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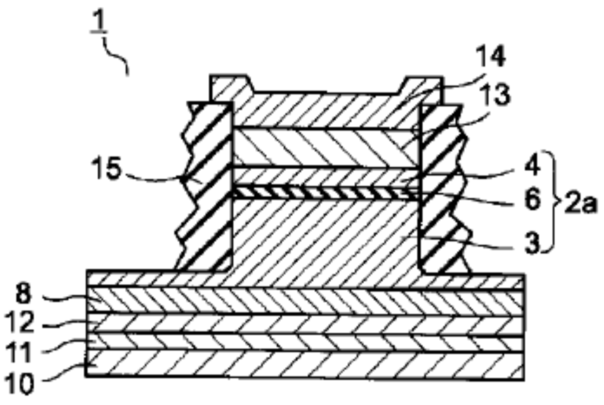
(54) [Title of the Invention] Magnetoresistance effect element, magnetic memory, magnetic head, and magnetic reproducing device

(57) [Abstract]
[Problem] To provide a magnetoresistance effect element, magnetic memory, magnetic head, and magnetic reproducing device that can maintain a sufficiently high magnetoresistance ratio and prevent an increase in the reversal magnetic field even when the size is reduced.
[Means for Solving] The magnetoresistance effect element 1 of the present invention comprises a first ferromagnetic layer 3 that maintains the direction of magnetization when no external magnetic field is applied in a predetermined external magnetic field, a second ferromagnetic layer 4 that can change the direction of magnetization when no external magnetic field is applied in the above external magnetic field, and a first tunnel barrier layer 6 interposed between the first ferromagnetic layer 3 and the second ferromagnetic layer 4,wherein the first ferromagnetic layer 3, the first tunnel barrier layer 4 [*sic*], and the second ferromagnetic layer 6 [*sic*] form a ferromagnetic tunnel junction, and the composition of the ferromagnetic material contained in the second ferromagnetic layer 6 is represented by the general formula $(CoFe)_{100-x}Y_x$ or the general formula $(CoFeNi)_{100-x}Y_x$, and the Y is at least one element selected from the group consisting of B, Si, Zr, P, Mo, Al, and Nb.



[Scope of Patent Claims]

[Claim 1] A magnetoresistance effect element characterized by comprising a first ferromagnetic layer that maintains the direction of magnetization when the external magnetic field is not applied in a predetermined external magnetic field, a second ferromagnetic layer that can change the direction of magnetization when the external magnetic field is not applied in the external magnetic field, and a first tunnel barrier layer interposed between the first ferromagnetic layer and the second ferromagnetic layer, the first ferromagnetic layer, wherein the first tunnel barrier layer, and the second ferromagnetic layer form a ferromagnetic tunnel junction,

and wherein the composition of the ferromagnetic material contained in the second ferromagnetic layer is expressed by the general formula $(CoFe)_{100-x}Y_x$ or the general formula $(CoFeN\ i)_{100-x}Y_X$, and the Y is at least one element selected from the group consisting of B, Si, Zr, P, Mo, Al, and Nb.

[Claim 2] The magnetoresistance effect element according to Claim 1, characterized in that the x satisfies the relationship shown in inequality $3 \leq x \leq 16$.

[Claim 3] The magnetoresistance effect element according to Claim 1 or Claim 2, characterized in that the film thickness of the second ferromagnetic layer is within the range of 0.3 nm to 2.5 nm.

[Claim 4] The magnetoresistance effect element according to any one of Claims 1 to 4, further comprising a third ferromagnetic layer and a second tunnel barrier layer that retain a direction of magnetization provided when the external magnetic field is not applied, wherein the third ferromagnetic layer and the second tunnel barrier layer are disposed such that the second ferromagnetic layer is interposed between the first tunnel barrier layer and the second tunnel barrier layer and the first and second tunnel barrier layers are interposed between the first ferromagnetic layer and the third ferromagnetic layer, and the third ferromagnetic layer form a ferromagnetic tunnel junction.

[Claim 5] A magnetic memory characterized in that it includes a magnetoresistance effect element according to any one of Claims 1 to 4, and first and second wiring intersecting the magnetoresistance effect element .

[Claim 6] A magnetic head characterized in that it includes a magnetoresistance effect element according to any one of Claims 1 to 4, a support supporting the magnetoresistance effect element, and a pair of electrodes connected to the magnetoresistance effect element.

[Claim 7] A magnetic reproducing device, characterized by comprising a magnetic recording medium,

a magnetic head comprising a magnetoresistance effect element according to any one of Claims 1 to 4, a support body supporting the magnetoresistance effect element, and a pair of electrodes connected to the magnetoresistance effect element and reading information recorded in the magnetic recording medium; and

a movement mechanism that moves the magnetic head relative to the magnetic recording medium.

[Detailed Description of the Invention]

[0001]

[Technical field to Which the Invention Belongs] The present invention relates to a magnetoresistance effect element, a magnetic memory, a magnetic head, and a magnetic reproducing device.

[0002]

[Prior Art] A ferromagnetic single tunnel junction has a structure in which a thin insulating layer is sandwiched between a pair of ferromagnetic layers. When a bias voltage is applied using these ferromagnetic layers as electrodes, a tunnel current flows through the ferromagnetic single tunnel junction.

