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TITLE OF THE INVENTION  
PERPENDICULAR MAGNETIC DISK APPARATUS

BACKGROUND OF THE INVENTION

One embodiment of the present invention relates  
5 to a perpendicular magnetic disk apparatus.

Magnetic disk apparatuses are perpetually  
demanded to improve recording densities. A solution  
to improve the recording density is to reduce the  
recording track width, thereby increasing the track  
10 density. However, as the track density increases,  
overwrite characteristics become worse. Thus, there  
is a demand for improvement in overwrite  
characteristics.

Conventionally, in order to improve the overwrite  
15 characteristics, there has been proposed a  
perpendicular magnetic head which includes, in  
addition to a main pole and a return pole, a third  
pole that is provided on the leading side of the main  
pole with a nonmagnetic film interposed therebetween  
20 (see Jpn. Pat. Appln. KOKAI Publication  
No. 2004-5826). The third pole has a function of  
reducing magnetic interference on a recording position  
due to magnetization recorded on the medium on the  
leading side of the main pole, thus preventing  
25 degradation in overwrite characteristics.

In this document, however, no detailed analysis  
is made on the overwrite characteristics. It is thus

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unclear whether the overwrite characteristics are enhanced under the most severe conditions. In addition, this perpendicular magnetic head includes the third pole additionally, which makes manufacturing thereof difficult.

There is known a magnetic disk apparatus wherein the magnetic write track width (MWW) is set at  $1.0\text{ }\mu\text{m}$  or less, and a difference between the magnetic write track width (MWW) and the magnetic read track width (MRW) is set in a range between  $0.2\text{ }\mu\text{m}$  and  $0.8\text{ }\mu\text{m}$  (see Jpn. Pat. Appln. KOKAI Publication No. 2002-150507). This document discloses that good overwrite characteristics can be obtained with this design.

This document, however, assumes a longitudinal recording-type magnetic disk apparatus, and is not applicable to a perpendicular recording-type magnetic disk apparatus.

#### BRIEF SUMMARY OF THE INVENTION

According to one embodiment of the present invention, there is provided a perpendicular magnetic disk apparatus comprising: a magnetic disk including a soft underlayer and a perpendicular magnetic recording layer; and a magnetic head comprising a write element including a main pole, a return pole and an exciting coil, and a read element including a magnetoresistive film and a pair of shield films disposed to sandwich

the magnetoresistive film, wherein a magnetic read track width (MRW) which is read by the magnetoresistive film is set to be smaller than a magnetic write track width (MWW) for signals recorded at a maximum frequency.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

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 limit the scope of the invention.

FIG. 1 is a perspective view of a magnetic disk apparatus according to an embodiment of the present invention;

FIG. 2 is a cross-sectional view of a magnetic disk according to an embodiment of the invention;

FIG. 3 is a cross-sectional view of a write element and a read element included in the magnetic head according to an embodiment of the invention;

FIG. 4 is a graph showing track profiles after overwrite (OW1) in longitudinal recording and perpendicular recording;

FIG. 5 is a graph showing track profiles after overwrite (OW2) in longitudinal recording and perpendicular recording;

FIG. 6 is a view showing definitions of MWW and

MRW;

FIG. 7 is a graph showing a relationship between a recording density and MWW in longitudinal recording and perpendicular recording;

5        FIG. 8 is a graph showing a relationship between OW2 and a bit error rate (BER) in perpendicular recording;

FIG. 9 is a graph showing Max OW2 and a double peak width (DPW);

10       FIG. 10 is a graph showing a relationship between Max OW2 and DPW; and

FIG. 11 is a graph showing a relationship between Hc of a magnetic disk and MWW.

#### DETAILED DESCRIPTION OF THE INVENTION

15       Various embodiments according to the invention will be described hereinafter with reference to the accompanying drawings.

FIG. 1 is a perspective view of a magnetic disk apparatus according to an embodiment of the present invention. In FIG. 1, a magnetic disk 10 is mounted  
20       on a spindle 51. An actuator arm 53 is rotatably attached to a pivot 52 that is disposed near the magnetic disk 10. A suspension 54 is attached to a distal end portion of the actuator arm 53. A head  
25       slider 55 is supported on a lower surface of the suspension 54. A magnetic head 20 comprising a write element and a read element is disposed on an end face

of the head slider 55 so as to face the magnetic disk 10.

FIG. 2 is a cross-sectional view of a magnetic disk according to the embodiment of the present invention. The magnetic disk 10 has a structure that a soft underlayer 12, an orientation control layer 13, a perpendicular magnetic recording layer 14 and a protective layer 15 are stacked in this order on a nonmagnetic substrate 11. Each layer may be composed of a plurality of films. For example, the films may be formed of materials having different compositions.

