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SPECIFICATION

TITLE OF THE INVENTION

MAGNETORESISTIVE EFFECT TYPE REPRODUCING HEAD AND MAGNETIC DISK APPARATUS EQUIPPED WITH THE REPRODUCING HEAD

BACKGROUND OF THE INVENTION

The present invention relates to a new magnetoresistive effect type reproducing head, and a recording-reproducing separation type magnetic head, a head disk assembly, and a magnetic disk apparatus, which use the reproducing head.

A magnetoresistive effect type reproducing head using a magnetoresistive effect or a giant magnetoresistive effect is made of a magnetic multi-layer film possessing the magnetoresistive effect or the giant magnetoresistive effect, a magnetoresistive effect type element including electrodes provided at both sides of the magnetic multi-layer film, and magnetic shield films arranged at the upper and lower sides of the magnetoresistive effect type element.

A principle of magnetic field detection using a magnetoresistive effect type element is to make use of phenomena that the electrical resistance of a magnetic multi-layer film changes corresponding to the strength of magnetic field applied to the magnetic multi-layer film possessing a magnetoresistive effect or a giant magnetoresistive effect. Further, changes of the applied

magnetic field are detected by flowing current in the magnetic multi-layer film and measuring a potential difference generating between both sides of the magnetic multi-layer film. However, this principle is well known.

In reproducing stray magnetic field from information magnetically recorded in a magnetic disk installed in a magnetic disk apparatus, it is well known to cover the upper and lower sides of a magnetoresistive effect type element with magnetic shield films via insulation substance in order to improve the spatial resolution and reduce magnetic field leaking from a motor and so on, which causes noise.

According to development for a method of more densely recording information in a magnetic disk apparatus, in order to improve the spatial resolution, it has been tried and is also well known that the distance between an upper magnetic shield and a lower magnetic shield, that is, a magnetic gap of a reproducing head, is reduced. Further, conventionally, 80Ni-Fe permalloy, Fe-Al-Si Sendust, Co noncrystalline magnetic material, etc., are mainly used for a magnetic shield film. In Japanese Patent Laid-Open 124121/1996, it is disclosed that a magnetic shield of Ni-Fe-P alloy or Ni-Fe-B alloy is formed by an electroplating method.

A magnetoresistive effect type reproducing head has the structure in which a magnetoresistive effect type element is formed on a lower magnetic shield via an insulation film,

and an upper magnetic shield is also formed on the magnetoresistive effect type element via an insulation film.

According to requirement for high increase of the recording density, especially, the linear recording density, in a magnetic disk apparatus, the distance between a lower magnetic shield and an upper magnetic shield is reduced to improve the spatial resolution. Consequently, the thickness of respective insulation films between a magnetoresistive effect type or giant magnetoresistive effect type element and each of the upper and lower magnetic shields is largely reduced. Thus, the withstand voltage between the magnetoresistive effect type and the respective upper and lower magnetic shields tends to be easily deteriorated. It is considered that the deterioration of the withstand voltage in the insulation films is caused by pin holes in the insulation films.

The respective resistivity ρ of a 80Ni-Fe permalloy film, a Fe-Al-Si Sendust film, and a Co-Nb-Zr alloy film, which are conventionally used for the upper and lower magnetic shield films, is approximately 20 $\mu\Omega \cdot$ cm, 80 $\mu\Omega \cdot$ cm, and 100 - 150 $\mu\Omega \cdot$ cm, respectively. On the other hand, the average resistivity ρ of a sensor part in a magnetoresistive effect type element, although the resistivity depends on the composition of the sensor part, is approximately 20 - 100

$\mu\Omega \cdot$ cm. That is, the resistivity of the sensor part in a magnetoresistive effect type element is approximately the same degree as that of the magnetic shields. Moreover, since the thickness of the sensor part in a magnetoresistive effect type element is about 50 nm, and that of the magnetic shields is about 1 - 3 nm, the resistance of the sensor part in a magnetoresistive effect type element is less than 1 / 20 of that of a corresponding region in each magnetic shield. Therefore, if the magnetic gap is reduced, it possibly occurs that current leaks from a pin hole generating part such as a boundary region between each electrode and the sensor part in a magnetoresistive effect type element, at which a thickness gap is large and the thickness of the insulation film tends to become thin, and an insulation break-down of the magnetoresistive effect type element is caused by the current leakage. Even if the current leak occurs without an element break-down, since the resistance of the sensor part in a magnetoresistive effect type element is less than 1 / 20 of that of a corresponding region in each magnetic shield, the most amount of current flows into the magnetic shields, and the information reproduction of the magnetoresistive effect type becomes impossible. This problem is inevitable in reducing the magnetic gap of the presently used structure in a magnetoresistive effect type element.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a new magnetoresistive effect type reproducing head, and a recording-reproducing separation type magnetic head, a head disk assembly, and a magnetic disk apparatus, using the reproducing head, which can prevent the degradation of the withstand voltage between a magnetoresistive effect type element and each of an upper magnetic shield and a lower magnetic shield, the degradation being caused when the thickness of an insulation film formed between a magnetoresistive effect type element and each of the magnetic shields is made very thin to correspond to requirement for a high recording density.

A feature of the present invention to attain the above object is to provide a magnetoresistive effect type reproducing head formed by stacking a lower magnetic shield made of magnetic material, a lower inter-layer insulation film made, a magnetoresistive effect type element including a magnetic part, an insulation part, and electrical conductivity parts, for detecting magnetic field by using one of a magnetoresistive effect and a giant magnetoresistive effect, an upper inter-layer insulation film, and an upper magnetic shield made of magnetic material, on a substrate in this order, and a recording-reproducing separation type magnetic head including a magnetic induction type recording

head and the reproducing head which are neighboring each other via a magnetic shield, wherein one or both of the lower and upper magnetic shields includes a magnetic layer of a resistivity of more than 200 $\mu\Omega \cdot$ cm.

