



166166

- 1 -

TITLE OF THE INVENTION

MAGNETIC RECORDING/REPRODUCING APPARATUS

BACKGROUND OF THE INVENTION

5 The present invention relates to a magnetic recording/reproducing apparatus using a current-perpendicular-to-plane magnetoresistive head.

10 An increase in recording density is always required in a magnetic recording/reproducing apparatus. Accordingly, a high-sensitive read head is required. As an element for a read head that satisfies such requirements, a tunneling magnetoresistive element (TMR element) or a current-perpendicular-to-plane giant magnetoresistive element (CPP-GMR element) are known.

15 In a read head using such an element, a sense current for magnetic field detection is flowed through a TMR film or a GMR film, having a stacked structure of a magnetization pinned layer, a spacer layer and a magnetization free layer, in a direction
20 substantially perpendicular to the film plane. For this reason, the read head can be called a current-perpendicular-to-plane magnetoresistive head. Examples of documents that disclose a magnetic head using a TMR element include, for example, U.S.
25 Patent No. 5,898,548. Examples of documents that disclose a magnetic head using a CPP-GMR element include, for example, Jpn. Pat. Appln. KOKAI



G00002

- 2 -

Publication No. 10-55512 and U.S. Patent
No. 5,668,688.

When a sense current is flowed through a read
head element, use of constant-current driving or
5 constant-voltage driving is determined depending on
various conditions. For example, it is known that the
constant-voltage driving is preferred for a read head
using a TMR element in order to absorb fluctuation in
element resistance.

10 The spacer layer in the TMR film or the GMR film,
having the stacked structure of the magnetization
pinned layer, the spacer layer and the magnetization
free layer described above, has a structure in which
fine conductive regions (referred to as pin holes or
15 metal holes) are distributed in a high-resistance
matrix. The reason why the spacer layer having such
a structure is employed is to control the resistance
of the spacer layer. The resistance of a high-
resistance tunnel barrier layer as the spacer layer in
20 the TMR element must be suppressed in consideration of
practical use as a read head. The fine conductive
regions in the tunnel barrier layer contribute to the
decrease in resistance (see, for example, U.S. Patent
No. 5,898,548, and IEEE Trans. Magn., Vol. 38, 2002,
25 p. 73). In a CPP-GMR element, a high-resistance thin
oxide film including fine metal holes is used as the
spacer layer so as to improve an MR ratio.

- 3 -

However, it has been found that these current-perpendicular-to-plane magnetoresistive heads may be deteriorated mainly due to heat generated by sense current concentrated on the fine conductive regions distributed in the spacer layer, resulting in shortened life-time thereof, which brings about a problem of lower reliability of a magnetic recording/reproducing apparatus.

BRIEF SUMMARY OF THE INVENTION

A magnetic recording/reproducing apparatus according to one aspect of the present invention comprises: a magnetoresistive head having a magnetoresistive film through which a current is flowed in a direction substantially perpendicular to a film plane and a pair of magnetic shields disposed to sandwich the magnetoresistive film; and a preamplifier which supplies a sense current to the magnetoresistive head in constant-current driving.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

FIG. 1 is a diagram showing a magnetoresistive film and a preamplifier in constant-current driving connected to the magnetoresistive film according to an embodiment of the present invention;

FIG. 2 is a perspective view schematically showing an example of a high-resistance spacer layer included in the magnetoresistive film;

FIG. 3 is a perspective view schematically

- 4 -

showing another example of the high-resistance spacer layer included in the magnetoresistive film;

FIG. 4 is a sectional view showing an example of a pinned layer, a high-resistance spacer layer and
5 a free layer;

FIG. 5 is a sectional view showing another example of the pinned layer, the high-resistance spacer layer and the free layer;

FIGS. 6A and 6B are diagrams for explaining
10 a problem caused when a sense current is flowed through the current-perpendicular-to-plane magnetoresistive head;

