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(54) **MONOLITHIC-CHIP AND HIGH-SENSITIVITY TYPE MAGNETO-RESISTOR LINEAR TRANSDUCER**

MONOLITHISCHER CHIP UND MAGNETWIDERSTANDSLINEARWANDLER MIT HOHER EMPFINDLICHKEIT

TRANSDUCTEUR LINÉAIRE MAGNÉTO-RÉSISTIF DE TYPE À PUCE MONOLITHIQUE ET À SENSIBILITÉ ÉLEVÉE

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(56) References cited:

CN-A- 101 290 343	**CN-A- 102 129 863**
CN-A- 103 630 855	**CN-A- 105 044 631**
CN-A- 105 259 518	**CN-A- 106 052 725**
CN-A- 106 324 534	**CN-A- 106 324 534**
CN-A- 106 871 778	**CN-A- 107 064 829**
CN-U- 206 147 081	**CN-U- 206 627 062**
CN-U- 206 671 519	**JP-A- 2011 027 495**
US-A1- 2003 062 975	**US-A1- 2016 327 617**

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Description

TECHNICAL FIELD

[0001] The present invention relates to the field of magnetic sensors, and in particular, to a single-chip high-sensitivity magnetoresistive linear sensor.

BACKGROUND

[0002] In a high-sensitivity single-axis magnetoresistive linear sensor, the external magnetic field is amplified using a soft ferromagnetic flux concentrator, along with a push-pull bridge structure to enhance the signal output, which is a basic design for a high-sensitivity linear low-noise linear magnetoresistive sensor.

[0003] For a TMR magnetoresistive sensor, an X-axis push magnetoresistive sensing unit chip and an X-axis pull magnetoresistive sensing unit chip are obtained generally by flipping one of the magnetoresistive sensing unit chips with a magnetic field with X-axis sensing direction, by 180 degrees with respect to the other, in order to form a push-pull bridge. This is advantageous in that the manufacturing method is simple, and only one type of chip structure is required, and the process corresponds to setting the ferromagnetic reference layers of the structure to form a push-pull bridge. It is disadvantageous in that two chips need to be accurately positioned within the same plane, which increases the possibility of measurement precision loss of the sensor caused by misalignment.

[0004] Through modification of the design of the ferromagnetic reference layer within a multi-layer film structure, push and pull magnetoresistive sensing units with opposite ferromagnetic reference layers can be manufactured by changing the number of layers of a multi-layer film composed of ferromagnetic layers and metal spacing layers exchange coupled to an anti-ferromagnetic layer, wherein one multi-layer film has an odd number of layers and the other has an even number of layers. This approach is disadvantageous in that the complexity of the process is increased as at least two kinds of multi-layer film structures need to be introduced in the deposition of the multi-layer films.

[0005] CN106324534A discloses a magnetoresistance sensor element layout used for laser writing system and laser scanning method. In a method for annealing a magnetic field using laser programmed heating as disclosed in CN106324534A, magnetoresistive sensing units are scanned and an anti-ferromagnetic layer is rapidly heated to a temperature above the blocking temperature; and meanwhile, a magnetic field can be applied in any direction during the cooling process to set orientations of magnetic field sensing directions of the magnetoresistive sensing units in any direction by scanning them one by one, or even chip by chip. Four kinds of orthogonally oriented magnetoresistive sensing units of double-axis magnetoresistive sensing units on a single chip and their arrays can be manufactured using the method, so that the difficulty of precise positioning of the flipped chip and complexity of micromachining process of depositing various magnetic multi-layer film structures can be overcome, and a single-chip dual-axis magnetoresistive angle sensor can be produced in batches.

[0006] US2016327617A1 discloses a high-sensitivity push-pull bridge magnetic sensor. CN105259518A discloses a high-sensitivity single-chip push-pull type TMR magnetic field sensor.

SUMMARY OF THE INVENTION

[0007] In order to solve the above technical problems, a single-chip high-sensitivity magnetoresistive linear sensor is proposed in the present invention, wherein the magnetic field sensing directions of magnetoresistive sensing units are set by laser assisted magnetic field annealing.

[0008] There is provided a single-chip high-sensitivity magnetoresistive linear sensor in accordance with the appended claims.

[0009] The single-chip high-sensitivity magnetoresistive linear sensor proposed in the present invention comprises:

a substrate located in the X-Y plane;
a soft ferromagnetic flux concentrator array located on the substrate, wherein the soft ferromagnetic flux concentrator array comprises several soft ferromagnetic flux concentrators, there is a gap between each two adjacent soft ferromagnetic flux concentrators, the long axis of the gap is in the Y direction, and the short axis of the gap is in the X direction; and
a +X magnetoresistive sensing unit array and a -X magnetoresistive sensing unit array located above or below the soft ferromagnetic flux concentrator array, the +X magnetoresistive sensing unit array and the -X magnetoresistive sensing unit array respectively comprising +X magnetoresistive sensing units and -X magnetoresistive sensing units located in the gaps of the soft ferromagnetic flux concentrators,
wherein the +X magnetoresistive sensing unit array is electrically interconnected to form an X push arm, the-X magnetoresistive sensing unit array is electrically interconnected to form an X pull arm, and the X push arm and the X pull arm are electrically interconnected to form a push pull X-axis magnetoresistive sensor,
wherein each of the magnetoresistive sensing units that have the same magnetic field sensing direction are arranged in adjacent locations,
the magnetoresistive sensing units each have the same magnetic multi-layer film structure:

i. comprising a seed layer, a lower electrode layer, an anti-ferromagnetic layer, a pinning layer, Ru, a reference layer, a nonmagnetic interlayer, a free layer, a magnetic bias layer, an upper electrode layer, and a passivation layer from the bottom up; or

ii. comprising a seed layer, a lower electrode layer, an anti-ferromagnetic layer, a reference layer, a nonmagnetic interlayer, a free layer, a magnetic bias layer, an upper electrode layer, and a passivation layer from the bottom up,

wherein the nonmagnetic interlayer is Al_2O_3 or MgO, the magnetic bias layer is a hard magnetic layer, another anti-ferromagnetic layer, or a synthetic anti-ferromagnetic layer structure,

the passivation layer is a material transparent to laser, and

wherein the +X magnetoresistive sensing unit array comprises a group of magnetic sensing units with a pinned magnetic layer oriented in the +X direction, and the -X magnetoresistive sensing unit array comprises a group of magnetic sensing units with a pinned layer oriented in the - X direction, and

the soft ferromagnetic flux concentrator array is configured to amplify an X-direction external magnetic field applied during laser annealing of the anti-ferromagnetic layer.

[0010] Preferably, magnetic field sensing directions of the +X magnetoresistive sensing unit array and the -X magnetoresistive sensing unit array are in +X and -X directions respectively, the long axes of the +X and -X magnetoresistive sensing unit arrays are in the Y direction, and the magnetoresistive sensing units are all MTJ magnetoresistive sensor elements each in an elliptic shape, or a shape with a rectangular middle portion and two triangular or fan-shaped end portions respectively located on two opposite sides of the middle portion.

[0011] Further, the soft ferromagnetic flux concentrator may be elongated, the long axis of the soft ferromagnetic flux concentrator is in the Y direction, the short axis is in the X direction, the length is 500-5000 μm, the width is 500-5000 μm, the thickness is 5-30 μm, the width of the gap is 6.5-10 μm, and the soft ferromagnetic flux concentrator is a high-permeability soft ferromagnetic alloy comprising one or more elements of Fe, Co, and Ni.

[0012] Further, the soft ferromagnetic flux concentrator array may be configured to configured to amplify an external X-direction external magnetic field at the magnetoresistive sensing units by a magnetic field gain factor of between 1 and 10; and

wherein the soft ferromagnetic flux concentrator array may have the same gap, and the width of the soft ferromagnetic flux concentrators on two ends may be greater than that of the soft ferromagnetic flux concentrators located between the soft ferromagnetic flux concentrators on the two ends, so that the gaps at the two ends and the gap in the middle position have the same magnetic field gain factor.

[0013] Further, the soft ferromagnetic flux concentrator array may comprise N soft ferromagnetic flux concentrators, wherein N is an integer greater than 0,

when N is an odd number, the magnetoresistive sensing unit array is distributed in N-1 gaps on two sides of the $(N+1)/2^{th}$ soft ferromagnetic flux concentrator; and

when N is an even number, the magnetoresistive sensing unit array is distributed in gaps between the 1^{st} to $N/2^{th}$ soft ferromagnetic flux concentrators and the $N/2+1^{th}$ to N^{th} soft ferromagnetic flux concentrators.

[0014] Further, the push pull magnetoresistive linear sensor may be a half-bridge, full-bridge or quasi-bridge structure.

[0015] Further, single-row magnetoresistive sensing units may be distributed in the gaps of the soft ferromagnetic flux concentrators; or double-row magnetoresistive sensing units are distributed in the gaps of the soft ferromagnetic flux concentrators and each equidistantly distributed on two sides of a centerline of the gaps of the soft ferromagnetic flux concentrators.

