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Abstract

PROBLEM TO BE SOLVED: To realize a ferromagnetic tunnel junction that is high in magnetoresistivity and relatively high in output voltage owing to its large resistance, and whose magnetoresistivity is lessened in bias voltage- and temperature-dependent properties so as to enhance the junction in practicability. SOLUTION: A magnetic element is possessed of a ferromagnetic tunnel junction 1 of layered structure composed of ferromagnetic layer 2/tunnel barrier layer 3/ferromagnetic layer 4 or a ferromagnetic double tunnel junction of layered structure composed of ferromagnetic layer/tunnel barrier layer/ferromagnetic layer/tunnel barrier layer/ferromagnetic layer, where it is utilized that a tunnel resistance changes with a relative angle of magnetization between ferromagnetic layers. The magnetic element increases positively in magnetoresistivity with an increase in an bias voltage. Moreover, the magnetic element decreases less in magnetoresistivity with an increase in temperature. Provided that the barrier height and barrier width of the tunnel barrier layer are represented by Φ [unit: eV] and S [unit: angstrom] respectively, the tunnel barrier layer is formed so as to satisfy a formula, $10 < S/(\Phi)^{1/2}$.

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[0001] BACKGROUND OF THE INVENTION 1. Field of the Invention The present invention relates to a magnetic element using a ferromagnetic tunnel junction, a magnetic memory using the same, a magnetic sensor, and a magnetic head.

[0002] 2. Description of the Related Art In a ferromagnetic tunnel junction consisting of two ferromagnetic layers separated by a thin insulating layer (dielectric layer), a tunnel current flows when a bias voltage is applied with the ferromagnetic layer as an electrode. At this time, the tunnel resistance changes depending on the relative angle formed by the magnetizations of the two ferromagnetic layers. Specifically, the tunnel resistance has a maximum value when the magnetizations of the two ferromagnetic layers are antiparallel, and has a minimum value when the magnetizations are parallel. A so-called magnetoresistive effect (MR) is obtained by such a change in tunnel resistance. Therefore, if two ferromagnetic layers are made of ferromagnetic materials having different coercive forces, a change in the external magnetic field can be detected as a resistance change.

[0003] A phenomenon very similar to this has been found in the metal artificial lattice film and is being put to practical use as a magnetic head. For example, a laminated film in which a ferromagnetic layer and a non-magnetic metal layer are laminated at a cycle of several nm has been found as a material exhibiting a giant magnetoresistive effect (GMR) depending on the spin direction. Fe/Cr artificial lattice film (Phys. Rev. Lett. 61, 2472 (1988)), Co/Cu artificial lattice film (J. Mag. Mag. Mater. 94) are used as the metal artificial lattice film exhibiting such GMR. , L1 (1991)) and the like, in which the interaction between ferromagnetic layers is antiferromagnetically coupled. However, the metal artificial lattice film using the antiferromagnetic coupling between the ferromagnetic layers has a problem that the antiferromagnetic exchange coupling constant is large, the saturation magnetic field is large, and the hysteresis is also very large.

[0004] In order to reduce the saturation magnetic field, an exchange bias is applied to one of the ferromagnetic layers of the sandwich laminated film of ferromagnetic layer/non-magnetic layer/ferromagnetic layer to fix the magnetization, and the other ferromagnetic layer is magnetized by an external magnetic field. A magnetic laminated film, a so-called spin valve film, has been developed which changes the relative angle between the magnetization directions of two ferromagnetic layers by reversing. However, the spin valve film has a smaller resistance change rate (magnetoresistance ratio) than the metal artificial lattice film, and when applied to a magnetic head or a memory element, it is considered difficult to achieve higher performance. There is.

[0005] On the other hand, in the above-mentioned ferromagnetic tunnel junction, it has recently been revealed that a large magnetoresistive ratio can be obtained as compared with a GMR material such as a spin valve film. Further, since the ferromagnetic tunnel junction has a large resistance as a laminated film as compared with a spin valve film or the like, a relatively large output voltage can be obtained. Based on these properties, ferromagnetic tunnel junctions are expected as a new GMR material. Further, since the magnetization of a ferromagnetic material exhibits hysteresis, its application to a memory element that constitutes a non-volatile memory is also under study.

[0006] As described above, although a large magnetoresistive ratio can be obtained in the ferromagnetic tunnel junction, this magnetoresistive ratio greatly depends on the bias voltage applied to the junction. That is, when the applied bias voltage increases, the tunnel current flowing through the junction rapidly increases and the magnitude of the resistance change decreases, and as a result, the magnetoresistive ratio of the junction decreases. This property puts a large limitation on the application of the ferromagnetic tunnel junction to the MR element.

[0007] In order to avoid such a defect, the following method can be considered. First, the device is operated with a small bias voltage such that the magnetoresistive ratio does not decrease so much. However, in this case, the output also becomes small, which is a problem in putting the ferromagnetic tunnel junction into practical use as an MR element.

[0008] Secondly, a junction having a high barrier potential formed by the insulator layer is used. Since such a junction originally provides a large magnetoresistive ratio, even if the magnetoresistive ratio is decreased by the bias voltage, it can be kept within the usable range. However, in this case, the resistance value itself becomes large, which causes a decrease in device speed and an increase in thermal noise. Therefore, it is conceivable to thin the insulator layer, but in this case, the manufacturing of the element itself becomes difficult.

[0009] As described above, the ferromagnetic tunnel junction has a problem that the magnetoresistive ratio depends on the bias voltage, and the magnetoresistive ratio decreases as the bias voltage increases. Further, in the ferromagnetic tunnel junction, the temperature dependence of the magnetoresistive ratio is also an issue as well as the voltage dependence of the magnetoresistive ratio. That is, in the ferromagnetic tunnel junction, the magnetoresistive ratio decreases as the temperature rises. Both the voltage dependence and the temperature dependence of the magnetoresistive ratio are considered to be due to the excitation of magnon waves. In fact, since the ambient temperature in which the ferromagnetic tunnel junction is used is room temperature or higher, it is a practical problem that the magnetoresistive ratio decreases as the temperature rises.

[0010] The present invention has been made to address such a problem, and a bias voltage of a ferromagnetic tunnel junction that can obtain a large magnetoresistive ratio and a relatively large output voltage because of a large resistance. It is intended to provide a magnetic element with improved practicality by improving the dependence of the magnetoresistive ratio on the magnetic field and the dependence of the magnetoresistive ratio on temperature, and by using such a magnetic element. , A magnetic memory and a magnetic sensor having improved characteristics and practicality are provided.

