Description

Field of the invention

The present invention relates to a magnetic transducer head utilizing magnetoresistance effect.

Background of the invention

A head comprising the features a, b, c and cl of the preamble of claim 1 as enclosed is known from US-A-4,356,523, whereas a head having the features a, a1, b, c and c2 of claim 1 as enclosed is described in EP-A-0 154 005.

Those heads use first and second soft magnetic layers sandwiching a non magnetic layer. In the head as described in the mentioned US-patent, the non magnetic layer is made of SiO_2 having a thickness of 6 microinches (about 1500 Å = 150 nm). EP-A-0 154 005 describes that the thickness of the non magnetic layer should be at least 200 Å (20 nm) in order to avoid mutual demagnetizing of the magnetic layers. In an embodiment described in that European application, the non magnetic layer is made of Ti having a thickness of 300 Å (30 nm).

Object and summary of the invention

It is the object of the present invention to provide a magnetic transducer head which utilizes the magnetoresistance effect and which effectively avoids the generation of Barkhausen noise.

The magnetic transducer head of the present invention is defined by the features of claim 1. It is characterized in that the non-magnetic layer has a thickness between 0,5 and below 19 nm. The material of said non-magnetic layer may be conductive, e. g. Ti, however the inventors found that it is possible to use also a material which is not electrically conductive, e. g. SiO_2 provided that this layer has a rather small thickness. In the preferred embodiments of the present invention, SiO_2-layers of between 20 and 50 Å (2 - 5 nm) were used as non magnetic layer.

The invention will now be explained in further detail through the description of the embodiments which are illustrated by figures.

Brief Description of the Drawings

Fig. 1 is a schematic enlarged plan view of an exemplary MR type magnetic head according to the present invention,

Fig. 2 is a cross-sectional view taken along the A - A line in Fig. 1,

Fig. 3 shows the magnetization state of a sensing element employed in the present invention,

Figs. 4A through 4C show the magnetization state of the sensing element upon application of external magnetic field thereto,

Figs. 5 through 7 show the operation of the magnetic transducer head according to the present invention,

Fig. 8 is a sectional view of another magnetic transducer head according to the present invention,

Figs. 9 through 11 show plan views of another embodiments of the sensing elements according to the present invention,

Fig. 12 is an enlarged plan view of further embodiment of the magnetic transducer head according to the present invention,

Fig. 13 is a sectional view taken along A - A line in Fig. 12,

Fig. 14 is a schematic illustration of the magnetic domain structure formed in a prior art single layer MR magnetic thin film,

Fig. 15 shows magnetization state of the sensing element for comparison MR head,

Figs. 16 and 17 shown plan views of the sensing element used for explaining the present invention, and

Fig. 18 is a graph showing the MR characteristics curve to explain the present invention.

Description of the Preferred Embodiments

As shown in a plan view of Fig. 1 and a sectional view of Fig. 1, an MR magnetic head of the present invention is equipped, on a substrate 1, with a thin-film sensing element 2 having magnetoresistance effect.

Denoted by a reference numeral 6 is a surface to be in contact with or opposed to a magnetic recording medium 7, which is transported in a direction perpendicular to the drawing paper face in Fig. 1.

In the present invention, the sensing element 2 is of a laminated structure where magnetic layers 4 and 5 of a soft magnetic material are superposed through a nonmagnetic intermediate layer 3, and at least one of such magnetic layers has magnetoresistance effect. The thickness of the nonmagnetic intermediate layer is selectively set to be over 5Å and under 10,000Å, e.g. within a range of 5 to 500Å so as to exert magnetostatic interaction between the two magnetic layers 4 and 5 more dominantly than exchange interaction. Meanwhile the saturation flux density, thickness and so forth of the magnetic layers 4 and 5 are properly selected for mutually equalizing the magnetic flux quantities thereof so that the magnetic flux as a whole is closed with respect to the two magnetic layers 4 and 5.

In case the two magnetic layers 4 and 5 of the sensing element 2 are both formed of the material having magnetoresistance effect, it is desired that the two layers 4 and 5 be composed of the same material and be equal to each other in shape and size. How-

ever, when merely one of them is composed of a material having no or little MR effect, the material and thickness of this magnetic layer need to be so selected that a sufficiently great resistance is obtained as compared with another magnetic layer having MR effect. In this case, it is necessary to satisfy the condition that the magnetic flux quantities of both magnetic layers become equal to each other.

In the present invention, a signal magnetic field Hs applied from a magnetic recording medium to the sensing element 2 and a sensing current $\underline{i}$ fed to flow in the sensing element 2 are so arranged as to act in the same direction, and each of the magnetic layers constituting the sensing element 2 is so formed as to have an easy axis of magnetization perpendicular to the signal magnetic field or to be isotropic without having anisotropy in the principal plane of the magnetic layer.