[0016] Further, the +X magnetoresistive sensing unit array and the -X magnetoresistive sensing unit array may be distributed on two sides of the X-direction centerline or two sides of the Y-direction centerline of the soft ferromagnetic flux concentrator array.

[0017] Further, the +X magnetoresistive sensing unit array may constitute two push arms and the -X magnetoresistive sensing unit array may constitute two pull arms of the push pull magnetoresistive sensor are spatially separated or spatially mixed, respectively, and the magnetoresistive sensing units comprised in the magnetoresistive sensing unit arrays are connected in series, connected in parallel, or connected in series and in parallel to form a two-port structure.

[0018] Further, the passivation layer may be a material transparent to ultraviolet laser or a material transparent to infrared laser, wherein the material transparent to ultraviolet laser comprises one of BCB. Si_3N_4, Al_2O_3, HfO_2, AlF_3, GdF_3, LaF_3, MgF_2, Sc_2O_3, HfO_2, and SiO_2, and the material transparent to infrared laser comprises one of a diamond-like carbon film, MgO, SiN, SiC, AlF_3, MgF_2, SiO_2, Al_2O_3, ThF_4, ZnS, ZnSe, ZrO_2, HfO_2, TiO_2, Ta_2O_7, Si, and Ge.

[0019] Further, the surface of the passivation layer may be coated with an anti-reflective coating.

[0020] Compared with the prior art, the prevent invention is advantageous in small size, high precision and low power consumption.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021]

FIG. 1 is a structural diagram of a single-chip high-sensitivity magnetoresistive linear sensor;

FIG. 2 is a positional diagram of a soft ferromagnetic flux concentrator array and a magnetoresistive sensing unit array;

FIG. 3 is a diagram showing magnetic field gain at positions of the magnetoresistive sensing units of the soft magnetic flux concentrator under the action of an external magnetic field;

FIG. 4 is a diagram showing a multi-layer film structure of an MTJ magnetoresistive sensor element;

FIG. 5(a1), FIG. 5(a2), FIG. 5(a3) and FIG. 5(b1), FIG. 5(b2), FIG. 5(b3) are partially enlarged diagrams of six different situations that can be used at A in FIG. 4 respectively;

FIG. 6a and FIG. 6b are shape diagrams of the MTJ magnetoresistive sensor element;

FIG. 7 is a structural diagram of a push-pull magnetoresistive sensor full-bridge;

FIG. 8 is a first arrangement diagram of +X and -X magnetoresistive sensing unit arrays and flux concentrators;

FIG. 9 is a second arrangement diagram of the +X and -X magnetoresistive sensing unit arrays and the flux concentrators;

FIG. 10 is a third arrangement diagram of the +X and -X magnetoresistive sensing unit arrays and the flux concentrators;

FIG. 11 is a fourth arrangement diagram of the +X and -X magnetoresistive sensing unit arrays and the flux concentrators;

FIG. 12 is a first arrangement diagram of +X and -X magnetoresistive sensing unit double-row arrays and the flux concentrators;

FIG. 13 is a second arrangement diagram of the +X and -X magnetoresistive sensing unit double-row arrays and the flux concentrators; and

FIG. 14 shows a typical laser magnetic annealing scanning method of the +X and -X magnetoresistive sensing unit arrays.

DETAILED DESCRIPTION

[0022] In order to illustrate the technical solution in embodiments of the present invention or in the prior art more clearly, the accompanying drawings needing to be used in the descriptions about the embodiments or the prior art will be introduced briefly in the following. It is apparent that the accompanying drawings in the following descriptions are merely some embodiments of the present invention. Those of ordinary skill in the art can also obtain other accompanying drawings according to the accompanying drawings without creative efforts.

[0023] FIG. 1 is a structural diagram of a single-chip high-sensitivity magnetoresistive linear sensor, including:

a substrate 1 located in the X-Y plane;

a soft ferromagnetic flux concentrator array 2 located on the substrate 1, wherein the soft ferromagnetic flux concentrator array includes N elongated soft ferromagnetic flux concentrators 21, 22, ..., 2N, there is a gap correspondingly between each two adjacent soft ferromagnetic flux concentrators 2i and 2(i+1), wherein i is a positive integer less than N, the long axis of the gap is in the Y direction, and the short axis of the gap is in the X direction; and

a +X magnetoresistive sensing unit array 3 and a -X magnetoresistive sensing unit array 4 with magnetic field sensing directions in +X and -X respectively, the +X magnetoresistive sensing unit array 3 comprising +X magnetoresistive sensing units 31, 32, ..., 3j, ..., 3M, the -X magnetoresistive sensing unit array 4 comprising -X magnetoresistive sensing units 41, 42, ..., 4j, ..., 4M, wherein j is a positive integer less than M. The +X magnetoresistive sensing units and the -X magnetoresistive sensing units are located in the gaps formed by the soft ferromagnetic flux concentrator array 2 respectively. The +X and -X magnetoresistive sensing unit arrays are electrically interconnected to form a +X push arm 5 and a -X pull arm 6 respectively. FIG. 1 shows a full bridge structure including two +X push arms 51 and 52 and two -X pull arms 61 and 62, and the push arm 5 and the pull arm 6 are electrically interconnected to form a push pull X-axis magnetoresistive sensor 7.

[0024] FIG. 2 is a positional diagram of magnetoresistive sensing units and soft ferromagnetic flux concentrators in an external magnetic field. The +X magnetoresistive sensing unit array 3 and the - X magnetoresistive sensing unit array 4 are located above or below the soft ferromagnetic flux concentrator array 2 and are centered in the gaps of two adjacent soft ferromagnetic flux concentrators. Under the action of an external magnetic field Hex, the X-direction magnetic field strength at the magnetoresistive sensing unit is Brx, and a magnetic field gain factor is $Brx/(\mu_0*Hex)$, wherein μ_0 denotes a vacuum permeability, the magnetic field gain factor ranges between 1 and 10. A distribution curve is shown in FIG. 3. The soft ferromagnetic flux concentrator array has the same gap, and all the magnetoresistive sensing units have the same magnetic field gain factor. The width of the soft ferromagnetic flux concentrators on the two ends is increased, so that the gap at the two ends and the gap in the middle position have the same magnetic field gain factor.

[0025] The soft ferromagnetic flux concentrator is elongated, the long axis and the short axis there are in the Y direction and the X direction respectively, the length is 500-5000 μm, the width is 500-5000 μm, the thickness is 5-30 μm, the width of the gap is 6.5-10 μm, and the soft ferromagnetic flux concentrator is a high-permeability soft ferromagnetic alloy including one or more elements of Fe, Co, and Ni.

[0026] FIG. 4 is a schematic diagram of a magnetic multi-layer film structure of a magnetoresistive sensing unit. Referring to FIG. 5(a1) to FIG. 5(a3) and FIG. 5(b1) to FIG. 5(b3), the magnetoresistive sensing unit is an MTJ element, including an upper electrode 91, a lower electrode 82, and a seed layer 81, and in addition, further including a ferromagnetic reference layer 86, a non-magnetic isolation layer 87, and a ferromagnetic free layer 88. The non-magnetic isolation layer is Al_2O_3 or MgO. The ferromagnetic reference layer 87 and the ferromagnetic free layer 88 are configured with orthogonal magnetization directions. The magnetization direction of the ferromagnetic reference layer 86 is determined by exchange coupling with an anti-ferromagnetic layer 83. There are two exchange coupling structures. One is exchange coupling of the anti-ferromagnetic layer 83/pinning layer 84/Ru/ ferromagnetic reference layer, wherein the magnetization direction of the pinning layer 84 is determined by the anti-ferromagnetic layer 83, the pinning layer 84 and the ferromagnetic reference layer 86 have opposite magnetization directions. The other one is direct coupling between the anti-ferromagnetic layer 83 and the ferromagnetic reference layer 86, of which the magnetization direction is determined by 83. The magnetization direction of the ferromagnetic free layer 88 is determined in three manners. The first manner is direct coupling of another anti-ferromagnetic layer 89 shown in FIG. 5(a1), the second manner is exchange coupling by the anti-ferromagnetic layer/another pinning layer 89/Ru/the ferromagnetic free layer 88 shown in FIG. 5(a2), and the third manner is magnetic field biasing of a hard magnetic layer 94 shown in FIG. 5(a3). In the three cases, the magnetization directions of the anti-ferromagnetic layer 89 and the hard magnetic layer 94 are both perpendicular to that of the anti-ferromagnetic layer 83 to obtain the orthogonality of magnetization directions of the free layer and the ferromagnetic reference layer. Therefore, there are three manners of pinning the free layer and two manners of pinning the reference layer, and thus there are six combinations in total.

[0027] The passivation layer is a material transparent to ultraviolet laser including BCB, Si_3N_4, Al_2O_3, HfO_2, AlF_3, GdF_3, LaF_3, MgF_2, Sc_2O_3, HfO_2, and SiO_2, or a material transparent to infrared laser including a diamond-like carbon film, MgO, SiN, SiC, AlF_3, MgF_2, SiO_2, Al_2O_3, ThF_4, ZnS, ZnSe, ZrO_2, HfO_2, TiO_2, Ta_2O_7, Si, and Ge. The surface of the passivation layer is coated with an anti-reflective coating.