[0011] According to a first aspect of the present invention, there is provided a magnetic element having at least two ferromagnetic layers and at least one tunnel interposed between the two ferromagnetic layers. In a magnetic element that has a ferromagnetic tunnel junction composed of a laminated film with a barrier layer and flows a tunnel current between the two ferromagnetic layers, it has a magnetoresistive ratio that increases with a positive slope with increasing bias voltage. It is characterized by that.

[0012] In the magnetic element described above, more specifically, as described in claim 2, the tunnel barrier layer is made of an insulator or a semiconductor having a potential barrier smaller than the value of the potential barrier having the minimum magnetoresistance ratio. Further, as described in claim 3, the thinnest portion of the tunnel barrier layer is thicker than 1.0 nm.

[0013] As described in claim 4, the magnetic element of the present invention is a strong film composed of a laminated film of at least two ferromagnetic layers and at least one tunnel barrier layer interposed between the two ferromagnetic layers. In a magnetic element having a magnetic tunnel junction and passing a tunnel current between the two ferromagnetic layers, the tunnel barrier height of the tunnel barrier layer is Φ [unit: eV], and the width of the tunnel barrier layer is S [unit: Å], the value of $S/(\Phi)^{1/2}$ satisfies $10 \leq S/(\Phi)^{1/2}$.

[0014] As described in claim 8, a magnetic memory of the present invention is characterized by including the above-described magnetic element of the present invention as a memory cell. Further, a magnetic sensor of the present invention is characterized by including the above-mentioned magnetic element of the present invention as described in claim 9.

[0015] In the magnetic element of the present invention, an insulator or semiconductor having a potential barrier smaller than the value of the potential barrier having the minimum magnetoresistive ratio is used for the tunnel barrier layer, that is, an insulator or semiconductor having a low potential barrier is used. By increasing the thickness of such a tunnel barrier layer, a ferromagnetic tunnel junction in which the magnetoresistive ratio increases with a positive slope with increasing bias voltage is realized. According to such a ferromagnetic tunnel junction, it becomes possible to obtain a good magnetoresistive ratio for a wide range of bias voltages.

[0016] More specifically, the tunnel barrier layer in the magnetic element of the present invention is $S/(\Phi)^{1/2}$ when the tunnel barrier height is Φ [unit: eV] and the tunnel barrier width is S [unit: angstrom]. The value of satisfies $10 \leq S/(\Phi)^{1/2}$. By applying such a tunnel barrier layer, it is possible to more reliably increase the magnetoresistive ratio with respect to an increase in bias voltage, and further it is possible to suppress a decrease in magnetoresistive ratio with respect to an increase in temperature.

[0017] That is, by using a tunnel barrier layer in which the value of $S/(\Phi)^{1/2}$ satisfies $10 \leq S/(\Phi)^{1/2}$, the spin configuration of two ferromagnetic layers is different from that in the antiparallel state. This is a ferromagnetic tunnel junction in which the conductance difference ΔG in the parallel state does not substantially decrease with

an increase in temperature, specifically, it is substantially constant or increases. According to such a ferromagnetic tunnel junction, it is possible to significantly suppress the decrease in the magnetoresistive ratio with the increase in temperature.

[0018] According to the magnetic element having the ferromagnetic tunnel junction as described above, the practicability of various elements utilizing the magnetoresistive effect based on the tunnel resistance that changes depending on the relative angle of the magnetization of the two ferromagnetic layers is significantly improved. be able to.

[0019] BEST MODE FOR CARRYING OUT THE INVENTION Modes for carrying out the present invention will be described below.

[0020] FIG. 1 is a sectional view showing a schematic structure of an embodiment of a magnetic element of the present invention. In the figure, 1 is a ferromagnetic tunnel junction having a three-layer laminated structure of a first ferromagnetic layer 2, a tunnel barrier layer 3 and a second ferromagnetic layer 4. Lead electrodes 5 and 6 are connected to the first and second ferromagnetic layers 2 and 4, respectively. In the figure, reference numeral 7 is a substrate, and 8 is an insulating layer.

[0021] The ferromagnetic tunnel junction 1 is configured so that a tunnel current flows between the first ferromagnetic layer 2 and the second ferromagnetic layer 4 via a tunnel barrier layer 3 made of an insulator or the like. Then, by utilizing the difference in coercive force between the first ferromagnetic layer 2 and the second ferromagnetic layer 4, for example, the magnetization of one ferromagnetic layer is reversed by an external magnetic field, and the two ferromagnetic layers 2, The magnetoresistive effect (MR) is obtained by the tunnel resistance (tunnel current) that changes depending on the relative angle of magnetization of No. 4.

[0022] That is, the tunnel resistance of the ferromagnetic tunnel junction 1 is minimum when the magnetizations of the first ferromagnetic layer 2 and the second ferromagnetic layer 4 are oriented in the same direction. From this state, the tunnel resistance of the ferromagnetic tunnel junction 1 is maximized by reversing only the magnetization of one ferromagnetic layer having a small coercive force by an external magnetic field. At this time, the magnetization of the other ferromagnetic layer is substantially fixed to the external magnetic field that reverses the magnetization of the one ferromagnetic layer. In this way, the magnetoresistive effect is obtained. The magnetic resistance ratio is defined by the ratio of these tunnel resistances (tunnel resistance change rate).

[0023] The constituent materials of the first and second ferromagnetic layers 2 and 4 are not particularly limited, and Ni—Fe alloys represented by Permalloy, Fe, Co, Ni exhibiting ferromagnetism and alloys containing them, NiMnSb. , Half metal such as Heusler alloy such as PtMnSb, oxide type half metal such as CrO₂, magnetite and Mn perovskite, various soft magnetic materials such as amorphous alloy, Co—Pt alloy, Fe—Pt alloy, transition metal -Various ferromagnetic materials can be used, up to hard magnetic materials such as rare earth alloys. In order to change only one magnetization direction (spin direction) of the first and second ferromagnetic layers 2 and 4, the difference in coercive force of the ferromagnetic material can be used as described above.

