

## Perpendicular Magnetic Recording Medium

### Technical Field to which the Invention Pertains

The present invention relates to a perpendicular magnetic recording medium that can be installed in various magnetic recording apparatuses.

### Prior Art

Accompanying increases in capacity of magnetic disk recording apparatuses, there have been heightened demands to increase the recording density of magnetic recording media. The longitudinal magnetic recording method occupies the mainstream among conventional magnetic recording methods, but recently the perpendicular magnetic recording method has started to attract attention as art for increasing the recording density of magnetic recording.

The constituent elements of a perpendicular magnetic recording medium include a magnetic recording layer of a hard magnetic material, and a under layer formed from a soft magnetic material that has a role of concentrating magnetic flux generated by the magnetic head used in recording into the magnetic recording layer. At present a CoCr type alloy crystalline film is predominantly used as the material for the magnetic recording layer used in a perpendicular magnetic recording medium. With such a film, the maximum value of the coercivity ( $H_c$ ) is about 4000 Oe at present, but to further increase

the recording density it is necessary to further increase  $H_c$ . However, there are technical difficulties in fulfilling this demand.

On the other hand, a rare earth - transition metal alloy amorphous film that is used as a material for magneto-optical recording has a high perpendicular magnetic anisotropy constant  $K_u$ , and hence is extremely promising as a material for the magnetic recording layer of a perpendicular magnetic recording medium. However, in magneto-optical recording, a composition close to the compensation point is used, and  $H_c$  for such a composition is considerable larger than the  $H_c$  required of a material for perpendicular magnetic recording, and hence it is problematic to use such a rare earth - transition metal alloy amorphous film as a perpendicular magnetic recording medium as is.

#### **Problems to be Solved by the Invention**

A Co type alloy crystalline magnetic recording material, which is predominantly used at present, has a columnar structure in which the crystal grains grow in the film thickness direction, and this is one main cause of noise originating from the medium during recording and playback. As the recording density is increased in the future, the influence of the crystal grain boundary on recorded signals will come to account for a larger and larger proportion.

To counteract this, attempts are being made to reduce the

influence by for example making the crystal grain size very small, but if the crystal grain size becomes too small, then the thermal stability of the recorded signal deteriorates abruptly, and in cases a so-called 'thermal fluctuation' problem in which the recorded signal vanishes may arise.

On the other hand, in the case that a rare earth - transition metal alloy amorphous film is used, due to being amorphous, crystal grain boundaries do not exist, and hence the above problem does not arise. However, because crystal grain boundaries do not exist there is nothing to act as a nucleus to keep a written signal in place, and hence there is a problem that the signal may shift or vanish. In particular, this phenomenon is prone to occur when recording at high frequency, and hence there is a problem that a rare earth - transition metal alloy amorphous film cannot be used as is as a material for perpendicular magnetic recording which aims for increased recording density.

In view of such problems, it is an object of the present invention to provide a perpendicular magnetic recording medium according to which there is no shift or loss of written signals even in the case of a high recording density in the rare earth - transition metal alloy amorphous film, and moreover productivity is excellent.

**Means for Solving the Problems**

Regarding the present invention, to attain such an object, the invention disclosed in claim 1 is a perpendicular magnetic recording medium comprising at least a soft magnetic under layer, an intermediate layer, a magnetic recording layer, a protective layer and a liquid lubricant layer built up in order on a nonmagnetic substrate, characterized in that the magnetic recording layer is constituted from a rare earth - transition metal alloy amorphous film, and at least one of Ti, Zr, Hf, V, Nb, Ta, Cr, Mo, W, B, Al, C and Si is contained in the rare earth - transition metal alloy amorphous film, with the form of existence thereof being that it is uniformly dispersed through the rare earth - transition metal alloy amorphous film.

Moreover, the invention disclosed in claim 2 is a perpendicular magnetic recording medium comprising at least a soft magnetic under layer, an intermediate layer, a magnetic recording layer, a protective layer and a liquid lubricant layer built up in order on a nonmagnetic substrate, characterized in that the magnetic recording layer is constituted from a rare earth - transition metal alloy amorphous film, and at least one boride of Ti, Zr, Hf, V, Nb, Ta, Cr, Mo, W, Al or Si is contained in the rare earth - transition metal alloy amorphous film, with the form of existence thereof being that it is uniformly dispersed through the rare earth - transition metal alloy amorphous film.

Moreover, the invention disclosed in claim 3 is a perpendicular magnetic recording medium comprising at least a soft magnetic under layer, an intermediate layer, a magnetic recording layer, a protective layer and a liquid lubricant layer built up in order on a nonmagnetic substrate, characterized in that the magnetic recording layer is constituted from a rare earth - transition metal alloy amorphous film, and at least one carbide of Ti, Zr, Hf, V, Nb, Ta, Cr, Mo, W, B, Al or Si is contained in the rare earth - transition metal alloy amorphous film, with the form of existence thereof being that it is uniformly dispersed through the rare earth - transition metal alloy amorphous film.

