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TITLE OF THE INVENTION



MAGNETIC DISK APPARATUS

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BACKGROUND OF THE INVENTION

One embodiment of the invention relates to a
5 magnetic disk apparatus using a current perpendicular
to plane (CPP) magnetic head.

In recent years, the size of a magnetic recording
apparatus, such as a hard disk unit, has been getting
increasingly smaller and the recording density has
10 been getting higher. This trend is expected to get
stronger in future. As the recording density is
getting higher, a higher-sensitivity sensor is
required. To meet this requirement, a CPP-GMR
(current perpendicular to plane - GMR) element has
15 been developed. Using CPP-GMR elements makes it
possible to form a high-density, high-output magnetic
head.

In a magnetic head using this type of
magnetoresistive effect element, sense current is
20 caused to flow across the film thickness of the
magnetic film. Therefore, as the head size reduces,
the cross-sectional area of the film surface which
bias current crosses decreases, resulting in an
increase in the current density. Then, in a
25 distinctive phenomenon, noise induced by the spin
transfer effect becomes conspicuous.

The spin transfer effect is such that torque to

change the direction of the magnetization of the element is produced by replacing electrons in a magnetic material with spin angular momentums when spin-polarized electrons flow in the magnetic material. This phenomenon becomes pronounced and noise in the reproduced signal becomes larger, making reading errors liable to occur. Therefore, suitable measures to deal with this problem are desired to be taken.

As related techniques, an example of measures against noise in the reproduced signal has been disclosed in Jpn. Pat. Appln. KOKAI Publication No. 6-259702. In this document, measures against noise resulting from the magnetic wall of the lining layer of a magnetic disk medium have been described. The magnetic head in the document is of a so-called single-magnetic-pole type which does recording and reproducing using the same element on the head. Moreover, in the document, there has been no description of CPP-GMR elements and it hasn't been expected that a sufficient reproduced output is obtained on the physical scale dealt with in the present invention.

As described above, in the current perpendicular to plane magnetic head, as the size of the head reduces, the effect of noise caused by the spin transfer effect becomes greater, making reading errors

liable to occur. Accordingly, a rise in the recording density may reach a ceiling and therefore suitable measures against this are desired to be taken.

BRIEF SUMMARY OF THE INVENTION

5 According to an aspect of the present invention, there is provided a magnetic disk apparatus with a magnetic disk medium capable of recording data magnetically, comprising a current perpendicular to plane magnetic reproducing head which includes a
10 magnetoresistive effect element composed of a plurality of magnetic films stacked one on top of another and causes sense current to flow in the direction perpendicular to the stacked faces of said plurality of magnetic films; a high-pass filter which
15 suppresses the low-frequency component of a reproduced signal output from the magnetic reproducing head; and a reproduced-signal processing section which reproduces the data from the reproduced signal which has the low-frequency component suppressed.

20 With such means, the low-frequency components of the reproduced signal are suppressed. Since the noise components caused by the spin transfer effect are biased toward the low-frequency side, the noise components can be removed effectively with the above
25 configuration, which makes it possible to improve the recording density of the magnetic disk apparatus more.

 According to the present invention, noise caused

by the spin transfer effect can be reduced and the recording density of the magnetic disk apparatus can be improved more.

For purposes of summarizing the invention,
5 certain aspects, advantages, and novel features of the invention have been described herein. It is to be understood that not necessarily all such advantages may be achieved in accordance with any particular embodiment of the invention. Thus, the invention may
10 be embodied or carried out in a manner that achieves or optimizes one advantage or group of advantages as taught herein without necessarily achieving other advantages as may be taught or suggested herein.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

15 A general architecture that implements the various feature of the invention will now be described with reference to the drawings. The drawings and the associated descriptions are provided to illustrate embodiments of the invention and not to limit the
20 scope of the invention.