[0024] Further, one of the ferromagnetic layers may be laminated with an antiferromagnetic film, and the magnetization of the ferromagnetic layer may be fixed by the exchange coupling between them. FIG. 2 is a diagram showing a configuration example of a ferromagnetic tunnel junction 1 using an antiferromagnetic film. In FIG. 2, an antiferromagnetic film 9 is laminated on the second ferromagnetic layer 4 of the first and second ferromagnetic layers 2 and 4 arranged with the tunnel barrier layer 3 interposed therebetween. An exchange bias is applied from the antiferromagnetic film 9 to the second ferromagnetic layer 4, and the magnetization of the second ferromagnetic layer 4 is fixed by this exchange bias. The ferromagnetic layer 4 in contact with the antiferromagnetic film 9 has a magnetization reversal even when the magnetic field of the present invention is applied to, for example, a magnetic memory element, even under application of a magnetic field (current magnetic field due to wiring) and signal reading many times. Can be prevented and a stable signal strength can be obtained.

[0025] At this time, the antiferromagnetic film 9 includes antiferromagnetic alloys such as FeMn, IrMn, PtMn, and NiMn, antiferromagnetic materials such as NiO and Fe₂O₃, and further Co/Ru/Co, Co/Ir/Co, and the like. The antiferromagnetic exchange coupling film can be used. Further, a pair of hard magnetic films or the like may be arranged adjacent to both ends of one ferromagnetic layer, and a bias magnetic field may be applied from this hard magnetic film to the ferromagnetic layer to fix the magnetization.

[0026] The magnetic element of the present invention is not limited to a ferromagnetic single tunnel junction having a laminated structure of a first ferromagnetic layer/a tunnel barrier layer/a second ferromagnetic layer, but may be a first ferromagnetic layer/a first tunnel barrier. Applicable to a ferromagnetic double tunnel junction having a laminated structure of layer/second ferromagnetic layer/second tunnel barrier layer/third ferromagnetic layer, and further to a ferromagnetic multiple tunnel junction of triple or more Is.

[0027] FIG. 3 is a diagram showing a specific configuration example of the ferromagnetic double tunnel junction. The ferromagnetic double tunnel junction 10 shown in FIG. 3 has a first ferromagnetic layer 11/a first tunnel barrier layer 12/a second ferromagnetic layer 13/a second tunnel barrier layer 14/a third ferromagnetic layer. It has a laminated film of the layer 15, and the first ferromagnetic layer 11 and the third ferromagnetic layer 15 are laminated with antiferromagnetic films 16 and 17, respectively. Exchange biases are applied to the first and third ferromagnetic layers 11 and 15 from the antiferromagnetic films 16 and 17, respectively, and the magnetizations of the first and third ferromagnetic layers 11 and 15 are applied by these exchange biases. Is fixed.

[0028] Further, in the ferromagnetic double tunnel junction 10, a ferromagnetic material-dielectric mixed layer can be used as the intermediate ferromagnetic layer (the second ferromagnetic layer 13 in FIG. 3). FIG. 4 shows an example of the structure of such a ferromagnetic double tunnel junction, and this ferromagnetic double tunnel junction 10 includes an antiferromagnetic film 16/first ferromagnetic layer 11/first tunnel barrier layer 12 It has a laminated structure of /ferromagnetic material-dielectric mixed layer 18/second tunnel barrier layer 14/third ferromagnetic layer 15/antiferromagnetic film 17. With such a ferromagnetic double tunnel junction 10, the same effect as that of the ferromagnetic double tunnel junction shown in FIG. 3 can be obtained.

[0029] Various materials can be used for the underlayer of the above-mentioned various ferromagnetic tunnel junctions (single or double), but Ta, Ti, Pt, Ti/Pt, Ti/Pd, Ta/Pt. , Ta/Pd, Al₂O₃, amorphous alloy, etc., can be used as the underlayer to flatten the upper laminated structure and change the crystal growth, so that the exchange bias of the antiferromagnetic film/ferromagnetic layer interface is strong. The advantages such as

[0030] The tunnel barrier layers 3, 12, and 14 may be made of any of various insulators and semiconductors as long as tunnel current can flow between the ferromagnetic layers, and are formed by the tunnel barrier layers 3, 12, and 14. As the potential barrier, an insulator or a semiconductor having a potential barrier smaller than the value of the potential barrier in which the magnetoresistive ratio in a certain thickness of the tunnel barrier layer has the minimum value is used.

[0031] As described above, in the present invention, the tunnel barrier layers 3, 12, and 14 are required to be made of a material having a low potential barrier. Here, the control of the potential barrier basically depends on the constituent material of the tunnel barrier layer. For this reason, an insulator or semiconductor having a small gap is suitable as a constituent material of the tunnel barrier layers 3, 12, and 14, and particularly, the gap is preferably smaller than 1 eV.

[0032] Specific constituent materials of the tunnel barrier layers 3, 12, and 14 include insulators (dielectrics) such as Al₂O₃, AlOx, SiO₂, SiOx, AlN, NiO, CoO, MgO, and HfO₂, FeSi, GeSb, and PbSe. , Narrow gap semiconductors such as PbTe and the like can be used. Among these, the potential barrier of the thin film made of the insulator as described above changes depending on the manufacturing conditions. For example, in the case of an Al₂O₃ (AlOx) film formed by oxidizing an Al film, the potential barrier changes within the range of 0 to 3 eV depending on the degree of oxidation of the Al film. Therefore, an insulator film (dielectric film) having a potential barrier satisfying the above-mentioned conditions can be obtained by controlling the degree of oxidation of the Al film. In the case of a narrow gap semiconductor, since the potential barrier is originally small, it is preferable to control the film forming conditions and the like so that the tunnel barrier layers 3, 12, 14 can have good functions.

[0033] As will be described later, it is important that the tunnel barrier layers 3, 12, and 14 have a thickness such that the tunnel current greatly changes with respect to the bias voltage. Specifically, the current easily flows in the thinnest portion. Considering the above, it is preferable that the film thickness of the thinnest part exceeds 1.0 nm. As a method of measuring such a film thickness, a method of measuring from known IV characteristics, a method of measuring from an image obtained by an enlarged electrophotography, or the like can be used. The overall set film thickness of the tunnel barrier layer is preferably 1.2 nm or more.

[0034] If the thickness of the tunnel barrier layer is too thin, a tunnel current flows to some extent even when the bias voltage is made small as will be described later, and the change in the magnetoresistive ratio with respect to

the bias voltage cannot be controlled. The same applies to changes in the magnetic resistance ratio with respect to temperature. However, if the tunnel barrier layer is too thick, the tunnel current cannot flow, so the thickness of the tunnel barrier layer is preferably 10 nm or less.

[0035] The ferromagnetic tunnel junctions 1 and 10 having the tunnel barrier layers 3, 12, and 14 as described above have a magnetoresistance ratio that increases with a positive slope with respect to an increase in bias voltage. This point will be described with reference to the calculation results based on the free electron model, taking the case of Fe/Al₂O₃/Fe as an example.

