

TITLE OF THE INVENTION

THIN FILM MAGNETIC HEAD, AND A METHOD OF MANUFACTURING
THE SAME

5

BACKGROUND OF THE INVENTION

The present invention relates to a magnetic disk
apparatus used for recording and regenerating information
for a computer or the like and a thin film magnetic head
10 used for the magnetic disk apparatus.

In a magnetic disk apparatus used for recording
information in a computer or the like, data signals are
recorded and regenerated on a magnetic disk using a
magnetic head. In order to increase a memory capacity per
15 unit area of a magnetic disk apparatus, an area record
density needs to be increased. For increasing an area
record density, there is a method to increase a track
density or a linear record density. The method of
increasing track density is to reduce a track width of head
20 which determines a track density. In an inductive type
magnetic head used for both recording and regenerating, the
area record density has been increased up to several
hundreds Mb/in², which causes a problem in that intensity of
regenerated output signal is weakened as the track width is
25 reduced. Therefore, a manifestative resistance effect type
head (MR head) utilizing an anisotropic magneto-resistance
effect is used for regeneration, and a recording-

regenerating-separate type thin film magnetic head
utilizing a conventional inductive type head is used for
recording. Film thickness of each layer in the MR head is
10 to 20 nm and the heat resistance is higher than 250°C.

5 The recording head comprises an upper and a lower magnetic
cores, a gap film, an induction coil and insulating films
for insulating the induction coil and the magnetic core.
Thermally cured photoresist is well known widely to be
useful as an insulating film between the induction coil and
10 the upper and the lower magnetic cores of the thin film
magnetic head. Curing the insulating film requires a
condition to keep it at a temperature above 250°C for a
period from several hours to several tens of hours.
Characteristics of the MR head used at present is not
15 deteriorated under this condition. An example of the thin
film magnetic head using the photoresist bonded in a manner
to intersect each other with an intersection bonding agent
activated by heating is disclosed in Japanese Patent
Application Laid-Open No.1-235016. Another example of the
20 thin film magnetic head using a ladder silicone resin
instead of the photoresist as an insulating film is
disclosed in Japanese Patent Application Laid-Open No.6-
28631.

When the area record density is further increased
25 above several Gb/in², the track width is reduced smaller and
intensity of the output signal becomes insufficient even if
the manifestative resistance effect type head (MR head)

utilizing an anisotropic magneto-resistance effect is used. Therefore, it is required to increase the intensity of the regenerated output signal by employing a giant magneto-resistance effect type head (GMR head) utilizing giant
5 magneto-resistance effect which has a larger resistance variation. Types of the head showing the giant magneto-resistance effect are a multi-layer film type head which is composed of films made of a ferromagnetic metal such Co or Fe and films made of a non-magnetic metal such as Cr or Cu;
10 a spin valve type head in which a film made of a non-magnetic metal such as Cr or Cu is put between magnetic films, and resistance variation is obtained by fixing magnetization of the magnetic film in one side and rotating magnetization of the magnetic film in the other side; and a
15 tunnel junction type head in which a film made of an insulator such as Al_2O_3 or SiO_2 is put between magnetic films, and resistance variation is obtained by tunnel effect through the insulating film. A magnetic recording apparatus utilizing the giant magneto-resistance effect
20 having a spin valve type head is disclosed in Japanese Patent Application Laid-Open No.8-7235.

In any case of the multi-layer film type, the spin valve type and the tunnel junction type, film thickness of each layer in the giant magneto-resistance effect film is
25 several tens nm. However, in order to attain a higher record density, the thickness is required to be thinner than, for example, 3 nm. The very thin film has a low heat

resistance because diffusion of elements is likely to occur in each interface of the layers and accordingly the limit temperature of heat resistance is about 230°C. Therefore, in the typical manufacturing process of a recording head described above, there is a problem in that the characteristic of the film is deteriorated in the thermal curing treatment (about 250°C, for several hours) of the insulating film made of photoresist, and accordingly the resistance variation is reduced. Therefore, the thermal curing treatment has been a large obstacle against improving performance of the magnetic head to increase the area record density of the magnetic disk apparatus.

A non-organic film made of Al_2O_3 , SiO_2 or the like is used for a gap film. When bonding force of the insulating film is weak, a failure of separating the gap film from the insulating film frequently occurs. Although the bonding force can be increased by elevating the temperature of the heat treatment of the insulating film, the higher temperature heat treatment makes it difficult to be adopted because the high temperature deteriorates the characteristic of the giant magneto-resistance effect film which is composed of a thin multi-layer film, as described previously. Therefore, a material curable at a low temperature and having a high bonding force is required. According to the invention of Japanese Patent Application Laid-Open No.1-235016, the condition of the heat treatment can be moderated to 80°C for 15 hours by employing a

photoresist which is cross-linked by a cross-linking agent activated by heating. However, if the temperature of the heat treatment is too low, the photoresist does not flow, and a taper angle at the end portion of the photoresist becomes high. Further, if baking temperature of the insulating film is low, a failure of a pattern being peeled off occurs because the bonding force of the photoresist is weakened. In the case of the invention of Japanese Patent Application Laid-Open No.6-28631 in which the ladder type silicone resin is used instead of the photoresist, the resistance variation is eliminated, as described previously, even not only in the giant magneto-resistance effect film but also in the MR film because the temperature of the heat treatment is higher than that in the case of the photoresist, and the heat treatment at 300 to 350°C for one hour or more is required. In Japanese Patent Application Laid-Open No.8-7235, there is no description on any insulating film of the recording head.

20 SUMMARY OF THE INVENTION

An object of the present invention is to provide a recording-regenerating separate type thin film magnetic head using the giant magneto-resistance effect which comprises an insulating film having a tight bonding capability and capable of being cured under a low temperature heat treatment condition without deteriorating the magnetic characteristic of the giant magneto-resistance

effect film of the multi-layer film type, the spin valve type and the tunnel junction type and a high record density magnetic disk apparatus mounting the recording-regenerating separate type thin film magnetic head.

5 The present invention is characterized by a thin film magnetic head comprising a lower magnetic film; an upper magnetic core laminated on the lower magnetic film, forming a magnetic circuit together with the lower magnetic film, one end of the upper magnetic core being continued to the
10 lower magnetic film, the other end being opposite to the lower magnetic film through a magnetic gap; a conductor coil provided between the lower magnetic film and the upper magnetic core; and an insulating film for electrically insulating the upper magnetic core and the conductor coil
15 from each other, wherein the insulating film is a cured body of a photoresist, a cross-linking agent and a cross-linking accelerating agent for the photoresist and the cross-linking agent.

It is preferable that the cross-linking agent is at
20 least one kind of resin selected from the group consisting of melamine resin and epoxy resin. It is also preferable that the cross-linking accelerating agent is composed of an organic compound generating an acid, and, particularly, the cross-linking accelerating agent is preferably composed of
25 an organic compound generating an acid by heating.

As an detailed example, the cross-linking accelerating agent is a compound selected from the group consisting of

bromoacetylbenzene,
p-bis(bromoacetyl)benzene,
m-bis(bromoacetyl)benzene,
p-bis(bromoacetyl)benzene,
5 m-bis(bromoacetyl)benzene,
1,3,5,-tris(bromoacetyl)benzene,
1,3,5,-tris(dibromoacetyl)benzene, and
1,3,5,-tris(chloroacetyl)benzene.

It is preferable that the photoresist is an acid
10 curing phenol resin, and particularly it is preferable that
the acid curing phenol resin is novolak.

The present invention is characterized by a magneto-
resistance effect type thin film magnetic head formed by
successively laminating an antiferromagnetic layer, a first
15 magnetic layer forming a fixed layer, a non-magnetic
metallic layer and a second magnetic layer forming a free
layer, wherein each of the first magnetic layer, the second
magnetic layer, and the non-magnetic layer has a thickness
not thicker than 3 nm.