[0003] In a ferromagnetic single tunnel junction, the tunnel resistance when tunnel current flows, i.e. tunnel conductance, varies depending on the angle between the magnetization direction of one ferromagnetic layer and the magnetization direction of the other ferromagnetic layer. In other words, the magnetoresistance effect obtained by the ferromagnetic single tunnel junction is based on the change in tunnel conductance depending on the angle at which the magnetization direction is made between the ferromagnetic layers. For example, if the magnetization direction of one ferromagnetic layer is a first direction parallel to the film surface and the magnetization direction of the other ferromagnetic layer is a second direction opposite the first direction, the tunnel conductance is the minimum. In addition, when the magnetization directions of both ferromagnetic layers are the first direction, the tunnel conductance is the maximum.

[0004] This type of ferromagnetic single tunnel junction is expected to be applied to various devices. For example, a ferromagnetic single tunnel junction in which one ferromagnetic layer is a magnetization fixed layer whose magnetization direction is fixed and the other ferromagnetic layer is a free layer whose magnetization direction can be changed according to an external magnetic field has been proposed for use as a memory cell of a solid-state magnetic memory (or magnetic random access memory: MRAM), and this MRAM has already been prototyped, although it has a low storage capacity.

[0005] MRAM is basically nonvolatile, capable of high-speed writing and reading, and has excellent characteristics such as high fatigue resistance against repeated writing and reading. However, as explained below, MRAM has a problem in that when the size of the memory cell is reduced to increase the capacity, the magnetic field required to reverse the magnetization direction of the free layer, the so-called reversal magnetic field, becomes larger, and a larger write current is required.

[0006] The reversal magnetic field of the free layer is proportional to 1/W (W: cell width). It is also known that this reversal magnetic field is proportional to the film thickness t and saturated magnetization M_s of the free layer. That is, the reversal magnetic field of the free layer is proportional to $t \cdot M_s/W$. Furthermore, the reason that the reversal magnetic field of the free layer is proportional to 1/W is that an external magnetic field that exceeds the demagnetizing field that occurs inside the free layer is required to reverse the magnetization direction of the free layer and rewrite the information stored in the MR AM cell, which is caused by the magnetic pole that occurs in the width direction of the cell.

[0007] As is clear from the above proportional relationship, in order to avoid an increase in the reversal magnetic field when the size of the memory cell is reduced, for example, the film thickness t of the free layer may be reduced. However, when the film thickness t is reduced, the free layer, which should be a continuous film, is not obtained, but is in the form of a large number of fine particles dispersed on the underlayer. The thin film formed by such a large number of fine particles becomes a paramagnetic material rather than a ferromagnetic material, and the magnetoresistance ratio decreases significantly.

[0008] Also, saturation magnetization $_{\text{Ms can be}}$ reduced to avoid an increase in the reverse magnetic field when the size of the memory cell is reduced. However, when a nonmagnetic material is added to the material constituting the free layer in order to reduce the saturation magnetization M_s, the spin polarization of the conduction electrons at the Fermi surface often also decreases, leading to a decrease in the magnetoresistance ratio.

[0009] In other words, in the prior art, when the size of the memory cell is reduced, it is not possible to prevent an increase in the reversal magnetic field of the free layer while maintaining a sufficiently high magnetoresistance ratio. Furthermore, the problems described in relation to MRAM also exist in magnetic heads utilizing ferromagnetic single tunnel junctions. In addition, the above-described problems with ferromagnetic single tunnel junctions are the same with ferromagnetic double tunnel junctions.

[0010]

[Problem to be solved by the invention] The present invention has been made in consideration of the above problems, and has as its object to provide a magnetoresistance effect element, a magnetic memory, a magnetic head, and a magnetic reproducing device which can maintain a sufficiently high magnetoresistance ratio and prevent an increase in the reversal magnetic field even when the size is reduced.

[0011]

[Means for Solving the Problem] In order to solve the above problem, the present invention provides a magnetoresistance effect element comprising a first ferromagnetic layer that maintains the direction of magnetization when a predetermined external magnetic field is not applied, a second ferromagnetic layer that can change the direction of magnetization when the external magnetic field is not applied, and a first tunnel barrier layer interposed between the first ferromagnetic layer and the second ferromagnetic layer, wherein the first ferromagnetic layer, the first tunnel barrier layer, and the second ferromagnetic layer form a ferromagnetic tunnel junction, and wherein the composition of the ferromagnetic material contained in the second ferromagnetic layer is expressed by the general formula $(CoFe)_{100-x}Y_x$ or the general formula $(CoFeNi)_{100-x}Y_x$, where Y is at least one element selected from the group consisting of B, Si, Zr, P, Mo, Al, and Nb.

[0012] The present invention also provides a magnetic memory comprising the magnetoresistance effect element and first and second wirings intersecting the magnetoresistance effect element.

[0013] Furthermore, the present invention provides a magnetic head comprising the magnetoresistance effect element, a support body supporting the magnetoresistance effect element, and a pair of electrodes connected to the magnetoresistance effect element.