[0036] It is assumed that the potential barrier used here is one-dimensional in the x direction, and taking into account the effect of the bias voltage, $U(x, y, z) = U_0 - eV/2$ for $0 < x < x_0$, and zero in other cases. Has the form. Here, x_0 is the thickness of the insulator layer, U_0 is the height of the potential barrier, V is the bias voltage, and e is the electron charge. Electrons belonging to the band with T_{2g} symmetry are mainly tunneled to the ferromagnet Fe, and the Fermi energy of the upward spin electrons is 2.2eV, the Fermi energy of the downward spins is 0.3eV, and the exchange splitting is 1.9eV. I am taking it.

[0037] First, the height dependence of the magnetoresistance ratio of the potential barrier will be described. As can be seen from FIG. 5, which shows the calculation results for the junction in which the thickness of the insulating layer is 2.0 nm, the magnetoresistive ratio draws a curve having a minimum value at about 0.6 eV. Such a curve is obtained when the spin polarization of the tunnel current changes due to the height of the potential barrier.

[0038] That is, the spin polarization of the tunnel current is equal to the spin polarization of the ferromagnet where the potential barrier is high, decreases as the barrier height decreases, and the sign reverses when the barrier height decreases, The value increases. Therefore, with respect to the barrier height at which the spin polarization of the tunnel current becomes zero, the tunnel current obviously does not depend on the relative angle of the magnetization of the ferromagnet, and is the minimum value when viewed as the magnetoresistive ratio. Although the minimum barrier height varies depending on the thickness of the insulator layer, the minimum barrier height is approximately 0.3 to 0.7 eV in the range of 1.0 to 5.0 nm.

[0039] Now, let us consider a ferromagnetic tunnel junction using an insulator layer whose barrier height is smaller than the above-mentioned minimum value. Fig. 6 shows the calculation results of the bias voltage dependence of the magnetoresistive ratio for the junction when the height of the potential barrier is 0.1 eV when the thickness of the insulator layer is 2.0 nm and 1.0 nm. Shown in. From this figure, it can be seen that when the thickness of the insulator layer is 2.0 nm, the magnetoresistive ratio increases with a positive slope with increasing bias voltage in the boundary range of up to about 0.3 eV. ..

[0040] This property is considered to be due to the following reasons. The tunnel junction generally exhibits a non-linear current-voltage characteristic, but when a bias voltage exceeding the potential barrier is applied, the current flowing through the junction rapidly increases. FIG. 7 shows the calculation results of the current-voltage characteristics when the potential barrier is 0.1 eV and the thickness of the insulator layer is 2.0 nm and 1.0 nm and the magnetizations are parallel. Here, due to the characteristics of the model, the potential barrier height becomes exactly zero when a voltage of 0.2 V is applied. Correspondingly, when a bias voltage greater than 0.2 V is applied, a sharp increase in current is seen.

[0041] Further, in FIG. 8, in the ferromagnetic tunnel junction, the tunnel resistance R_p when the magnetizations of the ferromagnetic layers are parallel, the tunnel resistance R_{ap} when the magnetizations are antiparallel, and the difference $\Delta R (=R_{ap} - R_p)$ between these resistances. showed that. From this figure, it can be seen that R_p and R_{ap} each exhibit non-linearity. On the other hand, the difference ΔR between these resistances becomes gentler than the change in the resistance value itself. The magnetoresistive ratio defined by the ratio between the tunnel resistance R_p and the tunnel resistance R_{ap} increases with a positive slope in a region where the bias voltage is small, has a peak at a certain point beyond the potential barrier, and has a high bias region. Then it will start to decrease.

[0042] Such a characteristic of the magnetoresistive ratio is not found in a junction in which the thickness of the insulating layer is sufficiently thin. Actually, FIG. 6 also shows the case where the thickness of the insulator layer is 1.0 nm, but when the thickness of this insulator layer is 1.0 nm, the magnetoresistive ratio with respect to the increase of the bias voltage is shown. Is decreasing monotonically. The difference due to such thickness appears for the following reason.

[0043] As shown in FIG. 7, when the insulator layer is sufficiently thin, the tunnel probability of electrons becomes considerably large, and a tunnel current flows to some extent even when the bias voltage is small. When the bias voltage is increased to a value exceeding the height of the potential barrier, the current further increases, but the rate of increase is not so large.

[0044] On the other hand, since the tunneling probability of electrons has an exponentially decreasing dependence on the thickness of the insulating layer, the tunnel current is significantly reduced as the insulating layer becomes thicker. However, when the bias voltage exceeds the potential barrier, a large current flows without being affected by the thickness. Therefore, when the insulator layer is thick, the current flowing in the region where the bias voltage is small is small, and when the bias voltage has a value exceeding the potential barrier, the current sharply increases, and this increase rate is large. Become. Due to the difference in the increase rate of the tunnel current due to the increase of the bias voltage, the difference due to the thickness described above appears.

[0045] In the present invention, by utilizing the above-described relationship between the bias voltage and the potential barrier of the insulating layer (tunnel barrier layer) and the change of the tunnel current based on the thickness of the insulating layer (tunnel barrier layer), the bias voltage realizes a magnetoresistive ratio that increases with a positive slope with increasing. According to the ferromagnetic tunnel junction having the magnetoresistive ratio exhibiting such a tendency, a good magnetoresistive ratio can be obtained for a wide range of bias voltage, and the magnetic memory and the magnetic memory using the ferromagnetic tunnel junction can be obtained. It is possible to improve the characteristics and practicality of the sensor.

[0046] For comparison with the present invention, consider the case of an insulator layer having a barrier higher than the value of the potential barrier at which the magnetoresistive ratio takes the minimum value. In this case, the magnetoresistive ratio monotonically decreases with the application of the bias voltage. This situation is shown in Fig. 9 as an example when the potential barrier is 3.0 eV. In FIG. 9, the thickness of the insulating layer is 2.0 nm and 1.0 nm.

[0047] FIG. 9 shows a range of the bias voltage from zero to 0.6 V, but clearly the bias voltage is smaller than the height of the potential barrier in this range. Therefore, although the current-voltage characteristic of the tunnel junction is non-linear, the tunnel current does not change so rapidly. The magnetic resistance ratio monotonically decreases. When the potential barrier is high, this property does not depend on the thickness in the range of the thickness of the insulating layer considered here, for example, in the range of 1.0 nm to 10 nm.