20 The present invention is characterized by a recording-
regenerating separate type thin film magnetic head
comprising an inductive type recording head formed on a
magneto-resistance effect type regenerating head through a
magnetic shield in a unit, wherein

25 the recording head comprises an upper magnetic core
laminated on the magnetic shield, forming a magnetic
circuit together with the magnetic shield, one end of the

upper magnetic core being continued to the magnetic shield,
the other end being opposite to the magnetic shield through
a magnetic gap; a conductor coil provided between the
magnetic shield and the upper magnetic core; and an
5 insulating film for electrically insulating the magnetic
shield, the upper magnetic core and the conductor coil from
one another; the insulating film being composed of a
photoresist containing a novolak resin as a main component,
a cross-linking agent and a curing agent of a cross-linking
10 accelerating agent;

the regenerating head comprising a first and a second
magnetic layers of a ferromagnetic material partitioned by
a non-magnetic metallic layer; an antiferromagnetic layer
provided in contact with any one of the magnetic layers; a
15 magnetized direction of the first magnetic layer of the
ferromagnetic material being in a direction perpendicular
to a magnetized direction of the second magnetic layer.

The present invention is characterized by a recording-
regenerating separate type thin film magnetic head
20 comprising an inductive type recording head formed on a
magneto-resistance effect type regenerating head through a
magnetic shield in a unit, wherein

the recording head comprises an upper magnetic core
laminated on the magnetic shield, forming a magnetic
25 circuit together with the magnetic shield, one end of the
upper magnetic core being continued to the magnetic shield,
the other end being opposite to the magnetic shield through

a magnetic gap; a conductor coil provided between the magnetic shield and the upper magnetic core; and an insulating film for electrically insulating the magnetic shield, the upper magnetic core and the conductor coil from one another; the insulating film being composed of a
5 novolak resin, a cross-linking agent and a curing agent of a cross-linking accelerating agent;

the regenerating head being formed by successively laminating an antiferromagnetic layer, a first magnetic
10 layer forming a fixed layer, a non-magnetic metallic layer and a second magnetic layer forming a free layer; each of the first magnetic layer, the second magnetic layer, and the non-magnetic layer having a thickness not thicker than 3 nm.

15 The present invention is characterized by a head disk assembly comprising a magnetic disk for recording information; a recording-regenerating separate type thin film magnetic head formed an inductive type recording head for writing the information in the magnetic disk and a
20 magneto-resistance effect type regenerating head for regenerating the written information in the magnetic disk in a unit; and a drive means for rotating the disk, wherein the recording head and/or the regenerating head is the thin film magnetic head described above which has a record
25 density not smaller than 3 Gb/in².

The present invention is characterized by a magnetic disk apparatus comprising a plurality of head disk

assemblies comprising a magnetic disk for recording information; a recording-regenerating separate type thin film magnetic head formed an inductive type recording head for writing said information in said magnetic disk and a
5 magneto-resistance effect type regenerating head for regenerating the written information in the magnetic disk in a unit; and a drive means for rotating the disk, wherein the recording head and/or the regenerating head is the thin film magnetic head described above.

10 The present invention is characterized by a magnetic disk apparatus having an area record density larger than 1 Gb/in², preferably larger than 3 Gb/in², particularly 5 Gb/in², and using a recording-regenerating separate type thin film magnetic head utilizing the spin valve giant
15 magneto-resistance effect for regeneration and an inductive type thin film magnetic head for recording.

A portion generating the giant magneto-resistance effect in the recording-regenerating separate type magnetic head is composed of a multi-layer film having three layers
20 or more.

The multi-layer film of the recording-regenerating separate type magnetic head includes a layer having a film thickness not thicker than 3 nm, a cured body of a mixture including a photoresist, and a cross-linking agent and a
25 cross-linking accelerating agent for the photoresist and the cross-linking agent is used as insulating films between the conductor coil and the upper and the lower magnetic

cores of the recording head in the recording-regenerating separate type thin film magnetic head, the main component of the photoresist being a novolak resin, the cross-linking agent being melamine resin or epoxy resin, the cross-
5 linking accelerating agent generates an acid by heating.

The cross-linking accelerating agent is a compound selected from or a mixture of two or more compounds selected from the group consisting of bromoacetylbenzene, p-bis(bromoacetyl)benzene, m-bis(bromoacetyl)benzene,
10 1,3,5,-tris(bromoacetyl)benzene, 1,3,5,-tris(dibromoacetyl)benzene and 1,3,5,-tris(chloroacetyl)benzene, and the curing is performed by thermal curing.

In order to attain high record density of a magnetic
15 disk, it is necessary to highly improve a performance of a magnetic head, as described above. In order to attain high sensitivity, it is necessary to separate a head into a recording head and a regenerating head and to utilize various kinds of magneto-resistance effects to the
20 regenerating head. Particularly, in a case of an area record density of 5 Gb/in², it is required to use the giant magneto-resistance effect such as the spin valve type or the tunnel junction type from the viewpoint of intensity of output signal of the regenerating head. In this case, since
25 film thickness of the thinnest film in the giant magneto-resistance effect film is as thin as 3 nm or less, the heat resistance of the film is decreased. Therefore, the

magnetic characteristic of the regenerating head is deteriorated by temperature of a thermal curing process of the photoresist used as an inter layer insulating film for keeping insulation between the conductor coil and the upper
5 and the lower magnetic cores of the recording head which is usually formed after forming the regenerating head.

Accordingly, it is required to reduce the temperature of the thermal curing process. The photoresist used for the insulating film is composed of novolak resin as a base
10 resin and diazonaphthoquinone group as a photosensitive agent, and an initiation temperature of the thermal curing is above 250°C. The novolak resin and diazonaphthoquinone group as a photosensitive agent generally used in manufacturing thin film magnetic heads and semiconductor
15 elements may be used for a photoresist to curing at a low temperature. Melamine resin in various types such as Seimel 300, Seimel 303, Seimel 325 and the like may be available from Mitsui Citech Company. Since the melamine and the epoxy resins have no effect on photosensitivity to exposure
20 of light, accuracy and stability of a pattern are completely the same as those in a conventional photoresist. Further, flatness of steps of the coil, and others is also the same as that in a conventional photoresist.

Neither of the melamine resin nor the epoxy resin
25 forms the cross-linking structure under a condition where no catalyst exists, even if it is mixed with novolak resin and heated because it is scarcely reactive. However, in the

presence of an acidic catalyst, either of the melamine resin and the epoxy resin causes the cross-linking reaction and is cured by heating. If the acidic catalyst exist in vanish resist, the cross-linking reaction starts at a relatively low temperature such as approximately 90°C. Therefore, the cross-linking starts at the pre-baking step after applying the resist, and the pattern having a preferable accuracy can not be formed. Therefore, by mixing an acid generating agent, which generates an acid in the baking step after forming the pattern, with the resist to form the pattern with a preferable accuracy, it becomes possible to start the cross-linking reaction and to cure the melamine resin or the epoxy resin and the novolak resin in the subsequent baking step. Examples of such acid generating agents are bromoacetylbenzene, p-bis(bromoacetyl)benzene, m-bis(bromoacetyl)benzene, 1,3,5,-tris(bromoacetyl)benzene, 1,3,5,-tris(dibromoacetyl)benzene and 1,3,5,-tris(chloroacetyl)benzene. The acid generating agent such as 1,3,5,-tris(bromoacetyl)benzene decomposes at approximately 150°C to generate an acid. Therefore, the melamine resin or the epoxy resin and the novolak resin start gradually the cross-linking reaction at 150°C. However. Because the novolak resin mixed with the melamine resin or the epoxy resin has a larger fluidity than the novolak resin itself, the taper angle at the end portion of the pattern can be reduced by baking at least at 150°C. Because of the small taper angle, the step coverage of the upper

magnetic core formed on the insulating film does not have any problem. In order to obtain a high adhesion as the insulating film, the baking condition is desirable in the range of 150 to 200°C for at least 30 minutes.