FIG. 1 is an exemplary functional block diagram of a first embodiment of a magnetic disk apparatus according to the present invention;

FIG. 2 is an exemplary external perspective view
25 of a hard disk unit in which a magnetic head related to the embodiment can be installed;

FIG. 3 is an exemplary sectional view showing a

schematic configuration of the reproducing head 1 of
FIG. 1;

FIG. 4 is an exemplary sectional view showing a
film configuration of the magnetoresistive effect film
5 10 of FIG. 3;

FIG. 5 shows an exemplary graph obtained by
measuring the spectrum of head noise at the
reproducing head 1 with and without a high-pass
filter 3;

10 FIG. 6 is an exemplary functional block diagram
of a second embodiment of a magnetic disk apparatus
according to the present invention;

FIG. 7 schematically shows an exemplary
magnetoresistive effect film in a third embodiment of
15 a magnetic disk apparatus according to the present
invention;

FIG. 8 shows a graph obtained by measuring the
spectrum of head noise at the reproducing head 1
having a magnetoresistive effect film 10 including a
20 current control layer in the case of the presence and
absence of a high-pass filter and differentiating
circuit 7;

FIG. 9 is an exemplary functional block diagram
of a fourth embodiment of a magnetic disk apparatus
25 according to the present invention; and

FIG. 10 is an exemplary diagram to help explain
the operation of the read bias adjusting circuit 8 of

FIG. 9.

DETAILED DESCRIPTION OF THE INVENTION

Various embodiments according to the invention will be described hereinafter with reference to the accompanying drawings. In general, according to one
5 embodiment of the invention, a magnetic disk apparatus with a magnetic disk medium capable of recording data magnetically, comprising a current perpendicular to plane magnetic reproducing head which includes a
10 magnetoresistive effect element composed of a plurality of magnetic films stacked one on top of another and causes sense current to flow in the direction perpendicular to the stacked faces of said plurality of magnetic films; a high-pass filter which
15 suppresses the low-frequency component of a reproduced signal output from the magnetic reproducing head; and a reproduced-signal processing section which reproduces the data from the reproduced signal which has the low-frequency component suppressed.

20 [First Embodiment]

According to an embodiment, FIG. 1 is an exemplary functional block diagram of a first embodiment of a magnetic disk apparatus according to the present invention. In FIG. 1, a reproducing head
25 1, which is used in proximity to a magnetic disk medium (not shown), and outputs a reproduced signal whose waveform corresponds to the magnetic field at

the surface of the medium. The reproduced signal is amplified by a read amplifier 2. Its low-frequency components are suppressed by a high-pass filter (HPF) 3. The low-frequency-suppressed reproduced signal is input to a reproduced-signal processing section 4, which reproduces the data on the disk medium. The reproduced-signal processing section 4 is connected to a hard disk controller (HDC) 5 and a CPU (Central Processing Unit) 6. The hard disk controller 5 and CPU 6 perform a reproduced data error correcting process and positioning control of the reproducing head 1.

The reproducing head of FIG. 1 includes a magnetoresistive effect element composed of a plurality of magnetic films stacked one on top of another. The resistance of the magnetoresistive effect element changes according to the radiation magnetic field from the surface of the disk medium. A reproduced signal is obtained by sensing the change. The reproducing head 1 of FIG. 1 is particularly of the current perpendicular to plane type. In this type of reproducing head, a sense current for sensing a change in the resistance flows in the direction perpendicular to the stacked faces of the magnetic films.

FIG. 2 is an exemplary external perspective view of a hard disk unit in which the magnetic head of the

embodiment can be installed. The magnetic head related to the invention can be installed in a magnetic reproducing apparatus which reads the digital data magnetically recorded on a magnetic disk medium.

5 A typical magnetic disk medium is a platter built in a hard disk drive. Moreover, the magnetic head of the invention can be installed in a magnetic recording/reproducing apparatus which also has the function of writing digital data onto a magnetic disk
10 medium.

In the hard disk unit 150 of FIG. 2, a rotary actuator is used to move the magnetic head. In FIG. 2, a recording disk medium 200 is mounted on a spindle 152. The disk medium 200 is rotated in the
15 direction shown by arrow A by a motor which responds to a control signal from a driving unit control section (not shown). More than one disk medium 200 may be provided. This type of apparatus is called a multi-platter type.