[0014] In addition, the present invention provides a magnetic reproducing device comprising a magnetic recording medium, a magnetic head comprising the magnetoresistance effect element, a support body supporting the magnetoresistance effect element, and a pair of electrodes connected to the magnetoresistance effect element, and reading information recorded on the magnetic recording medium, and a moving mechanism for moving the magnetic head relative to the magnetic recording medium.

[0015] In the present invention, it is preferred that the above x satisfy the relationship shown in inequality $3 \leq x \leq 16$. Also, in the present invention, the film thickness of the second ferromagnetic layer is preferably in the range of 0.3 nm to 2.5 nm.

[0016] In the present invention, said ferromagnetic tunnel junction may be a ferromagnetic single tunnel junction or may be a ferromagnetic double tunnel junction. In the latter case, the magnetoresistance effect element further includes a third ferromagnetic layer and a second tunnel barrier layer that maintain the direction of magnetization when the external magnetic field is not applied in the external magnetic field, wherein the third ferromagnetic layer and the second tunnel barrier layer are arranged such that the second ferromagnetic layer is interposed between the two tunnel barrier layers and the second ferromagnetic layer and the two tunnel barrier layers are interposed between the first and third ferromagnetic layers.

[0017]

[Embodiments of the invention] The present invention will be described in more detail below with reference to the drawings. In each drawing, the same or similar components are given the same reference symbols, and duplicated explanations are omitted.

[0018] Figure 1 is a cross-sectional view schematically illustrating a magnetoresistive effect element according to a first embodiment of the present invention; The magnetoresistive effect element 1 shown in Figure 1 has a ferromagnetic single tunnel junction 2 a. This ferromagnetic single tunnel junction 2 a has a structure in which a tunnel barrier layer 6 made of an insulator or the like is interposed between a pair of ferromagnetic layers 3 and 4. This ferromagnetic single-tunnel junction 2a is configured to allow tunnel current to flow between the ferromagnetic layers 3, 4 via the tunnel barrier layer 6.

[0019] An antiferromagnetic layer 8 is disposed on the rear surface of the ferromagnetic layer 3 opposite the surface in contact with the tunnel barrier layer 6. Thus, the magnetization direction of the ferromagnetic layer 3 does not change even when the external magnetic field is applied. On the other hand, the magnetization direction of the ferromagnetic layer 4 can basically rotate freely depending on the external magnetic field. That is, in the magnetoresistive effect element 1 shown in Figure 1, the ferromagnetic layer 3 is a first ferromagnetic layer, so-called magnetic bonding layer, with a fixed magnetization direction, and the ferromagnetic layer 4 is a second ferromagnetic layer, so-called free layer, in which the magnetization direction may vary depending on the external magnetic field. In other words, the magnetoresistance effect element 1 shown in Figure 1 utilizes the magnetoresistance effect that the tunnel resistance or tunnel current changes when the magnetization direction of the ferromagnetic layer 4 is reversed or rotated by an external magnetic field to change the angle between the magnetization direction of the ferromagnetic layer 3 and the magnetization direction of the ferromagnetic layer 4.

[0020] The above-mentioned ferromagnetic single tunnel junction 2a and antiferromagnetic layer 8 are usually formed by sequentially depositing various thin films on one main surface of the substrate 10. In the magnetoresistance effect element 1 of Figure 1, a diffusion barrier layer 11 and an orientation control layer 12 are sequentially stacked from the substrate 10 side between the substrate 10 and the antiferromagnetic layer 8, and a protective layer 13 and a wiring layer 14 are sequentially stacked on the ferromagnetic layer 4.

In addition, reference numeral 15 denotes an insulating layer.

[0021] Figure 2 is a cross-sectional view showing a schematic configuration of a magnetoresistance effect element according to a second embodiment of the present invention. The magnetoresistance effect element 1 shown in Figure 2 has a ferromagnetic double tunnel junction 2b instead of the ferromagnetic single tunnel junction 2a, and has an antiferromagnetic layer 9 between the ferromagnetic double tunnel junction 2b and the protective layer 13, and has a structure similar to that of the magnetoresistance effect element 1 shown in Figure 1.

[0022] In the magnetoresistance effect element 1 shown in Figure 2, the ferromagnetic double tunnel junction 2b has a structure in which a tunnel barrier layer 6 is interposed between the ferromagnetic layers 3 and 4, and a tunnel barrier layer 7 is interposed between the ferromagnetic layers 4 and 5. This ferromagnetic double tunnel junction 2b is configured so that a tunnel current flows between the ferromagnetic layers 3 and 4 and between the ferromagnetic layers 4 and 5 through the tunnel barrier layers 6 and 7.

[0023] In addition, in the magnetoresistance effect element 1 shown in Figure 2, as explained with respect to the ferromagnetic layer 3, the ferromagnetic layer 5 is also a magnetization fixed layer whose magnetization direction is fixed by the presence of the antiferromagnetic layer 9. The magnetoresistance effect element 1 shown in Figure 2 utilizes the magnetoresistance effect that the tunnel resistance or tunnel current changes when the magnetization direction of the ferromagnetic layer 4 is reversed or rotated by an external magnetic field to change the angle between the magnetization direction of the ferromagnetic layers 3 and 5 and the magnetization direction of the ferromagnetic layer 4.