5 As explained above, the insulating film used in the present invention can moderate significantly the baking condition to make it milder than the baking condition for the conventional resist such as 250°C for a period from several hours to several tens of hours while keeping
10 sufficient adhesion. Accordingly, in the giant magneto-resistance effect film of the spin valve type or the tunnel junction type composed of the very thin films having a thickness below 3 nm, the magnetic characteristic can be sufficiently maintained, and further it is possible to
15 manufacture a magnetic disk apparatus mounting a high performance magnetic head capable of obtaining an intensity of regenerated output signal necessary to attain an area record density above 5 Gbit/in².

(1) Recording head

20 The above-mentioned recording thin film magnetic head in accordance with the present invention is manufactured by forming a frame on a substrate having a magnetic film to be used as a lower magnetic core or an upper magnetic shield, a magnetic gap, a conductor coil and an insulating film,
25 and forming a plated film, and then forming an upper magnetic core by masking an area surrounded by the frame and etching the plated film. It is preferable that when a

track width w_1 , where the upper magnetic core is in contact with the magnetic gap, is $1.5 \mu\text{m}$, the ratio (t/w_1) of a thickness t of the upper magnetic core to the track width w_1 is not less than 2.

5 It is also preferable that a ratio (w_2/w_1) of a width (w_2) of the upper magnetic core to the track width (w_1) , where the upper magnetic core is in contact with the magnetic gap, is not larger than 1.3.

 In manufacturing the above-mentioned thin film
10 magnetic head by forming the frame on the substrate having the magnetic film to be used as the lower magnetic core or the upper magnetic shield, the magnetic gap, the conductor coil and the insulating film, and forming the plated film, and then forming the upper magnetic core by masking the
15 area surrounded by the frame and etching the plated film, the thin film magnetic head can be manufactured through a method comprising the steps of a first process in which a resist is formed on the substrate so as to have an optimum thickness on an area in the front end portion of the
20 substrate where the magnetic gap of the thin film magnetic head is formed, and the resist is patterned into a shape corresponding to at least the area in the front end portion of the upper magnetic core, and then the resist is cured to form a first frame corresponding to the area in the front
25 end portion of the upper magnetic core; and a second process in which a resist is applied onto an area in the rear portion having the conductor coil and the insulating

film of the conductor coil on the substrate having the first frame formed so that the thickness of the frame is optimized, and then a second frame corresponding a portion formed on the area in the rear portion of the magnetic core is formed by patterning the resist so as to be integrated in the first frame.

Reactive etching may be used in the etching process, and a silicon containing resist may be used for the uppermost layer resist. It is preferable that the multi-layer film is composed of three layer films of an organic film in the lowermost layer, an intermediate film and a photoresist in the uppermost layer, and particularly the intermediate film is an inorganic film formed of at least one compound or element selected from the group consisting of Si, SiO_2 , Al, Al_2O_3 , Ti, TiO_2 , Ta, Ta_2O_5 , W, Nb. Especially, in the case of SiO_2 , it is preferable to employ sputtering method or to perform sintering after applying spin-on glass.

The organic film is composed of a photoresist which is cured after forming the first frame. The curing process is performed by far ultraviolet irradiation or by reactive ion etching. The organic film contains at least one of polyimide and its derivatives, polydimethylglutarimide (PMGI) and its derivatives, polymethylmetacrylate (PMMA) and its derivatives, benzocyclobutene (BCB) and its derivatives, and epoxy and its derivatives; an electron beam resist may be used for the uppermost layer resist, an

electron beam drawing method may be used for exposure of the electron beam resist, and a phase shift method or a modified lighting method may be used for exposure of the uppermost layer resist.

5 Further, it is preferable that at least one of the upper magnetic core and the lower magnetic core of the recording magnetic core of the thin film magnetic head in accordance with the present invention is formed of an electroplated thin film of an Ni-Fe alloy containing Ni 38
10 ~ 60 atomic % and Fe 40 ~ 62 atomic % or a single layer or multi-layers film of Ni 75 ~86 atomic %-Fe alloy.

 Furthermore, it is preferable that the magnetic disk apparatus in accordance with the present invention comprises a disk-shaped magnetic disk having a media
15 transmission speed higher than 15 Mega-bites per second, an area record density of recording data larger than 1 Giga-bits per square inch and a diameter of information memory medium smaller than 3,5 inches; the magnetic disk is
rotated at a speed higher than 4000 rpm at recording and
20 regenerating time, and recording frequency is higher than 45 MHz; at least one of the upper magnetic core and the lower magnetic core of the recording magnetic core of the thin film magnetic head in accordance with the present
invention is formed of an electroplated thin film of an Ni-
25 Fe alloy containing Ni 38 ~ 85 atomic % and Fe 15 ~ 62 atomic %, the film thickness is 1 ~ 5 μm , the average grain size is smaller than 500 Å, the specific resistance is 40 ~

60 $\mu\Omega\text{cm}$, the magnetic coercive force in difficult axis of magnetization is smaller than 1.0 Oe, and the recording magneto-motive force of the recording magnetic head is larger than 0.5 Ampere-turns.

5 The magnetic core in accordance with the present invention may contain Co less than 15 wt% or at least one element of 3 wt% or less in total quantity selected from the group consisting of Mo, Cr, Pd, B and In.

(2) Regenerating head

10 The magneto-resistance effect head in accordance with the present invention comprises a magneto-resistance effect film having a plurality of laminated films in a size corresponding to a track width of a magnetic recording medium, magnetic domain control layers arranged adjacent to
15 both sides of a region in the width direction intersecting with the laminated layer direction of the magneto-resistance effect film, and a pair of electrodes laminated on the magnetic domain control layer and electrically connected to the magneto-resistance effect film; wherein
20 the magneto-resistance effect film comprises a first ferromagnetic film composed of single layer or plural layers of which the direction of magnetization is varied by a magnetic field from the magnetic recording medium, a second ferromagnetic film composed of single layer or
25 plural layers of which the direction of magnetization is fixed, a non-magnetic conductive film interposed between the first ferromagnetic film and the second ferromagnetic

film, and the second ferromagnetic film is directly laminated on an antiferromagnetic film or a permanent magnet film for fixing the direction of magnetization of the second ferromagnetic film; and part of each of the pair of electrodes is laminated on the magneto-resistance effect film. It is preferable that the electrodes are formed so that the gap between the electrodes is narrower than the width of the magneto-resistance effect film or the electrodes are arranged in such a position that current flows only the central portion of the magneto-resistance effect film, and the gap is smaller than $1.3 \mu\text{m}$. Particularly, the gap may be set to 0.25 to $1.0 \mu\text{m}$.

In the magneto-resistance effect type head, in which the second ferromagnetic film is directly laminated on the antiferromagnetic film or the permanent magnet film for fixing the direction of magnetization of the second ferromagnetic film, among the magneto-resistance effect type heads utilizing the giant magneto-resistance effect, it is possible to employ a construction where part of each of the pair of electrodes is laminated on the antiferromagnetic film or the permanent magnet film and the electrodes are formed so that the gap between the electrodes is narrower than the width of the magneto-resistance effect film.