FIG. 3 is a cross-sectional view of the write element and read element included in the magnetic head 20 according to the embodiment of the invention. The write element includes a main pole 21 which is formed of a high-permeability material that generates a perpendicular magnetic field to the magnetic disk 10; a return pole 22 which is disposed on the trailing side of the main pole 21 and has a function to efficiently close a magnetic path via the soft underlayer immediately below the main pole; and an exciting coil 23 which is wound around the magnetic path including the main pole 21 and the return pole 22. The return pole 22 may alternatively be disposed on the leading side of the main pole 21. The read element includes a magnetoresistive film 24, and shield films 25 and 26 which are disposed on the

trailing side and leading side of the magnetoresistive film 24 so as to sandwich the magnetoresistive film 24. Signals read by the read element are processed with a built-in signal processing system.

5           Next, overwrite (OW) characteristics of the magnetic disk apparatus will be described. The OW characteristics are defined as follows: When a recording pattern A with a certain frequency is first written and then a recording pattern B with a  
10 frequency different from that of the recording pattern A is overwritten on the recording pattern A, the OW characteristics are expressed by a difference in amplitude of the signal pattern A before and after  
15 overwrite. The OW characteristics are an index for evaluating the recording performance of the magnetic head.

          Herein, "OW1" is referred to as a case where a recording pattern at a low frequency (LF) is overwritten by a recording pattern at a high frequency  
20 (HF), and "OW2" is referred to as a case where a recording pattern at a high frequency (HF) is overwritten by a recording pattern at a low frequency (LF).

          FIG. 4 and FIG. 5 show examples of track profiles  
25 of a first signal after the first signal is overwritten by another signal. FIG. 4 shows a track profile of an output of a remaining unerased recording

pattern at 80 kFCI in a case where the recording  
pattern at 80 kFCI is overwritten by a recording  
pattern at 950 kFCI (OW1). The ordinate indicates the  
output normalized with the peak value of the initial  
5 output of the recording pattern at 80 kFCI. FIG. 5  
shows a track profile of an output of an unerased  
recording pattern at 470 kFCI in a case (OW2) where  
the recording pattern at 470 kFCI is overwritten a  
recording pattern at 60 kFCI. The ordinate indicates  
10 the output normalized with the peak value of the  
initial output of the recording pattern at 470 kFCI.  
Each of FIG. 4 and FIG. 5 shows results obtained in  
longitudinal recording and perpendicular recording.

Next, the definitions of a magnetic write track  
15 width (MWW) and a magnetic read track width (MRW)  
herein are described. FIG. 6 shows a read output  
waveform of a signal recorded at a recording density  
of, for example, 80 kFCI which is read by scanning the  
read head in the cross-track direction. MWW is  
20 defined as a width of a read output waveform at 50% of  
the read output peak. MRW is defined as a width of a  
read output waveform of a range within which the read  
output rises from 20% to 80% (or falls from 80% to  
20%).

25 FIG. 7 shows the relationship between the  
recording density and MWW in longitudinal recording  
and perpendicular recording. MWW is normalized

assuming that MWW of a recording pattern at 80 kFCI is unity.

Referring to FIG. 4, FIG. 5 and FIG. 7, a difference in OW characteristics between longitudinal recording and perpendicular recording is described.

#### 1. Longitudinal recording

As is shown in FIG. 7, in the longitudinal recording, MWW decreases as the recording density becomes higher. As shown in FIG. 4, under OW1 in the longitudinal recording, an LF pattern with a wide MWW is overwritten by an HF pattern with a narrow MWW, and as a result an unerased component is left remained at an edge of the first LF pattern. Conversely, as shown in FIG. 5, under OW2 in the longitudinal recording, an unerased component hardly occurs when an HF pattern with a narrow MWW is overwritten by an LF pattern with a wide MWW on. Thus, most of the non-erased component left remained after overwriting in the longitudinal recording is the LF component, and edge noise occurs at positions apart from the track center.

#### 2. Perpendicular recording

As is shown in FIG. 7, in the perpendicular recording, like the longitudinal recording, MWW decreases as the recording density becomes higher. In addition, the recording density dependency of MWW in the perpendicular recording is substantially the same as in the case of the longitudinal recording.

However, as shown in FIG. 4 and FIG. 5, the overwrite characteristics in the perpendicular recording are degraded under OW2 rather than under OW1. The reason why the overwrite characteristics are degraded under OW2 is as follows. That is, in the perpendicular recording, more stable magnetostatic coupling occurs in the HF pattern, which makes it hard to erase the HF pattern, and the magnetic field intensity is weaker at the track edges than at the track center. Thus, most of the unerased component left remained after overwriting in the perpendicular recording is the HF component. Besides, since the MWW of the HF component is narrow, edge noise occurs at positions near the track center.

