grain growth suppression layer **25** is Ru, Ta, Nb, Zr, or Hf and the two ferromagnetic anisotropic layers **26**, **27** are NiFe. In many embodiments, the grain growth suppression layer **25** is Ru or Ta and the two ferromagnetic anisotropic layers **26**, **27** are NiFe.
- [32] **FIG. 2A** is layer schematic diagram of an illustrative composite first shield **24**. The composite first shield **24** includes two ferromagnetic anisotropic layers **26**, **27** separated by a grain growth suppression layer **25**, as described above. In some embodiments the grain growth suppression layer **25** is non-magnetic. In some embodiments the grain growth suppression layer **25** is magnetic. The composite first shield **24** can further include an optional hard magnetic layer **28**. The hard magnetic layer **28** can be formed of any useful magnetic material that has an ability to magnetically couple to the bottom of the composite shield layers and have a magnetic coercivity high enough to withstand magnetization reversal from media and stray fields during operation.
- [33] **FIG. 2B** is a layer schematic diagram of another illustrative composite first shield **24**. The composite first shield **24** includes three ferromagnetic anisotropic layers **26**, **27**, **23**

separated by grain growth suppression layers **25, 29**, as described above. In some embodiments the grain growth suppression layer **25, 29** is non-magnetic. In some embodiments the grain growth suppression layer **25, 29** is magnetic. The composite first shield **24** further can include a hard magnetic layer like in **FIG. 2A**. The hard magnetic layer **28** can be formed of any useful magnetic material.

- [34] **FIG. 3A-3C** are layer schematic diagrams illustrating the method of forming an illustrative tunneling magneto-resistive (TMR) reader **10**. **FIG. 4** is a flow diagram of an illustrative method of forming an illustrative tunneling magneto-resistive (TMR) reader. The method includes depositing a first shield element **24** on a substrate **5**. The first shield element **24** can be sputter deposited using semiconductor fabrication techniques. The first shield element **24** includes two ferromagnetic anisotropic layers **27, 26** separated by a grain growth suppression layer **25** at block **101**. The first shield element **24** is described above.
- [35] Then the method includes annealing the first shield element **24** at a magnetic set anneal temperature to form a set annealed first shield at block **102**. A magnetic field is applied to the first shield element **24** at an elevated temperature to set the magnetic orientation of the at least one ferromagnetic layer **27, 26** of the first shield element **24**. In many embodiments the magnetic set anneal temperature is greater than 350 degrees centigrade, or greater than 390 degrees centigrade, or greater than 440 degrees centigrade. As described above, the grain growth suppression layer **25** inhibits grain growth and improves the anisotropy of the first shield element **24**.
- [36] Then the method includes depositing a tunneling magneto-resistive sensor stack **12** on the annealed first shield **24** at block **103**. The tunneling magneto-resistive sensor stack **12** includes a reference magnetic element **34**, a free magnetic element **30**, and a non-magnetic spacer **32** layer separating the reference magnetic element **34** from the free magnetic element **30**. The tunneling magneto-resistive sensor stack **12** is described above and can be sputter deposited using semiconductor fabrication techniques.
- [37] Then the tunneling magneto-resistive sensor stack **12** is annealed at a magnetic cross set anneal temperature to form a cross set annealed tunneling magneto-resistive sensor stack at block **104**. A magnetic field is applied to the tunneling magneto-resistive

sensor stack **12** at an elevated temperature to set the magnetic orientation of the at least one ferromagnetic layer **30**, **34** of the tunneling magneto-resistive sensor stack **12**. In many embodiments the cross set magnetic field is perpendicular to the magnetic set magnetic field. The magnetic cross set anneal temperature is below the set annealing temperature of the first shield element **24** so as not disturb the magnetic orientation of the first shield element **24** and above the blocking temperature of the antiferromagnet in the stack so the reference layer is pinned when it cools after annealing. In many embodiments, the magnetic cross set anneal temperature is greater than 350 degrees centigrade, or greater than 390 degrees centigrade. A second shield element **14** is then deposited on the cross set annealed tunneling magneto-resistive sensor stack **12** at block **105**, to form the tunneling magneto-resistive (TMR) reader **10**.

