

# MAGNETIC HEAD AND METHOD<sup>1</sup> FOR MANUFACTURING THE SAME

The present invention relates to a magnetic head and a method for manufacturing the same. More particularly, the present invention relates to a MIG (metal in gap) magnetic head that is suitable for recording and reproducing information at high density in a magnetic recording medium having a high coercive force used in systems such as digital VTRs and data streamers.

In magnetic recording systems such as VTRs and data streamers, higher densification is required. As a magnetic head that is suitable for high density magnetic recording and reproducing, magnetic heads that use magnetic metal materials such as a Co-based amorphous film and a Fe-based nitride film having a higher saturation magnetic flux density  $B_s$  than a ferrite material, especially MIG heads, have been developed increasingly.

The MIG magnetic head generally has a structure in which a magnetic metal layer 21 having a high saturation magnetic flux density is formed on a half-core 22 of a ferrite that is a magnetic core, as shown in Fig. 12. A magnetic gap 26 is provided between the magnetic metal layers 21. Conventionally, the gap material in the magnetic gap 26 has a structure in which metal Cr layers 28 are held between  $\text{SiO}_2$  layers 27, as shown in Fig. 13, which is an enlarged view of the sliding surface 25 of the MIG head. The half-cores 22 are bonded to each other with a lead glass 24, which has a low melting point.

A method for manufacturing the conventional MIG head will be

described below with reference to Figs. 14 (a)-(f). First, a winding groove 32 and a back glass groove 33 are formed in a ferrite core 31 (Figs. 14 (a) and (b)). Then, track grooves 34 are formed in the core 31 and gap-facing surfaces 35 are ground (Fig. 14 (c)). Furthermore, a magnetic metal layer 21, a  $\text{SiO}_2$  layer 27, and a Cr layer 28 are formed in this order e.g. by sputtering on a region of the core 31 including the gap-facing surfaces 35 (Fig. 14 (d)). A pair of half-cores on which a gap material is thus formed are butted against each other so that the gap surfaces face each other, and a lead glass 24 is placed in the groove portions (Fig. 14 (e)). Furthermore, the lead glass 24 is molded on the Cr layer 28 by heat treatment to bond the cores at the gap to manufacture one gapped bar (Fig. 14 (f)). The heat treatment for bonding the half-cores to each other is conducted in a nitrogen gas ( $\text{N}_2$ ) to prevent the oxidation of the magnetic metal layer 21. After this step, the gapped bar is cut to a predetermined head chip core width and a predetermined azimuth angle, and the sliding surface is ground to finish the head chip.

In the MIG head of the conventional structure, however, the accuracy of the magnetic gap length is not sufficient and the properties are not stable. As a result of the inventor's analyzing these problems, it has been found that in the conventional gap material, the metal Cr is oxidized partially and non-uniformly by the residual oxygen during the heat treatment and by the oxygen in the low melting point lead glass 24 to form an imperfect Cr oxide 29, causing volume expansion as shown in Fig. 15. Since the thickness of the imperfect oxide 29 is non-uniform, a magnetic gap

26 having a stable length cannot be obtained.

The metal Cr is used as a gap material for improving the wettability of the lead glass 24. If only the  $\text{SiO}_2$  layer is used without Cr, the flowability of the lead glass 24 worsens as shown in Fig. 16, so that a sufficient strength of the head chip cannot be obtained.

It is an object of the present invention to provide a magnetic head of MIG type having a magnetic gap with improved accuracy while ensuring the strength of the head chip. It is another object of the present invention to provide a method for manufacturing such a magnetic head of MIG type.

According to the present invention, a magnetic head of MIG type is provided that comprises a gap material in a magnetic gap, the gap material comprising non-magnetic oxide layers, whose main component is  $\text{SiO}_2$ , and  $\text{Cr}_2\text{O}_3$  layers held between the non-magnetic oxide layers.