In a state where no signal magnetic field is applied to the sensing element 2, a required bias magnetic field is applied thereto from an external source in such a manner that magnetization is effected at a predetermined angle of, e.g. 45°, to the direction of the sensing current $\underline{i}$.

According to the above-mentioned structure of the present invention, Barkhausen noise can be effectively eliminated as will be described below.

Referring first to the cause for generation of Barkhausen noise, in the conventional MR magnetic head where its sensing element comprises a single MR magnetic layer, this layer has a magnetic domain structure as shown in Fig. 14 so as to maintain a state where the sum of magnetic anisotropy energy, magnetostatic energy resulting from shape anisotropy and so forth is minimized with respect to the entire layer. In case the single magnetic layer is a rectangular thin-film magnetic layer 51 having magnetic anisotropy in its short-side or transverse direction, magnetic domains 52 alternately reverse relative to the direction of transverse magnetization are produced in the film plane, and sequentially reverse magnetic domains 53 are produced between the ends of the adjacent magnetic domains 52 in the long-side or longitudinal direction of the magnetic layer in such a manner that a closed loop is formed with regard to the adjacent magnetic domains 52. Therefore, if an external magnetic field is applied to such magnetic layer, domain walls 54 and 55 are displaced to consequently generate Barkhausen noise.

In the construction of the present invention, differing from the above, magnetic layers 4 and 5 are superposed through a nonmagnetic intermediate layer 3 so that, when no external magnetic field is applied, the magnetic layers 4 and 5 are magnetized in mutually reverse parallel directions along the respective easy axes of magnetization as indicated by arrows M1 and M2 in Fig. 3, whereby no magnetic domain wall exists. The nonexistence of any domain wall has been confirmed through observation of magnetic domains by the Bitter process using a magnetic fluid. When an external magnetic field H is gradually increased in intensity along the hard axis of magnetization of such sensing element 3, as typically shown in Fig. 4 A through C where solid-line arrows represent the magnetized state of the magnetic layer 5 and broken-line arrows represent that of the magnetic layer 4, the magnetization is rotated by the external magnetic field H from the mutually reverse parallel state of Fig. 4 A described in connection with Fig. 3 to the state of Fig. 4 B. And when a higher-intensity external magnetic field is applied, the magnetic layers 4 and 5 are magnetized in the same direction as shown in Fig. 4 C. In this case, the magnetization is rotated in the planes of the magnetic layers 4 and 5, so that no domain wall is produced to eventually avoid generation of Barkhausen noise. That is, by causing the flux flow to be directionally coincident with the hard axes of magnetization in both magnetic layers 4 and 5, it becomes possible to avoid Barkhausen noise that results from domain walls displacement.

Now the operation of the magnetic head according to the present invention will be described below with reference to Figs. 5 through 7, which typically show merely the two magnetic layers 4 and 5 of the sensing element 2. In the initial state, the magnetic layers 4 and 5 have easy axes of magnetization in the directions indicated by e.a in Fig. 5, and a sensing current $\underline{i}$ is fed to flow in the magnetic layers 4 and 5. Such energization generates mutually reverse magnetic fields perpendicular to the current flow in the magnetic layers 4 and 5 opposed mutually through a nonmagnetic intermediate layer (not shown), whereby the magnetic layers 4 and 5 are magnetized as indicated by a solid-line arrow M1 and a broken-line arrow M2. Meanwhile, when an external bias magnetic field H_B is applied to the sensing element 2 along the direction of the current $\underline{i}$, then the directions of magnetization of the magnetic layers 4 and 5 are rotated a required angle as indicated by arrows MB1 and MB2 in Fig. 6. The intensity of the bias magnetic field H_B is so selected that the direction of magnetization determined by such magnetic field H_B has an angle of approximately 45° to the flow of the current $\underline{i}$. The procedure for obtaining high sensitivity and linearity by applying the bias magnetic field H_B to induce magnetization of approximately 45° to the sensing current $\underline{i}$ is similar to that executed with respect to an ordinary MR magnetic head. In the above state, when a signal magnetic field Hs is applied along the direction of the sensing current $\underline{i}$ or along the hard axis of magnetization as shown in Fig. 7, the direction of magnetization is rotated clockwise and counterclockwise through angles of $\theta 1$ and $-\theta 1$ respectively as indicated by arrows Ms1 and Ms2. Consequently, if both magnetic layers 4 and 5 are made of material having MR effect, there occurs resistance variations therein.