FIG. 7 is a graph showing output changes with time when the current-perpendicular-to-plane magnetoresistive head is operated in constant-current
15 driving or in constant-voltage driving;

FIG. 8 is a graph showing output changes with time when the current-perpendicular-to-plane magnetoresistive head is operated in constant-current
20 driving with different current values;

FIG. 9 is a diagram showing a magnetoresistive film in which a temperature measuring element is incorporated, and a thermo-electromotive force detector and a preamplifier in constant-current
25 driving connected to the magnetoresistive film according to another embodiment of the present invention;

- 5 -

FIG. 10 is a graph showing a relationship between a temperature and a current controlled in the magnetoresistive film in FIG. 9;

FIG. 11 is a perspective view showing a magnetic head assembly, viewed from a disk, according to an embodiment of the present invention; and

FIG. 12 is a perspective view showing the internal structure of a magnetic recording/reproducing apparatus on which the magnetic head assembly shown in FIG. 11 is mounted.

DETAILED DESCRIPTION OF THE INVENTION

Embodiments of the present invention will be described below with reference to the accompanying drawings.

FIG. 1 is a sectional view showing an example of current-perpendicular-to-plane magnetoresistive element used in the present invention. FIG. 1 shows the air-bearing surface side of the magnetoresistive element opposing a magnetic recording medium (not shown). As shown in FIG. 1, an lower shield 1, an underlayer 2, an antiferromagnetic layer 3, a magnetization pinned layer (pinned layer) 4, a high-resistance spacer layer 5, a magnetization free layer (free layer) 6, a protective layer 7, and an upper shield 8 are stacked. The antiferromagnetic layer 3, the pinned layer 4, the high-resistance spacer layer 5, the free layer 6 constitute

- 6 -

a magnetoresistive film (TMR film or CPP-GMR film).
Biasing ferromagnetic layers 10 for stabilizing
magnetic domains in the free layer 6 are formed on
both sides of the magnetoresistive film with
5 intervening insulating layers 9.

The lower shield 1 and the upper shield 8 also
serve as electrodes to flow a sense current in
a direction substantially perpendicular to the film
plane of the magnetoresistive film. A material used
10 for the lower shield 1 and the upper shield 8 includes
a conductive ferromagnetic material such as NiFe.
The antiferromagnetic layer 3 has a function of
pinning the magnetization of the pinned layer 4.
A material used for the antiferromagnetic layer 3
15 includes, for example, PtMn. The free layer 6 serves
as a sensing area. When a sense current is flowed in
a direction substantially perpendicular to the film
plane of the magnetoresistive element, electric
signals can be output for magnetic signals sensed by
20 the free layer 6.

In the present invention, a preamplifier 30 to
supply a sense current in constant-current driving is
connected to the lower shield 1 and the upper
shield 8. An effect achieved by constant-current
25 driving will be described below. Here, the effect by
the constant-current driving specifically may be
exerted on the high-resistance spacer layer 5 included

- 7 -

in the magnetoresistive film. For this reason, the high-resistance spacer layer 5 will be described first.

As shown in FIG. 2 or 3, the high-resistance spacer layer 5 has a structure that fine conductive regions 12 are formed in a high-resistance matrix 11. The configuration of the conductive regions 12 may be one-dimensional holes (referred to as conductive holes) shown in FIG. 2 or two-dimensional grooves shown in FIG. 3. In any case, the section including the pinned layer 4, the high-resistance spacer layer 5 and the free layer 6 is as shown in FIG. 4.

In the TMR film, a high-resistance spacer layer (tunnel barrier layer) 5 having the above structure is formed depending on manufacturing methods. In the CPP-GMR film, the high-resistance spacer layer 5 having the structure is intentionally formed to increase an output. In the CPP-GMR film, the conductive regions 12 are formed to obtain a current confinement effect. In this case, if the area of the conductive regions 12 is about 10% or less of the film area (element area), the current confinement effect remarkably appears.