Further, a feature of the present invention is that in the above magnetoresistive effect type reproducing head, a magnetic layer possessing a resistivity of more than 200 $\mu\Omega \cdot$ cm is provided between at least one of the lower and upper magnetic shields and a corresponding one of the inter-layer insulation films.

Moreover, a feature of the present invention is that in the above magnetoresistive effect type reproducing head, a magnetic layer possessing a resistivity of more than 200 $\mu\Omega \cdot$ cm is provided in at least a region covering the magnetoresistive effect type element, in at least one of the lower inter-layer insulation film and the upper inter-layer insulation film.

Further, a feature of the present invention is that in the above magnetoresistive effect type reproducing head, at least one of the upper and lower magnetic shields includes a magnetic layer possessing a high resistivity of more than 200 $\mu\Omega \cdot$ cm and a low-resistance magnetic layer which neighbor each other via an insulation layer.

Further, a feature of the present invention is to

provide a magnetoresistive effect type reproducing head formed by stacking a lower inter-layer insulation film, a magnetoresistive effect type element for detecting magnetic field by using a magnetoresistive effect, and an upper inter-layer insulation film, wherein a magnetic layer possessing a resistivity of more than 200 $\mu\Omega \cdot$ cm is provided in at least a region covering a sensor part of the magnetoresistive effect type element, in at least one of the lower inter-layer insulation film and the upper inter-layer insulation film.

The above-mentioned magnetic layer of more than 200, preferably more than 350, more preferably more than 500, is made of a chemical compound including at least one element of a group of Co, Fe, and Ni and at least one element of a group of O, N, F, C, P, S, and B.

Another feature of the present invention is to provide a magnetic disk apparatus including a magnetic disk of a diameter of less than 3.5 inches, a means for rotating the magnetic disk, the above-mentioned magnetoresistive effect type reproducing head and a magnetic induction type thin film recording head.

In the present invention, a magnetic film of a high resistivity (more than 200 $\mu\Omega \cdot$ cm) is used at a part of at least one or both of an upper magnetic shield film and a lower magnetic shield film, in the vicinity of a magnetic

gap. Moreover, under the conditions that the resistance of the magnetic shield films is sufficiently larger than that of the sensor part in the magnetoresistive effect type element, even if sensing current leaks into the magnetic shield films, which is caused by pin holes generated in an insulation film between each magnetic shield film and a magnetoresistive effect type element, the leaking current is restricted, and the break-down of the magnetoresistive effect type element scarcely occurs. Assuming that sensing current shunts to the magnetic shield, it is possible to keep the decrease of a reproducing output of the head small by suppressing the leakage current to a small quantity. Thus, it is desirable to set the resistance of the magnetic shield films as approximately 10 times of that the sensor part of the magnetoresistive effect type element.

As a magnetic film of a high resistivity and an excellent soft magnetic performance, a magnetic film made of chemical compound material of (magnetic metal (Fe, Co, Ni)-metal-X (O, F, N)), or a magnetic film made of material produced by adding C, P, S, B, etc., to alloy of Ni-Fe, Fe-Co, Ni-Fe-Co, etc., is known.

In the present invention, magnetic material of a high resistivity is used for a part of at least one of the upper and lower magnetic shields in a reproducing head using a magnetoresistive or giant magnetoresistive effect, which is

used for a recording-reproducing separation type magnetic thin film head in a magnetic disk apparatus and so forth. Therefore, under the conditions that the magnetic gap determined by the distance between the upper and lower magnetic shields is narrow, even if sensing current leaks between the magnetoresistive effect type element and one of the upper and lower magnetic shields, the information reproducing is possible. By using the magnetoresistive effect type reproducing head of which the magnetic gap is narrow, according to the present invention, it is possible to provide a magnetic disk apparatus of a high linear recording density, further, of which an azimuth angle correction is small, since the distance between the reproducing head and a recording head can be made narrow.

Further, a feature of the present invention is to provide a head disk assembly having a magnetic disk in which information is recorded, a recording-reproducing separation type magnetic head composed of a magnetic induction type recording head for recording information in the magnetic disk, a magnetoresistive effect type reproducing head for reproducing information recorded in the magnetic disk, and a drive means for rotating the magnetic disk, wherein the magnetoresistive effect type reproducing head has any one of the above-mentioned features, and a record density is more than 10 G bits/in^2.

Furthermore, a feature of the present invention is to provide a magnetic disk apparatus including a plurality of head disk assemblies having a magnetic disk in which information is recorded, a recording-reproducing separation type magnetic head composed of a magnetic induction type recording head for recording information in the magnetic disk, a magnetoresistive effect type reproducing head for reproducing information recorded in the magnetic disk, and a drive means for rotating the magnetic disk, wherein each head disk assembly accords to the above latest feature of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is an elevational cross section facing a recording medium, of a magnetoresistive effect type reproducing head of a first embodiment according to the present invention.

Fig. 2 is an elevational cross section of a magnetoresistive effect type element.

Fig. 3 is a perspective view of a spin-valve magnetoresistive effect type reproducing head of another embodiment according to the present invention.

Fig. 4 is an elevational cross section facing a recording medium, of a magnetoresistive effect type reproducing head of another embodiment according to the

present invention.

Fig. 5A and Fig. 5B show an elevational cross section facing a recording medium, of a magnetoresistive effect type reproducing head of another embodiment according to the present invention, and a plan view of arrangement of the magnetoresistive effect type element and an upper magnetic shield of a high resistivity.

Fig. 6 is an elevational cross section facing a recording medium, of a magnetoresistive effect type reproducing head of another embodiment according to the present invention.

Fig. 7A and Fig. 7B show an elevational cross section facing a recording medium, of a magnetoresistive effect type reproducing head of another embodiment according to the present invention, and a plan view of arrangement of the magnetoresistive effect type element and an upper magnetic shield of a high resistivity.