According to the above magnetic head of MIG type in which the  $\text{Cr}_2\text{O}_3$  layer is substituted for the Cr layer, deterioration in the accuracy of the magnetic gap length caused by the partial and non-uniform oxidation of the gap material can be controlled while the flowability of a glass such as a lead glass used in the process of manufacturing the magnetic head is ensured. Also, the gap length can be precisely measured, because the  $\text{Cr}_2\text{O}_3$  layer is substantially transparent so that light reflection does not cause difficulties as it does when the Cr layer is used. The improvement in the accuracy of the gap length and the measurement accuracy improves the production yield of the magnetic heads greatly.

According to the present invention, a method for manufacturing a

magnetic head of MIG type is provided that comprises the steps of forming a magnetic metal layer, a non-magnetic oxide layer whose main component is  $\text{SiO}_2$ , and a  $\text{Cr}_2\text{O}_3$  layer in this order on each of a pair of half-cores, and bonding the pair of half-cores to each other with a bonding glass softened by heating so that at least a part of the  $\text{Cr}_2\text{O}_3$  layers are in contact with each other to define a magnetic gap with a gap material comprising the non-magnetic oxide layers and the  $\text{Cr}_2\text{O}_3$  layers held between the non-magnetic oxide layers.

In this manufacturing method, it is preferable that the bonding glass is softened by heating the bonding glass in an atmosphere containing oxygen at least in the following temperature range:

$$T_g - 85^\circ\text{C} \leq T \leq T_g - 35^\circ\text{C}$$

wherein  $T_g$  is the glass transition point of the bonding glass. This preferable manufacturing method improves the flowability of the glass.

The non-magnetic oxide layer whose main component is  $\text{SiO}_2$  is preferably a silicate glass layer, and more preferably a borosilicate glass layer, because the ill-balanced abrasion of the gap material occurs less easily than when the  $\text{SiO}_2$  glass is used, so that a stable head output can be obtained.

It is preferable that the non-magnetic oxide layer whose main component is  $\text{SiO}_2$  has a thickness of at least 30 nm, because the oxidation of the magnetic metal layer can be controlled.

It is preferable that the bonding glass is a low melting point glass having a softening point of not more than  $500^\circ\text{C}$  and more specifically a

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glass whose main component is PbO.

Fig. 1 shows a perspective view of a magnetic head of MIG type of the present invention;

Fig. 2 shows the magnetic gap and a portion near the magnetic gap of the sliding surface of the magnetic head of MIG type of the present invention;

Figs. 3 (a)-(f) show a method for manufacturing the magnetic head of MIG type of the present invention;

Fig. 4 shows changes in the layer thickness of Cr and  $\text{Cr}_2\text{O}_3$  after heat treatment;

Fig. 5 shows the abrasion condition of  $\text{Cr}_2\text{O}_3/\text{SiO}_2$  used as a gap material;

Fig. 6 shows the abrasion condition of  $\text{Cr}_2\text{O}_3$ /borosilicate glass used as a gap material;

Fig. 7 shows conditions for heat treatment;

Fig. 8 shows the wet angle of the lead glass on Cr and  $\text{Cr}_2\text{O}_3$  under the conditions for heat treatment in Fig. 7;

Fig. 9 shows the distribution of the gap length of a magnetic head having a conventional gap material of Cr/ $\text{SiO}_2$ ;

Fig. 10 shows the distribution of the gap length of a magnetic head having a gap material of  $\text{Cr}_2\text{O}_3$ /borosilicate glass;

Fig. 11 shows the magnetic gap and a portion near the magnetic gap of the sliding surface of another magnetic head of MIG type of the present invention;

Fig. 12 shows a perspective view of a conventional magnetic head of MIG type;

Fig. 13 shows the magnetic gap and a portion near the magnetic gap of the sliding surface of the conventional magnetic head of MIG type;

Figs. 14 (a)-(f) show a method for manufacturing the conventional magnetic head of MIG type;

Fig. 15 shows the magnetic gap and a portion near the magnetic gap of the sliding surface of a conventional magnetic head of MIG type having a Cr layer that is oxidized imperfectly and non-uniformly; and

Fig. 16 shows a perspective view of a magnetic head of MIG type wherein bonding with glass is not sufficient.

The preferred embodiments of the present invention will be described below with reference to the drawings. However, the following embodiments are not intended to limit the present invention.