[0048] The magnetic element of the present invention is characterized in that the tunnel barrier layers 3, 12, 14 are made of an insulator or semiconductor having a low potential barrier, and the tunnel barrier layers 3, 12, 14 are made thicker. This facilitates the resistance value of the junction element to be an appropriate value when applied to a memory element, for example. Further, since the tunnel barrier layers 3, 12 and 14 may be thick, it also has an advantage that the formation becomes easier in the manufacturing process.

[0049] As specific conditions of the tunnel barrier layers 3, 12, and 14 in the magnetic element of the present invention, the tunnel barrier height of the tunnel barrier layer is Φ [unit: eV], and the width of the tunnel barrier layer (tunnel barrier width) is S . When [unit: angstrom] is set, the physical quantity $S/(\Phi)^{1/2}$ satisfies $10 \leq S/(\Phi)^{1/2}$. By using the tunnel barrier layers 3, 12, and 14 that satisfy such conditions, the ferromagnetic tunnel junctions 1 and 10 having a magnetoresistance ratio that increases with a positive slope with respect to an increase in bias voltage can be more reliably formed. Can be realized.

[0050] Further, by using the tunnel barrier layers 3, 12, and 14 that satisfy the above-mentioned conditions, the ferromagnetic tunnel junctions 1 and 10 in which the decrease in the magnetoresistive ratio (rate of change in magnetoresistive) with the increase in temperature is suppressed are realized. be able to. That is, when the tunnel barrier width S is 1.0 to 5.0 nm (10 to 50 angstrom) and the barrier height is 0.3 to 1.0 eV, the value of $S/(\Phi)^{1/2}$ is $10 \leq S/(\Phi)^{1/2}$. It corresponds to the range of $2 \leq 91$ [angstrom/(eV)^{1/2}]. When the value of $S/(\Phi)^{1/2}$ is within such a range, it is possible to prevent the rate of change in magnetoresistance from decreasing with an increase in temperature. When applied to a magnetic memory, etc., the value of $S/(\Phi)^{1/2}$ is $10 \leq S/(\Phi)^{1/2} \leq 40$ [Angstrom/ (EV)^{1/2}] is more preferable.

[0051] If the value of $S/(\Phi)^{1/2}$ is within the above range, the tunnel barrier height of the tunnel barrier layer may be outside the range of 0.3 to 1.0 eV. For example, the barrier width S may be increased. If the barrier height exceeds 1.0 eV, the above effect can be obtained. In order to obtain the effect of increasing the magnetoresistive ratio with a positive slope with respect to the bias voltage and the effect of suppressing the

decrease of the magnetoresistive ratio with respect to temperature rise, the value of $S/(\Phi)^{1/2}$ is It is important to exist within the specified range.

[0052] The fact that the value of $S/(\Phi)^{1/2}$ of the ferromagnetic tunnel junction is within the above range means that the current-voltage characteristics of the ferromagnetic tunnel junction are measured as shown in FIG. Or the difference $\Delta G (=G_P - G_{AP})$ between the conductance G_{AP} when the spins of the two ferromagnetic layers adjacent to each other via the tunnel barrier layer are in the antiparallel state and the conductance G_P when the spins are in the parallel state. It can be easily determined by measuring the temperature dependence. FIG. 11 shows the temperature dependence of ΔG . As is clear from FIG. 11, when the value of $S/(\Phi)^{1/2}$ is 10 or more, ΔG is substantially constant or increases with the increase in temperature, whereas $S/(\Phi)^{1/2}$ If the value of is less than 10, ΔG decreases with increasing temperature.

[0053] The ferromagnetic double tunnel junction can be similarly determined by measuring the temperature dependence of ΔG . In addition, current-voltage characteristics are measured, and assuming that the voltage applied per layer is half, S and Φ are obtained using the Simmons equation, and $S/(\Phi)^{1/2}$ The relationship between the temperature dependence of the magnetoresistance ratio and $S/(\Phi)^{1/2}$ can also be determined by calculating $/2$. When determining the range of $S/(\Phi)^{1/2}$, the same value can be obtained by either method.

[0054] Thus, a tunnel barrier layer having a physical quantity $S/(\Phi)^{1/2}$ within the range of $10 \leq S/(\Phi)^{1/2}$, particularly $10 \leq S/(\Phi)^{1/2} \leq 40$ was used. According to the ferromagnetic tunnel junction, it is possible to significantly and surely suppress the decrease in the magnetoresistive ratio with the increase in temperature. Similarly, it is possible to obtain with good reproducibility the magnetoresistive ratio that increases with a positive slope with respect to the increase in bias voltage.

[0055] The above-described ferromagnetic tunnel junction of the present invention can be easily manufactured by various sputtering methods, vapor deposition methods, MBE methods, and the like. As a method of forming the insulator layer (dielectric layer) as the tunnel barrier layer, for example, after forming a film of Al, Si, Mg, a rare earth element, an alloy thereof, or the like, oxygen or oxygen and a rare gas such as Ar are mixed. Various methods such as a method of introducing a mixed gas to oxidize, a method of performing plasma oxidation in these gases, a method of directly sputtering a dielectric, and a method of directly plasma-oxidizing a dielectric and then performing plasma oxidation are applied. Can be easily manufactured.

[0056] The magnetic element of the above-described embodiment can be applied to a magnetic field sensor such as a magnetoresistive effect magnetic head, or a magnetic memory.

[0057] The magnetoresistive head using the magnetic element of the present invention can be configured in the same manner as the conventional magnetoresistive head. That is, of the first and second ferromagnetic layers 2 and 4, the ferromagnetic layer having a small coercive force is used as the magnetic sensing layer. For example, in the structure shown in FIG. 2, the first ferromagnetic layer 2 is a magnetic sensitive layer. In the structure shown in FIG. 3, the second ferromagnetic layer 13 is used as a magnetic sensitive layer, and in the structure shown in FIG. 4, the ferromagnetic-dielectric mixed layer 18 is used as a magnetic sensitive layer. The magnetization direction of these magnetic sensitive layers is changed according to, for example, a signal magnetic field. The signal magnetic field can be detected by measuring the resistance of the ferromagnetic tunnel junctions 1 and 10 at this time. This is effective as a reproducing head of a magnetic recording device. It can also be used as various magnetic field sensors.