Since the resistance variation in each MR magnetic layer is proportional to $\cos^2\theta$ (where θ is an angle variation), when the magnetization directions MB1 and MB2 in the layers 4 and 5 have a difference of 90° mutually in Fig. 6, the increases or decreases caused in the resistance variations relative to the two magnetic layers 4 and 5 by angle variations $\theta 1$ and $-\theta 1$ are coincident with each other. That is, if the resistance of one magnetic layer 4 increases, the resistance of another magnetic layer 5 also varies in the direction to increase. And a resistance variation is induced between terminals t1 and t2 of the sensing element 2 due to the resistance variations in the magnetic layers 4 and 5, so that such resistance variation can be detected in the form of a voltage variation between the terminals t1 and t2.

Thus, in the present invention, the direction of a sensing current $\underline{i}$ to a magnetic film having a prescribed magnetic anisotropy is selectively set to coincide with the direction of applying a signal magnetic field Hs. With regard to such construction where the sensing element 2 comprises magnetic layers 4, 5 and a nonmagnetic intermediate layer 3 sandwiched therebetween as in the above-described invention, the functional feature will become more obvious by comparison with an example where the direction of the sensing current $\underline{i}$ is set to be perpendicular to the direction of the signal magnetic field Hs. That is, in a state of Fig. 15 where a large current $\underline{i}$ is applied to the two magnetic layers 4 and 5 with the anisotropic magnetic field Hk thereof taken into consideration as described previously in connection with Fig. 5, a magnetic field generated as a result is exerted to magnetize the magnetic layers 4 and 5 perpendicularly to the current $\underline{i}$ as indicated by a solid line and a broken line respectively. And when a signal magnetic field Hs is applied in this state perpendicularly to the current $\underline{i}$, it coincides with the direction of magnetization caused by the current $\underline{i}$ in the magnetic layers 4 and 5, and the magnetic field Hs behaves in the same manner as in the case of application along the easy axis of magnetization. Consequently, there are generated magnetic domain walls and displacement thereof to eventually induce Barkhausen noise. In a construction where a sensing current $\underline{i}$ is fed to flow along the easy axis of magnetization in the magnetic layer and a signal magnetic field Hs is applied in the same direction as the sensing current, the magnetic layer fails to be magnetized perpendicularly to the sensing current $\underline{i}$ if this current is relatively small, so that the signal magnetic field Hs comes to be applied substantially along the easy axis of magnetization as in Fig. 15, whereby an undesired result is brought with generation of Barkhausen noise. Although in the example of Figs. 5 through 7 a description has been given with respect to a magnetic layer having an easy axis of magnetization perpendicular to the signal magnetic field Hs, similar effect is attainable also by the use of an isotropic magnetic layer having no magnetic anisotropy in its principal plane. In this case, flow of a relatively small sensing current renders the direction of magnetization perpendicular to the sensing current and hence to the signal magnetic field as well to eventually avoid generation of Barkhausen noise.

In the constitution of the present invention, as described above, the magnetic layers 4 and 5 of the MR sensing element 2 are magnetostatically coupled to each other due to the presence of a nonmagnetic intermediate layer 2 sandwiched therebetween, so that exchange interaction can be neglected while a sufficiently firm magnetostatic coupling is ensured by the interaction based on the Coulomb's law, and Barkhausen noise can be eliminated with certainty as the signal magnetic field Hs and the sensing current $\underline{i}$ are directionally coincident with each other.

The present invention is applicable to a variety of MR type magnetic heads of different structures including a nonshielded head, a shielded head, and a yoke type head where a signal magnetic flux picked up from a surface in contact with or opposed to a magnetic recording medium is introduced by means of a magnetic yoke and an MR sensing element is disposed in a cut portion formed in the magnetic yoke.

Hereinafter a preferred embodiment of the present invention will be described in detail with reference to Figs. 1 and 2. This embodiment represents an exemplary constitution of a yoke type MR head.

In this example, a substrate 1 is composed of a magnetic material such as Ni-Zn ferrite, Mn-Zn ferrite or the like. In case the substrate 1 is conductive, first an insulating layer 11 of SiO_2 or the like is formed thereon, subsequently a bias conductor 10 is formed on the layer 11 to generate a bias magnetic field when energized, and anothe insulating layer 11 is formed on the bias conductor 10 to form an MR sensing element 2. This element 2 extends perpendicularly to a surface 6 which is to be in contact with or opposed to a magnetic recording medium, and the bias conductor 10 is so disposed as to traverse under the MR sensing element 2.