In one embodiment of a metal in gap (MIG) magnetic head of the present invention as shown in Fig. 1, half-cores 2 of a ferrite, that are magnetic cores, are bonded with a lead glass 4, which has a low melting point, in a manner similar to that of the conventional MIG head. Gap-facing surfaces defining a magnetic gap 6 and groove portions for the lead glass 4, which bonds the half-cores to each other, are previously formed in the half-core 2. Also, a magnetic metal layer 1 having a high saturation magnetic flux density, such as a FeTaN layer, a borosilicate glass layer 7, and a  $\text{Cr}_2\text{O}_3$  layer 8 are formed on the half-core 2 in this order. These layers are formed to cover at least the gap-facing surfaces and the groove

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portions formed near the gap-facing surfaces.

As shown in Fig. 2, which is an enlarged view of the sliding surface 5 of the MIG head in Fig. 1, the  $\text{Cr}_2\text{O}_3$  layer 8 is substituted for the Cr layer in this MIG head. The gap material in the magnetic gap 6 has a structure in which the borosilicate glass layer 7 and the  $\text{Cr}_2\text{O}_3$  layer 8 formed on the half-core 2 are in contact with each other, so that the  $\text{Cr}_2\text{O}_3$  layers 8 are sandwiched between the borosilicate glass layers 7.

As shown in Fig. 3, this MIG head basically can be manufactured by a procedure similar to that of the conventional manufacturing method as shown in Fig. 14, except that the borosilicate glass layer 7 is substituted for the  $\text{SiO}_2$  layer 27 and that the  $\text{Cr}_2\text{O}_3$  layer 8 is substituted for the Cr layer 28. However, it is preferred to employ the conditions for heat treatment described below to improve the flowability of the glass 4, which bonds the half-cores to each other.

In order to confirm a change in the thickness of the Cr layer and the  $\text{Cr}_2\text{O}_3$  layer due to the heat treatment, both layers were subjected to a heat treatment in an electric furnace used for manufacturing the MIG head. As a result, it was confirmed that in a heat treatment conducted at  $520^\circ\text{C}$  for 10 minutes, for example, the Cr layer shows about 70% increase in thickness while the  $\text{Cr}_2\text{O}_3$  layer shows little or no change as shown in Fig. 4. Cr is turned into Cr imperfect oxide so that it expands, while  $\text{Cr}_2\text{O}_3$  is already oxidized so that its volume is substantially constant. This result shows that the use of the  $\text{Cr}_2\text{O}_3$  layer in the magnetic gap of the MIG head does not cause a change in the thickness of the layer due to heat treatment,

so that a stable gap length can be obtained.

Thus, the  $\text{Cr}_2\text{O}_3$  layer is substituted for the Cr layer in the MIG head of the present invention. Other component materials are not limited to those used in the above embodiment. For example, the half-core is not limited to ferrite, and other ferromagnetic oxides may be used. In a pair of half-cores, at least one half-core should form a magnetic core of a ferromagnetic oxide. Also, there is no limitation to use the lead glass for bonding the half-cores to each other. A low melting point glass having a softening point of not more than  $500^\circ\text{C}$  is preferably used. While FeTaN is illustrated as the magnetic metal layer, other magnetic materials such as Co-based amorphous, Sendust (Fe-Si-Al), or FeGaSiRu may be used in the magnetic metal layer. Also, there is no limitation to use the borosilicate glass layer. A non-magnetic oxide layer whose main component is  $\text{SiO}_2$  can be used. A glass layer whose main component is  $\text{SiO}_2$ , such as a  $\text{SiO}_2$  glass layer, an aluminosilicate glass layer, or a soda-lime silicate glass layer, is preferably used as the non-magnetic oxide layer.

In view of the abrasion of the gap material, it is preferable to use a silicate glass for the non-magnetic oxide layer to prevent the hardness of the entire gap material from becoming excessively high by using  $\text{Cr}_2\text{O}_3$ , having a higher hardness than Cr. The gap material having an excessively high hardness tends to cause ill-balanced abrasion, for example, when a metal tape such as a metal evaporation (ME) tape runs on the magnetic head for a long period. As shown in Fig. 5, if the gap material is formed of the  $\text{Cr}_2\text{O}_3$  layer 8 and the  $\text{SiO}_2$  layer 9, ill-balanced abrasion occurs in which the gap

material protrudes over the magnetic layers. Therefore, the head output easily decreases. However, if the borosilicate glass layer 7 having a relatively small hardness is substituted for the  $\text{SiO}_2$  layer 9, for example, the ill-balanced abrasion can be eliminated as shown in Fig. 6. Therefore, a stable running condition of a metal tape 10 and a stable head output can be obtained.