[0028] The +X magnetoresistive sensing units and the -X magnetoresistive sensing units may be MTJ magnetoresistive sensor elements. FIG. 6 is a shape diagram of the MTJ magnetoresistive sensor elements. They are in two shapes, one is an elliptic shape, and the other is a shape with a rectangular middle portion and two triangular or fan-shaped end portions respectively located on two opposite sides of the middle portion. The magnetization direction of the free layer is inclined to the direction of the long axis by shape anisotropy, so that it is perpendicular to the magnetization direction of the pinning layer in the direction of the short axis.

[0029] The push arm and the pull arm can be connected to form a half bridge, full bridge or quasi bridge. FIG. 7 is a schematic structural diagram of a magnetoresistive full bridge.

[0030] FIG. 8 and FIG. 9 are arrangement diagram of the magnetoresistive sensing units when the number N of the soft ferromagnetic flux concentrators included in the soft ferromagnetic flux concentrator array is an odd number or an even number. When the number of the soft ferromagnetic flux concentrators is an odd number, the magnetoresistive sensing units are distributed in the gaps on two sides of the $(N+1)/2^{th}$ soft ferromagnetic flux concentrator, as shown in FIG. 8. In other words, each gap corresponds to a row of magnetoresistive sensing units respectively. When the number of the soft ferromagnetic flux concentrators is an even number, the magnetoresistive sensing unit arrays are distributed in gaps between the 1^{st} to $N/2^{th}$ soft ferromagnetic flux concentrators and the $N/2+1^{th}$ to N^{th} soft ferromagnetic flux concentrators, as shown in FIG. 9. In other words, except for the middlemost gap (that is, the gap formed between the $N/2^{th}$ and the $N/2+1^{th}$ soft ferromagnetic flux concentrators), other gaps each correspond to a row of magnetoresistive sensing units.

[0031] FIG. 8 to FIG. 11 show four arrangement manners of the push-pull magnetoresistive sensing unit arrays. In FIG. 8 and FIG. 9, push magnetoresistive sensing unit arrays 103 and 104 are symmetric to pull magnetoresistive sensing unit arrays 105 and 106 relative to a Y-axis centerline 100 of the soft ferromagnetic flux concentrator array respectively. In addition, the same kind of magnetoresistive sensing unit arrays, for example, 103 and 104 as well as 105 and 106, are symmetric to each other relative to an X-axis centerline 101 respectively. In FIG. 10, the push magnetoresistive sensing unit arrays 103 and 104 are symmetric to the pull magnetoresistive sensing unit arrays 105 and 106 relative to the X-axis centerline respectively, and the two identical push magnetoresistive sensing unit arrays 103 and 104 and the two identical pull magnetoresistive sensing unit arrays 105 and 106 are symmetric to each other relative to the Y-axis centerline respectively. FIG. 11 shows a third arrangement manner, in which the two identical push or pull magnetoresistive sensing unit arrays are mixed into an array 103' or 106', and then are symmetrically arranged about the Y-axis centerline 100 or the X-axis centerline 101.

[0032] FIG. 12 and FIG. 13 show double-row arrangement manners of the magnetoresistive sensing units in the gaps of the soft ferromagnetic flux concentrator array. Magnetoresistive sensing unit rows 311 and 312 are located at the same gap and at the same distance relative to gap midlines 400 and 401 to ensure that they have the same magnetic field gain factor. FIG. 12 shows an arrangement manner in which two magnetoresistive sensing unit arrays of the same type are symmetric relative to the X-axis centerline. FIG. 13 shows an arrangement manner in which two magnetoresistive sensing unit arrays of the same type are mixed. The magnetoresistive sensing units included in the magnetoresistive sensing unit arrays are connected in series, connected in parallel or connected in series and in parallel to form a two-port structure.

[0033] FIG. 14 shows a typical laser magnetic annealing scanning manner of the +X and -X magnetoresistive sensing unit arrays. 103 and 104 denote magnetoresistive sensing unit arrays in the +X magnetic field sensing direction, 105 and 106 denote magnetoresistive sensing unit arrays in the -X magnetic field sensing direction, and they are symmetrically distributed in the gaps relative to the Y-axis centerline of the soft ferromagnetic flux concentrator. During scanning, the magnetoresistive sensing unit arrays are scanned in the gap direction respectively along laser spot paths 700 and 800, respectively, thus saving the time required by the scanning. 500 and 600 denote directions of an external magnetic field applied for magnetic field annealing, which can be enhanced by the gain effect of the soft ferromagnetic flux concentrator array. Although the present invention is illustrated and described in terms of preferred implementations, it should be appreciated by those skilled in the art that various changes and modifications can be made to the present invention as long as the changes and modifications do not go beyond the scope defined by the claims of the present invention.

Claims

1. A single-chip high-sensitivity magnetoresistive linear sensor, comprising:

a substrate (1) located in the X-Y plane;

a soft ferromagnetic flux concentrator array (2) located on the substrate, wherein the soft ferromagnetic flux concentrator array comprises several soft ferromagnetic flux concentrators (2i), and there is a gap between each two adjacent soft ferromagnetic flux concentrators, wherein the long axis of the gap is in the Y direction, and the short axis of the gap is in the X direction; and

a +X magnetoresistive sensing unit array (3) and a -X magnetoresistive sensing unit array (4) located above or below the soft ferromagnetic flux concentrator array, the +X magnetoresistive sensing unit array and the -X magnetoresistive sensing unit array respectively comprising +X magnetoresistive sensing units and -X magnetoresistive sensing units located in the gaps of the soft ferromagnetic flux concentrators,

wherein the +X magnetoresistive sensing unit array is electrically interconnected to form an X push arm (5), the -X magnetoresistive sensing unit array is electrically interconnected to form an X pull arm (6), and the X push arm and the X pull arm are electrically interconnected to form a push pull X-axis magnetoresistive sensor (7),

wherein each of the magnetoresistive sensing units (3, 4) that have the same magnetic field sensing direction are arranged in adjacent locations,

the magnetoresistive sensing units each have the same magnetic multi-layer film structure:

i. comprising a seed layer (81), a lower electrode layer (82), an anti-ferromagnetic layer (83), a pinning layer (84), Ru (85), a reference layer (86), a nonmagnetic interlayer (87), a free layer (88), a magnetic bias layer, an upper electrode layer (91), and a passivation layer from the bottom up; or

ii. comprising a seed layer (81), a lower electrode layer (82), an anti-ferromagnetic layer (83), a reference layer (86), a nonmagnetic interlayer (87), a free layer (88), a magnetic bias layer, an upper electrode layer (91), and a passivation layer from the bottom up,

wherein the nonmagnetic interlayer (87) is Al_2O_3 or MgO,

the magnetic bias layer is a hard magnetic layer (94), another anti-ferromagnetic layer (89), or a synthetic anti-ferromagnetic layer structure,

the passivation layer is a material transparent to laser, and

configured in that the +X magnetoresistive sensing unit array (3) comprises a group of magnetic sensing units with a pinned magnetic layer oriented in the +X direction, and the -X magnetoresistive sensing unit array (4) comprises a group of magnetic sensing units with a pinned layer oriented in the -X direction, and

the soft ferromagnetic flux concentrator array (2) is configured to amplify an X-direction external magnetic field applied during laser annealing of the anti-ferromagnetic layer.

2. The single-chip high-sensitivity magnetoresistive linear sensor according to claim 1, wherein magnetic field sensing directions of the +X magnetoresistive sensing unit array (3) and the -X magnetoresistive sensing unit array (4) are in +X and -X directions respectively, the long axes of the +X and -X magnetoresistive sensing unit arrays are in the Y direction, and the magnetoresistive sensing units are all MTJ magnetoresistive sensor elements each in an elliptic shape, or a shape with a rectangular middle portion and two triangular or fan-shaped end portions respectively located on two opposite sides of the middle portion.

3. The single-chip high-sensitivity magnetoresistive linear sensor according to claim 1, wherein the soft ferromagnetic flux concentrator (2) is elongated, the long axis of the soft ferromagnetic flux concentrator is in the Y direction, the short axis is in the X direction, the length is 500-5000 μm, the width is 500-5000 μm, the thickness is 5-30 μm, the width of the gap is 6.5-10 μm, and the soft ferromagnetic flux concentrator is a high-permeability soft ferromagnetic alloy comprising one or more elements of Fe, Co, and Ni.

4. The single-chip high-sensitivity magnetoresistive linear sensor according to claim 1, wherein the soft ferromagnetic flux concentrator array (2) is configured to amplify an X-direction external magnetic field at the magnetoresistive sensing units by a magnetic field gain factor of between 1 and 10; and
wherein the soft ferromagnetic flux concentrator array (2) has the same gap, and the width of the soft ferromagnetic flux concentrators on two ends is greater than that of the soft ferromagnetic flux concentrators located between the soft ferromagnetic flux concentrators on the two ends, so that the gaps at the two ends and the gap in the middle position have the same magnetic field gain factor.