It is preferable that the magnetic recording-regenerating apparatus in accordance with the present invention comprises a disk with a magnetic recording medium

having magnetically recorded signals; and a magnetic head, bringing its sliding surface close to the disk and moving relatively to the disk, for detecting magnetic field leaking from the recording medium; wherein the magnetic head comprises a first and a second magnetic layers made of a ferromagnetic and partitioned by a non-magnetic metallic layer; an antiferromagnetic layer provided in contact with any one of the magnetic layers, a direction of magnetization of the first magnetic layer made of a ferromagnetic is perpendicular to a direction of magnetization of the second magnetic layer when an applied magnetic field does not exist; a means for fixing the direction of magnetization of the second magnetic layer and the means does not exist; a means for generating current in the magneto-resistance sensor; a means for detecting electric resistance change produced by rotation of the magnetization of the first layer as a function of the magnetic field detected by the magneto-resistance sensor; the first and the second magnetic layer are made of Co or a Co alloy, and that antiferromagnetic layer is made of a Cr-Mn alloy.

The Cr-Mn alloy preferably contains 30 to 70 atomic % of Mn. In addition to this, the Cr-Mn alloy may contain 0.1 to 30 atomic % in total quantity of at least one element selected from the group consisting of Co, Ni, Cu, Ag, Au, Pt, Pd, Rh, Ru, Ir, Os and Re, and particularly, the total quantity of 5 to 15 atomic % is preferable.

It is preferable that the permanent magnet film is made of any one of materials of a Co-Pt alloy, a Co-Cr-Pt alloy and these alloys containing at least one substance among Ti oxide, V oxide, Zr oxide, Nb oxide, Mo oxide, Hf oxide, Ta oxide, W oxide, Al oxide, Si oxide and Cr oxide; and particularly it is preferable that the permanent magnet film is made of a material having a composition which satisfy the following Equation 1 or Equation 2.

$$\begin{array}{ll} \text{Co}_a\text{Cr}_b\text{Pt}_c & \text{or} \quad \dots (\text{Equation 1}) \\ 10 \quad (\text{Co}_a\text{Cr}_b\text{Pt}_c)_{1-x}(\text{MO}_y)_x & \dots (\text{Equation 2}) \end{array}$$

(where $x=0.01\sim0.20$, $y=0.4\sim3$, $a=0.7\sim0.9$, $b=0\sim0.15$, $c=0.03\sim0.15$, M: at least one of Ti, V, Zr, Mo, Hf, Ta, W, Al, Si and Cr)

It is preferable that specific resistance of a soft magnetic thin film for applying lateral bias magnetic field to the magneto-resistance effect film is larger than $70\mu\Omega$ cm. It is also preferable that the lateral bias film is made of a nickel-iron alloy containing nickel of 78 to 84 atomic %.

The multi-layer film is formed by laminating the first ferromagnetic film, the non-magnetic conductive film, the second ferromagnetic film and the antiferromagnetic film on the second ferromagnetic film. After laminated, the magneto-resistance effect film composed of the multi-layer film and the antiferromagnetic film are cut off in the both sides together so that the width of the magneto-resistance effect film (the width is defined by the narrowest width

among the widths of the first ferromagnetic film, the non-magnetic conductive film and the second ferromagnetic film) becomes a predetermined width, for example, 2 μm . The first ferromagnetic film as a free layer is formed of, for

5 example, a single layer film of $\text{Ni}_{80}\text{Fe}_{20}$, $\text{Ni}_{68}\text{Fe}_{17}\text{Co}_{15}$, $\text{Co}_{60}\text{Ni}_{20}\text{Fe}_{20}$, $\text{Co}_{90}\text{Fe}_{10}$ or Co, and the film thickness is set to an optimum value within the range of 2 to 15 nm. The non-magnetic conductive film is made of, for example, Cu, and the film thickness is set to an optimum value in the range

10 of, for example, 1 to 4 nm. The second ferromagnetic film as a fixed layer is formed of, for example, Co, and the film thickness is set to an optimum value in the range of, for example, 1 to 5 nm. Further, the second ferromagnetic film as a fixed layer may be formed of, for example, a

15 single layer film of $\text{Ni}_{80}\text{Fe}_{20}$, $\text{Ni}_{68}\text{Fe}_{17}\text{Co}_{15}$, $\text{Co}_{60}\text{Ni}_{20}\text{Fe}_{20}$, $\text{Co}_{90}\text{Fe}_{10}$ or Co, or a multi-layer film formed by laminating some of these films. The antiferromagnetic film is formed of, for example, $\text{Cr}_{45}\text{Mn}_{45}\text{Pt}_{10}$, and the film thickness is set to, for example, approximately 30 nm. Other than the

20 materials described above, the antiferromagnetic film is formed of, for example, $\text{Fe}_{50}\text{Mn}_{50}$, $\text{Mn}_{80}\text{Ir}_{20}$, $\text{Ni}_{50}\text{Mn}_{50}$. The direction of magnetization of the second ferromagnetic film is fixed so as to be oriented to the medium facing surface by exchange couple with the antiferromagnetic film. The

25 direction of magnetization of the first ferromagnetic film is set, for example, in the width direction of the magnetoresistance effect film, and the direction of magnetization

is varied by a magnetic field of the magnetic recording medium. Further, the antiferromagnetic film can be replaced to a permanent magnet.

The magnetic domain control layer is composed of a laminated film of, for example, a permanent magnet film and an orientation control base film, and the magnetic domain control layers are adjacently arranged in both sides of a region in the width direction intersecting with the laminating direction of the magneto-resistance effect film.

10 The permanent magnet film composing the magnetic domain control layer is made of, for example, $\text{Co}_{75}\text{Cr}_{10}\text{Pt}_{15}$, $\text{Co}_{75}\text{Cr}_{10}\text{Ta}_{15}$ or the like, and the orientation control base film is made of, for example, Cr. Further, the permanent magnet film composing the magnetic domain control layer may

15 be made of, for example, $\text{Co}_{80}\text{Pt}_{20}$, and may be also made of an alloy such as $\text{Co}_{75}\text{Cr}_{10}\text{Pt}_{15}$, $\text{Co}_{75}\text{Cr}_{10}\text{Ta}_{15}$ or $\text{Co}_{80}\text{Pt}_{20}$ added with an oxide such as ZrO_2 , SiO_2 , Ta_2O_5 or the like. In these cases, the orientation control base film may be eliminated, and the first ferromagnetic film is controlled in a single

20 magnetic domain by the magnetic field generated by the magnetic domain control layer. Further, the magnetic domain control layer may be formed in a laminated layer film together with the antiferromagnetic film, the ferromagnetic film and the orientation control base film. In that case,

25 it is desirable that the antiferromagnetic film is made of an alloy selected from $\text{Fe}_{50}\text{Mn}_{50}$, $\text{Mn}_{80}\text{Ir}_{20}$, $\text{Ni}_{50}\text{Mn}_{50}$, $\text{Cr}_{45}\text{Mn}_{45}\text{Pt}_{10}$ and the like, the ferromagnetic film is made of an alloy

selected from Ni-Fe group alloys, Co-Fe group alloys, Co-Ni group alloys, and the orientation control base film is made of Ta. Further, the antiferromagnetic film may be made of NiO or CoO, and in this case the orientation control base
5 film may be eliminated.

Each of the pair of electrodes is laminated on the magnetic domain control layer, and part of each electrode is laminated on the antiferromagnetic film. The width of the laminated layer of each of the electrodes and the
10 antiferromagnetic film is set to, for example, $0.5\mu\text{m}$. That is, since the width of the magneto-resistance effect film is smaller than $2\mu\text{m}$, each of the electrodes is laminated on the magnetic domain control layer and the antiferromagnetic film so that the electrode gap between the electrodes
15 becomes $1.0\mu\text{m}$. Each of the electrodes is made of a low resistance metal such as Ta, Au, Cu or the like.

In a spin valve head having the antiferromagnetic film made of an oxide such as NiO, CoO or the like, the magneto-resistance effect film is laminated on the
20 antiferromagnetic film. Therefore, each of the pair of electrodes is laminated on the magnetic domain control layer, and part of each electrode is laminated on the first ferromagnetic film. The antiferromagnetic film may be replaced to a magnet.

25

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic view showing a hard disk

apparatus in accordance with the present invention.