Next, preferable conditions for heat treatment in the process of manufacturing the MIG head of the present invention will be described. The flowability of the low melting point glass such as lead glass on  $\text{Cr}_2\text{O}_3$  is better than on the borosilicate glass, for example, but is worse than on the Cr. A decrease of the flowability of the low melting point glass is not desirable in view of sufficiently maintaining the gap strength of the MIG head. Therefore, it is preferable to improve the wettability of the glass for flowing by introducing an atmosphere containing oxygen (for example, air) in the heat treatment process. The object of improving the wettability of the glass on the  $\text{Cr}_2\text{O}_3$  layer can be achieved by introducing the atmosphere containing oxygen below a certain temperature during the process of increasing the temperature for heat treatment. Then, as shown in Fig. 7, a heat treatment was conducted in air at up to a temperature  $T_c$  and the air was replaced with nitrogen ( $\text{N}_2$ ) flow while the temperature of the heat treatment was increased. (A maximum temperature of  $510^\circ\text{C}$  was maintained for 10 minutes). The relationship between the wet angle of the lead glass (glass transition point  $T_g=385^\circ\text{C}$ ) on the Cr layer or the  $\text{Cr}_2\text{O}_3$  layer and the air substitution temperature  $T_c$  at which nitrogen is

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substituted for the air was examined.

As a result, the wet angle of the lead glass on the  $\text{Cr}_2\text{O}_3$  layer is poorer than that of the lead glass on the Cr layer at a  $T_c$  of about 200 to  $300^\circ\text{C}$ , while substantially the same wettability of the lead glass on the  $\text{Cr}_2\text{O}_3$  layer as the lead glass on the Cr layer can be obtained at a  $T_c$  of  $350^\circ\text{C}$  or more as shown in Fig. 8. Taking consideration of the actual condition of the heat treatment in defining  $T_c$ , it is preferable to conduct the heat treatment in an atmosphere containing oxygen such as the air at least up to  $300$  to  $350^\circ\text{C}$  in the temperature increasing process. This temperature differs according to the glass transition point  $T_g$  of the low melting point glass. The preferable temperature range is  $(T_g - 85^\circ\text{C})$  to  $(T_g - 35^\circ\text{C})$ . Similar experiments were conducted by substituting the  $\text{SiO}_2$  layer and the borosilicate glass layer for the  $\text{Cr}_2\text{O}_3$  layer. However, with these materials, the same wettability as on the Cr layer could not be obtained even by increasing  $T_c$  to  $510^\circ\text{C}$ .

The present invention will be described below in more detail with reference to the non-limiting examples.

#### Example 1

A MIG head having the structure as shown in Figs 1 and 2 was manufactured according to a process as shown in Fig. 3. More specifically, a Mn-Zn ferrite was used as the half-core 2, and a FeTaN layer having a saturation magnetic flux density  $B_s = 1.6$  T was used as the magnetic metal layer 1. Also, a borosilicate glass was used as the non-magnetic oxide, and a lead glass having a glass transition point  $T_g = 385^\circ\text{C}$  was used as the glass

for core bonding. Each thin film including the borosilicate glass layer and the  $\text{Cr}_2\text{O}_3$  layer was formed by sputtering. The thickness of  $\text{Cr}_2\text{O}_3$  was 30 nm and the thickness of the borosilicate glass was 50 nm in this example.

For molding the lead glass 4, the heat treatment process was conducted according to a temperature increasing and decreasing process similar to that in Fig. 7 with an air substitution temperature  $T_c$  of  $350^\circ\text{C}$ . More specifically, the heat treatment was conducted in air at up to  $350^\circ\text{C}$  in the temperature increasing process and then in nitrogen flow.