5. The single-chip high-sensitivity magnetoresistive linear sensor according to claim 1, wherein the soft ferromagnetic flux concentrator array (2) comprises N soft ferromagnetic flux concentrators, wherein N is an integer greater than 0,

when N is an odd number, the magnetoresistive sensing unit array is distributed in N-1 gaps on two sides of the $(N+1)/2^{th}$ soft ferromagnetic flux concentrator; and
when N is an even number, the magnetoresistive sensing unit array is distributed in gaps between the 1^{st} to $N/2^{th}$ soft ferromagnetic flux concentrators and the $N/2+1^{th}$ to N^{th} soft ferromagnetic flux concentrators.

6. The single-chip high-sensitivity magnetoresistive linear sensor according to claim 1, wherein the push pull magnetoresistive linear sensor is of a half-bridge, full-bridge (7) or quasi-bridge structure.

7. The single-chip high-sensitivity magnetoresistive linear sensor according to claim 1, wherein

single-row magnetoresistive sensing units (3j, 4j) are distributed in the gaps of the soft ferromagnetic flux concentrators (2); or
double-row magnetoresistive sensing units (311, 312) are distributed in the gaps of the soft ferromagnetic flux concentrators (2) and each equidistantly distributed on two sides of a centerline of the gap of the soft ferromagnetic flux concentrators.

8. The single-chip high-sensitivity magnetoresistive linear sensor according to claim 1, wherein the +X magnetoresistive sensing unit array (3) and the -X magnetoresistive sensing unit array (4) are distributed on two sides of the X-direction centerline or two sides of the Y-direction centerline of the soft ferromagnetic flux concentrator array.

9. The single-chip high-sensitivity magnetoresistive linear sensor according to claim 1, wherein the +X magnetoresistive sensing unit array (3) constitutes two push arms (5) and the -X magnetoresistive sensing unit array (4) constitutes two pull arms (6),

the push pull magnetoresistive sensor are spatially separated or spatially mixed, respectively, and
the magnetoresistive sensing units comprised in the magnetoresistive sensing unit arrays are connected in series, connected in parallel, or connected in series and in parallel to form a two-port structure.

10. The single-chip high-sensitivity magnetoresistive linear sensor according to claim 1, wherein the surface of the passivation layer is coated with an anti-reflective coating, the passivation layer is a material transparent to ultraviolet laser or a material transparent to infrared laser, wherein the material transparent to ultraviolet laser comprises one of BCB, Si_3N_4, Al_2O_3, HfO_2, AlF_3, GdF_3, LaF_3, MgF_2, Sc_2O_3, HfO_2, and SiO_2, and the material transparent to infrared laser comprises one of a diamond-like carbon film, MgO, SiN, SiC, AlF_3, MgF_2, SiO_2, Al_2O_3, ThF_4, ZnS, ZnSe, ZrO_2, HfO_2, TiO_2, Ta_2O_7, Si, and Ge.

Patentansprüche

1. Magnetoresistiver Einzelchip-Linearsensor mit hoher Empfindlichkeit, umfassend:

ein Substrat (1), das sich auf der X-Y-Ebene befindet,
eine Anordnung weicher ferromagnetischer Flusskonzentratoren (2), die sich auf dem Substrat befindet, wobei die Anordnung weicher ferromagnetischer Flusskonzentratoren mehrere weiche ferromagnetische Flusskonzentratoren (2i) umfasst und zwischen jeweils zwei benachbarten weichen ferromagnetischen Flusskonzentratoren ein Zwischenraum vorhanden ist, wobei die lange Achse des Zwischenraums in Y-Richtung verläuft und die kurze Achse des Zwischenraums in X-Richtung verläuft; und
eine magnetoresistive +X-Erfassungseinheitsanordnung (3) und eine magnetoresistive -X-Erfassungseinheitsanordnung (4), die sich über oder unter der Anordnung weicher ferromagne-

tischer Flusskonzentratoren befinden, wobei die magnetoresistive +X-Erfassungseinheitsanordnung und die magnetoresistive -X-Erfassungseinheitsanordnung jeweils magnetoresistive +X-Erfassungseinheiten und magnetoresistive -X-Erfassungseinheiten umfassen, die sich in den Zwischenräumen der weichen ferromagnetischen Flusskonzentratoren befinden

wobei die magnetoresistive +X-Erfassungseinheitsanordnung elektrisch miteinander verbunden ist, um einen X-Druckarm (5) zu bilden, die magnetoresistive -X-Erfassungseinheitsanordnung elektrisch miteinander verbunden ist, um einen X-Zugarm (6) zu bilden, und der X-Druckarm und der X-Zugarm elektrisch miteinander verbunden sind, um einen magnetoresistiven X-Achsen-Druck-Zug-Sensor (7) zu bilden,

wobei jede der magnetoresistiven Erfassungseinheiten (3, 4), welche die gleiche Magnetfelderfassungsvorrichtung aufweisen, an benachbarten Stellen angeordnet sind,

die magnetoresistiven Erfassungseinheiten die gleiche magnetische Mehrschichtfilmstruktur aufweisen:

i. umfassend eine Keimschicht (81), eine untere Elektrodenschicht (82), eine antiferromagnetische Schicht (83), eine Pinning-Schicht (84), Ru (85), eine Referenzschicht (86), eine nichtmagnetische Zwischenschicht (87), eine freie Schicht (88), eine magnetische Vormagnetisierungsschicht, eine obere Elektrodenschicht (91) und eine Passivierungsschicht von unten nach oben; oder

ii. umfassend eine Keimschicht (81), eine untere Elektrodenschicht (82), eine antiferromagnetische Schicht (83), eine Referenzschicht (86), eine nichtmagnetische Zwischenschicht (87), eine freie Schicht (88), eine magnetische Vormagnetisierungsschicht, eine obere Elektrodenschicht (91) und eine Passivierungsschicht von unten nach oben,

wobei die nichtmagnetische Zwischenschicht (87) Al_2O_3 oder MgO ist,

die magnetische Vormagnetisierungsschicht eine hartmagnetische Schicht (94), eine weitere antiferromagnetische Schicht (89) oder eine synthetische antiferromagnetische Schichtstruktur ist,

die Passivierungsschicht ein für Laser transparentes Material ist und

derart konfiguriert, dass die magnetoresistive +X-Erfassungseinheitsanordnung (3) eine Gruppe magnetischer Erfassungseinheiten mit einer fixierten magnetischen Schicht umfasst, die in der +X-Richtung ausgerichtet ist, und dass die magnetoresistive -X-Erfassungseinheitsanordnung (4) eine Gruppe magnetischer Erfassungseinheiten mit einer fixierten Schicht umfasst, die in der -X-Richtung ausgerichtet ist, und die Anordnung (2) weicher ferromagnetischer Flusskonzentratoren dazu konfiguriert ist, ein externes Magnetfeld in X-Richtung zu verstärken, das während des Laserglühens der antiferromagnetischen Schicht angelegt wird.

2. Magnetoresistiver Einzelchip-Linearsensor mit hoher Empfindlichkeit nach Anspruch 1, wobei die Magnetfelderfassungsrichtungen der magnetoresistiven +X-Erfassungseinheitsanordnung (3) und der magnetoresistiven -X-Erfassungseinheitsanordnung (4) jeweils in der +X- und -X-Richtung verlaufen, die langen Achsen der magnetoresistiven +X- und -X-Erfassungseinheiten jeweils in der Y-Richtung verlaufen und die magnetoresistiven Erfassungseinheiten alle magnetoresistive MTJ-Sensorelemente sind, jeweils in elliptischer Form oder einer Form mit einem rechteckigen mittleren Abschnitt und zwei dreieckigen oder fächerförmigen Endabschnitten, die sich jeweils auf zwei gegenüberliegenden Seiten des mittleren Abschnitts befinden.

3. Magnetoresistiver Einzelchip-Linearsensor mit hoher Empfindlichkeit nach Anspruch 1, wobei der weiche ferromagnetische Flusskonzentrator (2) länglich ist, die lange Achse des weichen ferromagnetischen Flusskonzentrators in Y-Richtung verläuft und die kurze Achse in X-Richtung verläuft, die Länge 500-5000 μm beträgt, die Breite 500-5000 μm beträgt, die Dicke 5-30 μm beträgt, die Breite des Zwischenraums 6,5-10 μm beträgt und der weiche ferromagnetische Flusskonzentrator eine weiche ferromagnetische Legierung mit hoher Permeabilität ist, die ein oder mehrere Elemente von Fe, Co und Ni umfasst.

4. Magnetoresistiver Einzelchip-Linearsensor mit hoher Empfindlichkeit nach Anspruch 1, wobei die Anordnung (2) weicher ferromagnetischer Flusskonzentratoren dazu konfiguriert ist, ein externes Magnetfeld in X-Richtung an den magnetoresistiven Erfassungseinheiten um einen Magnetfeldverstärkungsfaktor zwischen 1 und 10 zu verstärken; und wobei die Anordnung (2) weicher ferromagnetischer Flusskonzentratoren den gleichen Zwischenraum aufweist und die Breite der weichen ferromagnetischen Flusskonzentratoren an zwei Enden größer ist als die der weichen ferromagnetischen Flusskonzentratoren, die sich zwischen den weichen ferromagnetischen Flusskonzentratoren an den zwei Enden befinden, sodass die Zwischenräume an den zwei Enden und der Zwischenraum in der mittlere Position den gleichen Magnetfeldverstärkungsfaktor aufweisen.