- [38] **FIG. 5A-5D** are layer schematic diagrams illustrating the method of forming an illustrative first shield element. **FIG. 6** is a flow diagram of an illustrative method of forming an illustrative first shield element. The method includes depositing a first shield element **24**. The first shield element **24** including two ferromagnetic anisotropic layers **27**, **26** separated by a grain growth suppression layer **25**, and annealing the first shield element **24** to form a set annealed first shield, as described above. An exposed surface of the first shield element **24** is then polished to form a smooth exposed first shield surface, utilizing semiconductor fabrication techniques. The polishing step removes a minor amount of layer being polished. For example, the polishing step removes less than 2% or less than 1% of the ferromagnetic layer being polished.
- [39] The structure of the first shield element **24** can be defined by any useful method, such as patterning by photolithography and then etching, for example. The patterning can be preformed following the depositing step of block **201**. The resulting structure is described as a patterned first shield element **24** below.
- [40] In many embodiments, a chemical mechanical polishing (CMP) stop layer **50** is then deposited on the smooth exposed first shield surface at block **201**. The CMP stop layer **50** can be any useful CMP stop material such as chromium or a-carbon, for example. In many embodiments this structure is then patterned to form the desired first shield

element dimensions, utilizing semiconductor fabrication techniques. In other embodiments, a chemical mechanical polishing (CMP) stop layer **50** is not deposited.

- [41] An insulating material **60** is deposited about the patterned first shield element **24** at block **202**. The insulating material can be any useful electrically insulating material such as metal oxides or semiconductor oxides, for example. The insulating material **60** can encapsulate the patterned first shield element **24**.
- [42] Then the method includes removing insulating material **60** by chemical mechanical polishing down to the chemical mechanical polishing stop layer **50** at block **203**. The CMP method step forms a planar surface of insulating regions and CMP stop layer regions. Then the chemical mechanical polishing stop layer **50** is removed at block **204**. Then the sensor stack can be deposited on smooth exposed surface of the first shield element as described above.
- [43] This method provides layer thickness control of the top ferromagnetic layer of the composite first shield. Very little of the top ferromagnetic layer is removed during the CMP process and the smooth polish method step provides a smooth surface for depositing the sensor stack and improves the sensor stack uniformity during deposition.
- [44] Thus, embodiments of the MAGNETIC SENSOR WITH COMPOSITE MAGNETIC SHIELD are disclosed. The implementations described above and other implementations are within the scope of the following claims. One skilled in the art will appreciate that the present disclosure can be practiced with embodiments other than those disclosed. The disclosed embodiments are presented for purposes of illustration and not limitation, and the present invention is limited only by the claims that follow.

What is claimed is:

1. A magneto-resistive reader comprising:
a first magnetic shield element, the first shield element comprising two
ferromagnetic anisotropic layers separated by a grain growth suppression
layer;
a second magnetic shield element; and
a magneto-resistive sensor stack separating the first magnetic shield element
from the second magnetic shield element.
2. A magneto-resistive reader according to claim 1, wherein the magneto-resistive
is a tunneling magneto-resistive reader having a TMR ratio of 100 % or greater.
3. A magneto-resistive reader according to claims 1 or 2, wherein the grain growth
suppression layer has a thickness of less than 100 Angstroms.
4. A magneto-resistive reader according to claims 1 to 3, wherein the grain growth
suppression layer is non-magnetic.
5. A magneto-resistive reader according to claims 1 to 4, the grain growth
suppression layer is magnetic.
6. A magneto-resistive reader according to claim 4, wherein the first magnetic
shield element further comprises a hard magnetic layer.
7. A magneto-resistive reader according to claim 5, wherein the first magnetic
shield element further comprises a hard magnetic layer.
8. A magneto-resistive reader according to claims 1 to 7, wherein the
ferromagnetic anisotropic layers comprise NiFe and the grain growth suppression layer
comprises Ru.

9. A magneto-resistive reader according to claims 1 to 8, wherein the ferromagnetic anisotropic layers comprise NiFe and the grain growth suppression layer comprises or Ta.

10. A magneto-resistive reader according to claims 1 to 9, wherein the ferromagnetic anisotropic layers comprise NiFe and the grain growth suppression layer comprises Nb, Zr or Hf.