[0024] Now, the magnetoresistance effect element 1 according to the first and second embodiments described above is characterized in that the ferromagnetic layer 4 is made of the material described below. That is, in the magnetoresistive effect element 1 shown in Figures 1 and 2, the composition of the ferromagnetic layer 4 is represented by the general formula $(CoFe)_{100-x} Y_X$ or the general formula $(CoFeNi)_{100-x} Y_X$. In these general formulas, Y is at least one element selected from the group consisting of B, Si, Zr, P, Mo, Al, and Nb. Also, x is a number satisfying inequality $0<x<100$, preferably a number satisfying inequality $3<x<16$.

[0025] The materials shown in these general formulas have a smaller saturated magnetization M_s than materials having a similar composition except that they do not contain element Y, and therefore, even if the size of the magnetoresistance effect element 1 is reduced (or the width W of the ferromagnetic layer 4 is reduced), the reversal magnetic field does not become excessively large. Also, even if the film thickness t of the ferromagnetic layer 4 is reduced, crystallization is inhibited according to the above material containing element Y, so the ferromagnetic layer 4 can be formed as a continuous film. That is, even if the size of the magnetoresistance effect element 1 is reduced, the reversal magnetic field of the ferromagnetic layer 4, which is proportional to the formula $t \cdot M_s/W$, can be maintained at a sufficiently small value by using the material shown in the above general formula.

[0026] Figure 3 is a graph showing an example of the relationship between the composition of the ferromagnetic layer 4 of the magnetoresistance effect element 1 according to the first and second embodiments of the present invention and its magnetoresistance change rate. This graph is drawn based on data obtained for a magnetoresistance effect element 1 using a ferromagnetic layer 4 having a composition shown in the general formula $(Co_9Fe)_{100-x} B_x$ and a thickness of 1 nm, where the horizontal axis indicates x in the above general formula, which corresponds to the concentration of B in the ferromagnetic layer 4, and the vertical axis indicates the magnetoresistance change rate (%).

[0027] In a normal film formation method at room temperature, the lower limit of the film thickness at which a Co_9Fe film that does not contain B can be formed as a continuous film is about 1.5 nm. When a Co_9Fe film is formed as a discontinuous film, the discontinuous film is composed of an aggregate of fine particles with a diameter of several nm. Each of these fine particles loses its ferromagnetism at room temperature, and the magnetization direction becomes unstable, becoming so-called superparamagnetic. As a result, within the range of practical magnetic field strength, the magnetoresistance change rate drops significantly.

[0028] On the other hand, when B is added to Co_9Fe, a continuous film can be formed up to a film thickness of about 0.5 nm. For example, when the film thickness is 1 nm, as shown in Figure 3, by setting x between 3 and 16, a sufficiently high magnetoresistance change rate of 10% or more can be obtained, and by setting x to about 5, a magnetoresistance change rate of 20% or more can be obtained.

[0029] It should be noted that the data shown in Figure 3 was obtained when B was added as element Y, but similar trends were observed when Si, Zr, P, Mo, Al, and Nb were added as element Y.

[0030] The reason that an extremely thin continuous film can be formed when the element Y is added is that the addition of the element Y suppresses the diffusion or movement of atoms that reach the film formation surface during the film formation process, thereby suppressing crystallization. Conversely, if the element Y is not added, the atoms that reach the film formation surface diffuse or move relatively freely, making crystallization more likely to occur. Therefore, in the prior art, when the film thickness is thinned, island structures are formed in which each island has a diameter of about several nanometers, and although each island is a ferromagnetic material, it exhibits superparamagnetism, in which the magnetization direction fluctuates, resulting in a significantly low magnetoresistance change rate.

[0031] In addition, in Figure 3, when x increases beyond 5, the magnetoresistance change rate decreases. The reason is not entirely clear, but it is believed that as the concentration of element Y increases, the scattering of conduction electrons increases, and the spin polarization of the conduction electrons at the Fermi level decreases significantly.

[0032] As explained above, the material shown in the above general formula can be used to form an extremely thin continuous film, and can achieve a sufficiently high magnetoresistance change rate despite the inclusion of element Y, which is a nonmagnetic material. That is, by forming the ferromagnetic layer 4 from the material shown in the above general formula, even if the size of the magnetoresistance effect element 1 is reduced, it is possible to maintain a sufficiently high magnetoresistance ratio and prevent an increase in the reversal magnetic field.

[0033] In the above-mentioned magnetoresistance effect element 1, the material constituting the ferromagnetic layers 3 and 5 is not particularly limited, and various ferromagnetic materials can be used, such as NiFe alloys such as permalloy, Fe, Co, Ni, and alloys containing them, half-metals such as Heusler alloys such as NiMnSb and PtMnSb, oxide-based half-metals such as CrO_2, magnetite, and Mn perovskite, and amorphous alloys, as well as hard magnetic materials such as CoPt alloys, FePt alloys, and transition metal-rare earth alloys.

[0034] In the magnetoresistance effect element 1 described above, the antiferromagnetic layers 8 and 9 are provided to fix the magnetization directions of the ferromagnetic layers 3 and 5 by exchange coupling. The antiferromagnetic layers 8 and 9 may be, for example, antiferromagnetic alloys such as FeMn, IrMn, PtMn, NiMn, or thin films made of antiferromagnetic materials such as NiO or Fe_2O_3, or antiferromagnetic exchange coupling films such as Co/Ru/Co or Co/Au/Co.