A front magnetic yoke 8F and a back magnetic yoke 8B are disposed anterior and posterior to the MR sensing element 2, i.e. at the two ends proximate to the surface 6 and the reverse side respectively. The two magnetic layers 8F and 8B are composed of a metallic material which is electrically conductive without MR effect substantially and has magnetic anisotropy perpendicular to a sensing current. Terminal conductive layers 9F and 9B are electrically connected to the magnetic layers 8F and 8B respectively, and terminals t1 and t2 are led out therefrom. In order to prevent generation of Barkhausen noise caused by the magnetic layers 8F and 8B, such layers may be superposed with a nonmagnetic intermediate layer sandwiched therebetween. A portion of the back

magnetic layer 8B is magnetically connected to the magnetic substrate 1 through a window 11a bored in a nonmagnetic layer 11, so that a closed magnetic path is formed by way of substrate 1 - front magnetic layer 8F - MR sensing element 2 - back magnetic layer 8B - substrate 1. And between the fore end of the front magnetic layer 8F and the substrate 1, there is formed a magnetic gap g confronting the surface 6 which is to be in contact with or opposed to the magnetic recording medium, and the length of such gap g is prescribed by the thickness of a nonmagnetic layer such as the insulating layer 11.

The MR sensing element 2 can be produced in a single integrated step continuously by the technique of sputtering or vacuum evaporation. That is, the aforesaid magnetic layer 4, nonmagnetic intermediate layer 3 and magnetic layer 5 are formed in sequence by the use of a sputtering apparatus or a vacuum evaporation apparatus equipped respectively with sputter sources or evaporation sources of individual materials. In the example illustrated, each of the magnetic layers 4 and 5 has an easy axis of magnetization in the direction indicated by e.a and a hard axis of magnetization in the direction indicated by h,a. As mentioned previously, each of the magnetic layers 4 and 5 may be composed of an isotropic magnetic film having no anisotropy in its principal plane.

The nonmagnetic intermediate layer 3 is composed of an insulating or conductive nonmagnetic material such as SiO_2, Ti or the like, and its thickness is selectively set to an adequate value of, e.g. 20Å so that exchange interaction is substantially not exerted between the two magnetic layers 4 and 5 and also that magnetostatic coupling is effected therebetween due to the interaction according to the Coulomb's law.

Although the nonmagnetic intermediate layer 3 is so formed as to have an adequate thickness for inducing magnetostatic coupling between the two magnetic layers 4 and 5, practically the thickness required for ensuring electrical insulation is about ten times greater than the thickness selected for shutting off magnetic exchange interaction. Therefore, when reducing the thickness of the intermediate layer 3, electrical connection is substantially effected between the two magnetic layers 4 and 5. However, in case such electrical connection is not effected, it is necessary to electrically connect the terminal conductive layers 9F and 9B respectively to the magnetic layers 4 and 5. That is, in the above example, the magnetic layers 8F and 8B need to be electrically connected respectively to the magnetic layers 4 and 5 which constitute the sensing element.

It is possible to electrically insulate the magnetic layers 4 and 5 by the nonmagnetic intermediate layer 3 with a sufficient thickness, and cause a sense current in only one of the magnetic layer. In this case, both magnetic layers are, of course, magnetostatically coupled with each other, though, the resistance change of only one magnetic layer is detected upon application of the signal magnetic layer. By the construction it is possible to increase the sensitivity of the sensing element.

The layers 4 and 5 of the MR sensing element 2 may be formed of MR magnetic layers of the same composition and the same size and shape with uniaxial anisotropy or without anisotropy in the principal planes thereof. Such MR magnetic layers may be composed of a single metal such as Fe, Ni or Co, or an alloy of two or more thereof.

In the costitution mentioned above, the individual layers inclusive of insulating layer 11, bias conductor 10, magnetic layers 4 and 5 of the sensing element 2, nonmagnetic intermediate layer 3, magnetic yokes 8F and 8B, terminal conductive layers 9F and 9B and so forth can be formed by sputtering or evaporation, and each can be shaped into a desired pattern by photolithography technique.

In this constitution, the sensing element 2 is supplied with a dc sensing current i between its terminal conductive layers 9F and 9B, hence between the magnetic layers 8F and 8B, and a prescribed current is flowing in the bias conductor 10 so as to apply a required bias magnetic field. In such a state, a magnetic recording medium 7 is transported perpendicularly to the drawing paper face of Fig. 1 while being kept in contact with or opposite to the surface 6, whereby a signal magnetic flux corresponding to the recorded magnetization on the medium 7 is picked up from the magnetic gap g and then is fed to the closed magnetic path formed by way of the aforesaid magnetic layer 8F - MR sensing element 2 - magnetic layer 8B - substrate 1. Accordingly a signal magnetic field Hs derived from the magnetic recording medium 7 is applied to the MR sensing element 2 in the same direction as the sensing current i. It follows, therefore, that the recorded signal is read out from the magnetic recording medium 7 while generation of Barkhausen noise is avoided as described above.