5. Magnetoresistiver Einzelchip-Linearsensor mit hoher Empfindlichkeit nach Anspruch 1, wobei die Anordnung (2) weicher ferromagnetischer Flusskonzentratoren N weiche ferromagnetische Flusskonzentratoren umfasst, wobei N eine ganze Zahl größer als 0 ist,

wenn N eine ungerade Zahl ist, die magnetoresistive Erfassungseinheitsanordnung in N-1 Zwischenräumen auf zwei Seiten des (N+1)/2. weichen ferromagnetischen Flusskonzentrators verteilt ist; und
wenn N eine gerade Zahl ist, die magnetoresistive Erfassungseinheitsanordnung in Zwischenräumen zwischen dem 1. bis N/2. weichen ferromagnetischen Flusskonzentrator und dem N/2+1. bis N-ten weichen ferromagnetischen Flusskonzentrator verteilt ist.

6. Magnetoresistiver Einzelchip-Linearsensor mit hoher Empfindlichkeit nach Anspruch 1, wobei der magnetoresistive Druck-Zug-Linearsensor eine Halbbrücken-, Vollbrücken- (7) oder Quasibrückenstruktur aufweist.

7. Magnetoresistiver Einzelchip-Linearsensor mit hoher Empfindlichkeit nach Anspruch 1, wobei

einreihige magnetoresistive Erfassungseinheiten (3j, 4j) in den Zwischenräumen der weichen ferromagnetischen Flusskonzentratoren (2) verteilt sind; oder
zweireihige magnetoresistive Erfassungseinheiten (311, 312) in den Zwischenräumen der weichen ferromagnetischen Flusskonzentratoren (2) verteilt sind und jeweils äquidistant auf zwei Seiten einer Mittellinie des Zwischenraums der weichen ferromagnetischen Flusskonzentratoren verteilt sind.

8. Magnetoresistiver Einzelchip-Linearsensor mit hoher Empfindlichkeit nach Anspruch 1, wobei die magnetoresistive +X-Erfassungseinheitsanordnung (3) und die magnetoresistive -X-Erfassungseinheitsanordnung (4) auf zwei Seiten der Mittellinie in X-Richtung oder zwei Seiten der Mittellinie in Y-Richtung der Anordnung weicher ferromagnetischer Flusskonzentratoren verteilt sind.

9. Magnetoresistiver Einzelchip-Linearsensor mit hoher Empfindlichkeit nach Anspruch 1, wobei die magnetoresistive +X-Erfassungseinheitsanordnung (3) zwei Druckarme (5) bildet und die magnetoresistive -X-Erfassungseinheitsanordnung (4) zwei Zugarme (6) bildet,

der magnetoresistiven Zug-Druck-Sensor jeweils räumlich getrennt oder räumlich gemischt ist und
die magnetoresistiven Erfassungseinheiten, die in den magnetoresistiven Erfassungseinheitsanordnungen enthalten sind, in Reihe geschaltet, parallel geschaltet oder in Reihe und parallel geschaltet sind, um eine Zwei-Port-Struktur zu bilden.

10. Magnetoresistiver Einzelchip-Linearsensor mit hoher Empfindlichkeit nach Anspruch 1, wobei die Oberfläche der Passivierungsschicht mit einer Antireflexbeschichtung beschichtet ist, die Passivierungsschicht ein für Ultraviolettlaser transparentes Material oder ein für Infrarotlaser transparentes Material ist, wobei das für Ultraviolettlaser transparente Material eines von BCB, Si_3N_4, Al_2O_3, HfO_2, AlF_3, GdF_3, LaF_3, MgF_2, Sc_2O_3, HfO_2 und SiO_2 umfasst und das für Infrarotlaser transparente Material eines von einem diamantähnlichen Kohlenstofffilm, MgO, SiN, SiC, AlF_3, MgF_2, SiO_2, Al_2O_3, ThF_4, ZnS, ZnSe, ZrO_2, HfO_2, TiO_2, Ta_2O_7, Si und Ge umfasst.

Revendications

1. Capteur linéaire magnétorésistif monopuce à sensibilité élevée, comprenant :

un substrat (1) situé dans le plan X-Y ;
un réseau de concentrateurs de flux ferromagnétiques doux (2) situé sur le substrat, ledit réseau de concentrateurs de flux ferromagnétiques doux comprenant plusieurs concentrateurs de flux ferromagnétiques doux (2i), et un espace existe entre chacun des deux concentrateurs de flux ferromagnétiques doux adjacents, le grand axe de l'espace étant dans la direction Y, et le petit axe de l'espace est dans la direction X ; et
un réseau d'unités de détection magnétorésistives +X (3) et un réseau d'unités de détection magnétorésistives -X (4) situés au-dessus ou au-dessous du réseau de concentrateurs de flux ferromagnétiques doux, le réseau d'unités de détection magnétorésistives +X et le réseau d'unités de détection magnétorésistives -X comprenant respectivement des unités de détection magnétorésistives +X et des unités de détection magnétorésistives -X situées dans les espaces des concentrateurs de flux ferromagnétiques doux,
ledit réseau d'unités de détection magnétorésistives +X étant électriquement interconnecté pour former un bras de poussée X (5), ledit réseau d'unités de détection magnétorésistives -X étant électriquement interconnecté pour former

un bras de traction X (6), et ledit bras de poussée X et ledit bras de traction X étant électriquement interconnectés pour former un capteur magnétorésistif d'axe X symétrique (7),
chacune des unités de détection magnétorésistives (3, 4) qui comportent la même direction de détection de champ magnétique étant disposée dans des emplacements adjacents,
lesdites unités de détection magnétorésistives comportant chacune la même structure de film magnétique multicouche :

i. comprenant, de bas en haut, une couche de germination (81), une couche d'électrode inférieure (82), une couche antiferromagnétique (83), une couche de fixation (84), du Ru (85), une couche de référence (86), une couche intermédiaire non magnétique (87), une couche libre (88), une couche de polarisation magnétique, une couche d'électrode supérieure (91) et une couche de passivation ; ou
ii. comprenant, de bas en haut, une couche de germination (81), une couche d'électrode inférieure (82), une couche antiferromagnétique (83), une couche de référence (86), une couche intermédiaire non magnétique (87), une couche libre (88), une couche de polarisation magnétique, une couche d'électrode supérieure (91) et une couche de passivation,

ladite couche intermédiaire non magnétique (87) est Al_2O_3 ou MgO,
ladite couche de polarisation magnétique étant une couche magnétique dure (94), une autre couche antiferromagnétique (89) ou une structure de couche antiferromagnétique synthétique,
ladite couche de passivation étant un matériau transparent au laser, et
configuré en ce que le réseau d'unités de détection magnétorésistives +X (3) comprend un groupe d'unités de détection magnétique avec une couche magnétique fixée orientée dans la direction +X, et le réseau d'unités de détection magnétorésistives -X (4) comprend un groupe d'unités de détection magnétiques avec une couche fixée orientée dans la direction -X, et
le réseau de concentrateurs de flux ferromagnétiques doux (2) est configuré pour amplifier un champ magnétique externe dans la direction X appliqué durant le recuit laser de la couche antiferromagnétique.

2. Capteur linéaire magnétorésistif monopuce à sensibilité élevée selon la revendication 1, lesdites directions de détection de champ magnétique du réseau d'unités de détection magnétorésistives +X (3) et du réseau d'unités de détection magnétorésistives -X (4) étant dans les directions +X et -X respectivement, lesdits grands axes des réseaux d'unités de détection magnétorésistives +X et -X étant dans la direction Y, et lesdites unités de détection magnétorésistives étant toutes des éléments de capteur magnétorésistifs MTJ, chacune possédant une forme elliptique, ou une forme avec une partie médiane rectangulaire et deux parties d'extrémité triangulaires ou en forme d'éventail situées respectivement sur deux côtés opposés de la partie médiane.

3. Capteur linéaire magnétorésistif monopuce à sensibilité élevée selon la revendication 1, ledit concentrateur de flux ferromagnétique doux (2) étant allongé, ledit grand axe du concentrateur de flux ferromagnétique doux étant dans la direction Y, ledit petit axe étant dans la direction X, ladite longueur étant 500-5000 μm, ladite largeur étant 500-5000 μm, ladite épaisseur étant 5-30 μm, ladite largeur de l'espace étant 6,5-10 μm et ledit concentrateur de flux ferromagnétique doux étant un alliage ferromagnétique doux à perméabilité élevée comprenant un ou plusieurs éléments parmi Fe, Co et Ni.