The high-resistance matrix 11 contains, as a main component, oxide, nitride or carbide of any element selected from the group consisting of boron (B), silicon (Si), germanium (Ge), tantalum (Ta),

- 8 -

tungsten (W), niobium (Nb), aluminum (Al), molybdenum (Mo), phosphorous (P), vanadium (V), arsenic (As), antimony (Sb), zirconium (Zr), titanium (Ti), zinc (Zn), lead (Pb), thorium (Th), beryllium (Be), cadmium (Cd), scandium (Sc), lanthanum (La), yttrium (Y), praseodymium (Pr), chromium (Cr), tin (Sn), gallium (Ga), indium (In), rhodium (Rh), palladium (Pd), magnesium (Mg), lithium (Li), barium (Ba), calcium (Ca), strontium (Sr), manganese (Mn), iron (Fe), cobalt (Co), nickel (Ni), rubidium (Rb), and rare-earth metal, and has a resistivity of about $1 \times 10^E - 3 \Omega\text{cm}$ or more. A material used for the conductive regions 12 includes metal such as copper (Cu), gold (Au), silver (Ag), platinum (Pt), palladium (Pd), iridium (Ir), osmium (Os), iron (Fe), cobalt (Co) and nickel (Ni).

If the size of the conductive region 12 in the form of the one-dimensional hole (conductive hole) shown in FIG. 2 is about 0.1 to 10 nm, the function of the CPP-GMR film or the TMR film can be achieved, and element functions can be more improved. The conductive region 12 in the form the two-dimensional groove shown in FIG. 3 may have a groove width of 0.1 to 5 nm.

The high-resistance spacer layer 5 may not always include the conductive region 12 extending from the pinned layer 4 to the free layer 6. For example,

- 9 -

as shown in FIG. 5, if the high-resistance spacer layer 5 has an uneven surface in which the thickness of the projecting portions is 0.2 to 4 nm and the thickness of the recessed portions is half or less the thickness of the projecting portions, a tunnel current is flowed through the recessed portions, or a current is concentrated on the recessed portions due to resistance difference to achieve a current confinement effect. In other words, the recessed portions shown in FIG. 5 perform the same role as the conductive regions 12 in the form of the holes (conductive holes) shown in FIG. 4.

A problem caused when a sense current is flowed through the above current-perpendicular-to-plane magnetoresistive head will be described below with reference to FIGS. 6A and 6B. FIGS. 6A and 6B show a state that, in the stacked structure of the pinned layer 4, the high-resistance spacer layer 5 and the free layer 6, the sense current is locally flowed in the fine conductive regions 12 distributed in the high-resistance spacer layer 5. When the sense current is concentrated on the conductive regions 12 in such a manner, a high-resistance portion around the conductive regions 12 changes due to heat generation (Joule heat), so that the area of the conductive regions 12 becomes larger as shown in FIG. 6B than in FIG. 6A. In this case, shunt components are increased

- 10 -

in the TMR element, or current confinement is made weak in the CPP-GMR element, resulting in output drop. The occurrence of the output drop increases an error rate of the magnetic recording/reproducing apparatus
5 incorporating the above magnetoresistive head and shortens the lifetime the apparatus.

In the present invention, constant-current driving is employed to considerably suppress a reduction in lifetime of a magnetic
10 recording/reproducing apparatus caused by the aforementioned output drop.

FIG. 7 shows output changes with time when the current-perpendicular-to-plane magnetoresistive head is operated in constant-current driving or in
15 constant-voltage driving. The resistance of the head used in the experiments is 50 Ω . The value of an output at time 0 for constant-current driving is substantially equal to that for constant-voltage driving. Here, the output drop corresponding to
20 the limit of the error rate of the magnetic recording/reproducing apparatus using the head is assumed to be 10%. As shown in FIG. 7, the lifetime of the head operated in constant-current driving is about twice the lifetime of the head operated in
25 constant-voltage driving.