Fig. 8 is a conceptual diagram for showing a composition of a hard disk apparatus.

Fig. 9 is a longitudinal cross section of a magnetic induction type recording head.

Fig. 10 is a perspective view for a partially sectional diagram of a recording-reproducing separation type magnetic head.

Fig. 11 is a perspective view of a negative pressure

slider.

Fig. 12 is a perspective inside view of a magnetic disk apparatus.

DETAILED DESCRIPTION OF THE EMBODIMENTS

Embodiment 1:

Fig. 1 shows an elevational cross section facing a recording medium, of a magnetoresistive effect type reproducing head of a first embodiment according to the present invention. The multi-layer structure shown in Fig. 1 includes a substrate 11, a lower magnetic shield 12 formed on the substrate 11, a lower inter-layer insulation film 14, a sensor part 15 of a magnetoresistive effect type element, an upper inter-layer insulation film 14', an upper magnetic shield 13, which are piled in this order, further electrodes 16 being provided at both sides of the sensor part 15 of a magnetoresistive effect type element. In this embodiment, Fe-Si-O possessing the resistivity ρ of about 16000 $\mu\Omega \cdot$ cm is used for the upper and lower magnetic shields 12 and 13. The upper and lower magnetic shields 12 and 13 have the thickness of 1.6 μm, and the magnetic gap between the upper and lower magnetic shields 12 and 13 is set as 0.18 μm. As the magnetoresistive effect type element, a magnetic resistance reading converter including a later-mentioned

hard magnetic bias film is used. The sensor part 15 of the magnetoresistive effect type element has the multi-layer structure in which a magnetic film, an insulation film, and a conductive film, in this order from the upper part, and since the magnetoresistive effect film, an intermediate film, and a bias film, have the thickness of 20 nm, 10 nm, and 20 nm, respectively, the thickness of the lower inter-layer insulation film 14 formed on the lower magnetic shield 12 is set as 50 nm, and the upper inter-layer insulation film 14' formed on the magnetoresistive effect type element is set as 80 nm, so that the magnetoresistive effect film is positioned at the center of the magnetic gap. Since the average resistivity ρ of the sensor part 15 of the magnetoresistive effect type element is about 50 $\mu\Omega \cdot$cm, and its length, width, and thickness, are 1 μm, 1 μm, and 50 nm, respectively, the resistance of the sensor part 15 is 10 Ω. On the other hand, since the magnetic shields 12 and 13 have the resistivity ρ of about 16000 $\mu\Omega \cdot$cm, and their thickness is 1.6 μm, the resistance of each magnetic shield at the sensor region is 100 Ω. That is, since the resistance between both the electrodes 16 changes only by about 10 %, that is, from 10 Ω to 9.1 Ω, even if sensing current leaks to each magnetic shield, the sensor part 15 of the

magnetoresistive effect type element does not break down. Further, since sensing current flowing in the sensor part 15 decreases only by 9 %, the output of the sensor part 15 decreases about by 17 %, and the sensor part 15 still has a sufficient reproducing ability. In the above-mentioned estimation, it is assumed that a short-circuit is caused by pin holes and so on which are generated in the insulation film 14 or 14' between the sensor part 15 of the magnetoresistive effect type element and one of the magnetic shields 12 and 13. If a short circuit does not occur in the insulation films 14 and 14', the amount of current shunted to the magnetic shields 12 and 13 is less than the above-mentioned estimation, the decreased power of the reproduced output is also below the above-mentioned estimation level. Further, although the resistance of the magnetic shields 12 and 13 is estimated as for the sensor region of the magnetoresistive effect type element, the thickness of each magnetic shield, at the region other than the vicinity of the sensor part 15 is set as considerably thicker. Therefore, sensing current hardly leaks to the magnetic shields, and the above estimation model is reasonably conservative. In this embodiment, the upper and lower magnetic shield film 12 and 13 are composed of only a Fe-Si-O film possessing the resistivity ρ of 16000 $\mu\Omega \cdot$ cm. However, it is possible to use a magnetic multi-layer

film by alternately laminating a high-resistance magnetic film and an insulating film.

Fig. 2 shows a conceptual illustration of the magnetoresistive effect type element (hereafter, referred to as MR element). The MR element is composed of the sensor part 15 (MR layer) and the electrodes 16 including hard magnetic bias layers for generating a vertical bias in the MR layer. Further, the electrodes 16 including the hard magnetic bias layers possesses the electrical and magnetic continuity with the MR sensor 15. Although the hard magnetic bias film in the electrodes 16, each of which includes a hard magnetic bias layer, can be composed of a single alloy layer of CoCr, CoPt, CoCrPt, etc., it is desirable to compose the bias film with one of the above alloy layers and a metal layer of W, Au, Cr, etc., which is used as an upper or lower layer in the bias film. The thickness of the hard magnetic bias film is set as such that the predetermined bias flux can be obtained. Moreover, the lateral bias which is also necessary for the MR sensor 15 is realized by using a soft film bias, a branch bias, a spiral bias, or any other comformable lateral bias.

Fig. 3 shows a perspective view of a magnetic head using a spin-valve magnetoresistive film (MR sensor) of another embodiment according to the present invention.

The MR sensor of the present invention has a multi-layer

structure in which a first magnetic layer 32 of soft ferromagnetic material, a non-magnetic layer 1, and a second magnetic layer 2 of ferromagnetic material, are laminated on a substrate 31 made of glass, ceramic, etc.. The two ferromagnetic layers 32 and 2 are composed so that the angle between the magnetized directions of the two layers is about 90 deg. when the magnetic field is not applied to those layers. Further, the magnetized direction of the second magnetic layer 2 is fixed to the same direction of a magnetic record medium. The magnetized direction of the first magnetic layer 32 of soft ferromagnetic material declines by 90 deg. to the magnetic field direction of the second magnetic layer 2 if the magnetic field is not applied to the first magnetic layer 32. If the magnetic field is applied, the rotation of magnetization in the first magnetic layer 32 occurs in response to the application of the magnetic field, and the magnetization direction of the first magnetic layer 32 changes. Numeral 8 indicates electrodes.