[0035] Tunnel barrier layers 6 and 7 may each have a potential height and thickness in the range that can flow tunnel current between ferromagnetic layers 3 and 4 and between ferromagnetic layers 4 and 5. The materials of the tunnel barrier layers 6, 7 can include, for example, Al, Si, Mg, rare earth elements, or oxides or nitrides of alloys containing these elements. However, the potential barrier of a thin film made of an oxide insulator changes significantly depending on the manufacturing conditions, etc. The characteristics of the magnetoresistance effect element 1 change significantly depending on the width and height of the potential barrier. Therefore, when such an oxide insulator is used, the freedom in setting the element characteristics increases, but it is necessary to appropriately set the type and manufacturing conditions, etc. according to the element size.

[0036] n the magnetoresistance effect element 1, the substrate 10 may be, for example, a silicon single crystal substrate with a SiO_2 oxide film formed on the surface. The diffusion barrier layer 11 formed on the substrate 10 is for preventing diffusion, and materials thereof can include, for example, Ta, TaPt, Ti, TiN_x, and $CoSi_2$, etc. The orientation control layer 12 formed on the diffusion barrier layer is the underlayer for forming the antiferromagnetic layer 8 having the desired crystal orientation, and may be composed of materials such as, for example, NiFe, Cu, Ag, and Au. Also, for example, Ta or Au, etc., can be used as the material of the protective layer 13, and for example, Al, Cu, A g, and A u, etc., can be used as the material of the wiring layer 14.

[0037] Next, a magnetic memory using the magnetoresistance effect element 1 according to the first and second embodiments will be described. [0038] Figure 4 is a cross-sectional view that shows a schematic of a magnetic memory (MRAM) using the magnetoresistance effect element 1 according to the first and second embodiments of the present invention. Also, Figure 5 is an equivalent circuit diagram of the MRAM shown in Figure 4.

[0039] The MRAM 21 shown in Figure 4 has a silicon substrate 22. A gate electrode 24 is formed on the silicon substrate, and source and drain regions 25 and 26 are formed on the surface region of the silicon substrate 22 so as to sandwich the gate electrode 24. Thus, the MOS transistor 23 is configured. It should be noted that the gate electrode 24 comprises a word line (WL1) for readout. In addition, a write word line (WL2) 28 is formed on the word line (WL1) 24 via an insulating film 27.

[0040] One end of a contact metal 29 is connected to the drain region 26 of the MOS transistor 23, and the other end of the contact metal 29 is connected to the underlayer 30. A ferromagnetic tunnel junction element (TMR) 31 is formed at a position corresponding to the word line (WL2) 28 on the underlayer 30, and furthermore, a bit line 32 is formed on the TMR 31.

[0041] The cell of MRAM 21 is configured as described above. It should be noted that the TMR 31 and underlayer 30 shown in Figure 4 correspond to the structure of the magnetoresistance effect element 1 shown in Figure 1 and Figure 2, excluding the substrate 10, protective layer 13, wiring layer 14, and insulating layer 15.

[0042] The memory cells, each composed of the above-mentioned MOS transistor 23 and TMR 31, are arranged in an array as shown in Figure 5. The read word line (WL1) 24, which is the gate electrode of the transistor 23, and the write word line (WL2) 28 are arranged in parallel. In addition, the bit line (BL) 32 connected to the top of the TMR 31 is arranged so as to be perpendicular to the word line (WL1) 24 and the word line (WL2) 28.

[0043] Since this MRAM 21 uses the magnetoresistance effect element 1 according to the first and second embodiments, even if the size of the memory cell is reduced, it is possible to prevent an increase in the reversal magnetic field of the free layer while maintaining a sufficiently high magnetoresistance ratio. That is, in this MRAM 21, even if the memory cell size is reduced, information can be written with sufficient current.

[0044] In addition, in the MRAM21, a diode may be used instead of the transistor 23. For example, a memory cell consisting of a stack of a diode and TMR 31 can be formed on the word line 24, and a bit line 32 can be formed on the TMR 31 so as to be perpendicular to the word line 24, to obtain an MRAM 21.

[0045] Next, a magnetic head using the magnetoresistance effect element 1 according to the first and second embodiments will be described.

Figure 6 is a perspective view showing a magnetic head assembly having a magnetic head using the magnetoresistance effect element 1 according to the first and second embodiments of the present invention. The magnetic head assembly 41 shown in Figure 6 has an actuator arm 42 with, for example, a bobbin portion holding the drive coil. One end of a suspension 43 is attached to the actuator arm 42, and a head slider 44 is attached to the other end of the suspension 43. The magnetoresistance effect element 1 according to the first and second embodiments described above is used in a magnetic reproducing head incorporated in the head slider 44.

[0046] Lead wires 45 are formed on suspension 43 for writing and reading signals, and this lead wires 45 are each electrically connected to an electrode of a magnetic regeneration head incorporated into head slider 44. In Figure 6, reference number 46 indicates an electrode pad of the magnetic head assembly 41.