In addition to the foregoing example where both magnetic layers 4 and 5 of the MR sensing element are formed of MR layers, it is possible to produce a modification where merely one of the layers 4 and 5 is formed of a magnetic layer having almost no MR effect (hereinafter referred to as non-MR magnetic layer). In this case also the thickness and other conditions are so selected that the flux quantities of the two magnetic layers 4 and 5 become equal to each other as mentioned previously. Meanwhile, the magnetic layer having almost no MR effect may be composed of a high-resistivity, high-permeability magnetic material such as amorphous alloy of FeCoSiB, CoZrNb or Sendust alloy of Fe-Al-Si having great resistivity so that the resistance between the conductive magnetic layers 8F and 8B at the two ends becomes sufficiently high for allowing the sensing current to flow principally in the magnetic layer having

MR effect. Another recommendable material for the high-permeability magnetic layer having little MR effect is, for example, Mo permalloy. Such material is of course usable for the conductive magnetic layers 8F and 8B as well.

In addition to the above example where the bias conductor 10 is disposed under the sensing element 2 and an external magnetic field H_B is applied to the sensing element 2, the position and pattern of the bias conductor 10 may be modified in various manners, and it may be formed into a multilayer or spiral structure. Furthermore, the magnetic field to be applied is not limited to the one induced electrically, and a permanent-magnet thin film is usable as well. Fig. 18 graphically shows the MR characteristic of the MR sensing element according to the present invention. The curve represents the characteristic obtained when a sensing current of 10 mA is fed to flow in the sensing element of 4 μm x 4 μm where magnetic layers of Ni-Fe alloy having a thickness of 300Å are superposed through an intermediate layer of SiO_2 having a thickness of 40Å, and a magnetic field is applied in the same direction as the sensing current. In this case, each of the magnetic layers is composed of an isotropic film having no magnetic anisotropy in its plane. AS is apparent from the graph, there is no generation of Barkhausen noise.

Besides the above example of a yoke type structure where a closed magnetic path including the sensing element 2 is formed by the magnetic substrate 1 and the magnetic layers 4 and 5, it may be modified to another structure where the sensing element 2 substantially confronts the magnetic recording medium, or to a single pole structure where a closed magnetic path is not formed by the magnetic head itself.

Fig. 8 shows an example of applying the present invention to a shielded MR type magnetic head, in which a sensing element 2 is spaced apart by a predetermined distance as an insulating layer 11 is interposed between two magnetic substrates 1 and 12. However, the substrate 12 may be composed of a thin film as well. In the figure, designated by 9F and 9B are terminal conductive layers which are electrically connected to two magnetic layers 4 and 5 superposed through a nonmagnetic intermediate layer 3. The discontinuous portion between the conductive layers 9F and 9B functions as the sensing element 2, and a sensing current i is fed to flow therein as shown. The terminal conductive layer 9F may also serve as a path for introducing a magnetic flux to the sensing element 2, and it may be composed of a conductive magnetic material having a thickness of 2000Å or so.

Relative to this example, a type having none of such magnetic substrates 1 and 12 is termed a non-shielded MR head.

In the magnetic head of the present invention, a sensing current is fed to flow in its MR sensing element 2 perpendicularly to the track width W_T as shown in Fig. 1, and the leakage magnetic field Hs from the magnetic recording medium 7 is obtained by detecting the resistance variation between the fore end and the hind end of the sensing element 2, whereby the recorded signal is reproduced. In this stage, if the track width W_T corresponding to the width of the MR sensing element 2 is large, there arises a problem with respect to the signal-to-noise ratio. That is, the signal magnetic field Hs from the recording medium 7 suddenly attenuates with increase of the distance from the medium 7. such attenuation changes depending on the wavelength and tends to be greater as the wavelength becomes shorter. It is desired that the MR sensing element 2 be disposed within the effective reach of the magnetic field from the recording medium 7. If disposed outside of such reach, the sensing element 2 fails to function properly and brings about reduction of the signal-to-noise ratio. Suppose now that the depth D_E equivalent to the reach of the magnetic field from the recording medium is smaller than the track width W_T and, as shown in Fig. 16, the length in the direction of the sensing current flow through substantial current-conducting terminals 19F and 19B at the two ends of the sensing element 2 is set to be equal to the depth D_E. Then, there arises a disadvantage that the resistance value to be detected as a resistance variation in the MR sensing element 2 fails to be sufficiently large for easy signal processing. To the contrary, if the above length of the MR sensing element 2 is set to be greater than the reach of the magnetic field from the recording medium as shown in Fig. 17, the ineffective portion is rendered large to eventually bring about reduction of the signal-to-noise ratio. Thus, the problem of the resistance value and that of the signal-to-noise ratio are incompatible with each other. Meanwhile, the Barkhausen noise suppression effect becomes higher as the current density increases. It is therefore desired that the direction of the sensing current flow be coincident with the longitudinal direction of the MR sensing element.