Moreover, the invention disclosed in claim 4 is the invention disclosed in any of claims 1 through 3, characterized in that the concentration of the at least one of Ti, Zr, Hf, V, Nb, Ta, Cr, Mo, W, B, Al, C and Si or boride or carbide thereof contained in the rare earth - transition metal alloy amorphous film is at least 1% but not more than 20%.

Moreover, the invention disclosed in claim 5 is the invention disclosed in any of claims 1 through 4, characterized by having one or a plurality of underlayers and a magnetic domain controlling layer between the nonmagnetic substrate and the soft magnetic under layer.

# **Brief Description of the Drawings**

Fig. 1

A schematic sectional view showing an embodiment of the perpendicular magnetic recording medium of the present invention.

Fig. 2

A schematic sectional view showing another embodiment of the perpendicular magnetic recording medium of the present invention.

Fig. 3

A diagram for explaining embodiments of the present invention, showing one cycle of the output waveform obtained using a spin stand tester for a perpendicular magnetic recording medium produced in Example 8 and a perpendicular magnetic recording medium produced in Example 1.

## **Embodiments of the Invention**

Following is a description of embodiments of the present invention with reference to the drawings.

Fig. 1 is a schematic sectional view showing an embodiment of the perpendicular magnetic recording medium of the present invention; this perpendicular magnetic recording medium has a structure in which at least a soft magnetic under layer 4, an intermediate layer 5, a magnetic recording layer 6 and a protective layer 7 are formed in order on a nonmagnetic

substrate 1, and moreover a liquid lubricant layer 8 is formed thereupon.

Fig. 2 is a schematic sectional view showing another embodiment of the perpendicular magnetic recording medium of the present invention; this perpendicular magnetic recording medium has a structure in which at least one or a plurality of underlayers 2, a magnetic domain controlling layer 3, a soft magnetic under layer 4, an intermediate layer 5, a magnetic recording layer 6 and a protective layer 7 are formed in order on a nonmagnetic substrate 1, and moreover a liquid lubricant layer 8 is formed thereupon.

In the present invention, for example a crystallized glass, a strengthened glass, or an Al alloy plated with NiP as commonly used for magnetic recording media can be used as the nonmagnetic substrate 1. An antiferromagnetic film comprising an alloy system containing Mn, or a hard magnetic film in which the magnetization has been oriented in the radial direction of the nonmagnetic substrate 1, can be used as the magnetic domain controlling layer 3. The thickness of the magnetic domain controlling layer 3 is preferably about 5 to 300nm.

In the case that an Mn alloy system antiferromagnetic film is used as the magnetic domain controlling layer 3, it is preferable to use for example a nonmagnetic alloy or a nonmagnetic pure metal having a face-centered cubic structure as the underlayer 2. In this case, an underlayer may be

further provided between the nonmagnetic substrate 1 and the under layer 2 to control the fine structure of the under layer 2.

Moreover, in the case that a hard magnetic film is used as the magnetic domain controlling layer 3, a Cr alloy or the like can be used as the underlayer 2. In this case as well, a plurality of underlayers may be further provided between the nonmagnetic substrate 1 and the underlayer 2 to control the fine structure of the underlayer 2.

An NiFe alloy, a sendust (FeSiAl) alloy or the like can be used as the soft magnetic under layer 4, but by using an amorphous Co alloy, for example CoNbZr, CoTaZr or the like, good electromagnetic conversion characteristics can be obtained. Regarding the thickness of the soft magnetic under layer 4, the optimum value varies according to the structure and characteristics of the magnetic head used in recording, but it is preferable for this thickness to be at least 10nm but not more than 300nm in view of productivity.

The intermediate layer 5 is used to magnetically separate the soft magnetic under layer 4 and the magnetic recording layer 6, and also to control the characteristics of the magnetic recording layer 6; a nonmagnetic element or a nonmagnetic alloy can be used as appropriate. The thickness is preferably from 5 to 30nm.

The magnetic recording layer 6 comprises a rare earth - transition metal alloy amorphous film. Examples of the rare

earth - transition metal alloy amorphous material include TbCo and TbFeCo, but there is no limitation to these. Moreover, at least one of Ti, Zr, Hf, V, Nb, Ta, Cr, Mo, W, B, Al, C and Si is contained in the rare earth - transition metal alloy amorphous film, with the form of existence thereof being that it is uniformly dispersed through the rare earth - transition metal alloy amorphous film.