FIG. 2 is a perspective view showing a recording-regenerating separate type thin film magnetic head.

FIG. 3 is a perspective view showing a negative
5 pressure slider in accordance with the present invention.

FIG. 4 is an overall view showing a magnetic disk apparatus in accordance with the present invention.

FIG. 5 is a conceptual diagram of a disk array apparatus in accordance with the present invention.

10 FIG. 6 is a cross-sectional view showing a spin valve head in accordance with the present invention.

FIG. 7 is a cross-sectional view showing a spin valve head in accordance with the present invention.

FIG. 8 is a cross-sectional view showing a spin valve
15 head in accordance with the present invention.

FIG. 9 is a cross-sectional view showing an inductive type recording head in accordance with the present invention.

FIG. 10 is a view showing the manufacturing process of
20 the recording-regenerating separate type thin film magnetic head in accordance with the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

(Embodiment)

25 FIG. 1 is a schematic view showing a hard disk apparatus having a magneto-resistance effect type regenerating head of spin valve type in accordance with the

present invention. The apparatus comprises a disk rotating shaft 64 and a spindle motor 65 for rotating the disk rotating shaft at a high speed, and one disk or a plurality of disks 40 (two disks in this embodiment) are attached
5 onto the disk rotating shaft 64 in a certain spacing between the disks. Therefore, each of the disks 40 is rotated together with the disk rotating shaft 64. The disk 40 is a disk having a certain radius and a certain thickness, and permanent magnet films are formed on the
10 both surfaces to be used for information recording surfaces. The apparatus further comprises a head positioning rotating shaft 62 and a voice coil motor 63 for driving the rotating shaft outside the disks 40, and a plurality of access arms 61 are attached onto the head positioning rotating shaft 62,
15 and a recording-regenerating head (hereinafter, referred to as "head") 60 is attached to a top end of each of the access arms 61. Thereby, each of the heads is moved along the radial direction on each disk 40 and positioned at a predetermined position by rotating the head positioning
20 rotating shaft 62 by a predetermined angle. Each of the head 60 is held at a position being several tens of nm distant from the surface of the disk 40 using balance between a buoyant force produced when the disk 40 is rotated at a high speed and a pushing force of a gimbal of
25 elastic body composing a part of the access arm 61. The spindle motor 65 and the voice coil motor 63 are respectively connected to a head disk controller 66 which

controls rotating speed of the disk 40 and position of the head 60.

FIG. 2 is a perspective view showing a magnetic head having an inductive type recording head and a magneto-
5 resistance effect type regenerating head in accordance with the present invention. The magnetic head mounts a regenerating head which comprises a lower shield 21, a magneto-resistance effect film 23, a magnetic domain control film 25, and electrode terminals 11; and an
10 inductive type recording head, a lower gap and an upper gap which are not shown in the figure, and a coil 7 which generates a magneto-motive force in an upper magnetic core 9 and an upper shield 4 which concurrently operates as a lower magnetic core.

15 FIG. 3 is a perspective view showing a negative pressure slider. The negative pressure slider 70 comprises an air introducing surface 71; a negative pressure generating surface 78 surrounded by two positive pressure generating surfaces 77, 77 for generating a buoyant force;
20 and a groove 74 having a step larger than the step of the negative pressure generating surface 78 in the boundary between the air introducing surface 79 and the negative pressure generating surface 78, and between the two positive pressure generating surfaces 77, 77 and the
25 negative pressure generating surface 78. In air exhaust ends 75 there are arranged an inductive type recording head, to be described later, for recording information into a

magnetic disk and an MR sensor, to be described later, for regenerating which have thin film magnetic head elements 76 of recording-regenerating separate type having the structure shown in FIG. 2.

5 When the negative pressure slider 70 is floating, air introduced through the air introducing surface 79 is expanded in the negative pressure surface 78. Since part of the air flows toward the groove 74 at that time, an air flow from the air introducing surface 79 to the air exhaust
10 end 79 exists inside the groove 74. Therefore, even if dust suspending in air is introduced through the air introducing surface 71 when the negative pressure slider 70 is floating, the dust is introduced inside the groove 74 and is carried away by the air flow inside the groove 74 to be exhausted
15 outside the negative pressure slider 70 through the air exhaust ends 78. Further, since air inside the groove 74 always flows and does not stagnate when the negative pressure slider 70 is floating, the dust cannot be flocculated.

20 FIG. 4 is an overall perspective view showing an embodiment of a magnetic disk apparatus in accordance with the present invention. The magnetic disk apparatus comprises a magnetic disk for recording information, a DC motor, not shown in the figure, for rotating the magnetic
25 disk, a magnetic head for writing and reading the information, a positioning mechanism for supporting and changing the position of the magnetic head to the magnetic

disk, that is, an actuator and a voice coil motor. The figure shows an example in which five magnetic disks are attached to a single rotating shaft to increase the total memory capacity.

5 According to this embodiment, it is possible to obtain a high sensitive MR sensor having excellent MR effects such as capability of recording to a high magnetic coercive force medium in a high frequency band, a media transmission speed higher than 15 MB/second, a recording frequency
10 higher than 45 MHz, a data transmission speed higher than magnetic disk 400 rpm, reducing of access time, increasing of recording capacity. Therefore, it is possible to provide a magnetic disk apparatus having an area record density larger than 3 Gb/in².

15 FIG. 5 shows an example of a disk array apparatus which is assembled by combining a plurality of magnetic recording-regenerating apparatuses described above. In this case, capability of processing information is improved and reliability of the apparatus is also improved since the
20 plurality of magnetic recording-regenerating apparatuses are operated at a time. There is no need to said that performance (low error rate, small consuming electric power) of each of the magnetic recording-regenerating apparatuses is high. Therefore, the high performance
25 complex head is also inevitable in this case.

FIG. 6 is a structural view of an embodiment of a spin valve head showing the surface facing a recording medium.

Referring to FIG. 6, the spin valve head (giant magneto-resistance effect type head) constructed as a regenerating magneto-resistance type effect head comprises a magneto-resistance effect film 10, a magnetic domain control layer 12 and a pair of electrodes 14, and the magneto-resistance effect film 10 is laminated on an antiferromagnetic film 16. The magneto-resistance effect film 10 is formed in a multi-layer by laminating a plurality of films having a size corresponding to a track width of a magnetic recording medium. The multi-layer film is composed of a first ferromagnetic film 18, a non-magnetic conductive film 20, second ferromagnetic films 22, 24, and the second ferromagnetic film 24 is laminated on an antiferromagnetic film 16. The multi-layered films are laminated in a state of being cut off in a size corresponding to a certain width (width 26 of the magneto-resistance effect film). The first ferromagnetic film 18 as a free layer is formed of, for example, Ni-Fe, Co-Fe, Co-Ni-Fe or the like, and the film thickness is set to 5 nm, preferably 2 to 15 nm. The non-magnetic conductive film 20 is made of, for example, Cu, and the film thickness is set to 2 nm, preferably 1 to 5 nm. The second ferromagnetic films 22, 24 compose a laminated film as a fixed layer, and is formed of, for example, Co, and the film thickness is set to 1 nm, preferably 1 to 5 nm in the both second ferromagnetic films. The antiferromagnetic film 16 is formed of NiO, and the film thickness is set to 50 nm, preferably 20 to 80 nm. The

direction of magnetization of the second ferromagnetic films 22, 24 is fixed so as to be oriented to the medium facing surface by exchange couple with the antiferromagnetic film 16. The direction of magnetization of the first ferromagnetic film 18 is set, for example, in the width direction of the magneto-resistance effect film, and the direction of magnetization is varied in a direction normal to the plane of the figure by a magnetic field of the magnetic recording medium. The thickness of the first ferromagnetic film 18 is approximately 2 to 3 times as thick as the total thickness of the second ferromagnetic films 22, 24.