[0047] The magnetic head assembly 41 can be mounted, for example, in a magnetic recording and reproducing device as described below. Figure 7 is a perspective view showing a magnetic recording and reproducing device equipped with the magnetic head assembly 41 shown in Figure 6. In the magnetic recording and reproducing device 51 shown in Figure 7, the magnetic recording medium, that is, the magnetic disk 52, is rotatably supported by the spindle 53. A motor (not shown in the figure) that operates in response to a control signal from a control unit (not shown in the figure) is connected to the spindle 53, thereby making it possible to control the rotation of the magnetic disk 52.

[0048] A fixed shaft 54 is arranged near the circumference of the magnetic disk 52, and this fixed shaft 54 supports the magnetic head assembly 41 shown in Figure 6 in a swingable manner via ball bearings (not shown in the figure) arranged at two points above and below it. A coil (not shown in the figure) is wound around the bobbin portion of the magnetic head assembly 41, and the coil, the permanent magnets arranged opposite to each other, and the opposing yoke form a magnetic circuit and also constitute a voice coil motor 55. This voice coil motor 55 allows the head slider 44 at the tip of the magnetic head assembly 41 to be positioned on a desired track of the magnetic disk 52. Furthermore, in this magnetic recording and reproducing device 51, information is recorded and reproduced by rotating the magnetic disk 52 and floating the head slider 44 above the magnetic disk 52.

[0049] As described above, the magnetoresistance effect element 1 according to the first and second embodiments can be used in a magnetic memory, a magnetic head, a magnetic reproducing device, and a magnetic recording and reproducing device. In addition, the magnetoresistance effect element 1 according to the first and second embodiments can also be used in a magnetic sensor and a magnetic field detection device using the same.

[0050]

[Examples of Embodiment] Embodiments of the present invention are described below. (Example of Embodiment) The magnetoresistive effect element 1 shown in Figure 2 was made by the method described below. First, the Si/SiO_2 substrate 10 was carried into the sputtering device. The initial vacuum level in the device was then set to 2×10^{-7} Torr or less, and then Ar was introduced into the device to set the pressure to 2×10^{-3}. Then, on one major surface of the Si/SiO_2 substrate 10, a diffusion barrier layer 11 consisting of a 5 nm thick Ta, an orientation control layer 12 consisting of a 15 n m thick NiFe, an antiferromagnetic layer 8 consisting of an $Ir_{22}Mn_{78}$ having a 17 nm thickness, and a ferromagnetic layer 3 consisting of a 3 nm thick CoFe were sequentially deposited.

[0051] Next, an Al_2O_x layer with a thickness of 1.5 nm was formed on the ferromagnetic layer 3 by sputtering an Al_2O_3 target in Ar gas. Next, pure oxygen was introduced into the device without breaking the vacuum and glow discharge was performed to generate oxygen plasma, and the Al_2O_x was oxidized to Al_2O_3 using this oxygen plasma to obtain the tunnel barrier layer 6. At this time, the degree of conversion from Al_2O_x to Al_2O_3 was adjusted by controlling the power and oxidation time during glow discharge.

[0052] After exhausting pure oxygen from the device, a ferromagnetic layer 4 consisting of $(Co_9Fe)_{0.95}$ $B_{0.5}$ having a thickness of 1.5 nm was deposited on the tunnel barrier layer 6 by performing sputtering under the same conditions described above. Next, the Al_2O_X layer was deposited in the Ar gas under the same conditions as described above on the ferromagnetic layer 4, and the Al_2O_x layer was treated with oxygen plasma to obtain a tunnel barrier layer 7 consisting of Al_2O_3. Further, by performing sputtering under the same conditions as described above, a protective film 13 consisting of a ferromagnetic layer 5 consisting of 5 nm thick CoFe, an antiferromagnetic layer 9 consisting of 17 nm thick $Ir_{22}Mn_{78}$, and a 5 nm thick Ta was sequentially deposited on the tunnel barrier layer 7.

[0053] After that, using conventional photolithography technology and ion milling technology, these thin films were patterned to have a width W of 2 to 0.25 μm and a length L three times the width W, thereby defining a double tunnel junction. In this way, a magnetoresistive effect element 1 shown in Figure 2 was obtained.

[0054] Furthermore, the magnetization direction of the ferromagnetic layer 3 and the magnetization direction of the ferromagnetic layer 5 were fixed in the same direction parallel to the substrate surface by means of the antiferromagnetic layers 8 and 9. With this configuration, the magnetization directions of the ferromagnetic layers 3 and 5 do not change due to a weak external magnetic field of about several thousand e, and the magnetization direction of the ferromagnetic layer 4 changes in response to the external magnetic field. In addition, in this magnetoresistance effect element 1, the resistance of the ferromagnetic double tunnel junction 2b is lowest when the magnetization directions of the ferromagnetic layers 3 and 5 and the ferromagnetic layer 4 are the same, and is highest when the magnetization directions of the ferromagnetic layers 3 and 5 and the ferromagnetic layer 4 are opposite.

[0055] (Comparative example) Magnetoresistive effect element 1 shown in Figure 2 was made by a method similar to that described in the above embodiment, except that instead of forming a 1.5 nm thick $(Co_9Fe)_{0}.9_5B_{0}.5$ film as ferromagnetic layer 4, a 3 nm thick Co_9Fe film was formed.