For comparison, a magnetic head having a conventional  $\text{Cr}/\text{SiO}_2$  gap was manufactured. The gap length of this magnetic head and the magnetic head having the above  $\text{Cr}_2\text{O}_3$ /borosilicate glass gap according to this example was measured after heat treatment.

Fig. 9 shows the distribution of the gap length of the gap material of the conventional magnetic heads. Fig. 10 shows the distribution of the gap length of the gap material of the magnetic heads in this example. As shown in Figs. 9 and 10, variation in the gap material in this example (standard deviation:  $0.01\ \mu\text{m}$ ) is smaller than variation in the conventional gap material (standard deviation:  $0.03\ \mu\text{m}$ ).

In the magnetic head in this example, a good magnetic gap was obtained without oxidation of the surface of the magnetic metal layer due to heat treatment. Stable head output was maintained without the protrusion of the gap material over the magnetic metal layer even when a metal tape such as a metal evaporation (ME) tape ran on this magnetic head for a long period.

Thus, the accuracy of the gap length improved, so that a MIG head having stable head properties was manufactured. As shown in the above example, according to the present invention, the production yield can be improved in commercially manufacturing the MIG heads.

### Example 2

MIG heads were manufactured in the same manner as described in Example 1, varying the thickness of the  $\text{Cr}_2\text{O}_3$  layer and the borosilicate glass layer. The total thickness of the gap material of the above two layers was 80nm. For the magnetic heads thus obtained, the condition of the film oxidation of the magnetic metal layer of the magnetic head, the presence of the protrusion of the gap material when the ME tape runs on the magnetic head, and the flowability of the lead glass were examined. The results are shown in Table 1.

Table 1

[unit: nm]

| Thickness | $\text{Cr}_2\text{O}_3$ | 0  | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 |
|-----------|-------------------------|----|----|----|----|----|----|----|----|----|
|           | borosilicate glass      | 80 | 70 | 60 | 50 | 40 | 30 | 20 | 10 | 0  |
| Property  | Film oxidation          | A  | A  | A  | A  | A  | A  | B  | B  | B  |
|           | Gap protrusion          | A  | A  | A  | A  | A  | A  | A  | A  | A  |
|           | Glass flow              | B  | A  | A  | A  | A  | A  | A  | A  | A  |

Magnetic heads having the structure of  $\text{Cr}_2\text{O}_3/\text{SiO}_2$  substituted for the above structure of  $\text{Cr}_2\text{O}_3$ /borosilicate glass were similarly manufactured, varying the thickness of the  $\text{Cr}_2\text{O}_3$  layer and the  $\text{SiO}_2$  layer with an entire

gap length of 80 nm. The properties of these magnetic heads were evaluated similarly as above. The results are shown in Table 2.

Table 2

[unit: nm]

| Thickness | Cr <sub>2</sub> O <sub>3</sub> | 0  | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 |
|-----------|--------------------------------|----|----|----|----|----|----|----|----|----|
|           | SiO <sub>2</sub>               | 80 | 70 | 60 | 50 | 40 | 30 | 20 | 10 | 0  |
| Property  | Film oxidation                 | A  | A  | A  | A  | A  | A  | B  | B  | B  |
|           | Gap protrusion                 | B  | B  | B  | B  | B  | B  | A  | A  | A  |
|           | Glass flow                     | B  | A  | A  | A  | A  | A  | A  | A  | A  |

In Tables 1 and 2, A indicates that the magnetic metal layer is not oxidized, the protrusion of the gap is less than 10 nm, or the lead glass flows well, and B indicates otherwise.

As seen from Tables 1 and 2, the film oxidation of the magnetic metal layer occurs when the thickness of the borosilicate glass layer or the SiO<sub>2</sub> layer is 20 nm or less. Therefore, the thickness of the non-magnetic oxide layer such as the borosilicate glass layer is preferably 30 nm or more. Also, it is confirmed that the protrusion of the gap material after long-time use is controlled by using the borosilicate glass layer as the non-magnetic oxide layer, instead of the SiO<sub>2</sub> layer.