The magnetic domain control layer 12 is composed of a laminated film of a permanent magnet film 28 and an orientation control base film 30, and the magnetic domain control layers 12 are adjacently arranged in both sides of a region in the width direction intersecting with the laminating direction of the magneto-resistance effect film 10. The permanent magnet film 28 is made of, for example, a Co-Cr-Pt alloy, and the orientation control base film 30 is made of Cr, and has a thickness of 10 nm, preferably 5 to 20 nm. The first ferromagnetic film 18 is controlled in a single magnetic domain by the magnetic field generated by the magnetic domain control layer 12. The magnetic domain control layer 12 is arranged in nearly the same level as the first ferromagnetic film 18, and the thickness of the magnetic domain control layer is set to 10 nm, preferably 4

to 30 nm, and more preferably 5 to 15 nm.

Each of the pair of electrodes 14 is laminated on the magnetic domain control layer 12, and part of each electrode 14 is laminated on the first ferromagnetic film 18. That is, each of the electrodes 14 is laminated on the first ferromagnetic film 18 and the magnetic domain control layer 12 so as to keep an electrode gap 32 between the electrodes. Each of the electrodes 14 is made of a metal such as Ta, Au, Cu or the like, and the electrode gap 32 between the both electrodes 14 is set narrower than the width 26 of the magneto-resistance effect film.

In a spin valve head, intensity of the output signal is proportional to a product of specific resistance change $\Delta\rho$, which is an intrinsic property of the spin valve film, and cosine $\cos\Delta\theta$ of an angle $\Delta\theta$ between directions of magnetization of the first ferromagnetic film and the second ferromagnetic film. It is known that the spin valve head is more sensitive than an AMR head because the specific resistance change $\Delta\rho$ of the spin valve head is two or more as high as that of the AMR head. Here, assuming that the direction of magnetization of the second ferromagnetic film is fixed in a direction perpendicular to the medium facing surface, for example, in a nearly downward direction (minus 90°), $\cos\Delta\theta$ can be rewritten as $\cos(\theta+90^\circ)$ using an angle θ between the direction of magnetization of the first ferromagnetic film and the medium facing surface. That is, the intensity of the output

signal is proportional to $\sin\theta$. Therefore, in order to make intensity of the output signal changed linearly to the change of θ , it is desirable that θ is near 0° . Therefore, the direction of magnetization of the first ferromagnetic
 5 film is set to in a direction parallel to the medium facing surface, that is, in a nearly lateral direction.

FIG. 7 is a structural view showing a spin valve head in which an alloy such as Fe-Mn group alloys, Ni-Mn group alloys or Cr-Mn group alloys is used for the
 10 antiferromagnetic film 16 of the spin valve instead of NiO. One of the second ferromagnetic films 22, 24 may be eliminated. As shown in FIG. 7, laminating direction of the magneto-resistance effect film 10 is different from that of FIG. 6, and the antiferromagnetic film 16 is laminated on
 15 the magneto-resistance effect film 10. Further, in both cases of FIG. 6 and FIG. 7, the antiferromagnetic film 16 can be replaced to a permanent magnet film. The thickness of each layer in this figure is the same as that in FIG. 6. The magnetic domain control layer 12 is in a level lower
 20 than the upper surface of the antiferromagnetic film 16.

Further, a spin valve type giant magneto-resistance effect film using an Fe-Mn alloy as the antiferromagnetic film 16 comprises a film construction of FeMn (10 nm)/ NiFe (5 nm)/ Cu (2 nm)/ NiFe (5 nm) 23, electrodes 28 for
 25 conducting current and a magnetic domain control film 25 for stabilizing magnetic domain of the giant magneto-resistance effect film. The regenerating track width is 0.8

μm . Instead of a spin valve type giant magneto-resistance effect film 23, a tunnel junction type giant magneto-resistance effect film may comprise a film construction of FeMn (10 nm)/ NiFe (5 nm)/ Co (3 nm)/Al₂O₃ (1 nm)/ Co (3 nm)/ NiFe (5 nm).

Further, another example of a film construction of the spin valve head is that layers of Ta (5 nm), NiFe (5 nm), CoFe (1 nm), Cu (25 nm), CoFe (3 nm), CrMnPt (30 nm) and Ta (5 nm) are successively laminated from the side of the lower magnetic shield 1, and Co-Cr-Pt alloy layers as hard bias layers in the both sides and electrodes (Ta) 28 are provided. By doing so, the resistance varying rate of 6.5% can be attained. The CoFe layer in the upper layer becomes a fixed layer, and the CoFe layer and the NiFe layer in the lower layer become free layers.

Furthermore, a still other example of a film construction of the spin valve head is that layers of Ta (5 nm), NiFe (5 nm), Cu (2 nm), Co (1 nm), FeNi (1 nm), CrMnPt (50 nm) and Ta (5 nm) are successively laminated from the side of the lower magnetic shield 1, and hard bias layers and electrodes are provided as the same as in the above.

FIG. 8 is a structural view showing a dual spin valve head which is an application of the spin valve head in order to increase intensity of output signal of the spin valve head. The construction of the magneto-resistance effect film 10 in this case is composed of a first ferromagnetic film 18, second ferromagnetic films 22, 24

each of which has fixed direction of magnetization, third ferromagnetic films 36, 38, a non-magnetic conductive film 20 inserted between the first ferromagnetic film 18 and the second ferromagnetic film 22, and a non-magnetic conductive film 34 inserted between the first ferromagnetic film 18 and the third ferromagnetic film 36. The second ferromagnetic films 22, 24 are laminated on an antiferromagnetic film 16, and an antiferromagnetic film 40 is laminated on the third ferromagnetic films 36, 38. The first ferromagnetic film 18 is constructed as a free layer which is made of, for example, NiFe, CoFe, CoNiFe, or the like, and has a film thickness of 5 nm. Each of the non-magnetic conductive films 22, 24 and the third ferromagnetic films 36, 38 composes the laminated film as a fixed layer. The second ferromagnetic film 22 and the third ferromagnetic film 36 are made, for example, of Co, and the film thickness of each of the both films is set to 1 nm. For example, a NiFe alloy is used for the second ferromagnetic film 24 and the third ferromagnetic film 38, and the film thickness of the both films is set to 1 nm, preferably 0.5 to 3 nm. The antiferromagnetic films 16, 40 are made of an appropriate material selected from the group consisting of oxides such as NiO, CoO and Fe-Mn group alloys, Ni-Mn group alloys, Cr-Mn group alloys. Therein, the antiferromagnetic films 16, 40 may be made of the same material or may be made of different materials, and may be replaced to permanent magnets. Further, one of the second

ferromagnetic films 22, 24 may be eliminated, and similarly one of the third ferromagnetic films 36, 38 may be eliminated. The thickness of each of the other layers is the same as that of FIG. 6.

5 In each of the above-mentioned spin valve heads, the permanent magnet film 28 may be replaced to a laminated film of a Ni-Fe group alloy film and an antiferromagnetic film of an alloy such as Fe-Mn group alloys, Mn-Ir group alloys, Ni-Mn group alloys, Cr-Mn group alloys. In this
10 case, better characteristics can be obtained when the orientation control base film 30 is replaced to a Ta film or the like. The magnetic domain control film 12 is formed in a level lower than the upper surface of the magneto-resistance effect film 10.

15 FIG. 9 is a cross-sectional view showing a recording head portion of an inductive type thin film head used in the hard disk apparatus of the present embodiment. The thin film head comprises a lower magnetic film 84 and an upper magnetic film 85. A non-magnetic insulator 89 is attached
20 between these magnetic films. Part of the insulator defines a magnetic gap 88. A supporting body is a form of slider having an air bearing surface (ABS), and the slider accesses to a rotating disk medium to float while the disk file is being operated.