20 A head slider 153, which is provided at the tip of a thin-film suspension 154, stores information onto the disk medium 200 and reproduces the information recorded on the disk medium 200. The head slider 153 has the reproducing head 1 of FIG. 1 installed near
25 its tip. The disk medium 200 rotates, causing the medium facing side (ABS) of the head slider 153 to float up a constant distance from the surface of the

disk medium 200. The magnetic head of the invention may be applied to a so-called contact travel type which causes the slider to come into contact with the disk medium 200.

5 A suspension 154 is connected to one end of an actuator arm 155 which includes a bobbin section (not shown) holding a driving coil (not shown). To the other end of the actuator arm 155, a voice coil motor 156, a kind of linear motor, is provided. The voice
10 coil motor 156 is composed of a driving coil (not shown) wound around the bobbin section of the actuator arm 155 and a magnetic circuit made up of a permanent magnet and a facing yoke arranged so as to face each other with the coil sandwiched between them. The
15 actuator 155 is held by ball bearings (not shown) provided at the top and bottom, two places, of the spindle 157 in such a manner that it can pivotally slide freely with the voice coil motor 156.

 Furthermore, the hard disk unit 150 includes a
20 signal processing section 158 formed on a flexible substrate. The read amplifier, high-pass filter 3, reproduced-signal processing section 4, hard disk controller 5, and CPU 6 are mounted chiefly on the signal processing section 158. The read amplifier 2
25 may be mounted in the vicinity of the reproducing head 1 of the suspension 154.

FIG. 3 is an exemplary sectional view showing a

schematic configuration of the reproducing head of
FIG. 1. The reproducing head 1 includes a
magnetoresistive effect film 10 composed of a
plurality of magnetic films stacked one on top of
5 another. On each side of the magnetoresistive effect
film 10, a bias layer 23 for applying a bias magnetic
field to the magnetoresistive effect film 10 is formed
in such a manner that it is wrapped in an insulating
layer 24. An upper electrode and magnetic shield
10 layer 21 and a lower electrode and magnetic shield
layer 22 are formed on the top and bottom of the
magnetoresistive effect film 10 and insulating layer
24, respectively. A read bias voltage is applied to
these electrodes 21, 22, causing sense current to flow
15 in the direction perpendicular to the film surface of
the magnetoresistive effect film 10. A change in the
sense current is input via a head amplifier to the
read amplifier (FIG. 1). The magnetoresistive effect
film 10 of FIG. 3 is of the current perpendicular to
20 plane type. Even if it is of a small element size,
for example, 90 nm × 90 nm, a sufficient reproduced
output can be obtained in the magnetic disk apparatus.

FIG. 4 is an exemplary sectional view showing a
film configuration of the magnetoresistive effect film
25 10 of FIG. 3. In FIG. 4, on a substrate (not shown),
a lower electrode 11, a foundation layer 12, an
antiferromagnetic layer 13, a magnetization fixing

layer 14, a nonmagnetic intermediate layer 15, a magnetization free layer 16, a protective layer 17, and an upper electrode 18 are stacked one on top of another in that order.

5 FIG. 5 shows an exemplary graph obtained by measuring the spectrum of head noise at the reproducing head 1 with and without the high-pass filter 3. This graph shows the result of measurements under the following condition: the read bias voltage =
10 100 mV. As shown in FIG. 5, in the state where the high-pass filter 3 is provided, the noise level in the low-frequency region apparently decreases. Therefore, the S/N ratio of the reproduced signal is improved, which enables the occurrence of errors to be
15 suppressed. Consequently, it is possible to make the recording density much higher.

 It is characteristic of the current perpendicular to plane magnetoresistive effect film that the more its size is reduced, the more conspicuous noise caused
20 by the spin transfer effect becomes. Since the noise appears as 1/f type noise, noise in the low-frequency region becomes larger. In the embodiment, to overcome this problem, the high-pass filter 3 is provided, thereby suppressing low-frequency noise, which lowers
25 the overall noise power. This not only suppresses the distortion of the waveform of the reproduced signal but also improves the S/N ratio, which makes it

possible to reduce reading errors.