To keep a single magnetic domain state in the first magnetic layer 32 oriented in the direction parallel to the surface of this paper, a means for generating a vertical bias is provided for the first magnetic layer 32. The hard ferromagnetic layer 7 possessing a high saturation magnetic coercive force, a high orthogonal magnetic property, and a high resistance, is used as the means for generating the

vertical bias. The hard ferromagnetic layer 7 contacts the side end region in the surface of the first magnetic layer 32 of soft ferromagnetic material. The magnetized direction of the hard ferromagnetic layer 7 is parallel to the surface of this paper.

Further, it is also possible to generate the necessary vertical bias by contacting an antiferromagnetic layer to the side end region of the first magnetic layer 32 in place of the ferromagnetic layer 7. As for this antiferromagnetic layer, it is desirable to use antiferromagnetic material possessing the blocking temperature sufficiently different from that of the antiferromagnetic layer 3 used to fix the magnetized direction of the second magnetic layer 2 of ferromagnetic material.

Embodiment 2:

Fig. 4 shows an elevational cross section facing a recording medium, of a magnetoresistive effect type reproducing head of another embodiment according to the present invention. In this embodiment, each of the upper magnetic shield 12 and the lower magnetic shield 13 has the multi-layer structure which is composed of a lower low-resistance magnetic shield film 122 or 132 of a 46Ni-Fe film (ρ: about 45 $\mu\Omega \cdot$cm, and the thickness: 1.5 μm) formed by an electroplating method and an upper high-resistance magnetic shield film 121 or 131 of a Fe-Ni-O ferrite film(ρ:

about 1 Ω · cm, the thickness: 0.5 μm) formed by an electroplating method. Moreover, a spin-valve type giant magnetoresistive effect film is used for the sensor part 15 of the magnetoresistive effect type element, and the sensor part 15 has the multi-layer structure composed by laminating layers of Ta (5 nm) / CrMnPt (30 nm) / CoFe (3 nm) / Cu (2 nm) / CoFe (1 nm) / NiFe (5 nm) / Ta (5 nm) in this order from the upper part. Since the free layer in the spin-valve type film is made of a CoFe / NiFe layer in this embodiment, the thickness of the lower inter-layer insulation film 14 formed on the lower magnetic shield 12 and the thickness of the upper inter-layer insulation film 14' formed on the magnetoresistive effect type element are set as 85 nm and 50 nm, respectively, so that the free layer is positioned at the center of the magnetic gap. That is, the interval of the magnetic gap is 0.186 μm. In ferrite material such as Fe-Ni-O used in this embodiment, since its resistivity is high enough, the insulation break-down of the magnetoresistive effect type element occurs hardly. Further, it is possible to set the thickness of the insulation film between the magnetoresistive effect type element and each of the upper and lower magnetic shields as almost 0 by optimizing the high-resistance shield films (high resistivity, very thin thickness, and improvement in soft magnetic characteristics). For example, in the spin-valve

type giant magnetoresistive effect film, it is possible to set the thickness of the insulation film formed on the lower magnetic shield 12 as 35 nm, and set the thickness of the insulation film formed on the magnetoresistive effect type element as 0. That is, it is possible to reduce the interval of the magnetic gap to 86 nm. Furthermore, it is possible to use a magnetic multi-layer film formed by alternately laminating a magnetic film and an insulation film for one or one pair of the high-resistance upper and lower magnetic shields 121 and 131, and one or one pair of the low-resistance upper and lower magnetic shields 122 and 132.

Embodiment 3:

Fig. 5A and Fig. 5B show a composition of a magnetoresistive effect type reproducing head of another embodiment according to the present invention. Fig. 5A is an elevational cross section facing a recording medium, and Fig. 5B is a plan view of arrangement of the sensor part 15 a magnetoresistive effect type element, the electrodes 16, and an upper magnetic shield 131 (region surrounded by dotted lines) of a high resistivity. In this embodiment, the interval between the high-resistance upper and lower magnetic shield 131 and 121 is set as 0.146 μm. In a method of producing the magnetoresistive effect type reproducing head of this embodiment, at first, a 46Ni-Fe film of a 2 μ m thickness is formed on the substrate 11, and processed to

have the shape of the lower magnetic shield. Further, after a Fe-Ni-O ferrite film (ρ: about 1 $\Omega \cdot$cm) of a 0.5 μm thickness is piled up by an electroplating method, a mask to cover the region forming the sensing part of the magnetoresistive effect type element is formed, and an Al_2O_3 film is piled up by 0.5 μm. Further, Al_2O_3 piled up on the mask is removed together with the mask. After an Al_2O_3 film is piled up by 65 nm, the sensor part 15 of the spin-valve type magnetoresistive effect element and the electrodes 16 are formed. Furthermore, an Al_2O_3 film is piled up by 30 nm, and a Fe-Ni-O ferrite film of a 0.5 μm thickness is formed by an electroplating method. A mask to cover the region forming the sensing part of the magnetoresistive effect type element is formed, and an Al_2O_3 film is piled up by 0.5 μm. Further, Al_2O_3 piled up on the mask is removed together with the mask. Further, 46Ni-Fe film is piled up by 2 μm, and processed to have the shape of the upper magnetic shield. In ferrite material such as Fe-Ni-O used in this embodiment, since its resistivity is high enough, the insulation break-down of the magnetoresistive effect type element occurs hardly. Further, it is possible to set the thickness of the insulation film formed between the magnetoresistive effect type element and one of the upper and lower magnetic shields as almost 0 by optimizing the high-resistance shield

films. Furthermore, it is possible to use a magnetic multi-layer film formed by alternately laminating a magnetic film and an insulation film for one or one pair of the high-resistance upper and lower magnetic shields 121 and 131, and one or one pair the low-resistance upper and lower magnetic shields 122 and 132.