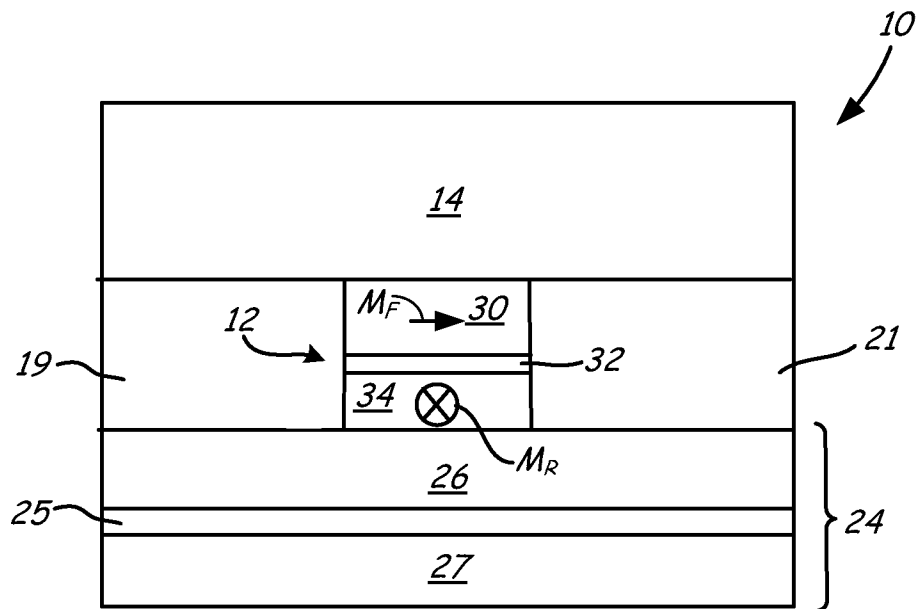
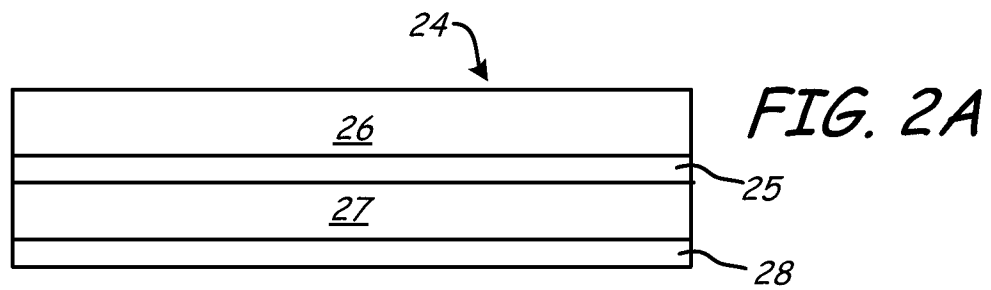
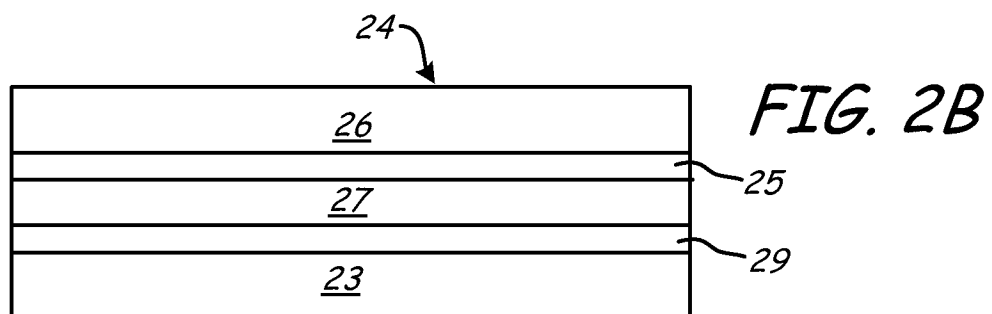
11. A magneto-resistive reader according to claims 1 to 10, wherein the two ferromagnetic anisotropic layers have about equal thicknesses.

12. A magneto-resistive reader according to claims 1 to 11, wherein the grain growth suppression layer inhibits diffusion, defect mobility, and grain crystallization during magnetic annealing of the magneto-resistive reader.

13. A magneto-resistive reader according to claims 1 to 12, wherein the first magnetic shield element further comprises a third ferromagnetic anisotropic layer, and a second grain growth suppression layer is located between the third ferromagnetic anisotropic layer and the second ferromagnetic anisotropic layer.