Although this is apparently inconsistent with the concept of constant-voltage driving in which the

- 11 -

entire voltage does not drop even when the resistance is decreased, it is believed to be effected by the following mechanism. That is, when the magnetic recording/reproducing apparatus is operated in
5 constant-voltage driving, the Joule heat W generated in the conductive region 12 is in inverse proportion to the resistance R of the conductive region as described in the following expression:

$$W \text{ (in constant-voltage driving)} \propto V^2/R.$$

10 In this case, if the size of the conductive region 12 is enlarged after a long-time operation, the resistance R is decreased and thus the Joule heat W is increased. Therefore, when the magnetic recording/reproducing apparatus is operated in
15 constant-voltage driving, the enlargement of the conductive region 12 is accelerated, and the lifetime of the magnetic recording/reproducing apparatus becomes short.

On the other hand, the Joule heat W generated
20 when the current-perpendicular-to-plane magnetoresistive head is operated in constant-current driving is in proportion to the resistance R of the conductive region as described in the following expression. Therefore, when the magnetic
25 recording/reproducing device is operated in constant-current-driven, the enlargement of the conductive region 12 is not accelerated, so that the lifetime of

- 12 -

the magnetic recording/reproducing device is prevented from being shortened:

$$W \text{ (in constant-current driving)} \propto I^2 \times R.$$

FIG. 8 shows an output curve with time when
5 a driving current is increased by about 20% in constant-current driving. When a current is increased by 20% in constant-current driving, the lifetime of the magnetic recording/reproducing apparatus is substantially equal to the lifetime obtained when
10 the magnetic recording/reproducing apparatus is operated in constant-voltage driving as shown in FIG. 7. Therefore, an output gain obtained by employing constant-current driving under the above conditions can be approximated to about 20%.

15 As described above, in the present invention, when the current-perpendicular-to-plane magnetoresistive head is operated in constant-current driving, the lifetime can be considerably extended, or the output can be considerably increased.

20 In the present invention, based on measurement of the temperature of the current-confinement portion (high-resistance spacer layer), the preamplifier can be feedback controlled to lower the current value where the temperature is raised to an extent to cause
25 deterioration. In the case where such a mechanism is provided, more excellent effect than that obtained in the simple constant-current driving can be obtained.

- 13 -

The constitution of the magnetic recording/reproducing apparatus having such a mechanism will be described below with reference to FIG. 9. In the current-perpendicular-to-plane magnetoresistive element, a Cu layer 21 is inserted between the high-resistance spacer layer 5 and the free layer 6 in the stacked structure shown in FIG. 1. Even when the Cu layer 21 is inserted, the TMR effect or the GMR effect is not disturbed. A Cu lead 22 is connected to one end of the Cu layer 21, and a CuNi (constantan) lead 23 is connected to the other end. In addition, the Cu lead 22 and the CuNi (constantan) lead 23 are connected to a reference junction 24 set at room temperature. Since this constitution generates thermo-electromotive force between Cu and CuNi, the temperature of the high-resistance spacer layer 5 can be measured with a thermo-electromotive force detector 25 connected in the middle of the Cu lead 22. Therefore, the preamplifier 30 operated in constant-current driving can be feedback controlled so as to lower the value of the sense current, based on the temperature of the high-resistance spacer layer 5 measured with the thermo-electromotive force detector (controller) 25.

For example, in FIG. 10, the preamplifier 30 operated in constant-current driving is controlled so as to lower the value of the sense current, when the

- 14 -

temperature of the high-resistance spacer layer 5 measured with the thermo-electromotive force detector 25 exceeds 150°C.

Incidentally, the junction between Cu and CuNi (constantan) serving as a heat sensing portion may be separated from the element, and the preamplifier 30 operated in constant-current driving may be controlled so as to change the value of the sense current based on the ambient temperature near the element.

Next, a magnetic head assembly and a magnetic recording/reproducing apparatus using a magnetoresistive head according to an embodiment of the present invention will be described below.