In this example, the thickness of the gap material was 80 nm and the thickness of the non-magnetic oxide was changed within this range. However, the MIG head of the present invention also can be applied to a head having a gap length of about 2  $\mu$  m, for example. Therefore, there is

no specific upper limit for the thickness of the non-magnetic oxide layer. For example, the upper limit is less than  $2\mu\text{m}$  when the MIG head of the present invention is applied to a magnetic head having a gap length of  $2\mu\text{m}$ .

### Example 3

MIG heads were manufactured in the same manner as described in Example 1 except for using an electrical discharge processing. This MIG head has such a feature that the track width is controlled by the electrical discharge machining as shown in Fig. 11. More specifically, the manufacturing method of this MIG head is different from that of Example 1 in that a low melting point lead glass is first molded in a back groove, the electrical discharge machining is conducted for controlling the track, and then the low melting point lead glass is molded in the track grooves in the step of Fig. 3 (e). In such a MIG head, a magnetic gap having a high accuracy was obtained similarly to Example 1 by using the gap material of the structure in which the  $\text{Cr}_2\text{O}_3$  layers are held between the borosilicate glass layers.

The invention may be embodied in other forms without departing from the spirit or essential characteristics thereof. The embodiments disclosed in this application are to be considered in all respects as illustrative and not limitative, the scope of the invention is indicated by the appended claims rather than by the foregoing description, and all changes which come within the meaning and range of equivalency of the claims are intended to be embraced therein.



## WHAT IS CLAIMED IS:

1. A magnetic head of MIG type comprising a gap material in a magnetic gap, the gap material comprising non-magnetic oxide layers, whose main component is  $\text{SiO}_2$ , and  $\text{Cr}_2\text{O}_3$  layers held between the non-magnetic oxide layers.
2. The magnetic head according to claim 1, wherein the non-magnetic oxide layer whose main component is  $\text{SiO}_2$  is a silicate glass layer.
3. The magnetic head according to claim 2, wherein the silicate glass layer is a borosilicate glass layer.
4. The magnetic head according to claim 1, wherein the non-magnetic oxide layer whose main component is  $\text{SiO}_2$  has a thickness of at least 30 nm.
5. The magnetic head according to claim 1, being obtainable by forming a magnetic metal layer, a non-magnetic oxide layer whose main component is  $\text{SiO}_2$ , and a  $\text{Cr}_2\text{O}_3$  layer in this order on each of a pair of half-cores, and bonding the pair of half-cores to each other with a bonding glass softened by heating so that at least a part of the  $\text{Cr}_2\text{O}_3$  layers are in contact with each other.
6. The magnetic head according to claim 5, wherein the bonding glass has a softening point of not more than  $500^\circ\text{C}$ .
7. The magnetic head according to claim 5, wherein the main component of the bonding glass is  $\text{PbO}$ .
8. A method for manufacturing a magnetic head of MIG type comprising the steps of:



forming a magnetic metal layer, a non-magnetic oxide layer whose main component is  $\text{SiO}_2$ , and a  $\text{Cr}_2\text{O}_3$  layer in this order on each of a pair of half-cores; and

bonding the pair of half-cores to each other with a bonding glass softened by heating so that at least a part of the  $\text{Cr}_2\text{O}_3$  layers are in contact with each other to define a magnetic gap with a gap material comprising the non-magnetic oxide layers and the  $\text{Cr}_2\text{O}_3$  layers held between the non-magnetic oxide layers.

9. The method according to claim 8, wherein the bonding glass is softened by heating the bonding glass in an atmosphere containing oxygen at least in the following temperature range:

$$T_g - 85^\circ\text{C} \leq T \leq T_g - 35^\circ\text{C},$$

wherein  $T_g$  is the glass transition point of the bonding glass.

10. The method according to claim 8, wherein the non-magnetic oxide layer whose main component is  $\text{SiO}_2$  is a silicate glass layer.

11. The method according to claim 10, wherein the silicate glass layer is a borosilicate glass layer.

12. The method according to claim 8, wherein the non-magnetic oxide layer whose main component is  $\text{SiO}_2$  has a thickness of at least 30 nm.

13. The method according to claim 8, wherein the bonding glass has a softening point of not more than  $500^\circ\text{C}$ .

14. The method according to claim 8, wherein the main component of the bonding glass is  $\text{PbO}$ .