[0056] Next, the magnetoresistance ratio (TMR) of the magnetoresistive effect element 1 made in the above embodiments and comparative examples was investigated. In addition, when the minimum resistance of the ferromagnetic double tunnel junction 2b is $R_{min}$and the maximum resistance is R_{max}, TMR is defined by the following equation:

TMR (%)=$[(R_{max} - R_{min})/R_{min}]/100$

[0057] Figure 8 is a graph showing the magnetoresistance ratio of the magnetoresistance effect element 1 according to the embodiment of the present invention and the comparative example. In the figure, the horizontal axis shows the inverse of the width W of the tunnel junction 1/W (μm^{-1}), and the longitudinal axis shows the magnetic field strength H_c (Oe) required to reverse the magnetization direction of the ferromagnetic layer 4. In addition, in the figure, the curve 61 shows the data obtained for the magnetoresistance effect element 1 according to the embodiment of the present invention, and the curve 62 shows the data obtained for the magnetoresistance effect element 1 according to the comparative example.

[0058] As shown in Figure 8, in the magnetoresistance effect element 1 according to the embodiment of the present invention, even if the width W of the tunnel junction is reduced to about 0.25 μm, the magnetic field strength H_c required to reverse the magnetization direction of the ferromagnetic layer 4 is sufficiently small, at 400 e or less. Moreover, the rate of change of the magnetic field strength H_c with respect to the width W is small, so it can be seen that it is possible to accommodate further miniaturization.

[0059] In contrast, in the magnetoresistance effect element 1 according to the comparative example, when the width W of the tunnel junction is about 0.25μm, the strength of the magnetic field H_c required to reverse the magnetization direction of the ferromagnetic layer 4 exceeds 1000e, making it difficult to practically reverse the magnetization direction of the ferromagnetic layer 4.

[0060] It should be noted that the magnetoresistance effect elements 1 according to the embodiment and the comparative example were manufactured by the same method as described above, except that Si, Zr, P, Mo, Al, and Nb were used instead of B as the element Y, and when they were compared, the same tendency was observed as when B was used as the element Y. Furthermore, when a similar comparison was made using a material represented by the general formula $(CoFe)_{100-x}Y_x$ instead of the material represented by the general formula $(CoFeNi)_{100-x}Y_x$as the material for the ferromagnetic layer 4, the same tendency as described above was observed.

[0061]

[Effects of the Invention] As explained above, in the present invention, a specific material is used that can form an extremely thin continuous film in the ferromagnetic layer whose magnetization direction can change in response to an external magnetic field, and that can obtain a sufficiently high magnetoresistance change rate. Therefore, even when the size is reduced, it is possible to maintain a sufficiently high magnetoresistance ratio and prevent an increase in the reversal magnetic field. That is, according to the present invention, a magnetoresistance effect element, a magnetic memory, a magnetic head, and a magnetic reproducing device that can maintain a sufficiently high magnetoresistance ratio and prevent an increase in the reversal magnetic field even when the size is reduced are provided.

[Brief Description of the Drawings]

[Figure 1] A cross-sectional view schematically showing a magnetoresistive effect element according to a first embodiment of the present invention.

[Figure 2] A cross-sectional view schematically showing a magnetoresistive effect element according to a second embodiment of the present invention.

[Figure 3] A graph showing an example of the relationship between the composition of the ferromagnetic layer of the magnetoresistive effect element according to the first and second embodiments of the present invention and the magnetoresistance change rate thereof.

[Figure 4] A cross-sectional view showing a schematic diagram of a magnetic memory using the magnetoresistive effect elements according to the first and second embodiments of the present invention.

[Figure 5] An equivalent circuit diagram of the magnetic memory shown in Figure 4.

[Figure 6] A perspective view showing a schematic diagram of a magnetic head assembly having a magnetic head using the magnetoresistive effect elements according to the first and second embodiments of the present invention.

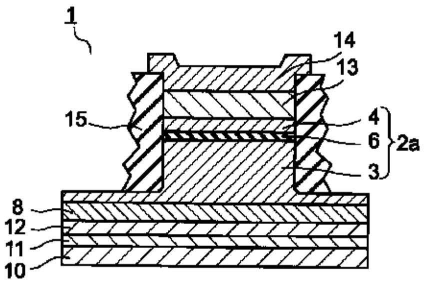
[Figure 7] A perspective view showing a schematic diagram of a magnetic recording and reproducing device equipped with the magnetic head assembly shown in Figure 6.

[Figure 8] A graph showing the magnetoresistance ratio of magnetoresistance effect elements according to the embodiment and comparative example of the present invention.