Embodiment 4:

Fig. 6 shows an elevational cross section facing a recording medium, of a magnetoresistive effect type reproducing head of another embodiment according to the present invention. In this embodiment, the lower and upper magnetic shields 12 and 13 are composed of a low-resistance magnetic shield film (122 or 132) of 80Ni-Fe permalloy, an inter-layer insulation film(123 or 133) of Al_2O_3, and a high-resistance magnetic shield film (121 or 131) of Fe-Hf-O (ρ: about 2000 $\mu\Omega \cdot$ cm). The thickness of each of the lower and upper magnetic shield films is 2 μm, and the distance in the magnetic gap is 0.18 μm. The upper magnetic shield is composed by laminating layers of 80Ni-Fe (1.8 μm) / Al_2O_3 (50 nm) / Fe-Hf-O (0.2 μm) in this order from the upper part, and The lower magnetic shield is composed by laminating those layers in the reverse order. The composition of the magnetoresistive effect type element used in this embodiment is similar to that in the first embodiment,

and the resistance of the sensor part 15 is about 10 Ω. Further, since the resistivity ρ of the high-resistance magnetic shield film is approximately 2000 $\mu\Omega \cdot$ cm, and its thickness is 0.2 μm, the resistance of a part of the magnetic shield film, which is positioned over or under the sensor region, is approximately 100, and sufficiently larger than that of the sensor part 15. Therefore, even if current leaks to the magnetic shield, the output of the sensor part 15 decreases only a little, and its reproducing ability can be kept. Furthermore, it is possible to use a magnetic multi-layer film formed by alternately laminating a magnetic film and an insulation film for one or one pair of the high-resistance upper and lower magnetic shields 121 and 131, and one or one pair of the low-resistance upper and lower magnetic shields 122 and 132.

Embodiment 5:

Fig. 7A and Fig. 7B show a composition of a magnetoresistive effect type reproducing head of another embodiment according to the present invention. Fig. 7A is an elevational cross section facing a recording medium, and Fig. 7B is a plan view of arrangement of the high-resistance upper magnetic shield 131 (a region surrounded by dotted lines), the sensor part 15 of the magnetoresistive effect type element, and the electrodes 16. In this embodiment, the

interval between the high-resistance upper and lower magnetic shields 131 and 121 is set as 0.14 μm. In a method of producing the magnetoresistive effect type reproducing head of this embodiment, at first, a 80Ni-Fe film of a 2 μm thickness is formed on the substrate 11, and processed to have the shape of the lower magnetic shield. Further, after Al_2O_3 is piled up by 30 nm, a Co-Fe-B-Si-O ferrite film (ρ: about 500 $\mu\Omega \cdot$cm) of a 0.5 nm thickness is formed, and a mask to cover the region forming the sensing part of the magnetoresistive effect type element is shaped. Further, an Al_2O_3 film is piled up by 50 nm, and the Al_2O_3 piled up on the mask is removed together with the mask. After an Al_2O_3 film is piled up by 30 nm, the sensor part 15 and the electrodes 16 are formed. Furthermore, an Al_2O_3 film is piled up by 60 nm, and a Co-Fe-B-Si-O ferrite film of a 50 nm thickness is formed by an electroplating method. A mask to cover the region forming the sensing part of the magnetoresistive effect type element is formed, and an Al_2O_3 film is piled up by 50 nm. Further, after the Al_2O_3 piled up on the mask is removed together with the mask, and Al_2O_3 is piled up by 30 nm. Lastly, 46Ni-Fe film is piled up by 2 μm, and processed to have the shape of the upper magnetic shield. Since the resistance of the sensor part 15 of the magnetoresistive effect type element is about 10 Ω, and the resistivity ρ of the high-resistance

magnetic shield film and its thickness are approximately 2000 $\mu\Omega \cdot$ cm and 0.2 μm, respectively, the resistance of a part of the magnetic shield film, which is positioned over or under the sensor region, is approximately 100 Ω, and sufficiently larger than that of the sensor part 15. Therefore, even if current leaks to the magnetic shield, the output of the sensor part 15 decreases only a little, and its reproducing ability can be kept. Furthermore, it is possible to use a magnetic multi-layer film formed by alternately laminating a magnetic film and an insulation film for one or one pair of the high-resistance upper and lower magnetic shields 121 and 131, and one or one pair of the low-resistance upper and lower magnetic shields 122 and 132.

Embodiment 6:

In the above embodiments 1 - 5, the structure of the upper magnetic shield 13 is the same as that of the lower magnetic shield 12. However, it is possible to use a 80Ni-Fe permalloy film, a Fe-Al-Si Sendust film, a Co non-crystalline film, or a magnetic multi-layer film composed by alternately laminating one of those magnetic films and an insulation film, which have been conventionally used, for the lower magnetic shield, and use the high-resistance magnetic material for only the upper magnetic shield 13. Furthermore, it is also possible to use a multi-layer film composed of a conventional material layer, an insulation layer, and the high-resistance

magnetic material layer, as shown in Fig. 5, for the lower magnetic shield 12, and use the high-resistance material for only the part in the upper magnetic shield 13, which is positioned over or under the sensor region, as shown in Fig. 6, and further, use a combination of the compositions shown in Fig. 5 and Fig. 6. Moreover, although the insulation films of Al_2O_3 are used in the above embodiments, it is possible to use oxide such as SiO_2 or nitride such as SiN for the insulation films. Furthermore, in not only the second and third embodiment but also any one of the above-mentioned embodiments, it is possible to set the thickness of one or both the insulation film formed between the magnetoresistive effect type element and one of the upper and lower magnetic shields as almost 0 by optimizing the high-resistance shield films.

Moreover, although the magnetic resistance reading converter including a hard magnetic bias film is used as the magnetoresistive effect type element in the embodiments 1 -5, it is possible to use a magnetoresistive effect type element to which the exchange coupling with an antiferromagnetic film is applied, for magnetic domain controlling.