Particularly under the conditions of FIG. 5, it is desirable that the cut-off frequency of the high-pass filter 3 should be set at 20 MHz. Specifically,
5 the cut-off frequency of the high-pass filter 3 is set to 0.01 MHz or higher and 20 MHz or lower, preferably to 0.1 MHz or higher and 10 MHz or lower. When the cut-off frequency is 0.01 MHz or lower, it is difficult to suppress low frequencies effectively.
10 Moreover, when the cut-off frequency is 20 MHz or higher, even the reproduced signal is suppressed.

As described above, in the embodiment, use of the high-pass filter 3 suppresses low-frequency noise in the reproduced signal, thereby eliminating an adverse
15 effect caused by the spin transfer effect inherent to the current perpendicular to plane reproducing head. This improves the S/N ratio. In addition to this, use of the current perpendicular to plane magnetoresistive effect film 10 enables a sufficient reproduced output
20 to be produced. Furthermore, since the element size can be reduced, the recording density can be made much higher.

[Second Embodiment]

FIG. 6 is an exemplary functional block diagram
25 of a second embodiment of a magnetic disk apparatus according to the present invention. The magnetic disk apparatus of FIG. 6 is such that the characteristic of

the high-pass filter 3 of FIG. 1 is set suitably so as to function as a differentiating circuit. That is, in FIG. 6, a high-pass filter and differentiating circuit 7 is inserted between the read amplifier 2 that

5 amplifies the reproduced signal from the reproducing head 1 and the reproduced-signal processing section 4. The high-pass filter and differentiating circuit 7 is obtained by setting the cut-off frequency of the high-pass filter 3 (FIG. 1) to a value that enables a
10 reduction in noise caused by the spin transfer effect and the generation of differential waveforms to be compatible with each other.

The configuration of FIG. 6 can be used suitably in a perpendicular recording magnetic disk apparatus.
15 As is well known, the waveform of the reproduced signal in the perpendicular recording method is rectangular. The waveform of the reproduced signal in the in-plane recording method is shaped like a pulse. Therefore, applying the configuration of FIG. 6 to the
20 perpendicular recording magnetic disk apparatus makes it possible to differentiate a rectangular waveform to obtain a pulse waveform, which enables the same signal processing system as that of the in-plane recording method to be shared. Accordingly, it is possible to
25 reduce costs by sharing parts and gain large merits in manufacturing products.

[Third Embodiment]

FIG. 7 schematically shows an exemplary magnetoresistive effect film 10 in a third embodiment of a magnetic disk apparatus according to the present invention. In the third embodiment, the configuration of the nonmagnetic intermediate layer 17 in the magnetoresistive effect film 10 of FIG. 4 is changed. Specifically, instead of the uniform composition, the nonmagnetic intermediate layer (indicated by numeral 10 31) is so configured that a conductive material 34 lies scattered in an insulating material 33 as shown in FIG. 7. The insulating material 33 insulates adjacent layers (the magnetization fixing layer 14 and magnetization free layer 16 of FIG. 4) from one another electrically. The conductive material 34, 15 which is formed dispersively in the insulating material 33, connects the magnetization fixing layer 14 and magnetization free layer 16 electrically. This causes sense current to pass through the conductive material in a confined manner. This phenomenon is 20 known as the current confining effect. It is known that the effect makes the resistance of the nonmagnetic intermediate layer 3 larger. A layer having the configuration of FIG. 7 is referred to as a current control layer. 25

Since the magnetoresistive effect element having the current control layer of FIG. 7 has a high

resistance changing rate, a higher recording-density magnetic disk apparatus can be realized. Meanwhile, since its size is small, noise caused by the spin transfer effect is conspicuous, with the result that the S/N ratio according to an increase in the output cannot be expected. To overcome this drawback, noise in the low-frequency region is removed by the high-pass filter, which makes it possible not only to suppress the distortion of the waveform of the reproduced signal and improve the S/N ratio but also reduce reading errors.

FIG. 8 shows a graph obtained by measuring the spectrum of head noise at the reproducing head 1 having a magnetoresistive effect film 10 including a current control layer in the case of the presence and absence of a high-pass filter and differentiating circuit 7. The graph shows the result of measurements under the following condition: the read bias voltage = 100 mV. As shown in FIG. 8, in the state where the high-pass filter and differentiating circuit 7 is provided, the noise level in the low-frequency region apparently decreases. Therefore, the S/N ratio of the reproduced signal is improved, which enables the occurrence of errors to be suppressed. Consequently, it is possible to make the recording density much higher.