FIG. 11 is a perspective view showing a magnetic head assembly 50, viewed from a disk, using a current-perpendicular-to-plane magnetoresistive head according to an embodiment of the present invention. The actuator arm 51 has a hole to be fitted on a pivot in a magnetic disk apparatus. The suspension 52 is fixed to one end of the actuator arm 51. The head slider 53 on which the current-perpendicular-to-plane magnetoresistive head is mounted is supported on the distal end of the suspension 52. The lead wires 54 for writing and reading signals are formed on the suspension 52. One ends of the lead wires 54 are connected to electrodes of the magnetic head, and the other ends of the lead wires 54 are connected to

- 15 -

electrode pads 55.

FIG. 12 is a perspective view showing the internal structure of a magnetic recording apparatus (hard disk drive) 100 in which the magnetic head assembly shown in FIG. 11 is installed. The magnetic disk 101 is fixed on the spindle 102, and is rotated in response to control signals supplied from drive controller (not shown). The actuator arm 51 shown in FIG. 11 is fitted to the pivot 103 and supported with ball bearings (not shown) arranged at upper and lower positions of the pivot 103, and the actuator arm 51 supports the suspension 52 and the magnetic head slider 53 arranged at the distal end of the suspension 52. The voice coil motor 104, a type of a linear motor, is arranged at the proximal end of the actuator arm 51. The voice coil motor 104 comprises a magnetic circuit constituted by a driving coil wound around a bobbin unit, and a permanent magnet and a counter yoke that are arranged opposite each other to sandwich the coil. The actuator arm 51 can be freely actuated with the voice coil motor 104. When the magnetic disk 101 is rotated, the magnetic head slider 53 is held such that the magnetic head slider 53 is floated over the magnetic disk 101 or is in contact with the surface of the magnetic disk 101, so that information can be written or read by means of the magnetic head. The cover 105 is put on the

- 16 -

housing that stores these components.

Additional advantages and modifications will readily occur to those skilled in the art. Therefore, the invention in its broader aspects is not limited to
5 the specific details and representative embodiments shown and described herein. Accordingly, various modifications may be made without departing from the spirit or scope of the general inventive concept as defined by the appended claims and their equivalents.

- 17 -

WHAT IS CLAIMED IS:

1. A magnetic recording/reproducing apparatus comprising:

a magnetoresistive head having a magnetoresistive
5 film through which a current is flowed in a direction
substantially perpendicular to a film plane and
a pair of magnetic shields disposed to sandwich the
magnetoresistive film;

a preamplifier which supplies a sense current to
10 the magnetoresistive head in constant-current driving;
and

wherein the magnetoresistive film has a stacked
structure of a magnetization pinned layer, a high-
resistance spacer layer including a high-resistance
15 matrix and conductive regions formed in the high-
resistance matrix, and a magnetization free layer.

2. The apparatus according to claim 1, wherein
the high-resistance matrix is selected from the group
consisting of metal oxide, metal nitride and metal
20 carbide, and the conductive regions contain a metal
selected from the group consisting of copper, gold and
silver.

3. The apparatus according to claim 1, wherein
an area ratio of the conductive regions is 10% or less
25 of an area of the spacer layer.

4. The apparatus according to claim 1, wherein
the high-resistance spacer layer is a tunnel barrier

- 18 -

layer.

5. The apparatus according to claim 1, further comprising:

5 a temperature measuring element measuring
a temperature of the high-resistance spacer layer
included in the magnetoresistive film; and

a controller controlling a value of the sense
current supplied by the preamplifier based on data of
the temperature measuring element.

10 6. The apparatus according to claim 5,
wherein the temperature measuring element includes
a conductive layer of a first metal stacked on the
high-resistance spacer layer of the magnetoresistive
film and a lead of a second metal, the conductive
15 layer and the lead forming a junction so as to
generate thermo-electromotive force.