For solving the problems of the aforesaid resistance viaue, signal-to-noise ratio and current density in such a case where the track width W_T is greater than the depth D_E of reach of the magnetic field from the recording medium, the MR sensing element 2 is divided into a plurality of regions at least on its rear side with respect to the direction of the track width and at least in the inner portion thereof within the depth D_E of reach of the magnetic field from the recording medium. For example, as shown in Fig. 9, the whole MR sensing element 2 is so shaped as to have a predetermined track width T_W, and a slit 21 is formed at its center perpendicularly to the surface 6 which is to be in contact with or opposed to the magnetic recording medium, in such a manner as to extend over the entire area from the hind end to the fore

end, or the fore end is partially left unsplit as shown in Fig. 10, whereby the MR sensing element 2 is divided into at least two MR sensing regions 2A1 and 2A2. A coupling layer 29 being at least conductive and having a high permeability and soft magnetic property without MR effect is deposited to extend over the fore ends of such two sensing regions, and terminals t1 and t2 are led out respectively from terminal conductive layers 9B1 and 9B2 which are deposited at the hind ends of such MR sensing regions 2A1 and 2A2. Although the entire width of the MR sensing element 2 is sufficiently great for forming the required track width T_W in the above structure, the path of a sensing current $\underline{i}$ fed between the terminals t1 and t2 can be defined in the longitudinal direction of the narrowed regions 2A1 and 2A2 along a signal magnetic field Hs from the magnetic recording medium. Although the coupling layer 29 may be composed of a nonmagnetic conductive material as mentioned previously, a conductive high-permeability magnetic material is usable as well. If the coupling layer is composed of a conductive high-permeability magnetic material, it becomes possible to eliminate any portion that is not sensitive to the magnetic flux between the two MR sensing regions 2A1 and 2A2, thereby preventing reduction of the signal magnetic flux flowing into the MR sensing regions. When the coupling layer 29 is formed by the use of a conductive high-permeability magnetic material, it may be shaped into a multilayer structure with a nonmagnetic intermediate layer so as to avert generation of Barkhausen noise.

In case the MR sensing element 2 is shaped into a structure divided with respect to the direction of the track width, the actual path of the sensing current $\underline{i}$ can be narrowed if the track width W_T is great, thereby ensuring advantages that a sufficiently large resistance value can be obtained and the current density is increasable even when the depth of the MR sensing element 2 is decreased in accordance with the depth D_E of reach of the signal magnetic field.

The MR sensing element 2 is not limited to the above examples of Figs. 9 and 10 divided into two sensing regions 2A1 and 2A2 with respect to the common track width W_T. And it may be modified to a structure of Fig. 11 where three or more MR sensing regions 2A1, 2A2, 2A3 .... 2An are formed for one track, and the respective fore ends and hind ends of the adjacent regions 2A1 -2A2, 2A2 - 2A3 and so forth are coupled alternately to each other by means of coupling layers 29 to form a zigzag-pattern path of a sensing current $\underline{i}$.

Thus, even with a modified magnetic head structure where a common track is shaped by two or more MR sensing regions 2A1, 2A2 and so forth, it is also possible to constitute a shielded, nonshielded or yoke type head as in the foregoing embodiment having a single sensing element 2. Fig. 12 is a plan view of an exemplary yoke type head, and Fig. 13 is its sectional view taken along the line A-A. In Figs. 12 and 13, component members corresponding to those employed in Figs. 1, 2 and 11 are denoted by the same reference numerals, and a repeated explanation is omitted here. In this embodiment, a front magnetic layer 8F and a back magnetic layer 8B extend across fore ends and hind ends of MR sensing regions 2A1, 2A2 .... 2An respectively. In such constitution, the MR sensing element 2 (2A1, 2A2 .... 2An) comprises magnetic layers 4 and 5 of NiFe alloy each having a thickness of 300Å and a nonmagnetic intermediate layer 3 of SiO_2 having a thickness of 50Å. Furthermore, the front magnetic layer 8F has a thickness of 2000Å and a width (depth) W_F of 3 μm while the back magnetic layer 8B also has a thickness of 2000Å and a width (depth) W_B of 12 μm, and such two magnetic layers 8F and 8B are spaced spart from each other by a distance of 8 μm. Moreover, a protective plate 12 is disposed opposite to the substrate 1. It is a matter of course that the protective plate 12 may be composed of a thin film. Coupling layers 29 are electrically isolated from the front magnetic layer 8F and the back magnetic layer 8B respectively through an insulating layer 11. In case the MR sensing element 2 is divided into a plurality of regions as mentioned above and the fore ends thereof are mutually separated to have a discontinuous portion within the common track width W_T, it is rendered possible to achieve the same effect as in the preceding example of a single continuous track by setting the fore-end width of the slit 21 at a small valaue.