4. Capteur linéaire magnétorésistif monopuce à sensibilité élevée selon la revendication 1, ledit réseau de concentrateurs de flux ferromagnétiques doux (2) étant configuré pour amplifier un champ magnétique externe dans la direction X au niveau des unités de détection magnétorésistives par un facteur de gain de champ magnétique compris entre 1 et 10 ; et
ledit réseau de concentrateurs de flux ferromagnétiques doux (2) comportant le même espace, et ladite largeur des concentrateurs de flux ferromagnétiques doux sur deux extrémités étant supérieure à celle des concentrateurs de flux ferromagnétiques doux situés entre les concentrateurs de flux ferromagnétiques doux sur les deux extrémités, afin que les espaces au niveau des deux extrémités et l'espace en position médiane comportent le même facteur de gain de champ magnétique.

5. Capteur linéaire magnétorésistif monopuce à sensibilité élevée selon la revendication 1, ledit réseau de concentrateurs de flux ferromagnétiques doux (2) comprenant N concentrateurs de flux ferromagnétiques doux, N étant un nombre entier supérieur à 0,

lorsque N est un nombre impair, ledit réseau d'unités de détection magnétorésistives étant réparti dans N-1 espaces sur deux côtés du (N+1)/2^{e} concentrateur de flux ferromagnétique doux ; et
lorsque N est un nombre pair, ledit réseau d'unités de détection magnétorésistives étant réparti dans les espaces entre les 1er et N/2^{e} concen-

trateurs de flux ferromagnétiques doux et les N/2+1e et Ne concentrateurs de flux ferromagnétiques doux.

6. Capteur linéaire magnétorésistif monopuce à sensibilité élevée selon la revendication 1, ledit capteur linéaire magnétorésistif symétrique est d'une structure en demi-pont, en pont complet (7) ou en quasi-pont.

7. Capteur linéaire magnétorésistif monopuce à sensibilité élevée selon la revendication 1,

des unités de détection magnétorésistives à une seule rangée (3j, 4j) étant réparties dans les espaces des concentrateurs de flux ferromagnétiques doux (2) ; ou
des unités de détection magnétorésistives à double rangée (311, 312) étant réparties dans les espaces des concentrateurs de flux ferromagnétiques doux (2) et chacune étant répartie de manière équidistante sur deux côtés d'une ligne centrale de l'espace des concentrateurs de flux ferromagnétiques doux.

8. Capteur linéaire magnétorésistif monopuce à sensibilité élevée selon la revendication 1, ledit réseau d'unités de détection magnétorésistives +X (3) et ledit réseau d'unités de détection magnétorésistives -X (4) étant répartis sur deux côtés de la ligne centrale de direction X ou deux côtés de la ligne centrale de la direction Y du réseau de concentrateurs de flux ferromagnétiques doux.

9. Capteur linéaire magnétorésistif monopuce à sensibilité élevée selon la revendication 1, ledit réseau d'unités de détection magnétorésistives +X (3) constituant deux bras de poussée (5) et ledit réseau d'unités de détection magnétorésistives -X (4) constituant deux bras de traction (6),

ledit capteur magnétorésistif symétrique étant respectivement séparés spatialement ou mélangés spatialement, et
lesdites unités de détection magnétorésistives comprises dans les réseaux d'unités de détection magnétorésistives étant connectées en série, connectées en parallèle, ou connectées en série et en parallèle pour former une structure à deux ports.

10. Capteur linéaire magnétorésistif monopuce à sensibilité élevée selon la revendication 1, ladite surface de la couche de passivation étant recouverte d'un revêtement antireflet, ladite couche de passivation étant un matériau transparent au laser ultraviolet ou un matériau transparent au laser infrarouge, ledit matériau transparent au laser ultraviolet comprenant un parmi BCB, Si_3N_4, Al_2O_3, HfO_2, AlF_3, GdF_3, LaF_3, MgF_2, Sc_2O_3, HfO_2 et SiO_2, et ledit matériau transparent au laser infrarouge comprenant un parmi un film de carbone de type diamant, MgO, SiN, SiC, AlF_3, MgF_2, SiO_2, Al_2O_3, ThF_4, ZnS, ZnSe, ZrO_2, HfO_2, TiO_2, Ta_2O_7, Si et Ge.