[Fourth Embodiment]

FIG. 9 is an exemplary functional block diagram of a fourth embodiment of a magnetic disk apparatus according to the present invention. The magnetic disk
5 apparatus of FIG. 9 is such that a read bias adjusting circuit 8 is added to the configuration of FIG. 1. The read bias adjusting circuit 8 performs feedback control of the read bias voltage of the reproducing head 1 on the basis of the incidence of errors in
10 reading the reproduced signal or the S/N ratio.

FIG. 10 is an exemplary diagram to help explain the operation of the read bias adjusting circuit 8. This graph shows the result of measuring the relationship between the read bias voltage and the bit
15 error rate (BER) in the current perpendicular to plane reproducing head of FIG. 3. The magnetoresistive effect film 10 was 70 nm wide and 70 nm long.

Under the above conditions, the read bias adjusting circuit 8 was caused to function by feedback
20 from the reproduced-signal processing section 4, with the result that the read bias to minimize BER was 120 mV. That is, when BER was measured with the read bias being changed independently as shown in FIG. 10, BER became the smallest at a read bias voltage of
25 120 mV.

Although the reproduced output of the reproducing head 1 increases as the read bias voltage is raised,

noise caused by the spin transfer effect increases accordingly. Moreover, the dependence of the noise on the read bias changes with the resistance of the reproducing head 1 or the intensity of the bias magnetic field from the bias layer 23. That is, the read bias value to minimize BER varies one reproducing head 1 to another. Actually, the resistance of the reproducing head or the intensity of the bias magnetic field from the bias layer varies according to variations in the manufacture, so that it is difficult to set the optimum value in advance.

In contrast, the fourth embodiment makes it possible to set the optimum read bias values separately to individual current perpendicular to plane magnetic heads differing in conditions from one another. Accordingly, it is possible to stably manufacture a magnetic disk apparatus with the minimized incidence of reading errors.

This invention is not limited to the above embodiments. For instance, in the forth embodiment, the sense current may be changed directly instead of the read bias voltage.

While certain embodiments of the inventions have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the inventions. Indeed, the novel apparatuses and systems described herein may be

embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of the apparatuses described herein may be made without departing from the spirit of the inventions.

5 The accompanying claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of the inventions.

WHAT IS CLAIMED IS:

1. A magnetic disk apparatus with a magnetic disk medium capable of recording data magnetically, comprising:

5 a current perpendicular to plane magnetic reproducing head which includes a magnetoresistive effect element composed of a plurality of magnetic films stacked one on top of another and causes sense current to flow in the direction perpendicular to the
10 stacked faces of said plurality of magnetic films;

 a high-pass filter which suppresses the low-frequency component of a reproduced signal output from the magnetic reproducing head; and

 a reproduced-signal processing section which
15 reproduces the data from the reproduced signal which has the low-frequency component suppressed.

2. The magnetic disk apparatus according to claim 1, wherein the cut-off frequency of the high-pass filter is 0.01 MHz or higher and 20 MHz or lower.

20 3. The magnetic disk apparatus according to claim 1, wherein the magnetoresistive effect element includes a nonmagnetic intermediate layer, and

 the nonmagnetic intermediate layer includes
 an insulating material which insulates
25 adjacent layers from each other electrically, and

 a conductive material which is formed dispersively the insulating material, connects the

adjacent layers to each other electrically, and causes the sense current to pass through in a confined manner.

5 4. The magnetic disk apparatus according to claim 1, wherein the magnetic disk medium uses a perpendicular recording method.

10 5. The magnetic disk apparatus according to claim 4, wherein the cut-off frequency of the high-pass filter is set so as to input a differential waveform of the reproduced signal to the reproduced-signal processing section.

6. The magnetic disk apparatus according to claim 1, wherein the magnetic disk medium uses an in-plane recording method.

15 7. The magnetic disk apparatus according to claim 1, further comprising: a bias control section which performs feedback control of the read bias voltage of the magnetic reproducing head on the basis of the incidence of errors in reading the reproduced
20 signal.