[0058] Next, a case where the magnetic element of the present invention is applied to a magnetic memory will be described. In this case, of the first and second ferromagnetic layers 2 and 4, the ferromagnetic layer having a small coercive force is the storage layer and the other is the fixed magnetization layer. For example, in the structure shown in FIG. 2, the first ferromagnetic layer 2 is used as a storage layer, in the structure shown in FIG. 3, the second ferromagnetic layer 13 is used, and in the structure shown in FIG. The mixed layer 18 is used as a storage layer. The coercive force of these storage layers is preferably 100 Oe or less in consideration of reducing energy consumption in a current magnetic field. Then, the magnetization of the ferromagnetic layer as the storage layer is reversed, and "1" and "0" are designated in parallel or antiparallel to the magnetization of the other ferromagnetic layer.

[0059] In the reproduction, if the voltage of the ferromagnetic tunnel junction is directly measured, the reproduction voltage is different depending on "1" or "0" due to the magnetoresistive effect, so that it can be identified. The recording of "1" or "0" in the storage layer is performed, for example, by providing a word line close to the ferromagnetic layer as the storage layer, passing a pulse current through it, and switching its

direction. In such an operation, the magnetization of the other ferromagnetic layer does not change its direction due to its relatively large coercive force or the exchange bias due to the antiferromagnetic film.

[0060] As a specific form of the magnetic memory (MRAM), for example, as shown in FIGS. 12 and 13, there is a structure in which a magnetic element of the present invention, that is, a ferromagnetic tunnel junction element 22 is formed on a CMOS transistor 21. In these figures, 23 and 24 are word lines and 25 is a bit line. Further, as shown in FIGS. 14 and 15, a diode 26 is arranged in contact with the lower part or the upper part of the ferromagnetic tunnel junction element 22, and at the intersections of the word line 23 and the bit line 25 where these are crossed. Arranged structures can also be adopted.

[0061] **EXAMPLES** Next, specific examples of the magnetic element of the present invention will be described.

[0062] **Example 1** Example 1 shows an example of a ferromagnetic tunnel junction in which Fe is used as the ferromagnetic layers 2 and 4 and AlOx is used as the tunnel barrier layer 3 in FIG.

[0063] This ferromagnetic tunnel junction can be manufactured as follows. First, the first ferromagnetic layer 2 is formed on the substrate to a thickness of 100 nm by the ion beam sputtering method. Subsequently, Al is deposited in a thickness of 1 nm to 10 nm by the same method. After that, AlOx is formed by natural oxidation or plasma oxidation.

[0064] At this time, it is preferable that the oxidation process does not exceed 1 hour in natural oxidation. In plasma oxidation, oxygen is introduced into the chamber after forming an Al film and RF reverse sputtering is performed, but it is preferable that the oxidation time does not exceed about 60 seconds. This is to prevent the barrier height from becoming too high due to long-time oxidation, and also to prevent the Fe layer below the Al film from being oxidized. Then, an Fe layer is formed as an upper electrode to a similar thickness of 100 nm.

[0065] Here, when the characteristics of the ferromagnetic tunnel junction with the thickness of the insulator layer of 2.0 nm and the junction area of $4 \times 4 \mu\text{m}^2$ are examined, the height of the potential barrier is about 0.3 eV from the current-voltage characteristics. It is estimated that

[0066] Therefore, when evaluating the bias voltage dependence for a junction with a potential barrier of 0.3 eV, the magnetoresistive ratio is about 7% for a bias voltage of 0.1 V, and at 0.7 V the magnetoresistive ratio is about 24%. Up to. Even with a larger bias voltage, a magnetoresistive ratio of 10% or more can be obtained up to a bias voltage of 1.0V. When this ferromagnetic tunnel junction is used as a memory cell, for example, there is a magnetoresistive ratio of 20% or more from 0.65V to 0.75V, and even at 1.0V, the magnetoresistive ratio is about 10%, and stable operation as an element is achieved. Can be expected.

[0067] **Example 2** Example 2 shows an example of a ferromagnetic tunnel junction in which Fe is used as the ferromagnetic layers 2 and 4 and SiOx is used as the tunnel barrier layer 3 in FIG.

[0068] A first Fe layer having a thickness of 100 nm is formed on a glass substrate by the ion beam method. Then, a SiO2 film is formed to a thickness of 2.0 nm using a SiO2 target. Further, a second Fe layer is formed with a thickness of 100 nm. These processes can be subsequently carried out in a vacuum chamber of the order of 10⁻⁶ Torr.

[0069] From the current-voltage characteristics of this junction, the height of the potential barrier is estimated to be about 0.1 eV. When the bias voltage dependence of the magnetoresistive ratio is evaluated, it is 26% when a bias voltage of 0.1 V is applied, and the magnetoresistive ratio increases up to a bias voltage of about 0.27 V, reaching a maximum value of 34%. Furthermore, it takes a value of 10% or more up to 0.8V. Therefore, for example, when it is operated as a memory cell, a large magnetoresistive ratio of 30% or more is obtained at around 0.3V, and a magnetoresistive ratio of 10% or more is obtained up to 0.8V, which is suitable for device application.

[0070] **Example 3** In Example 3, the structure shown in FIG. 2 was formed on the Si/SiO2 substrate or SiO2 substrate by using the sputtering apparatus, that is, the Ta underlayer/NiFe/CoFe/Al2O3/CoFe/IrMn/Ta protective layer was laminated. An example of manufacturing a ferromagnetic tunnel junction having a structure is shown.

[0071] First, at the initial degree of vacuum of 2×10^{-7} Torr, the above-mentioned laminated film was formed into a lower wiring shape with a width of 50 μm by using ordinary photolithography technology and ion milling

technology. At that time, the designed film thickness was Ta5nm/NiFe15nm/CoFe5nm/Al₂O₃ 1.8nm/CoFe4nm/Ir22Mn7814nm/Ta5nm.

[0072] The tunnel barrier layer made of Al₂O₃ is formed by first introducing pure Ar gas and continuously forming an AlO_x film on the ferromagnetic layer (NiFe15nm/CoFe5nm) in vacuum using an Al₂O₃ target, without breaking the vacuum. A thin tunnel barrier layer without oxygen defects was produced on the AlO_x surface by introducing oxygen and exposing the oxygen defects in the dielectric layer to plasma oxygen. Several tunnel barrier layers with different $S/(\Phi)^{1/2}$ were prepared by changing the oxidation time and the output.