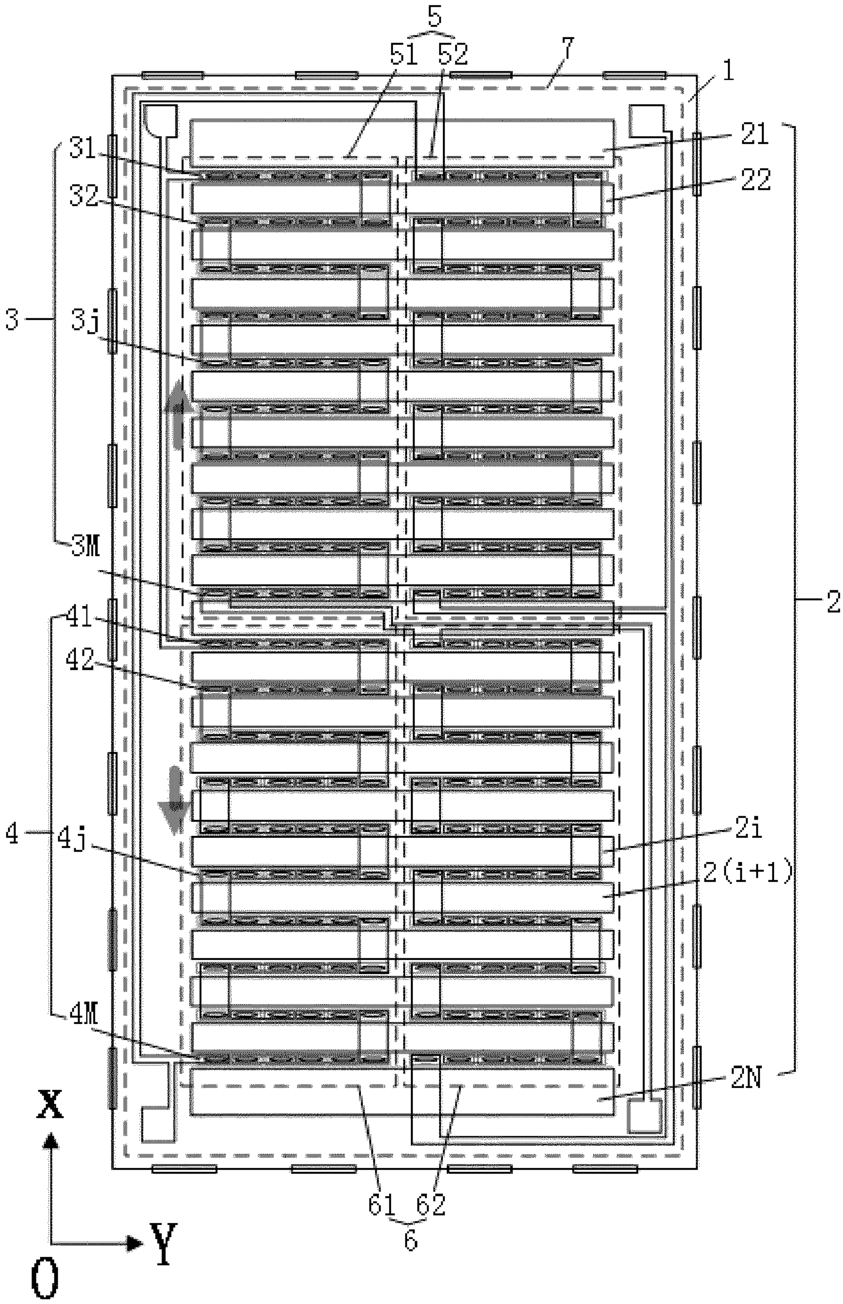

Fig. 1

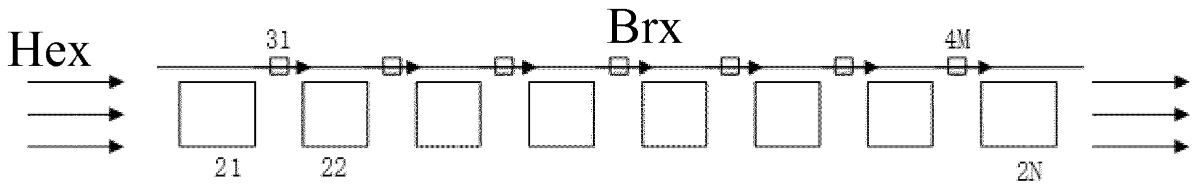

Fig. 2

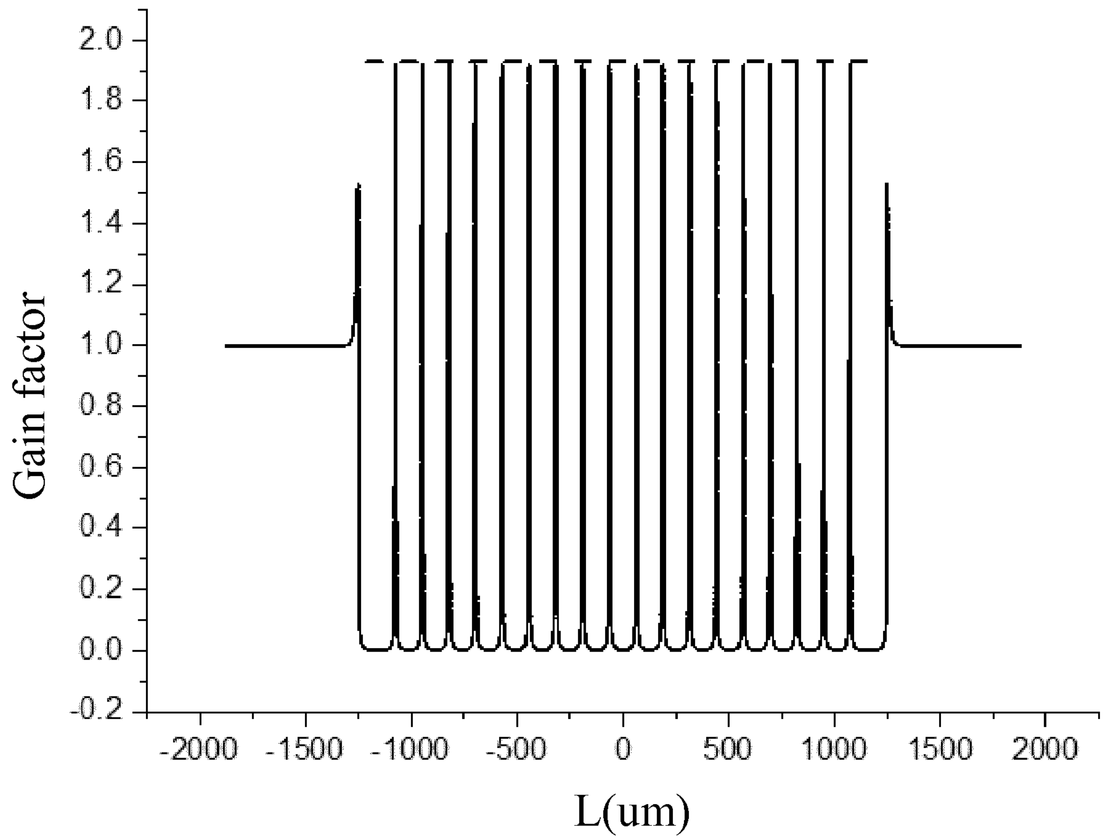

Fig. 3

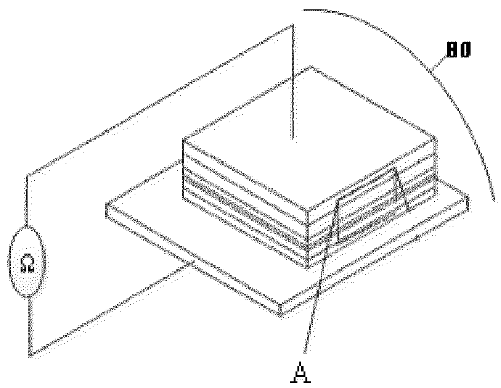

Fig. 4

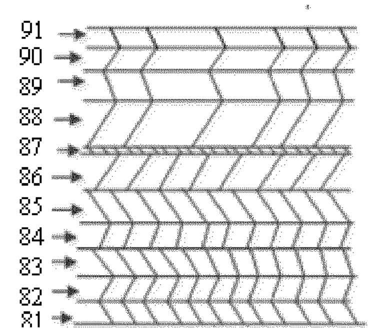

Fig. 5(a1)

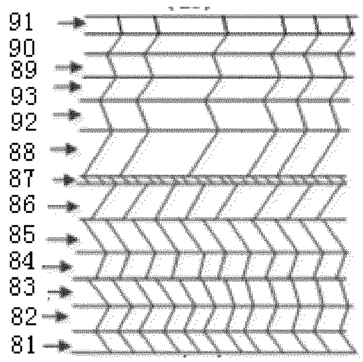

Fig. 5(a2)

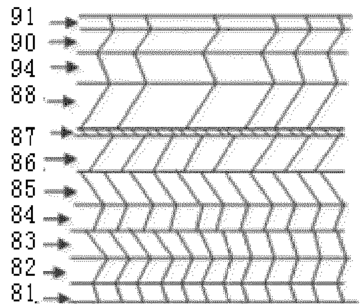

Fig. 5(a3)

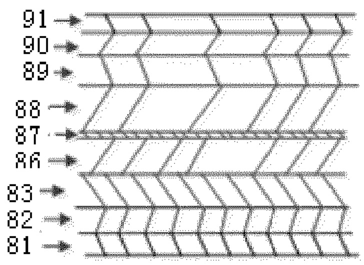

Fig. 5(b1)

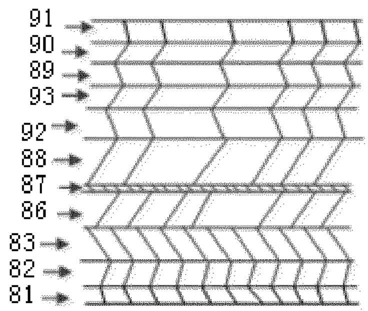

Fig. 5(b2)

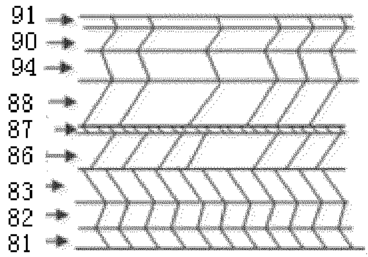

Fig. 5(b3)

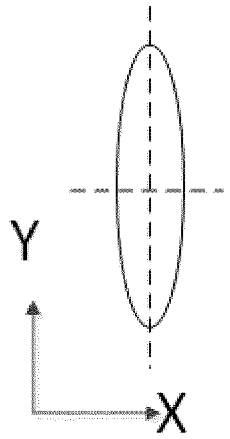

Fig. 6a

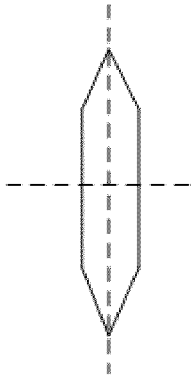

Fig. 6b

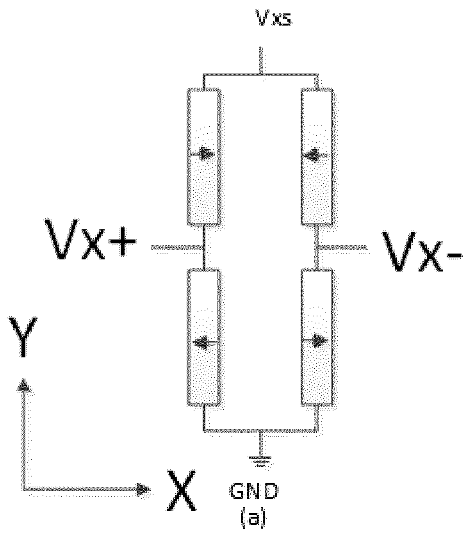

Fig. 7

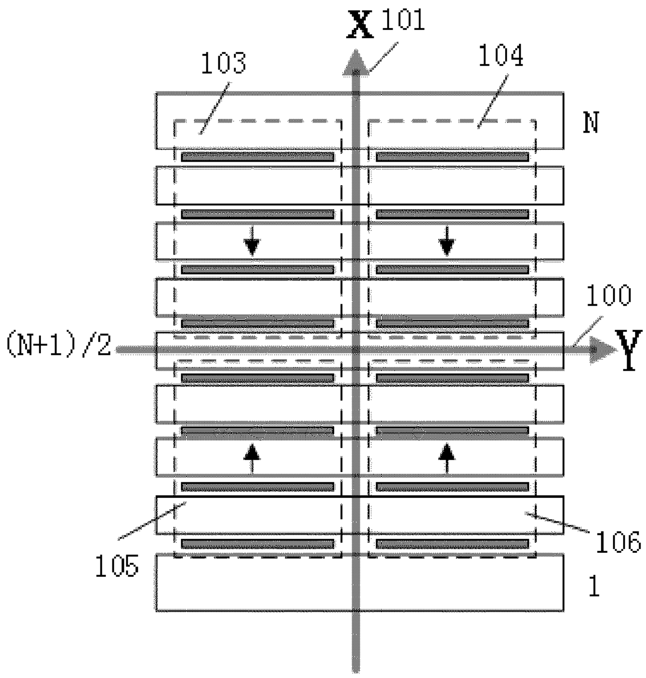
X
101
103
104
N
100
(N+1)/2
Y
105
106
1

Fig. 8

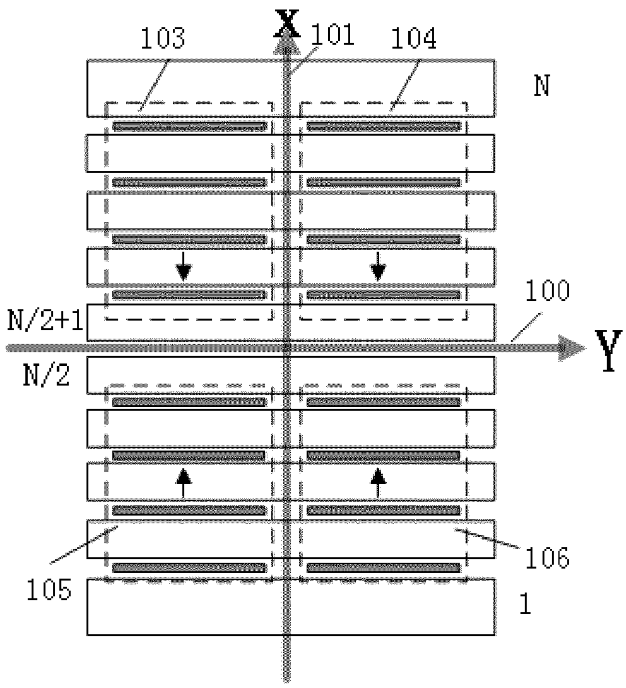
X
101
103
104
N
100
N/2+1
N/2
Y
105
106
1