25 The thin film head has a back gap 90 formed by the upper magnetic film 85 and the lower magnetic film 84. The back gap 90 is separated from the magnetic gap through an

interposed coil 87.

The continuous coil 87 is a layer formed on the lower magnetic film 84 by, for example, plating, and the coil 87 and the lower magnetic film 84 are electro-magnetically
5 coupled. The coil 87, which is buried in the insulator 89, has an electric contact point in the center of the coil and a larger electric contact point in the terminal point in the outer end portion of the coil. The contact points are connected to an external line and a reading-and-writing
10 signal processing head circuit, not shown in the figure.

In this embodiment, the coil 87 formed in a single layer has a slightly distorted oval-shape, and a portion of the coil having small cross-sectional area is placed at a position close to the magnetic gap and the cross-sectional
15 area gradually increases as the distance from the magnetic gap increases.

However, the oval-shaped coil has a comparatively higher density of coil wires between the back gap 90 and the magnetic gap 88, and accordingly the coil width or
20 cross-sectional diameter in this region is small. Further, large decrease of the cross section at a portion far distant from the magnetic gap results in decrease of its electric resistance. Furthermore, the oval-shaped (elliptic) coil has a small resistance to current since it
25 has no corners, no sharp edges and no sharp ends. In addition to this, the oval-shaped coil can make the total length of the conductor shorter compared to a rectangular

coil and a circular (ring-shaped) coil. As a result of these advantages, the total resistance of the coil can be suppressed relatively low and accordingly the heat generating rate can be decreased, and an appropriate heat radiation can be attained. The large decrease in the thermal load prevent film-collapse, elongation and expansion of the thin film layer, and eliminates the cause of ball-chip projection in the air bearing surface.

A conventional plating method, which is more economical than a sputtering method or a vapor deposition method, is available to form the oval-shaped coil in which the width of the coil changes nearly uniformly. In a coil having another shape, particularly a shape with corners, the structure of plated width is likely to become uneven. Elimination of corners and sharp edge portions affects less mechanical stress on a completed coil.

In this embodiment, the coil with many turns is oval-shaped and is formed between the magnetic cores, and the cross-sectional diameter gradually expands from the magnetic gap toward the back gap, and the intensity of output signal is increased and the heat generating rate is decreased.

In this embodiment, the upper and the lower magnetic films of the inductive type recording head were formed by the electroplating method as described below.

An inductive type thin film head having an upper and a lower magnetic cores was manufactured. The upper and the

lower magnetic cores were formed by frame-plating under a condition of pH of 3.0 and plating current density of 15 mA/cm² in a plating bath containing Ni⁺⁺ of 16.7 g/l, Fe⁺⁺ of 2.4 g/l and a common stress-release agent and a common surface-active agent. The track width was 1.0 μ m, and the gap length was 0.4 μ m. The composition of the magnetic films was 42.4 Ni-Fe (weight %), and the magnetic properties were that the saturation magnetic flux density (B_s) was 1.64 T, the difficult axis magnetic coercive force (H_{CH}) was 0.5 Oe and the specific resistance (ρ) was 48.1 μ Ω cm. The thin film magnetic head comprised the upper magnetic core 85, the lower magnetic core 84 also serving as an upper shield layer and a coil 87. The thin film magnetic head further comprised a magneto-resistance effect type element 86 for regeneration, electrodes for feeding sensing current to the magneto-resistance effect type element, a lower shield layer and a slider. The grain size of the magnetic core in this embodiment was 100 to 500 Å, and the difficult axis magnetic coercive force was smaller than 1.0 Oe.

In order to evaluate the above-mentioned construction in accordance with to the present invention, performance (over-write characteristic) of the recording head was measured, and the result showed good recording performance of approximately -50 dB even in a high frequency band above 40 MHz.

According to the embodiment, a large magneto-

resistance (MR) response can be obtained by a low applied magnetic field by the magneto-resistance (MR) effect sensor having a multi-layer dual spin valve structure. The MR structure is a laminated structure comprising a first, a
5 second and a third ferromagnetic thin films formed on a substrate and separated by non-magnetic metallic thin films. Directions of magnetization of the outer layers of the first and the third ferromagnetic films are fixed. The intermediate layer of the second film is soft magnetic, and
10 the direction of magnetization is essentially perpendicular to the fixed directions of magnetization of the two ferromagnetic films in the outer sides when the applied magnetic field is zero. The directions of magnetization of the first and the third ferromagnetic films are fixed by
15 various methods including hard bias or exchange bias by adjacent antiferromagnetic films.

The directions of magnetization of the two ferromagnetic layers in the outer sides are fixed in parallel to and opposite to each other, and therefore, one
20 of the fixed layer acts to hold magnetic flux of the other of the fixed layer. The direction of magnetization of the intermediate second ferromagnetic layer can be freely rotated by an applied magnetic field. Electric resistance of the first ferromagnetic layer and the second
25 ferromagnetic layer and electric resistance of the second ferromagnetic layer and the third ferromagnetic layer are vary as a cosine function of an angle between the

directions of magnetization of the pair of the ferromagnetic layers. When the direction of magnetization of the intermediate free layer is rotated from a direction nearly parallel to the direction of magnetization of the first fixed layer to a direction nearly parallel to the direction of magnetization of the third fixed layer, the resistance of the sensor changes from the minimum value to the maximum value.

Further, as a preferable example, it is possible to employ a multi-layer spin valve structure in which the directions of magnetization of the two ferromagnetic layers in the outer sides are parallel to each other and the both are perpendicular to the direction of magnetization of the intermediate ferromagnetic free layer.

FIG. 10 is a cross-sectional view showing the manufacturing process of the recording-regenerating separate type magnetic head. A recording head portion is composed of an upper magnetic core 9, a lower magnetic core, a magnetic gap film 5, a conductor coil 7 and an insulating film 68 for insulating the conductor coil 7 and the upper and the lower magnetic cores. In this figure, an upper magnetic shield of the regenerating head also serves as the lower magnetic core of the recording head. FIG. 10 (a) indicates that the regenerating head portion is formed by forming the lower magnetic shield 1, the spin valve type giant magneto-resistance effect film 2, the electrode and the magnetic domain control film 3 and the upper magnetic

shield 4 also serving as the lower magnetic core of the recording head, and then forming the gap film 5. The regenerating track width is $0.8 \mu\text{m}$, and a tunnel-junction type giant magneto-resistance effect film can be used in
5 instead of the spin valve type giant magneto-resistance effect film. FIG. 10 (b) indicates that photoresist mixed with melamine resin (Seimel 303) by 25 % by weight to total weight of resin and 1,3,5-tris(bromoacetyl)benzene by 5% by weight is further applied. Then, after a pattern is formed
10 by irradiating ultraviolet rays on the applied photoresist through a photo-mask and developing the exposed photoresist using a developing solution (DE-4: a product of Tokyo Applied Chemical Industry Company) consecutively, the insulating film 6 is formed by baking the pattern at 200°C
15 in a vacuum for 30 minutes. Naturally, the melamine resin may be replaced with epoxy resin, and the 1,3,5-tris(bromoacetyl)benzene and other compounds described above may be used as the acid generating agent. The taper angle at the end portion of the insulating film 6 was
20 approximately 45 degrees. The insulating film had a significant adhesive force, caused no failure such as separation of the pattern and no deterioration in the characteristics of the spin valve type giant magneto-resistance effect film, because a cross-linking reaction
25 between the novolak resin and the melamine resin was progressed to form a high polymer. FIG. 10 (c) indicates that, after forming the conductor coil 7, the insulating

film 8 is formed through the same process as the process for forming the insulating film 6, and the upper magnetic core 9 is formed thereon. A preferable recording magnetic head could be manufactured because moldability of the
5 resist in the gap between the coils and flatness of surface of the coil were the same as the conventional resist. The recording track width is 1.0 μm . At that time, since the heat treatment of the insulating film was substantially moderated from the conventional condition of 250°C for
10 several hours to the present condition of 200°C for 30 minutes, the recording-regenerating separate type magnetic head can be manufactured without deteriorating characteristics of the regenerating head. By mounting this head, a magnetic disk apparatus having an area record
15 density of 5 Gbit/in² could be obtained.