[0073] Next, after exhausting oxygen, CoFe4nm of the upper part was produced, and Ir22Mn7814nm and Ta5nm were sputter-deposited in pure Ar gas. The Ar partial pressure during film formation was set to 1×10^{-3} Torr. After that, a resist pattern for defining a junction dimension was formed on CoFe4nm/Ir22Mn7814nm/Ta5nm by using a normal photolithography technique and ion milling technique, and CoFe on the upper portion was ion milled. An interlayer insulating film made of a SiO₂ film having a thickness of 300 nm was sputtered while leaving the resist, and then the resist was lifted off. Further, after forming a resist pattern for forming the upper wiring and cleaning the surface of the sample by reverse sputtering, Al electrode wiring was formed. Then, it was introduced into a heat treatment furnace in a magnetic field, and unidirectional anisotropy was introduced into the magnetization fixed layer.

[0074] The temperature dependence of the magnetoresistance change rate of these samples was measured. The results are shown in Fig. 16. FIG. 16 shows the temperature dependence of the sample having $S/(\Phi)^{1/2}$ of 34 [Angstrom/(eV)^{1/2}] and the sample of 8 [Angstrom/(eV)^{1/2}]. The sample with $S/(\Phi)^{1/2}$ of 34 has a smaller temperature dependence of the magnetoresistance change rate than the sample with $S/(\Phi)^{1/2}$ of 8 and the decrease of the magnetic resistance is small even at room temperature or higher. It can be seen that a large magnetoresistance change rate can be obtained.

[0075] In addition, in the above-mentioned film structure, the ratio of the magnetoresistance change rate (MR(380K)/MR(280K)) of 280K and 380K of the ferromagnetic tunnel junction in which the oxidation time and the output of the tunnel barrier film are variously changed is $S/(\Phi)^{1/2}$. FIG. 17 shows the measurement results of the $S/(\Phi)^{1/2}$ dependence. When $S/(\Phi)^{1/2}$ is 10 or more, there is little decrease in MR change rate due to temperature rise, and it is effective when used as a magnetoresistive head, magnetic sensor, or magnetic memory element. I understand. If $S/(\Phi)^{1/2}$ exceeds 40 [Angstrom/(eV)^{1/2}], the element characteristics will fluctuate when a voltage of 0.5 V is applied. For example, when a magnetic memory element is assumed, It can be seen that it is preferable to use the ferromagnetic tunnel junction device in the range of $10 \leq S/(\Phi)^{1/2} \leq 40$ [Angstrom/(eV)^{1/2}].

[0076] A similar tendency was observed when SiO₂, AlN or MgO was used for the dielectric layer as the tunnel barrier layer.

[0077] Example 4 In Example 4, the structure shown in FIG. 3 was formed on a Si/SiO₂ substrate or SiO₂ substrate by using a sputtering apparatus, that is, Ta underlayer/Fe-Mn/NiFe/CoFe/Al₂O₃ /CoFe/Al₂O₃. An example in which a ferromagnetic double tunnel junction having a laminated structure of a /CoFe/NiFe/Fe-Mn/Ta protective layer is prepared will be shown.

[0078] First, with the initial vacuum degree of 2×10^{-7} Torr, the above laminated film was formed into a lower wiring shape with a width of 1 mm by using ordinary photolithography technology and ion milling technology. At that time, the film thickness was set to Ta5nm/Fe-Mn18nm/NiFe4nm/CoFe2nm/Al₂O₃ 1.8nm/CoFe3.5nm/Al₂O₃ 2.5nm/CoFe2nm/NiFe4nm/Fe-Mn18nm/Ta5nm.

[0079] The Al₂O₃ barrier layer was prepared in the same manner as in Example 3. By changing the oxidation time and output at this time, several ferromagnetic double tunnel junctions with different $S/(\Phi)^{1/2}$ were prepared.

[0080] Next, using a usual photolithography technique and ion milling technique, a resist pattern for defining the junction size was formed on CoFe2nm/NiFe4nm/Fe-Mn18nm/Ta5nm, and ion milling was performed up to the upper CoFe layer. An interlayer insulating film made of an Al₂O₃ film having a thickness of 300 nm was subjected to electron beam evaporation while leaving the resist, and then the resist was lifted off. Next, after forming a resist pattern for forming the upper wiring and cleaning the sample surface by reverse sputtering, Al electrode wiring was formed. Then, it was introduced into a heat treatment furnace in a magnetic field to introduce unidirectional anisotropy in the magnetization fixed layer.

[0081] The temperature dependence of the magnetoresistance change rate of each of these samples was measured. The measurement result is shown in FIG. The sample with $S/(\Phi)^{1/2}$ of 25 [Angstrom/(eV)^{1/2}] is more magnetic than the sample with $S/(\Phi)^{1/2}$ of 9 [Angstrom/(eV)^{1/2}]. It can be seen that the temperature dependence of the resistance change rate is small, the decrease in the magnetoresistance change rate is small even at room temperature or higher, and a large magnetoresistance change rate can be obtained.

[0082] In addition, in the above-mentioned film structure, the ratio (MR(380K)/MR(280K)) of the MR ratio of MR tunnels at 280K and 380K of the ferromagnetic tunnel junction in which the oxidation time and output of the tunnel barrier layer are variously changed is $S/(\Phi)^{1/2}$ (FIG. 19 shows the measurement results of the $S/(\Phi)^{1/2}$ dependence). When $S/(\Phi)^{1/2}$ is in the range of 10 or more, there is little decrease in MR change rate due to temperature rise, and it is effective when used as a magnetoresistive head, a magnetic sensor, or a magnetic memory element. I understand. If $S/(\Phi)^{1/2}$ exceeds 40 [Angstrom/(eV)^{1/2}], the element characteristics will fluctuate when a voltage of 0.5 V is applied. For example, when assuming a magnetic memory element, 10 It can be seen that it is preferable to use the ferromagnetic tunnel junction device in the range of $\leq S/(\Phi)^{1/2} \leq 40$ [angstrom/(eV)^{1/2}].

[0083] A similar tendency was observed when SiO₂, AlN or MgO was used for the dielectric layer as the tunnel barrier layer.

[0084] Example 5 In Example 5, a structure shown in FIG. 3 was used on a Si/SiO₂ substrate or a SiO₂ substrate, that is, a Ta underlayer/Fe-Mn/NiFe/CoFe/Al₂O₃/CoFe-Al₂O₃. An example of producing a ferromagnetic double tunnel junction having a laminated structure of mixed layer/Al₂O₃/CoFe/NiFe/Fe-Mn/Ta layer will be shown.

[0085] First, at the initial vacuum degree of 2×10^{-7} Torr, the above-mentioned laminated film was formed into a 1 mm width lower wiring shape using a metal mask. At that time, the film thickness was Ta5nm/Fe-Mn16nm/NiFe5nm/CoFe3nm/Al₂O₃ 1.7nm/CoFe-Al₂O₃ mixed layer 3.5nm/Al₂O₃ 2.3nm/CoFe3nm/NiFe5nm/Fe-Mn16nm/Ta5nm.