Fig. 9

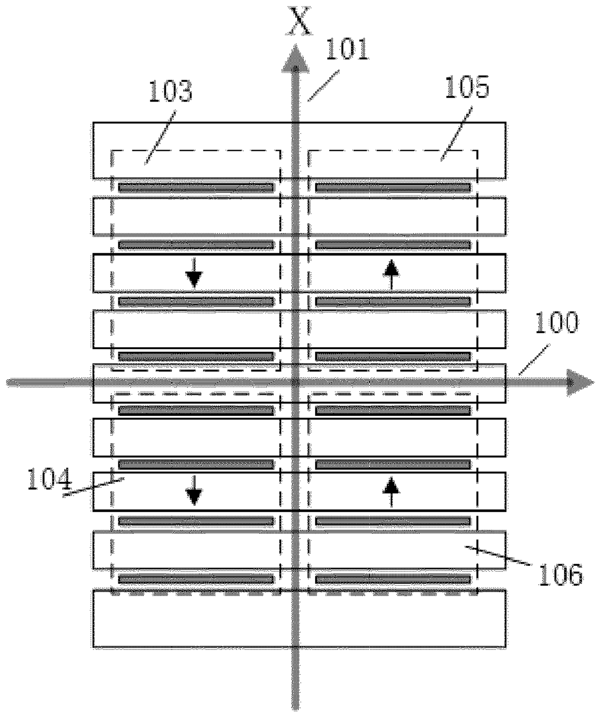

Fig. 10

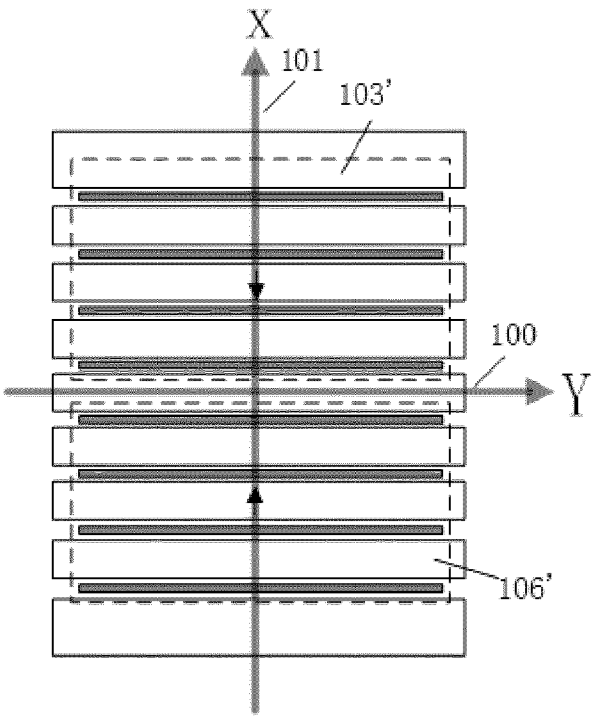

Fig. 11

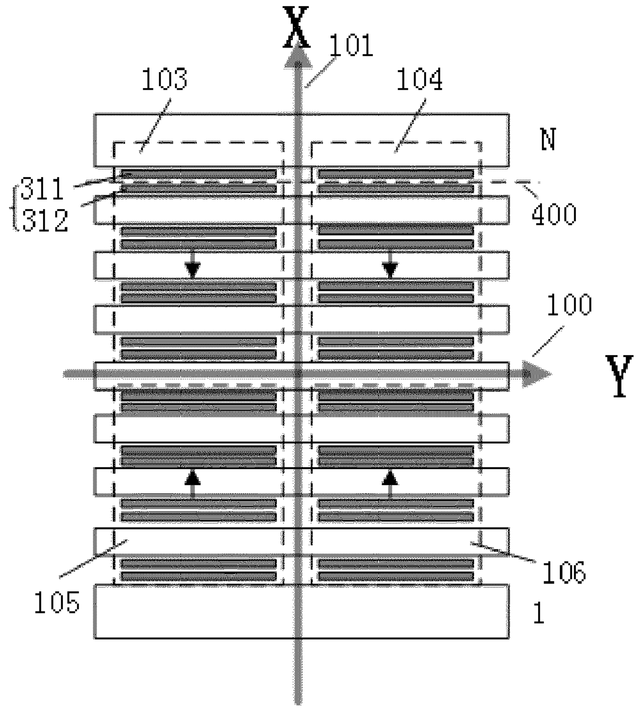
X
101
103
104
N
311
312
400
100
Y
105
106
1

Fig. 12

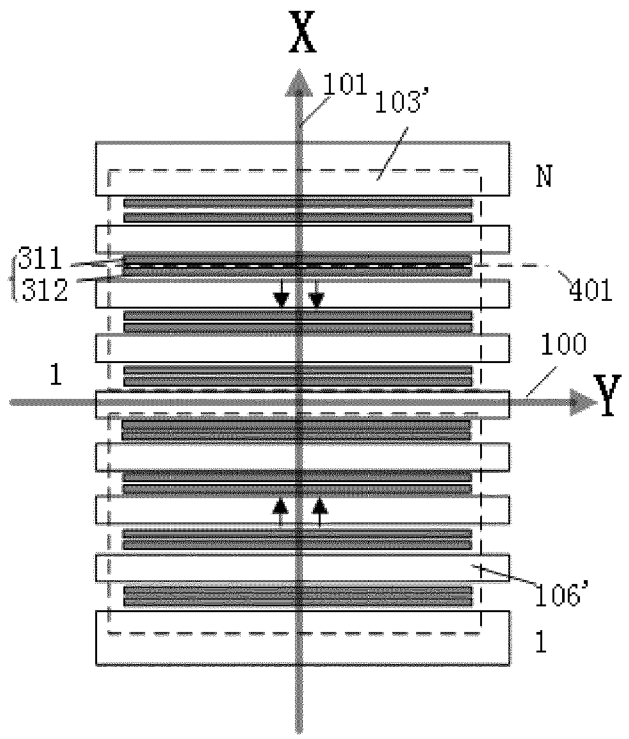
X
101
103'
N
311
312
401
100
1
Y
106'
1

Fig. 13

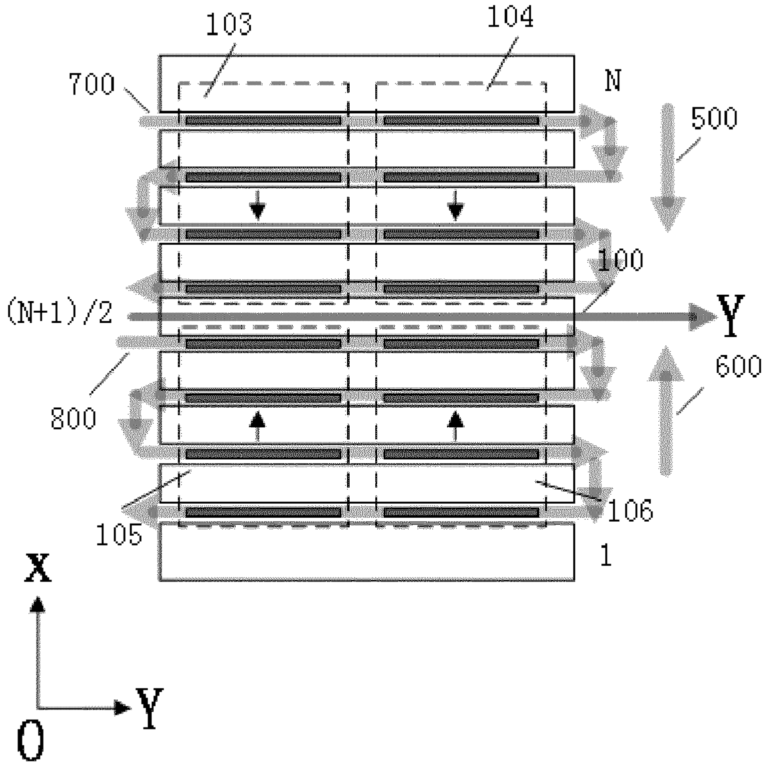

Fig. 14

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- CN 106324534 A **[0005]**
- US 2016327617 A1 **[0006]**
- CN 105259518 A **[0006]**