Alternatively, at least one boride of Ti, Zr, Hf, V, Nb, Ta, Cr, Mo, W, Al or Si is contained in the rare earth - transition metal alloy amorphous film, with the form of existence thereof being that it is uniformly dispersed through the rare earth - transition metal alloy amorphous film. Alternatively, at least one carbide of Ti, Zr, Hf, V, Nb, Ta, Cr, Mo, W, B, Al or Si is contained in the rare earth - transition metal alloy amorphous film, with the form of existence thereof being that it is uniformly dispersed through the rare earth - transition metal alloy amorphous film. Due to the element(s) or boride(s) or carbide(s) being uniformly dispersed through the rare earth - transition metal alloy amorphous film, magnetic domain walls existing between recorded bits are fixed in the written positions through the existence of the additive(s), and hence shifting or loss of recorded signals is suppressed even during recording at high recording density.

To achieve a high recording density, it is necessary to disperse fine additive(s) uniformly through the film. As a

method of adding the element(s) or boride(s) or carbide(s) into the rare earth - transition metal alloy amorphous film, a method in which a target into which the additive(s) has/have been added is produced and the additive(s) is/are deposited together with the rare earth - transition metal alloy, or a method in which chips of the additive(s) are placed on a rare earth - transition metal alloy amorphous target and deposition is carried out, can be used.

It is necessary for the concentration of the element(s) or boride(s) or carbide(s) in the film to be at least 1% but not more than 20%. In the case that the concentration of the additive(s) is less than 1%, then because the amount of the additive(s) is too low, it will not be possible to sufficiently fix the magnetic domain walls; if the concentration of the additive(s) is greater than 20%, then because the amount of the additive(s) is too high, characteristics as a rare earth - transition metal alloy amorphous film will not be obtained sufficiently, and the medium will no longer function as a perpendicular magnetic recording medium. To obtain sufficient characteristics as a perpendicular magnetic recording medium, the proportion of the additive(s) must thus be at least 1% but not more than 20%.

When depositing the magnetic recording layer 6 of the present invention, it is preferable to make the pressure of the gas used during the deposition at least 10mTorr but not more

than 200mTorr. The thickness of the magnetic recording layer 6 is from 5 to 100nm, preferably from 10 to 50nm.

A conventionally used protective film can be used as the protective layer 7. Regarding the conditions of the protective layer 7 such as the thickness, the conditions used with a normal magnetic recording medium can be used as is. Moreover, a conventionally used material can also be used for the liquid lubricant layer 8. For example, a perfluoropolyether type lubricant can be used. Regarding the conditions of the liquid lubricant layer 8 such as the thickness, the conditions used with a normal magnetic recording medium can be used as is.

#### Example 1

Following is a description of examples of the present invention; however, the following examples are merely suitable representative examples of the present invention, and do not limit the present invention in any way.

Using a chemically strengthened glass substrate having smooth surfaces (for example, an N-5 glass substrate made by Hoya) as the nonmagnetic substrate 1, this was washed and then put into a sputtering apparatus, and a CoZrNb amorphous soft magnetic under layer was deposited to 200nm, and a TiCr intermediate film to 15nm. Next, using a composite target in which Ti, Zr, Hf, V, Nb, Ta, Cr, Mo, W, B, Al, C or Si chips were placed on a TbCo target, deposition of the magnetic recording layer was carried out at a gas pressure of 20mTorr.

The proportion of the additive was adjusted by changing the number of chips placed on the target. The thickness of the magnetic recording layer was made constant at 30nm. Finally, a 5nm protective layer comprising carbon was deposited, and then the medium was removed from the vacuum apparatus. All of the deposition except that of the magnetic recording layer 6 was carried out using a DC magnetron sputtering method under a gas pressure of 5mTorr. Afterwards, a 2nm liquid lubricant layer comprising a perfluoropolyether was formed using a dipping method, thus producing the perpendicular magnetic recording medium.

Using the above-mentioned method, perpendicular magnetic recording media were produced, variously changing the type of the additive added to the magnetic recording layer 6. The magnetic characteristics were calculated by measuring the magnetization curve using a vibrating sample magnetometer. Regarding the electromagnetic conversion characteristics of the perpendicular magnetic recording media for which all of the layers were deposited using the method indicated in the above example, measurement was carried out with an MR head using a spin stand tester.

The coercivity  $H_c$  and the SNR value (signal-to-noise ratio, an electromagnetic conversion characteristic) at a track recording density of 350kFCI are shown in Table 1 for

perpendicular magnetic recording media that were produced adding about 10at% of Ti, Zr, Hf, V, Nb, Ta, Cr, Mo, W, B, Al, C or Si to the rare earth - transition metal alloy amorphous film.