WHAT IS CLAIMED IS:

1. A thin film magnetic head comprising a lower magnetic film; an upper magnetic core laminated on said lower
5 magnetic film, forming a magnetic circuit together with said lower magnetic film, one end of the upper magnetic core being continued to said lower magnetic film, the other end being opposite to said lower magnetic film through a magnetic gap; a conductor coil provided between said lower
10 magnetic film and said upper magnetic core; and an insulating film for electrically insulating said upper magnetic core and said conductor coil from each other, wherein said insulating film is a cured body of a photoresist, a cross-linking agent and a cross-linking
15 accelerating agent for said photoresist and said cross-linking agent.
2. A thin film magnetic head according to claim 1,
wherein said cross-linking agent is at least one kind of
20 resin selected from the group consisting of melamine resin and epoxy resin.
3. A thin film magnetic head according to any one of
claim 1 and claim 2, wherein said cross-linking
25 accelerating agent is composed of an organic compound generating an acid.



* C L M S *

4. A thin film magnetic head according to claim 3, wherein said cross-linking accelerating agent is composed of an organic compound generating an acid by heating.
5. A thin film magnetic head according to any one of claim 1 to claim 4, wherein said cross-linking accelerating agent is a compound selected from the group consisting of bromoacetylbenzene, p-bis(bromoacetyl)benzene, m-bis(bromoacetyl)benzene, 1,3,5,-tris(bromoacetyl)benzene, 1,3,5,-tris(dibromoacetyl)benzene, and 1,3,5,-tris(chloroacetyl)benzene.
6. A thin film magnetic head according to any one of claim 1 to claim 5, wherein said photoresist is an acid curing phenol resin.
7. A thin film magnetic head according to claim 6, wherein said acid curing phenol resin is novolak.
8. A magneto-resistance effect type thin film magnetic head formed by successively laminating an antiferromagnetic layer, a first magnetic layer forming a fixed layer, a non-magnetic metallic layer and a second magnetic layer forming a free layer, wherein each of said first magnetic layer and said second magnetic layer has a thickness not thicker than



5 nm.

9. A recording-regenerating separate type thin film magnetic head comprising an inductive type recording head
5 formed on a magneto-resistance effect type regenerating head through a magnetic shield in a unit, wherein

said recording head comprises an upper magnetic core laminated on said magnetic shield, forming a magnetic circuit together with said magnetic shield, one end of the
10 upper magnetic core being continued to said magnetic shield, the other end being opposite to said magnetic shield through a magnetic gap; a conductor coil provided between said magnetic shield and said upper magnetic core; and an insulating film for electrically insulating said magnetic
15 shield, said upper magnetic core and said conductor coil from one another; said insulating film being composed of a novolak resin, a cross-linking agent and a curing agent of a cross-linking accelerating agent;

said regenerating head comprising a first and a second
20 magnetic layers of a ferromagnetic material partitioned by a non-magnetic metallic layer; an antiferromagnetic layer provided in contact with any one of said magnetic layers; a magnetized direction of said first magnetic layer of the ferromagnetic material being in a direction perpendicular
25 to a magnetized direction of said second magnetic layer.

10. A recording-regenerating separate type thin film



magnetic head comprising an inductive type recording head formed on a magneto-resistance effect type regenerating head through a magnetic shield in a unit, wherein

said recording head comprises an upper magnetic core
5 laminated on said magnetic shield, forming a magnetic circuit together with said magnetic shield, one end of the upper magnetic core being continued to said magnetic shield, the other end being opposite to said magnetic shield through a magnetic gap; a conductor coil provided between
10 said magnetic shield and said upper magnetic core; and an insulating film for electrically insulating said magnetic shield, said upper magnetic core and said conductor coil from one another; said insulating film being composed of a novolak resin, a cross-linking agent and a curing agent of
15 a cross-linking accelerating agent;

said regenerating head being formed by successively laminating an antiferromagnetic layer, a first magnetic layer forming a fixed layer, a non-magnetic metallic layer and a second magnetic layer forming a free layer; each of
20 said first magnetic layer and said second magnetic layer having a thickness not thicker than 5 nm.

11. A head disk assembly comprising a magnetic disk for recording information; a recording-regenerating separate
25 type thin film magnetic head formed an inductive type recording head for writing said information in said magnetic disk and a magneto-resistance effect type



regenerating head for regenerating the written information in said magnetic disk in a unit; and a drive means for rotating said disk, wherein said recording head and/or said regenerating head is a thin film magnetic head according to
5 any one of claim 1 to claim 10, having a record density not smaller than 1 Gb/in².

12. A magnetic disk apparatus comprising a plurality of head disk assemblies comprising a magnetic disk for
10 recording information; a recording-regenerating separate type thin film magnetic head formed an inductive type recording head for writing said information in said magnetic disk and a magneto-resistance effect type regenerating head for regenerating the written information
15 in said magnetic disk in a unit; and a drive means for rotating said disk, wherein said recording head and/or said regenerating head is a thin film magnetic head according to any one of claim 1 to claim 10.

20 13. A method for manufacturing a recording-regenerating separate type thin film magnetic head which comprises an inductive type recording head formed on a magneto-resistance effect type regenerating head through a magnetic shield with an inductive type recording head in a unit,
25 comprising the steps of;

manufacturing said regenerating head by;

forming a first and a second magnetic layers of a



ferromagnetic material partitioned by a non-magnetic metallic layer, and

an antiferromagnetic layer provided in contact with any one of said magnetic layers, and

5 directing a magnetized direction of said first magnetic layer of the ferromagnetic material to a direction perpendicular to a magnetized direction of said second magnetic layer, when an applied magnetic field from a recording medium is zero, and

10 manufacturing said recording head, subsequent to the above manufacturing step of said regenerating head, by;

forming an upper magnetic core on said magnetic shield, which forms a magnetic circuit together with said magnetic shield, one end of the upper magnetic core being continued
15 to said magnetic shield, the other end being faced to said magnetic shield through a magnetic gap,

a conductor coil provided between said magnetic shield and said upper magnetic core, and

an insulating film for electrically insulating said
20 magnetic shield, said upper magnetic core and said conductor coil from one another which comprises a photoresist, a crosslinking agent, and a cross-linking accelerating agent for said photoresist and said crosslinking agent.

25

14. A method for manufacturing a recording-regenerating separate type thin film magnetic head which comprises an



inductive type recording head formed on a magneto-resistance effect type regenerating head through a magnetic shield with an inductive type recording head in a unit, comprising the steps of;

5 manufacturing said regenerating head by;

laminating orderly an antiferromagnetic layer, a first magnetic layer which will be a fixed layer, a non-magnetic layer, and a second magnetic layer which will be a free layer, wherein a thickness of each of said first magnetic
10 layer, said second magnetic layer, and said non-magnetic layer is utmost 3 nm, and

manufacturing said recording head, subsequent to the above manufacturing step of said regenerating head, by;

forming an upper magnetic core on said magnetic shield,
15 which forms a magnetic circuit together with said magnetic shield, one end of the upper magnetic core being continued to said magnetic shield, the other end being faced to said magnetic shield through a magnetic gap,

a conductor coil provided between said magnetic shield
20 and said upper magnetic core, and

an insulating film for electrically insulating said magnetic shield, said upper magnetic core and said conductor coil from one another which comprises a photoresist, a crosslinking agent, and a cross-linking
25 accelerating agent for said photoresist and said crosslinking agent.