[0086] For the Al₂O₃ barrier layer, pure Ar gas is introduced, an Al film is formed in vacuum using an Al target, and then oxygen is introduced without breaking the vacuum to expose oxygen defects in the dielectric layer to plasma oxygen. It was produced by By changing the oxidation time and output at this time, several ferromagnetic double tunnel junctions with different $S/(\Phi)^{1/2}$ were prepared.

[0087] Next, using a normal photolithography technique and an ion milling technique, a resist pattern for defining a junction size was formed on CoFe3nm/NiFe5nm/Fe-Mn16nm/Ta5nm, and ion milling was performed up to the upper CoFe layer. After leaving the resist, an interlayer insulating film made of an Al₂O₃ film having a thickness of 300 nm was electron-beam evaporated, and then lift-off to the resist was performed. Next, after forming a resist pattern for forming the upper wiring and cleaning the sample surface by reverse sputtering, Al electrode wiring was formed. Then, it was introduced into a heat treatment furnace in a magnetic field, and unidirectional anisotropy was introduced into the magnetization fixed layer.

[0088] The temperature dependence of the magnetoresistance change rate of each of these samples was measured. The measurement result is shown in FIG. The sample with $S/(\Phi)^{1/2}$ of 15 [Angstrom/(eV)^{1/2}] is more magnetic than the sample with $S/(\Phi)^{1/2}$ of 9.8 [Angstrom/(eV)^{1/2}]. It can be seen that the temperature dependence of the resistance change rate is small, the decrease in the magnetoresistance change is small even at room temperature or higher, and a large magnetoresistance change rate can be obtained.

[0089] In addition, in the above-mentioned film structure, the ratio (MR(380K)/MR(280K)) of the MR ratio of MR tunnels at 280K and 380K of the ferromagnetic tunnel junction in which the oxidation time and output of the tunnel barrier layer are variously changed is $S/(\Phi)^{1/2}$ (FIG. 21 shows the measurement results of $S/(\Phi)^{1/2}$ dependence). When $S/(\Phi)^{1/2}$ is in the range of 10 or more, there is little decrease in MR change rate due to temperature rise, and it is effective when used as a magnetoresistive head, a magnetic sensor, or a magnetic memory element. I understand. If $S/(\Phi)^{1/2}$ exceeds 40 [Angstrom/(eV)^{1/2}], the element characteristics will fluctuate when a voltage of 0.5 V is applied. For example, when assuming a magnetic memory element, 10 It can be seen that it is preferable to use the ferromagnetic tunnel junction device in the range of $\leq S/(\Phi)^{1/2} \leq 40$ [angstrom/(eV)^{1/2}].

[0090] A similar tendency was observed when SiO₂, AlN or MgO was used for the dielectric layer as the tunnel barrier layer.

[0091] Example 6 Using a sputtering apparatus, a 20×20 μm square ferromagnetic tunnel junction (single or double) was prepared on a thermally oxidized Si substrate. Table 1 shows the structure of the ferromagnetic tunnel junction. Any one of Ta, Ti, Pt, Ti/Pt, Ti/Pd, Ta/Pt, Ta/Pd, and Al₂O₃ was used for the underlayer and the protective layer. The manufacture of the ferromagnetic tunnel junction was the same as in Examples 3-5.

[0092] Several ferromagnetic tunnel junctions with different $S/(\Phi)^{1/2}$ were prepared by changing the oxidation time and the output when forming the tunnel barrier layer. The ratio (MR(380K)/MR(280K)) of the rate of change in MR at 280K and 380K of these samples was measured. The results are also shown in Table 1. When $S/(\Phi)^{1/2}$ is in the range of 10 or more, the decrease in MR change rate with temperature rise is small, and it is effective when used as a magnetoresistive head, a magnetic sensor, or a magnetic memory element. I know there is.

[0094] As described above, according to the magnetic element of the present invention, it is possible to reduce the large dependence of the magnetic resistance ratio on the bias voltage or the temperature, which has been a problem in the conventional ferromagnetic tunnel junction. .. This makes it possible to obtain a good magnetoresistive ratio over a wide range of bias voltage and under a wide temperature range. Therefore, when applied to a magnetic memory, a magnetic sensor, or the like, it is possible to provide a magnetic element having excellent practicability.

**JP2000106462A MAGNETIC ELEMENT, MAGNETIC MEMORY PROVIDED THEREWITH, AND
MAGNETIC SENSOR**

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It has a ferromagnetic tunnel junction composed of a laminated film of at least two ferromagnetic layers and at least one tunnel barrier layer interposed between the two ferromagnetic layers, and tunnels between the two ferromagnetic layers. A magnetic element that allows a current to flow, and has a magnetoresistive ratio that increases with a positive slope with respect to an increase in bias voltage.

2. The magnetic element according to claim 1, wherein the tunnel barrier layer is made of an insulator or a semiconductor having a potential barrier smaller than the value of the potential barrier having the minimum magnetoresistive ratio.

The magnetic element according to claim 1, wherein the thinnest portion of the tunnel barrier layer is thicker than 1.0 nm.

It has a ferromagnetic tunnel junction composed of a laminated film of at least two ferromagnetic layers and at least one tunnel barrier layer interposed between the two ferromagnetic layers, and tunnels between the two ferromagnetic layers. In a magnetic element for passing a current, when the tunnel barrier height of the tunnel barrier layer is Φ [unit: eV] and the width of the tunnel barrier layer is S [unit: angstrom], $S/(\Phi)^{1/2}$ A magnetic element having a value satisfying $10 \leq S/(\Phi)^{1/2}$.

The magnetic element according to claim 4, wherein the value of $S/(\Phi)^{1/2}$ satisfies $10 \leq S/(\Phi)^{1/2} \leq 40$.

5. The magnetic element according to claim 4, wherein the difference in conductance between when the spin arrangements of the two ferromagnetic layers are in the antiparallel state and in the parallel state is substantially constant or increases with increasing temperature. A magnetic element that does.

The magnetic element according to claim 1 or 4, wherein an antiferromagnetic film for imparting an exchange bias to one of the two ferromagnetic layers is closely arranged. element.

A magnetic memory comprising the magnetic element according to any one of claims 1 to 7 as a memory cell.

A magnetic sensor comprising the magnetic element according to any one of claims 1 to 7.









