**Table 1**

Table 1: Coercivity and SNR value

|              | H <sub>c</sub><br>(Oe) | SNR(at 350kFCU)<br>(dB) |
|--------------|------------------------|-------------------------|
| TbCo         | 4290                   | 13.8                    |
| TbCo-9at%Ti  | 3880                   | 21.7                    |
| TbCo-10at%Zr | 3720                   | 20.4                    |
| TbCo-9at%Hf  | 3430                   | 20                      |
| TbCo-11at%V  | 3680                   | 18.9                    |
| TbCo-11at%Nb | 3780                   | 20.5                    |
| TbCo-10at%Ta | 3990                   | 21.8                    |
| TbCo-12at%Cr | 3390                   | 19.2                    |
| TbCo-10at%Mo | 3840                   | 20.1                    |
| TbCo-10at%W  | 3500                   | 19.8                    |
| TbCo-10at%B  | 4120                   | 22.1                    |
| TbCo-9at%Al  | 3420                   | 19.5                    |
| TbCo-10at%C  | 3960                   | 20.7                    |
| TbCo-9at%Si  | 3710                   | 20.6                    |

As a comparative example, the H<sub>c</sub> and SNR values are also shown for a perpendicular magnetic recording medium that was produced without carrying out addition of an element. In the

case of adding any of the elements,  $H_c$  dropped slightly compared with the case that addition was not carried out, but a relatively high value of  $H_c$  of above 3000 Oe was still obtained.

Moreover, it can be seen that in the case that addition of an element was not carried out, the SNR value at a recording density of 350kFCI was about 13.8dB, but by adding Ti, Zr, Hf, V, Nb, Ta, Cr, Mo, W, B, Al, C or Si, the characteristic improved by about 5.1 to 8.3dB. Moreover, in the case of combining two or more of the above-mentioned additives, similarly good magnetic characteristics and electromagnetic conversion characteristics can be obtained.

#### **Example 2**

Perpendicular media were produced as in Example 1, except that the type of the chips placed on the TbCo target was made to be a boride of Ti, Zr, Hf, V, Nb, Ta, Cr, Mo, W, Al or Si.

The coercivity  $H_c$  and the SNR value at a linear recording density of 350kFCI are shown in Table 2 for perpendicular magnetic recording media that were produced adding about 10 at% of a boride of Ti, Zr, Hf, V, Nb, Ta, Cr, Mo, W, Al or Si to the rare earth-transition metal alloy amorphous film.

Table 2

Table 2: Coercivity and SNR value

|                           | H <sub>c</sub><br>(Oe) | SNR(at 350kFCI)<br>(dB) |
|---------------------------|------------------------|-------------------------|
| TbCo                      | 4290                   | 13.8                    |
| TbCo-10%TiB <sub>2</sub>  | 3670                   | 24.5                    |
| TbCo-10%ZrB <sub>2</sub>  | 3590                   | 23.6                    |
| TbCo-11%HfB <sub>2</sub>  | 3440                   | 23.9                    |
| TbCo-11%VB <sub>2</sub>   | 3570                   | 22.4                    |
| TbCo-10%NbB <sub>2</sub>  | 3710                   | 23.1                    |
| TbCo-10%TaB <sub>2</sub>  | 4020                   | 25.5                    |
| TbCo-12%CrB <sub>2</sub>  | 3330                   | 24.3                    |
| TbCo-9%MoB <sub>2</sub>   | 3240                   | 22.9                    |
| TbCo-10%WB                | 3560                   | 23.7                    |
| TbCo-10%AlB <sub>2</sub>  | 3720                   | 22.1                    |
| TbCo-9at%SiB <sub>6</sub> | 3660                   | 23.4                    |

As a comparative example, the H<sub>c</sub> and SNR values are also shown for a perpendicular magnetic recording medium that was produced without carrying out addition of an element. As with the results shown in Table 1, in the case of adding any of the borides, H<sub>c</sub> dropped slightly compared with the case that addition was not carried out, with the highest coercivity of 4020 Oe being obtained in the case that TbB<sub>2</sub> was added. Even in the case of adding MoB<sub>2</sub>, for which the lowest coercivity was shown, a value of about 3240 Oe was obtained.

Regarding the SNR value, it can be seen that in the cases of all of the additives, the characteristic improved by about 8.3 to 11.7dB compared with the comparative example in which addition was not carried out. The case for which the highest

SNR value was obtained was when  $TaB_2$  was added, with a good characteristic of 25.5dB being obtained. Moreover, in the case of combining two or more of the above-mentioned borides, similarly good magnetic characteristics and electromagnetic conversion characteristics can be obtained.

### Example 3

Perpendicular media were produced as in Example 1, except that the type of the chips placed on the TbCo target was made to be a carbide of Ti, Zr, Hf, V, Nb, Ta, Cr, Mo, W, B, Al or Si.