As described above, in the case of the perpendicular recording, OW characteristics are degraded under OW2 in which the LF pattern is overwritten by the HF pattern, and edge noise of the HF component remains. The edge noise forms double peaks. In order to improve the OW characteristics, it is necessary to design the MRW so as not to read the edge noise. Such a design principle in the perpendicular recording differs from that in the longitudinal recording.

An embodiment of the present invention provides a perpendicular magnetic disk apparatus in which MRW is set to be smaller than MWW of a signal recorded at a

maximum frequency ( $1T$ ), and prevents degradation of a  
bit error rate (BER) due to edge noise caused by an  
uneraser component (HF component). In the case where  
the recording frequency is expressed by  $nT$ , assuming  
5 that the maximum frequency is  $F_{\max}$  [MHz], the  
recording frequency is defined by  $nT = F_{\max}/n$  [MHz].

The principle of the present invention will be  
described below.

FIG. 8 shows the relationship between OW2 and BER  
10 in the perpendicular recording. It is found from  
FIG. 8 that the degradation of BER increases if the  
absolute value of OW2 falls below 40 dB (hereinafter  
the value of OW2 is discussed based on the absolute  
value).

15 FIG. 9 shows a double-peak width (DPW) of an  
uneraser component and a maximum OW2 value (Max OW2)  
at the track center. FIG. 9 shows a track profile of  
an uneraser output of a 2T pattern after the 2T  
pattern is overwritten by a 15T pattern. The ordinate  
20 indicates the output normalized with the peak value of  
the initial output of the 2T pattern.

FIG. 10 shows the relationship between Max OW2  
and DPW. DPW is normalized with the MWW of the HF  
pattern prior to overwriting. It is found from  
25 FIG. 10 that Max OW2 worsens as the DPW becomes  
narrower. As described with reference to FIG. 8, it  
is preferable that Max OW2 be 40 dB or more. As shown

in FIG. 10, when Max OW2 is 40 dB, DPW/MWW(HF) is 1, which means that DPW coincides with MWW of the HF pattern. Hence, it is understood that in order to ensure Max OW2 of 40 dB or more, the magnetic read track width MRW should be set at MWW of the HF pattern or less. In the case of a pattern with a maximum recording density, which is recorded at 1T, the maximum frequency, the signal recorded on the magnetic disk takes a narrowest MWW. In other words, when the first signal is the 1T pattern, DPW takes a minimum value. Accordingly, by setting the MRW at a value not greater than the narrowest DPW, i.e., not greater than MWW at 1T, it becomes possible to avoid occurrence of edge noise caused by an unerased 1T pattern after overwriting, and to enhance the BER. The lower limit value of MRW is determined as a value where sensing of servo signals is made ineffective.

FIG. 11 shows an example of variation of MWW relative to coercivity ( $H_c$ ) of the magnetic disk. Here, MWW is normalized assuming that MWW is unity when  $H_c$  is 3 kOe. Therefore, by examining the variation of MWW relative to  $H_c$  of the magnetic disk and the variation of MWW relative to the recording density (recording frequency) as shown in FIG. 7, it becomes possible to estimate the MWW at the maximum frequency 1T and to determine a desirable MRW.

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  
methods and systems described herein may be embodied  
5 in a variety of other forms; furthermore, various  
omissions, substitutions and changes in the form of  
the methods and systems described herein may be made  
without departing from the spirit of the inventions.  
The accompanying claims and their equivalents are  
10 intended to cover such forms or modifications as would  
fall within the scope and spirit of the inventions.

WHAT IS CLAIMED IS:

1. A perpendicular magnetic disk apparatus  
comprising:

5 a magnetic disk including a soft underlayer and a  
perpendicular magnetic recording layer; and

a magnetic head comprising a write element  
including a main pole, a return pole and an exciting  
coil, and a read element including a magnetoresistive  
film and a pair of shield films disposed to sandwich  
10 the magnetoresistive film,

wherein a magnetic read track width (MRW) which  
is read by the magnetoresistive film is set to be  
smaller than a magnetic write track width (MWW) for  
signals recorded at a maximum frequency.

15 2. The perpendicular magnetic disk apparatus  
according to claim 1, wherein the MRW has a lower  
limit value determined as a value where sensing of  
servo signals is made ineffective.

20 3. The perpendicular magnetic disk apparatus  
according to claim 1, wherein the MWW is defined as a  
width of a read output waveform in a cross-track  
direction at 50% of a read output peak, and wherein  
the MRW is defined as a width of the read output  
waveform of a range within which a read output rises  
25 from 20% to 80% or falls from 80% to 20%.