14. A method of forming a magneto-resistive reader comprising:
depositing a first shield element, the first shield element comprising two ferromagnetic anisotropic layers separated by a grain growth suppression layer;
annealing the first shield element at a magnetic set anneal temperature to form an set annealed first shield;
depositing a magneto-resistive sensor stack on the annealed first shield;
annealing the magneto-resistive sensor stack at a magnetic cross set anneal temperature to form a cross set annealed magneto-resistive sensor stack; and
depositing a second shield element on the cross set annealed magneto-resistive sensor stack.

15. A method according to claim 14, wherein the magnetic set anneal temperature is greater than 390 degrees centigrade.
16. A method according to claims 14 to 15, wherein the magnetic cross set anneal temperature is greater than 300 degrees centigrade.
17. A method according to claims 14 to 16, wherein the grain growth suppression layer has a thickness of less than 100 Angstroms.
18. A method according to claim 17, wherein the grain growth suppression layer is non-magnetic.
19. A method of forming a first shield for a tunneling magneto-resistive reader comprising:
depositing a first shield element, the first shield element comprising two ferromagnetic anisotropic layers separated by a grain growth suppression layer;
annealing the first shield element at a magnetic set anneal temperature to form an set annealed first shield;
polishing an exposed surface of the first shield element to form a smooth exposed first shield surface;
depositing a chemical mechanical polishing stop layer on the smooth exposed first shield surface;
depositing an insulating material about the first shield element;
removing insulating material by chemical mechanical polishing down to the chemical mechanical polishing stop layer; and
removing the chemical mechanical polishing stop layer, forming a polished first shield element.
20. A method according to claim 19, wherein the polishing step removes less than 2% of the ferromagnetic anisotropic layer being polished.