The coercivity  $H_c$  and the SNR value at a linear recording density of 350kFCI are shown in Table 3 for perpendicular magnetic recording media that were produced adding about 10at% of a carbide of Ti, Zr, Hf, V, Nb, Ta, Cr, Mo, W, B, Al or Si to the rare earth - transition metal alloy amorphous film.

**Table 3**

Table 3: Coercivity and SNR value

|                                        | $H_c$<br>(Oe) | SNR(at 350kFCI)<br>(dB) |
|----------------------------------------|---------------|-------------------------|
| TbCo                                   | 4290          | 13.8                    |
| TbCo-10%TiC                            | 3680          | 22.7                    |
| TbCo-10%ZrC                            | 3440          | 23.4                    |
| TbCo-8%HfC                             | 3550          | 24.1                    |
| TbCo-11%VC                             | 3720          | 23.9                    |
| TbCo-11%NbC                            | 3530          | 23.7                    |
| TbCo-10%TaC                            | 3490          | 24.1                    |
| TbCo-10%Cr <sub>3</sub> C <sub>2</sub> | 3660          | 22.5                    |
| TbCo-11%Mo <sub>2</sub> C              | 3570          | 21.8                    |
| TbCo-10%W <sub>2</sub> C               | 3710          | 23.5                    |
| TbCo-10%B <sub>4</sub> C               | 3870          | 23.6                    |
| TbCo-9%Al <sub>4</sub> C <sub>3</sub>  | 3480          | 22.9                    |
| TbCo-9%SiC                             | 3420          | 23.7                    |

As a comparative example, the Hc and SNR values are also shown for a perpendicular magnetic recording medium that was produced without carrying out addition of an element. As with the results shown in Table 1, in the case of adding any of the carbides, Hc dropped slightly compared with the case that addition was not carried out. However, even in the case of SiC, for which the coercivity value was lowest, a value of about 3240 Oe was obtained.

Regarding the SNR value, it can be seen that in the cases of all of the additives, the characteristic improved by about 8 to 10.3dB compared with the perpendicular magnetic recording medium of the comparative example for which addition was not carried out. The highest SNR value was obtained when HfC or TaC was added, with the SNR at a linear recording density of 350kFCI being 24.1dB. Moreover, in the case of combining two or more of the above-mentioned carbides, similarly good magnetic characteristics and electromagnetic conversion characteristics can be obtained.

#### **Example 4**

As an example of cases in which a pure element is added, using a composite target in which V or B chips were placed on a TbCo target, perpendicular magnetic recording media were produced, with the proportion of the additive contained in the rare earth - transition metal alloy amorphous film being adjusted by changing the number of chips placed on the target.

The coercivity  $H_c$  and the SNR value at a linear recording density of 350kFCI are shown in Table 4 for perpendicular magnetic recording media that were produced with the concentration of the additive being changed. B is shown as the additive for which the characteristics were best, and V as the additive for which the characteristics were worst.

**Table 4**

Table 4: Coercivity and SNR value

|             | $H_c$<br>(Oe) | SNR(at 350kFCI)<br>(dB) |
|-------------|---------------|-------------------------|
| TbCo        | 4290          | 13.8                    |
| TbCo-1at%V  | 4150          | 15.1                    |
| TbCo-11at%V | 3680          | 18.9                    |
| TbCo-18at%V | 3080          | 15.7                    |
| TbCo-25at%V | 2130          | 8.6                     |
| TbCo-1at%B  | 4220          | 16.5                    |
| TbCo-10at%B | 4120          | 22.1                    |
| TbCo-20at%B | 3680          | 16.3                    |
| TbCo-26at%B | 2450          | 10.1                    |

As a comparative example, the  $H_c$  and SNR values are also shown for a perpendicular magnetic recording medium that was produced without carrying out addition of an element. In the case of either element,  $H_c$  decreases monotonically as the concentration of the additive increases, and in the case that more than 20at% is added,  $H_c$  becomes a value less than 3000 Oe. In the case of either element, by adding 1 at% or more, the SNR value at a recording density of 350kFCI shows a good value of over 15dB.

However, in the case of adding either element, if the amount added exceeds 20at% then the SNR value drops abruptly, becoming a value of 8.6dB in the case of V and 10.1dB in the case of B. It can thus be seen that in the case of either of the elements, it is necessary to make the amount added at least 1at% but not more than 20at%.

#### **Example 5**

As an example of cases in which a boride is added, using a composite target in which  $TaB_2$  or  $AlB_2$  chips were placed on a TbCo target, perpendicular magnetic recording media were produced, with the proportion of the additive contained in the rare earth - transition metal alloy amorphous film being adjusted by changing the number of chips placed on the target.