Further, in the examples 1 - 5, it is possible to use any one of the MR element shown in Fig. 2, the spin valve magnetoresistive effect type element shown in Fig. 3, and

the giant magnetoresistive effect element, as the magnetoresistive effect type element.

Embodiment 7:

Fig. 8 is a conceptual diagram for showing a composition of a hard disk apparatus using the magnetoresistive effect type reproducing head and the spin-valve magnetoresistive effect type reproducing head mentioned in the embodiments 1 - 7. This hard disk apparatus has a disk rotating shaft 164 and a spindle motor 165 for rotating the shaft 164 at a high speed, and one or more (two in this embodiment) magnetic disks 167 are attached to the disk rotating shaft 164 at a predetermined distance. The attached magnetic disks 167 rotate together with the disk rotating shaft 164. Each magnetic disk is a circular plate of a predetermined radius and a predetermined thickness, and permanent magnet films are formed on both surfaces of each magnetic disk, each permanent magnet film composing an information recording surface. Moreover, this magnetic disk apparatus includes a rotating shaft 162 for positioning a magnetic head slightly apart from the magnetic disks 167, and a voice coil motor 163 for driving the shaft 162. Further, a plurality of access arms 161 are attached to the rotating shaft 162, and a recording / reproducing head 160 (hereafter, simply referred to as head) is attached at the top of each access arm 161. Therefore, each head 160 moves in the radius direction by

rotating the head 160 by a predetermined angle with the rotating shaft 162, and is positioned at a designated place. Moreover, the position of each head 160 is kept apart from the surface of each disk 167 by about tens nm by a balance between buoyancy generated by the high-speed rotation of the disk 167 and the pressing force due to a gimbals of an elastic member composing a part of the arm 161. The spindle motor 165 and the voice coil motor 163 are connected to a hard disk controller 166, and the rotation speed and the positioning of the head 160 are controlled by the hard disk controller 166.

Fig. 9 shows a longitudinal cross section of a magnetic induction type thin film recording head used in the hard disk apparatus according to the present invention. This thin film head includes a lower magnetic shield film 186, a lower magnetic film 184 formed on the film 186, and an upper magnetic film 185. A non-magnetic insulation substance 189 exists between the magnetic films 184 and 185. Numeral 188 indicates a magnetic gap. A slider having an air bearing surface (ABS) supports the head. Further, while a disk is rotated, the slider approaches the recording medium of the rotating disk and generates the buoyancy.

Furthermore, the thin film magnetic head possesses a back gap 190 which is formed by the upper and lower magnetic films 185 and 184. The back gap 190 is separated from the

top part of the magnetic gap 188 via a coil 187.

The coil 187 is formed above the lower magnetic film 184, for example, by an electroplating method, and the coil 187 and the film 184 are electromagnetically connected to each other. Further, the coil 187 is buried in the insulation substance 189, and electrical contacts are provided at its central part and outside end terminal. Those contacts are connected to an electrical power line and a head circuit for reading out / writing in information (which are not shown in a figure).

In the present invention, a thin film wire forming the coil 187 is wound in a somewhat distorted elliptic shape, and a narrower width part in the thin film wire is arranged nearest to the magnetic gap 188. The width of the thin film wire is made gradually larger as the wire is farther away from the magnetic gaps 188.

The coil 187 provided between the gap 190 and the magnetic 188 has dens and many turns, and the width of the thin film wire forming the coil 187 is comparatively narrow in the vicinity of the gap 190 or the magnetic gap 188. The rapid increase of the width in the thin film wire in a region far away from the magnetic gap 188 causes the decrease of the resistance. Further, since the elliptic coil 187 has not an angle part or a sharp corner, it does not include a part of a specially large resistance. Moreover, an elliptic coil

has a shorter length in comparison with an rectangular coil or a circular coil. Therefore, the total resistance of the coil 187 is comparatively small, and the heat generated in it is also comparatively a little. Further, the adequate heat radiating performance can be realized in the elliptic coil 187. Accordingly, since the heat generation is reduced, the layer destruction in the multi-layer thin film, and the layer elongation or the layer expansion of the multi-layer thin film, can be prevented. Thus, the cause of a ball-chip projection at the air bearing surface (ABS) can be removed.

An elliptic coil in which the width of a thin film layer coil wire is changed at a constant change rate can be formed by a conventional cheap electroplating method such as a sputtering method, a vapor deposition method, and so forth. In a coil of other shape, especially, shape having an angle part, the width in a coil wire formed by an electroplating method tends to be non-uniform. In an elliptic coil, removing small parts projected from sides of a thing film layer wire formed to a coil loads only a small stress to the coil.

In this embodiment, a coil of many turns is formed into an approximately elliptic shape between the magnetic cores (magnetic films) 184 and 185, and its width is made gradually larger from the magnetic gap 188 toward the back gap 190. Corresponding to the increase in the coil wire width, a signal output increases, and the generated heat decreases.

Fig. 10 is a perspective view for a partially sectional diagram of a recording-reproducing separation type magnetic head including the magnetic induction type recording head and the magnetoresistive effect type reproducing head according to the present invention. The recording-reproducing separation type magnetic head consists of the reproducing head including a lower magnetic shield 182, a magnetoresistive effect film 110, a magnetic domain control film 141, and electrode terminals 140, which are formed on a substrate 150 serving also as a head slider, and the magnetic induction type recording head in which magneto-motive force is generated between the upper magnetic core 185 serving also as an upper magnetic shield and the lower magnetic core 186 serving also as a lower magnetic shield by an electromagnetic effect by a coil 142.