**FIG. 1****FIG. 2A****FIG. 2B**

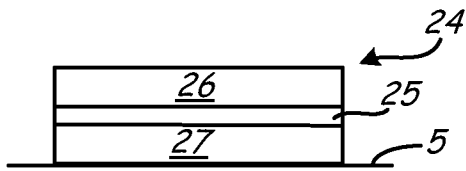


FIG. 3A

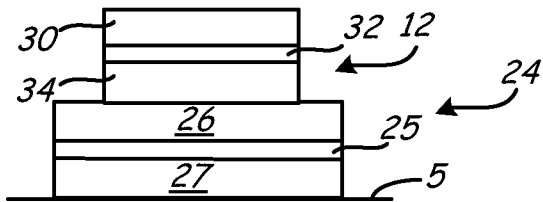


FIG. 3B

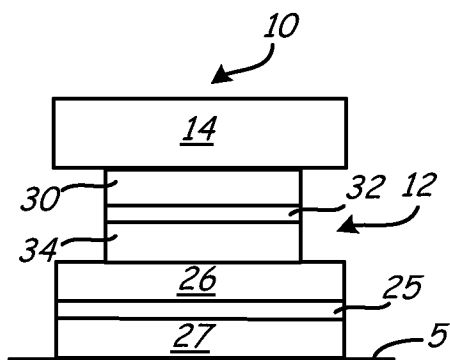


FIG. 3C

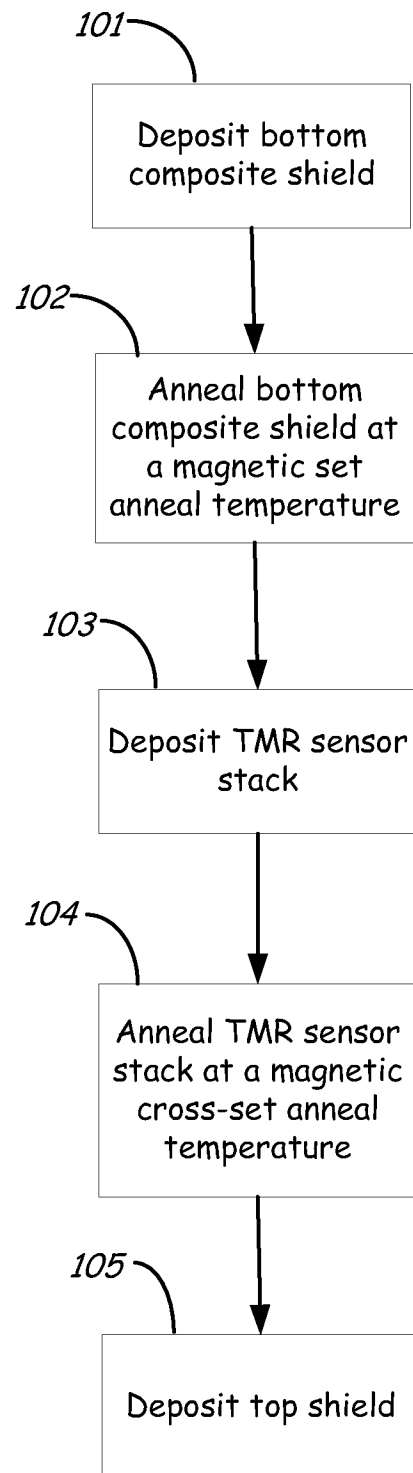
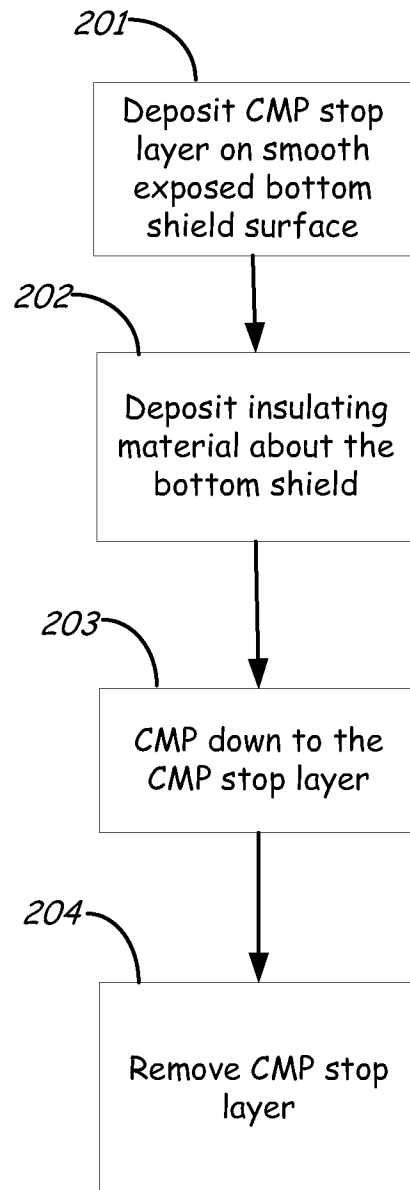
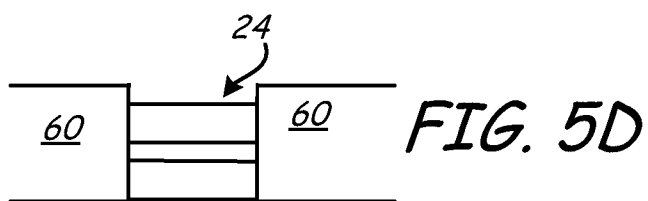
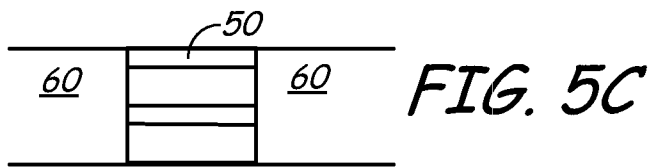
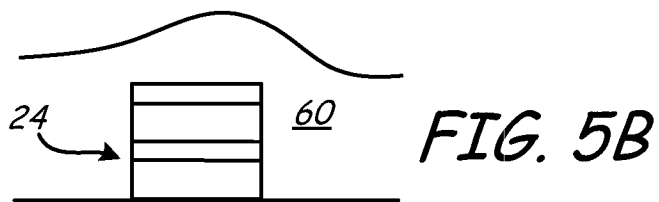
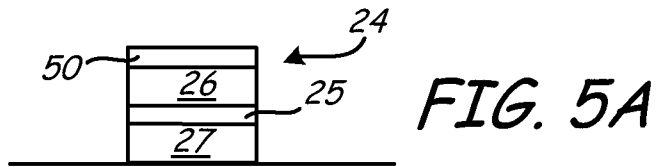


FIG. 4

**FIG. 6**

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2010/041285

A. CLASSIFICATION OF SUBJECT MATTER

INV. G11B5/39

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)

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 practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|-----------|---|-----------------------|
| X | US 2008/158741 A1 (LIN TSANN [US]) 3 July 2008 (2008-07-03) | 1-18 |
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Further documents are listed in the continuation of Box C.



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