The coercivity  $H_c$  and the SNR value at a track recording density of 350kFCI are shown in Table 5 for perpendicular magnetic recording media that were produced while changing the concentration added of the  $TaB_2$  or  $AlB_2$ .  $TaB_2$  is shown as the additive for which the characteristics were best, and  $AlB_2$  as the additive for which the characteristics was lowest out of the borides that were deposited.

**Table 5**

Table 5: Coercivity and SNR value

|              | Hc<br>(Oe) | SNR(at 350kFCI)<br>(dB) |
|--------------|------------|-------------------------|
| TbCo         | 4290       | 13.8                    |
| TbCo-1%TaB2  | 4180       | 16.7                    |
| TbCo-10%TaB2 | 4020       | 25.5                    |
| TbCo-19%TaB2 | 3770       | 17.1                    |
| TbCo-25%TaB2 | 2590       | 12.5                    |
| TbCo-1%AIB2  | 4190       | 15.3                    |
| TbCo-10%AIB2 | 3720       | 22.1                    |
| TbCo-19%AIB2 | 3210       | 16.7                    |
| TbCo-23%AIB2 | 2580       | 12.6                    |

As a comparative example, the Hc and SNR values are also shown for a perpendicular magnetic recording medium that was produced without carrying out addition of an element. In the case of either boride, Hc decreases monotonically as the concentration added increases, and in the case that more than 20at% is added, Hc becomes a value less than 3000 Oe. In the case of either boride, by adding 1at% or more, the SNR value at a recording density of 350kFCI shows a good value of over 15dB.

However, in the case of adding either boride, if the amount added exceeds 20at% then the SNR value drops abruptly, becoming

a value of 12.5dB in the case of  $TaB_2$  and 12.6dB in the case of  $AlB_2$ . It can thus be seen that in the case of either of the borides, it is necessary to make the amount added at least 1at% but not more than 20at%.

#### Example 6

As an example of cases in which a carbide is added, using a composite target in which HfC or  $Mo_2C$  chips were placed on a TbCo target, perpendicular magnetic recording media were produced, with the proportion of the additive contained in the rare earth - transition metal alloy amorphous film being adjusted by changing the number of chips placed on the target.

The coercivity  $H_c$  and the SNR value at a track recording density of 350kFCI are shown in Table 6 for perpendicular magnetic recording media that were produced while changing the concentration added of the HfC or  $Mo_2C$ . HfC is shown as the additive for which the characteristics were best, and  $Mo_2C$  as the additive for which the characteristics was lowest out of the carbides that were deposited.

Table 6

Table 6: Coercivity and SNR value

|                           | Hc<br>(Oe) | SNR(at 350kFCI)<br>(dB) |
|---------------------------|------------|-------------------------|
| TbCo                      | 4290       | 13.8                    |
| TbCo-1%HfC                | 4200       | 16.3                    |
| TbCo-8%HfC                | 3550       | 24.1                    |
| TbCo-20%HfC               | 3010       | 15.7                    |
| TbCo-22%HfC               | 2760       | 13.6                    |
| TbCo-1%Mo <sub>2</sub> C  | 4180       | 15.9                    |
| TbCo-11%Mo <sub>2</sub> C | 3570       | 21.8                    |
| TbCo-20%Mo <sub>2</sub> C | 3170       | 15.4                    |
| TbCo-24%Mo <sub>2</sub> C | 2330       | 11.1                    |

As a comparative example, the Hc and SNR values are also shown for a perpendicular magnetic recording medium that was produced without carrying out addition of an element. In the case of either carbide, Hc decreases monotonically as the concentration added increases, and in the case that more than 20at% is added, Hc becomes a value less than 3000 Oe. In the case of either carbide, by adding 1at% or more, the SNR value at a recording density of 350kFCI shows a good value of over 15dB.

However, in the case of adding either carbide, if the amount added exceeds 20at% then the SNR value drops abruptly, becoming a value of 13.6dB in the case of HfC and 11.1dB in the case of Mo<sub>2</sub>C. It can thus be seen that in the case of either of the carbides, it is necessary to make the amount added at least 1at% but not more than 20at%.

**Example 7**

As an example of cases in which a pure element and a carbide, or a pure element and a boride, or a carbide and a boride are added at the same time, using a composite target in which Ta and  $W_2C$  chips, or Zr and  $NbB_2$  chips, or  $TiB_2$  and  $Cr_3C_2$  chips were placed on a TbCo target, perpendicular magnetic recording media were produced, with the proportions of the additives contained in the rare earth - transition metal alloy amorphous film being adjusted by changing the number of chips placed on the target.

The coercivity  $H_c$  and the SNR value at a track recording density of 350kFCI are shown in Table 7 for the perpendicular magnetic recording media produced.