In addition to the illustrated embodiments where the magnetic head has a single track, various modifications may be contrived such as a multitrack or multichannel magnetic head structure where a plurality of MR sensing elements 2 are arrayed on a common substrate 1 with a plurality of tracks confronting the surface 6 which is to be in contact with or opposed to a common magnetic recording medium.

In the magnetic head of the present invention where its MR sensing element 2 comprises two magnetic layers 4 and 5 superposed through a nonmagnetic intermediate layer 3, application of a signal magnetic field Hs to the MR sensing element 2 is executed in the same direction as a sensing current $\underline{i}$ fed to flow therein, the magnetic layers 4 and 5 are so formed as to have anisotropy in a specific direction or to be isotropic, thereby effectively eliminating generation of Barkhausen noise to realize an improved reproducing magnetic head of a high signal-to-noise ratio. And due to the thin-film magnetic head structure, a high efficiency is achievable in mass production and multitrack MR type magnetic heads can be manufactured with facility.

Claims

1. A magnetic transducer head utilizing magnetoresistance effect comprising:
   a) a sensing element means (2) composed of superposed first and second soft magnetic layers (4, 5) having a non magnetic layer (3) between said first and second soft magnetic layers, at least one of said soft magnetic layers having magnetoresistance effect and said first and second soft magnetic layers being magnetostatically coupled through said non magnetic layer;
   a1) whereby said non magnetic layer (3) provides for electrical connection between said first and second soft magnetic layers (4, 5);
   b) an electrode means (8B + 9B, 8F + 9F) being connected to said sensing element means (2) at first and second end portions of said sensing element means to flow a sense current (i) through said sensing element along one direction between said first and second end portions;
   c) said sensing element means receiving a signal magnetic field parallel to said one direction, and said soft magnetic layers (4, 5) having
      c1) either an easy axis of magnetization substantially perpendicular to said one direction;
      c2) or having an isotropic magnetic characteristic in a major surface of said soft magnetic layers;
   characterized in that said non magnetic layer (3) has a thickness between 5 and below 190 Å (0,5 - below 19nm).

2. A head according to claim 1, **characterized in that** said non magnetic layer (3) is made of Ti.

3. A head according to claims 1, **characterized in that** said non magnetic layer (3) is made of SiO_2 and has a thickness low enough to provide for electrical connection between said first and second soft magnetic layers (4,5).

4. A head according to one of the preceding claims, **characterized in that** said sensing element means is composed of at least two parallelly connected sensing elements ($2A_1$, $2A_1$; $2A_1$, ..., $2A_n$).

5. A head according to one of the preceding claims, **characterized in that** said first soft magnetic layer (4) has magnetoresistance effect, and said second soft magnetic layer (5) has little magnetoresistance effect.

6. A head according to one of the preceding claims, **characterized by** means (10) for applying a bias magnetic field to said sensing element means (4, 5) along said one direction.

Patentansprüche

1. Magnetischer Wandlerkopf, der den Magnetowiderstandseffekt verwendet, mit:
   a) einer Meßelementeinrichtung (2), die aus einer ersten und einer zweiten weichmagnetischen Schicht (4, 5) besteht, die übereinandergelegt sind, wobei eine unmagnetische Schicht (3) zwischen der ersten und der zweiten weichmagnetischen Schicht liegt, wobei mindestens eine der weichmagnetischen Schichten den Magnetowiderstandseffekt aufweist, und wobei die erste und die zweite weichmagnetische Schicht über die unmagnetische Schicht magnetostatisch gekoppelt sind;
   a1) wobei die unmagnetische Schicht (3) für die Herstellung einer elektrischen Verbindung zwischen der ersten und der zweiten weichmagnetischen Schicht (4, 5) sorgt;
   b) einer Elektrodeneinrichtung (8B + 9B, 8F + 9F), die mit der Meßelementeinrichtung (2) in einem ersten und einem zweiten Endabschnitt der Meßelementeinrichtung verbunden ist, um einen Meßstrom (i) entlang einer Richtung zwischen dem ersten und dem zweiten Endabschnitt durch das Meßelement zu schicken;
   c) wobei die Meßelementeinrichtung ein Signal-Magnetfeld rechtwinklig zur genannten einen Richtung erfährt und die weichmagnetischen Schichten (4, 5) folgendes aufweisen:
      c1) entweder eine leichte Magnetisierungsachse im wesentlichen rechtwinklig zur genannten einen Richtung;
      c2) oder isotrope, magnetische Eigenschaft in der Hauptflä- che der weichmagnetischen Schichten;
   dadurch gekennzeichnet, daß die unmagnetische Schicht (3) eine Dicke zwischen 5 und unter 190 Å (0,5 - unter 19 nm) aufweist.