Fig. 11 is a perspective view of a negative pressure slider. The negative pressure slider 170 is composed of a negative pressure generating surface 178 surrounded by an air introducing surface 179 and two positive pressure generating surfaces 177 for generating buoyancy and a groove 174 provide at a boundary region between the negative pressure generating surface 178 and both the air introducing surface 179 and the positive pressure generating surfaces 177. At the end sides 175 of air outlets, the recording-reproducing separation type magnetic thin film head elements 176

including the magnetic induction type recording head for recording information in the magnetic disk and the MR sensor for reproducing the information recorded in the magnetic disk are installed.

While the negative pressure slider 170 is floating, air introduced through the air introducing surface 179 is expanded on the negative pressure generating surface 178. Further, since an air flow is also branched to the groove 174, an air flow passing from the air introducing surface 179 to the end sides of air outlets 175 exists in the groove 174. Therefore, even if floating dusts are introduced through the air introducing surface 179 while the negative pressure slider 170 is floating, the dusts are led inside the groove 174. Further, the dusts are swept along in the air flow, and exhausted from the end sides 175 of air outlets to the outside of the negative pressure slider 170. Furthermore, since air always flows and stagnation of air does not exist while the negative pressure slider 170 is floating, the introduced dusts does not cohere.

Fig. 12 shows a perspective inside view of a magnetic disk apparatus. The magnetic disk apparatus is composed of a magnetic disk for recording information, a DC motor for rotating the magnetic disk (not shown in a figure), a magnetic head for writing in / reading out information, and a positioning device including an actuator, a voice coil motor,

etc., for supporting the magnetic head and positioning it toward the magnetic disk. In this example, five disks are attached to a rotating shaft to increase the total memory capacity.

According to this embodiment, also for a medium with high coercive force, the MR sensor has the excellent performance in a high frequency region, indicating the data transmission rate of more than 15 MB / s, and the recording frequency of more than 45 MHz, in a state of the disk rotation speed of more than 4000 rpm. That is, it becomes possible to obtain a highly sensitive MR sensor exhibiting excellent MR effects such as reduction of access time, increase of a memory capacity. Thus, it is possible to realize a magnetic disk apparatus possessing the surface recording density of more than 10 Gb / in^2.

In accordance with the present invention, even if sensing current shunts to one of upper and lower magnetic shields because of degradation in the withstand voltage between a magnetoresistive effect type element and each magnetic shield, which is caused when the magnetic gap of a reproducing head determined by the interval between the upper and lower magnetic shields is narrowed, the degradation in the withstand voltage can be prevented, and the insulation break-down in the magnetoresistive effect type element hardly occurs, since the resistance of the magnetic shields

is high, and the shunting amount of the sensing current is restricted. Further, it is possible to provide a magnetoresistive effect type reproducing head in which even if sensing current shunts to the magnetic shields, the reproducing output decreases only a little, and the reproducing ability of the head can be kept. Furthermore, by using a magnetoresistive effect type reproducing head of which the magnetic gap is narrow, according to the present invention, since the interval between a recording head and a recording head can be also narrowed, it is possible to provide a magnetic disk in which the linear recording density is high, and a necessary azimuth correction is small.

WHAT IS CLAIMED IS:

1. A magnetoresistive effect type reproducing head formed by stacking a lower magnetic shield made of magnetic material, a lower inter-layer insulation film, a magnetoresistive effect type element for detecting magnetic field by using a magnetoresistive effect, an upper inter-layer insulation film, and an upper magnetic shield made of magnetic material, on a substrate in this order, wherein a resistivity of at least one of said lower and upper magnetic shields is more than 200 $\mu\Omega \cdot$cm.

2. A magnetoresistive effect type reproducing head according to claim 1, wherein said one of said lower and upper magnetic shields possessing a resistivity of more than 200 $\mu\Omega \cdot$cm is made of a chemical compound including at least one element of a group of Co, Fe, and Ni and at least one element of a group of O, N, F, C, P, S, and B.

3. A magnetoresistive effect type reproducing head formed by stacking a lower magnetic shield made of magnetic material, a lower inter-layer insulation film, a magnetoresistive effect type element for detecting magnetic field by using a magnetoresistive effect, an upper inter-layer insulation film, and an upper magnetic shield made of magnetic material,

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on a substrate in this order, wherein a magnetic layer possessing a resistivity of more than 200 $\mu\Omega \cdot$ cm is provided between one of said lower and upper magnetic shields and a corresponding one of said lower and upper inter-layer insulation films.

4. A magnetoresistive effect type reproducing head formed by stacking a lower magnetic shield made of magnetic material, a lower inter-layer insulation film, a magnetoresistive effect type element for detecting magnetic field by using a magnetoresistive effect, an upper inter-layer insulation film, and an upper magnetic shield made of magnetic material, on a substrate in this order, wherein a magnetic layer possessing a resistivity of more than 200 $\mu\Omega \cdot$ cm is provided in at least a region covering said magnetoresistive effect type element, in at least one of said lower and upper inter-layer insulation films.

5. A magnetoresistive effect type reproducing head formed by stacking a lower magnetic shield made of magnetic material, a lower inter-layer insulation film, a magnetoresistive effect type element for detecting magnetic field by using a magnetoresistive effect, an upper inter-layer insulation film, and an upper magnetic shield made of magnetic material, on a substrate in this order, wherein at least one of said

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lower and upper magnetic shields includes a low-resistance magnetic layer and a magnetic layer possessing a high resistivity of more than 200 $\mu\Omega \cdot$ cm which neighbor each other via insulation material.

6. A magnetoresistive effect type reproducing head formed by stacking a lower inter-layer insulation film, a magnetoresistive effect type element for detecting magnetic field by using a magnetoresistive effect, and an upper inter-layer insulation film, on a substrate in this order, wherein a magnetic layer possessing a resistivity of more than 200 $\mu\Omega \cdot$ cm is provided inside at least one of said lower and upper inter-layer insulation films.

7. A magnetoresistive effect type reproducing head according to one of claims 2 - 6, wherein said magnetic layer possessing a resistivity of more than 200 $\mu\Omega \cdot$ cm is made of a chemical compound including at least one element of a group of Co, Fe, and Ni and at least one element of a group of O, N, F, C, P, S, and B.