**Table 7**

Table 7: Coercivity and SNR value

|                                   | $H_c$<br>(Oe) | SNR(at 350kFCI)<br>(dB) |
|-----------------------------------|---------------|-------------------------|
| TbCo                              | 4290          | 13.8                    |
| TbCo-1at%Ta-1% $W_2C$             | 4080          | 16.7                    |
| TbCo-6at%Ta-5% $W_2C$             | 3490          | 22.4                    |
| TbCo-11at%Ta-9% $W_2C$            | 3150          | 15.8                    |
| TbCo-13at%Ta-11% $W_2C$           | 2260          | 11.5                    |
| TbCo-1at%Zr-1% $NbB_2$            | 4110          | 15.3                    |
| TbCo-5at%Zr-5% $NbB_2$            | 3580          | 20.7                    |
| TbCo-9at%Zr-9% $NbB_2$            | 3300          | 17.9                    |
| TbCo-11at%Zr-11% $NbB_2$          | 2940          | 13.9                    |
| TbCo-1at% $TiB_2$ -1% $Cr_3C_2$   | 4200          | 16.2                    |
| TbCo-5at% $TiB_2$ -4% $Cr_3C_2$   | 3660          | 23.4                    |
| TbCo-10at% $TiB_2$ -9% $Cr_3C_2$  | 3130          | 16.1                    |
| TbCo-11at% $TiB_2$ -10% $Cr_3C_2$ | 2470          | 14.5                    |

As a comparative example, the Hc and SNR values are also shown for a perpendicular magnetic recording medium that was produced without carrying out addition of elements. In the cases that a plurality of added elements are combined, as with the cases that addition of a single additive is carried out, by adding 1at% or more, the SNR value at a recording density of 350kFCI shows a good value of over 15dB.

However, if the amount added exceeds 20at% then the SNR value drops abruptly, becoming a value less than 15dB. It can thus be seen that in the case that addition of a combination of a plurality of a pure element, a boride and a carbide is carried out as well, it is necessary to make the amount added at least 1at% but not more than 20at%.

#### **Example 8**

Using a chemically strengthened glass substrate having smooth surfaces (for example, an N-5 glass substrate made by Hoya) as the nonmagnetic substrate 1, this was washed and then put into a sputtering apparatus, and a Ta underlayer was deposited to 5nm, an NiFeCr orientation controlling layer to 5nm, an IrMn magnetic domain controlling layer to 10nm, a CoZrNb amorphous soft magnetic under layer to 200nm, and a TiCr intermediate film to 15nm. Next, chips of Ti, Zr, Hf, V, Nb, Ta, Cr, Mo, W, B, Al, C or Si or a boride or carbide thereof were placed on a TbCo target, and deposition was carried out at a gas pressure of 20mTorr.

The proportion of the additive was adjusted by changing the number of chips placed on the target. The thickness of the magnetic recording layer was made constant at 30nm. Finally, a 5nm protective layer comprising carbon was deposited, and then the medium was removed from the vacuum apparatus. All of the deposition except that of the magnetic recording layer 6 was carried out using a DC magnetron sputtering method under a gas pressure of 5mTorr. Afterwards, a 2nm liquid lubricant layer comprising a perfluoropolyether was formed using a dipping method, thus producing the perpendicular magnetic recording medium.

Using the above-mentioned method, perpendicular magnetic recording media were produced, variously changing the type and proportion of the additive added to the magnetic recording layer 6. The magnetic characteristics were calculated by measuring the magnetization curve using a vibrating sample magnetometer. Regarding the electromagnetic conversion characteristics of the perpendicular magnetic recording media for which all of the layers were deposited using the method indicated in the above example, measurement was carried out with an MR head using a spin stand tester.

No particular difference was found in the magnetic characteristics or the SNR between the perpendicular magnetic recording media produced using the method of Example 8 and the perpendicular magnetic recording media produced using the method of Example 1.

One cycle of the output waveform obtained using a spin stand tester for a perpendicular magnetic recording medium of Example 8 is shown in Fig. 3. As a comparative example, the output waveform for a perpendicular magnetic recording medium of Example 1 in which an underlayer and a magnetic domain controlling layer are not provided is also shown in Fig. 3. In the case that there are no underlayer and magnetic domain controlling layer, uneven spike noise occurs throughout the whole cycle. In contrast, it can be seen that if an underlayer and a magnetic domain controlling layer are provided, then no spike noise occurs at all. This is because if an underlayer and a magnetic domain controlling layer are provided, then magnetic domain walls are not formed in the soft magnetic under layer.