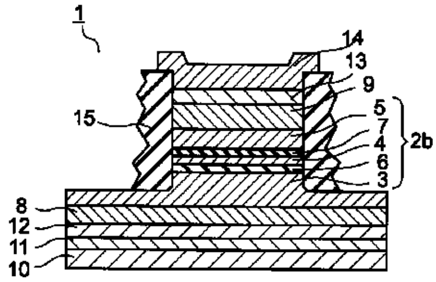
[Explanation of References]

1....Magnetoresistance effect element
2a... Ferromagnetic single tunnel junction
2 b...Ferromagnetic double tunnel junction
3 to 5...Ferromagnetic layer
6, 7 - Tunnel barrier layer
8, 9... Antiferromagnetic layer
10... Substrate
11...Diffusion barrier layer
12...Orientation control layer
13...Protective layer
14...Wiring layer
15...Insulation layer

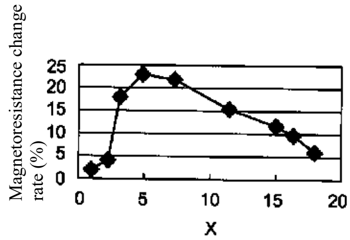
[Figure 1]



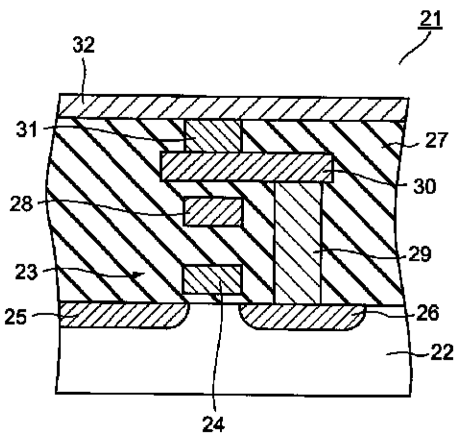
[Figure 2]



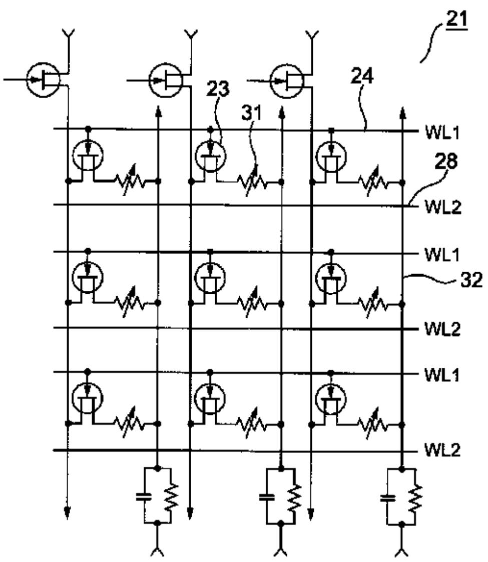
[Figure 3]



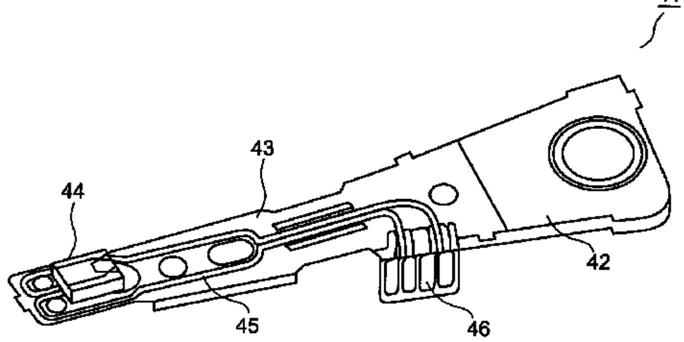
[Figure 4]



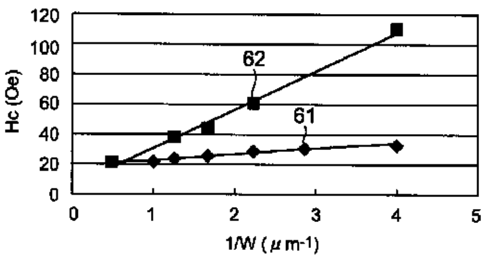
[Figure 5]



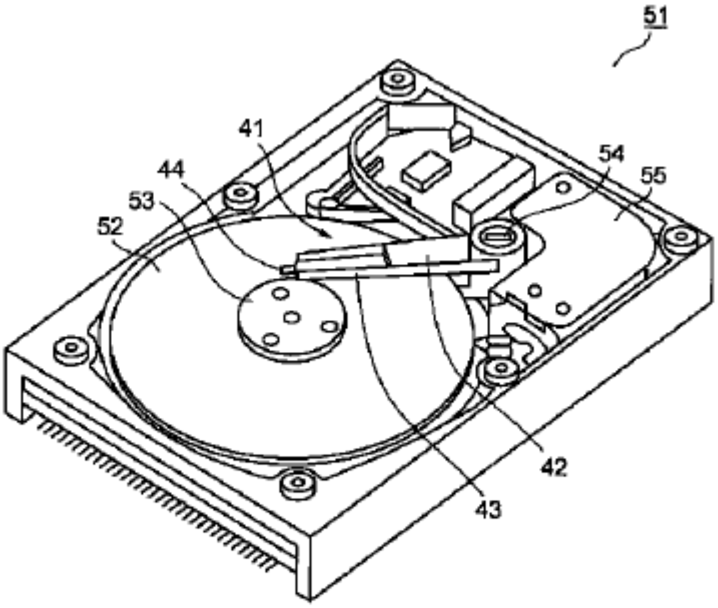
[Figure 6]



[Figure 8]



[Figure 7]



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