2. Kopf nach Anspruch 1, **dadurch gekennzeichnet, daß** die unmagnetische Schicht (3) aus Ti besteht.

3. Kopf nach Anspruch 1, **dadurch gekennzeichnet, daß** die unmagnetische Schicht (3) aus SiO_2 besteht und eine Dicke aufweist, die ausreichend klein dafür ist, daß es zu einer elektrischen Verbindung zwischen der ersten und zweiten weichmagnetischen Schicht (4, 5) kommt.

4. Kopf nach einem der vorstehenden Ansprüche, **dadurch gekennzeichnet, daß** die Meßelementeinrichtung aus mindestens zwei parallel miteinander verbundenen Meßelementen ($2A_1$, $2A_2$; $2A_1$, ..., $2A_n$) besteht.

5. Kopf nach einem der vorstehenden Ansprüche, **dadurch gekennzeichnet, daß** die erste weichmagnetische Schicht (4) den Magnetowiderstandseffekt aufweist, und daß die zweite weichmagnetische Schicht (5) geringen Magnetowiderstandseffekt aufweist.

6. Kopf nach einem der vorstehenden Ansprüche, **gekennzeichnet durch** eine Einrichtung (10) zum Anlegen eines Vormagnetisierungsfelds entlang der genannten einen Richtung an die Meßelementeinrichtung (4, 5).

Revendications

1. Tête de transduction magnétique utilisant l'effet de magnétorésistance comprenant :
   a) un moyen formant élément de détection (2) composé de première et seconde couches de matériau magnétique doux (4, 5) superposées, ayant une couche non magnétique (3) entre lesdites première et seconde couches de matériau magnétique doux, au moins l'une desdites couches de matériau magnétique doux ayant un effet de magnétorésistance et lesdites première et secondes couches de matériau magnétique doux étant couplées de façon magnétostatique à travers ladite couche non magnétique ;
   a1) ce par quoi ladite couche non magnétique (3) réalise une connexion électrique entre lesdites première et seconde couches de matériau magnétique doux (4, 5) ;
   b) un moyen formant électrode (8B + 9B, 8F + 9F) étant connecté audit moyen formant élément de détection (2) au droit de première et seconde parties extrémités dudit moyen formant élément de détection pour permettre l'écoulement d'un courant de détection (i) dans ledit élément de détection suivant une direction entre lesdites première et seconde parties extrémités ;
   c) ledit moyen formant élément de détection recevant un champ magnétique de signal parallèle à ladite une direction, et lesdites couches de matériau magnétique doux (4, 5) possédant :
   c1) soit un axe de magnétisation privilégié sensiblement perpendiculaire à ladite une direction ;
   c2) soit une caractéristique magnétique isotrope dans la majeure partie de la surface desdites couches de matériau magnétique doux ;
   caractérisé en ce que ladite couche non magnétique (3) a une épaisseur allant de 5 à moins de 190 Å (0,5 à moins de 19 nm).

2. Tête selon la revendication 1, caractérisée en ce que ladite couche non magnétique (3) est faite de Ti.

3. Tête selon la revendication 1, caractérisée en ce que ladite couche non magnétique (3) est faite de SiO_2 et a une épaisseur suffisamment faible pour réaliser une connexion électrique entre lesdites première et seconde couches de matériau magnétique doux (4, 5).

4. Tête magnétique selon l'une quelconque des revendications précédentes, caractérisée en ce que ledit moyen formant élément de détection est composé d'au moins deux éléments de détection connectés parallèlement (2A1, 2A2 ; 2A1, ..., 2An)

5. Tête magnétique selon l'une quelconque des revendications précédentes, caractérisée en ce que ladite première couche de matériau magnétique doux (4) a un effet de magnétorésistance et en ce que ladite seconde couche de matériau magnétique doux (5) a peu d'effet de magnétorésistance.

6. Tête magnétique selon l'une quelconque des revendications précédentes, caractérisée par un moyen (10) pour appliquer un champ magnétique de polarisation audit moyen formant élément de détection (4, 5) suivant ladite une direction.