8. A recording-reproducing separation type magnetic head including a magnetoresistive effect type reproducing head and a magnetic induction type recording head which are

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separated from each other via a magnetic shield, wherein said magnetoresistive effect type reproducing head is formed by stacking a lower magnetic shield made of magnetic material, a lower inter-layer insulation film, a magnetoresistive effect type element for detecting magnetic field by using a magnetoresistive effect, an upper inter-layer insulation film, and an upper magnetic shield made of magnetic material, on a substrate in this order, wherein a resistivity of at least one of said lower and upper magnetic shields is more than 200 $\mu\Omega \cdot$ cm.

9. A recording-reproducing separation type magnetic head according to claim 8, wherein said one of said lower and upper magnetic shields possessing a resistivity of more than 200 $\mu\Omega \cdot$ cm is made of a chemical compound including at least one element of a group of Co, Fe, and Ni and at least one element of a group of O, N, F, C, P, S, and B.

10. A recording-reproducing separation type magnetic head including a magnetoresistive effect type reproducing head and a magnetic induction type recording head which are separated from each other via a magnetic shield, wherein said magnetoresistive effect type reproducing head is formed by stacking a lower magnetic shield made of magnetic material,

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a lower inter-layer insulation film, a magnetoresistive effect type element for detecting magnetic field by using a magnetoresistive effect, an upper inter-layer insulation film, and an upper magnetic shield made of magnetic material, on a substrate in this order, wherein a magnetic layer possessing a resistivity of more than 200 $\mu\Omega \cdot$ cm is provided between one of said lower and upper magnetic shields and a corresponding one of said lower and upper inter-layer insulation films.

11. A recording-reproducing separation type magnetic head including a magnetoresistive effect type reproducing head and a magnetic induction type recording head which are separated from each other via a magnetic shield, wherein said magnetoresistive effect type reproducing head is formed by stacking a lower magnetic shield made of magnetic material, a lower inter-layer insulation film, a magnetoresistive effect type element for detecting magnetic field by using a magnetoresistive effect, an upper inter-layer insulation film, and an upper magnetic shield made of magnetic material, on a substrate in this order, wherein a magnetic layer possessing a resistivity of more than 200 $\mu\Omega \cdot$ cm is provided in at least a region covering said magnetoresistive effect type element, in at least one of said lower and upper inter-layer insulation films.

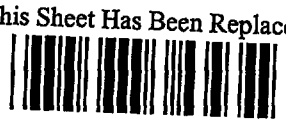
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12. A recording-reproducing separation type magnetic head including a magnetoresistive effect type reproducing head and a magnetic induction type recording head which are separated from each other via a magnetic shield, wherein said magnetoresistive effect type reproducing head is formed by stacking a lower magnetic shield made of magnetic material, a lower inter-layer insulation film, a magnetoresistive effect type element for detecting magnetic field by using a magnetoresistive effect, an upper inter-layer insulation film, and an upper magnetic shield made of magnetic material, on a substrate in this order, wherein at least one of said lower and upper magnetic shields includes a low-resistance magnetic layer and a magnetic layer possessing a high resistivity of more than 200 $\mu\Omega \cdot cm$ which neighbor each other via insulation material.

13. A recording-reproducing separation type magnetic head including a magnetoresistive effect type reproducing head and a magnetic induction type recording head which are separated from each other via a magnetic shield, wherein said magnetoresistive effect type reproducing head is formed by stacking a lower inter-layer insulation film, a magnetoresistive effect type element for detecting magnetic field by using a magnetoresistive effect, and an upper

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inter-layer insulation film, on a substrate in this order, wherein a magnetic layer possessing a resistivity of more than 200 $\mu\Omega \cdot$ cm is provided inside at least one of said lower and upper inter-layer insulation films.

14. A recording-reproducing separation type magnetic head according to one of claims 10 - 13, wherein said magnetic layer possessing a resistivity of more than 200 $\mu\Omega \cdot$ cm is made of a chemical compound including at least one element of a group of Co, Fe, and Ni and at least one element of a group of O, N, F, C, P, S, and B.

15. A magnetic disk apparatus comprising: a magnetic disk of a diameter of less than 3.5 inches, means for rotating said magnetic disk, said magnetoresistive effect type reproducing head according to one of claims 1 - 7, and an induction type magnetic thin film recording head.

16. A magnetic disk apparatus comprising: a magnetic disk of a diameter of less than 3.5 inches, means for rotating said magnetic disk, and said recording-reproducing separation type magnetic head according to one of claims 8 - 14.



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17. A head disk assembly including a magnetic disk in which information is recorded, a recording-reproducing separation type magnetic head composed of a magnetic induction type recording head for recording information in said magnetic disk, a magnetoresistive effect type reproducing head for reproducing information recorded in said magnetic disk, and a drive means for rotating said magnetic disk, wherein said magnetoresistive effect type reproducing head accords to one of claims 1 -7, and a record density is more than 3 G bits/in^2.

18. A head disk assembly including a magnetic disk in which information is recorded, a recording-reproducing separation type magnetic head composed of a magnetic induction type recording head for recording information in said magnetic disk, a magnetoresistive effect type reproducing head for reproducing information recorded in said magnetic disk, and a drive means for rotating said magnetic disk, wherein said recording-reproducing separation type magnetic head accords to one of claims 8 - 14, and a record density is more than 3 G bits/in^2.

19. A magnetic disk apparatus comprising a plurality of head disk assemblies, each assembly including a magnetic disk in which information is recorded, a recording-reproducing separation type magnetic head composed of a magnetic



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induction type recording head for recording information in said magnetic disk, a magnetoresistive effect type reproducing head for reproducing information recorded in said magnetic disk, and a drive means for rotating said magnetic disk, wherein each head disk assembly accords to claim 15 or 16.