#### **Advantageous Effects of the Invention**

As described above, according to the present invention, in a perpendicular magnetic recording medium comprising at least a soft magnetic under layer, an intermediate layer, a magnetic recording layer, a protective layer and a liquid lubricant layer built up in order on a nonmagnetic substrate, the magnetic recording layer is constituted from a rare earth - transition metal alloy amorphous film, and at least one of Ti, Zr, Hf, V, Nb, Ta, Cr, Mo, W, B, Al, C and Si or a boride or carbide thereof is contained in the rare earth - transition metal alloy amorphous film, with the form of existence thereof being

that it is uniformly dispersed through the rare earth - transition metal alloy amorphous film; as a result, compared with the case that the perpendicular magnetic recording medium is produced without carrying out such addition, extremely good characteristics can be obtained at high recording density. It is necessary to make the concentration of the element(s) or boride(s) or carbide(s) thereof added be at least 1% but not more than 20%, and even if a plurality of additives are added at the same time, a perpendicular magnetic recording medium exhibiting good characteristics can be produced.

Moreover, by providing one or a plurality of underlayers and an antiferromagnetic layer for magnetic domain control of the soft magnetic under layer between the nonmagnetic substrate and the soft magnetic under layer, spike noise due to magnetic domain wall formation in the soft magnetic layer can be completely suppressed, which is extremely desirable when making the perpendicular magnetic recording medium fit for practical use.

Furthermore, the method of manufacturing the perpendicular magnetic recording medium of the present invention can be carried out using an existing manufacturing apparatus, and hence this method is suited to mass production of high-capacity magnetic recording media.

## Claims

1. A perpendicular magnetic recording medium, comprising:
  - a soft magnetic under layer;
  - an intermediate layer;
  - a magnetic recording layer, comprising a rare earth-transition metal alloy amorphous film and at least one of Ti, Zr, Hf, V, Nb, Mo, W, B, Al, C and Si uniformly dispersed in the rare earth-transition metal alloy amorphous film;
  - a protective layer;
  - a liquid lubricant layer; and
  - a nonmagnetic substrate,wherein the soft magnetic under layer, the intermediate layer, the magnetic recording layer, and the protective layer are built up in a predetermined order on the nonmagnetic substrate.
2. A perpendicular magnetic recording medium, comprising:
  - a soft magnetic under layer;
  - an intermediate layer;
  - a magnetic recording layer, comprising a rare earth-transition metal alloy amorphous film and at least one of Ti, Zr, Hf, V, Nb, Ta, Cr, Mo, W, B, Al, C and Si uniformly dispersed in the rare earth-transition metal alloy amorphous film;
  - a protective layer;
  - a liquid lubricant layer; and

a nonmagnetic substrate,  
wherein the soft magnetic under layer, the intermediate layer,  
the magnetic recording layer, and the protective layer are built  
up in a predetermined order on the nonmagnetic substrate,  
wherein a concentration of at least one of Ti, Zr, Hf, V, Nb,  
Ta, Cr, Mo, W, Al, C and Si in the rare earth - transition metal  
alloy amorphous film is at least 1 atomic % but no more than  
20 atomic %.

3. The perpendicular magnetic recording medium as claimed  
in claim 1, further comprising:

an underlayer; and

a magnetic domain controlling layer, wherein the  
underlayer and the magnetic domain controlling layer are between  
the nonmagnetic substrate and the soft magnetic under layer.

4. A perpendicular magnetic recording medium, comprising:

a soft magnetic under layer,

an intermediate layer,

a magnetic recording layer comprising a rare  
earth-transition metal alloy amorphous film and at least one  
boride of Ti, Zr, Hf, V, Nb, Ta, Cr, Mo, W, Al or Si uniformly  
dispersed in the rare earth-transition metal alloy amorphous  
film;

a protective layer; and

a nonmagnetic substrate, wherein the soft magnetic under

layer, the intermediate layer, the magnetic recording layer, and the protective layer are built up in a predetermined order on the nonmagnetic substrate.

5. The perpendicular magnetic recording medium as claimed in claim 4, further comprising:

an underlayer; and

a magnetic domain controlling layer, wherein the underlayer and the magnetic domain controlling layer are between the nonmagnetic substrate and the soft magnetic under layer.

6. A perpendicular magnetic recording medium, comprising:

a soft magnetic under layer;

an intermediate layer;

a magnetic recording layer comprising a rare earth-transition metal alloy amorphous film and at least one carbide of Ti, Zr, Hf, V, Nb, Ta, Cr, Mo, W, B, Al or Si uniformly dispersed in the rare earth-transition metal alloy amorphous film;

a protective layer;

a liquid lubricant layer; and

a nonmagnetic substrate, wherein the soft magnetic under layer, the intermediate layer, the magnetic recording layer, and the protective layer are built up in a predetermined order on the nonmagnetic substrate.

7. The perpendicular magnetic recording medium as claimed in claim 6, wherein a concentration of at least one carbide of Ti, Zr, Hf, V, Nb, Ta, Cr, Mo, W, B, Al, C and Si in the rare earth-transition metal alloy amorphous film is at least 1 atomic % but no more than 20 atomic %.