

ALLOY FOR SOFT MAGNETIC FILM LAYERS, WHICH HAS LOW
SATURATION MAGNETIC FLUX DENSITY AND IS TO BE USED IN
MAGNETIC RECORDING MEDIUM, AND SPUTTERING TARGET
MATERIAL

5

[Cross-Reference to Related Application]

[0001]

This application claims priority to Japanese Patent Application
No. 2012-22096 filed on February 3, 2012, the entire content of
10 which is incorporated herein by reference.

[Technical Field]

[0002]

The present invention relates to an alloy and a sputtering target
material for a soft magnetic film layer used in a magnetic
15 recording medium and having low saturation magnetic flux
density.

[Background Art]

[0003]

In recent years, there have been remarkable progresses in
20 magnetic recording technology, heightening of recording
densities in magnetic recording media has been proceeding due
to increasing drive capacities, and perpendicular magnetic
recording system, which achieves further high recording density
when compared to longitudinal magnetic recording media
25 conventionally used, has been put into practical use.
Furthermore, as an application of the perpendicular magnetic
recording system, a method for assisting recording by heat or
microwaves has also been examined.

[0004]

30 The perpendicular magnetic recording system described above
is a system in which a magnetization-easy axis is oriented in the
direction perpendicular to the medium surface of a magnetic
film of a perpendicular magnetic recording medium, and is a
method suitable for high recording density. For perpendicular
35 magnetic recording system, a double-layer recording medium
having a magnetic recording film layer with an increased

recording sensitivity and a soft magnetic film layer has been developed. For the magnetic recording film layer, a CoCrPt-SiO₂-based alloy is commonly used.

[0005]

5 Further, an Ru film is generally inserted between soft magnetic film layers, and antiferromagnetic coupling (hereinafter referred to as AFC coupling) between the soft magnetic films and the Ru films imparts immunity (hereinafter referred to as H_{bias}) to an external magnetic field. This is for enhancing resistance to an
10 external noise magnetic field in an environment in which a magnetic recording medium is used as disclosed, for example, in Japanese Patent Laid-Open Publication No. 2011-86356 (Patent Literature 1). The alloy for a soft magnetic film layer according to the present invention can be used in these media
15 with the perpendicular magnetic recording system.

[0006]

Further, as for a conventional soft magnetic film layer, high saturation magnetic flux density (hereinafter referred to as B_s) and high amorphous forming ability (hereinafter referred to as
20 an amorphous property) have been essential and, in addition, various properties such as high corrosion resistance and high hardness have been additionally required depending on applications of perpendicular magnetic recording media and environments in which they are used. Among the required
25 properties described above, high B_s is particularly important; for example, Patent Literature 1, Japanese Patent Laid-Open Publication No. 2011-181140 (Patent Literature 2), and Japanese Patent Laid-Open Publication No. 2008-299905 (Patent Literature 3) also aim at high B_s. The reason that such high B_s
30 is required is because B_s that is not less than a certain value is necessary for stabilizing the magnetization of a recording film and is to impart great H_{bias}.

[0007]

However, use of a soft magnetic film with high B_s also has a
35 drawback. The use of the soft magnetic film exhibiting high B_s tends to result in greater H_{bias} and provides high external noise

magnetic field resistance, but also excessively great magnetic flux included in the soft magnetic film significantly influences the surroundings in the case of recording magnetization being magnetized, resulting in a larger space needed for writing and in decreased recording density. Furthermore, it is also observed that the use of the film with high H_{bias} tends to result in gentle reaction of magnetization (hereinafter referred to as the rise of magnetization) for an applied magnetic field greater than or equal to H_{bias} .

10 [0008]

The rise of magnetization for a magnetic field greater than or equal to H_{bias} is schematically shown in Figure 1. In general, a magnetic field that allows magnetization of a soft magnetic film to be saturated is applied in the case of magnetizing on a recording film by writing head. Accordingly, when the rise of magnetization is allowed to be gentle, magnetization requires application of a greater magnetic field corresponding thereto. As mentioned above, increase in magnetic field for magnetization results in unavoidable excessive influence on surroundings, as a consequence, precludes recoding in a limited small region, and also causes a recording density to be decreased. The two phenomena of decreasing a recording density described above are also referred to as so-called "blurred writing"; although the effect of improving blurred writing is provided by suppressing one phenomenon, the effect of improving blurred writing is further provided by suppressing both phenomena.

[Citation List]

[0009]

30 [Patent Literature]

[PTL 1] Japanese Patent Laid-Open Publication No. 2011-86356

[PTL 2] Japanese Patent Laid-Open Publication No. 2011-181140

[PTL 3] Japanese Patent Laid-Open Publication No. 2008-299905

[Summary of the Invention]

35 [0010]

As a result of extensively pursuing development for solving the

above-mentioned problems, the present inventors considered that high resistance to an external magnetic field and a high recording density due to suppression of "blurred writing" become compatible by developing a soft magnetic alloy having high H_{bias} even at comparatively low B_s while having B_s of more than 0.5 T, which can be considered to be B_s minimum for stabilizing magnetization of a recording film, as well as having a sharp rise of magnetization even at high H_{bias}.

[0011]

According to one embodiment of the present invention, there is provided an alloy for a soft magnetic thin film layer in a magnetic recording medium, wherein

the alloy comprises one or more selected from the group consisting of Y, Ti, Zr, Hf, V, Nb, Ta, Cr, Mo, W, Mn, Ni, Cu, Al, B, C, Si, P, Zn, Ga, Ge, and Sn, and the balance Co and Fe; and

in at%, the following formulae (1) to (3):

(1) $0.50 \leq \text{Fe}\% / (\text{Fe}\% + \text{Co}\%) \leq 0.90$;

(2) $5 \leq \text{TAM} \leq 25$; and

(3) $15 \leq \text{TAM} + \text{TNM} \leq 25$

are satisfied,

with the proviso that TAM and TNM are:

$\text{TAM} = \text{Y}\% + \text{Ti}\% + \text{Zr}\% + \text{Hf}\% + \text{V}\% + \text{Nb}\% + \text{Ta}\% + \text{B}\% / 2$; and

$\text{TNM} = \text{Cr}\% + \text{Mo}\% + \text{W}\% + \text{Mn}\% + \text{Ni}\% / 3 + \text{Cu}\% / 3 + \text{Al}\% + \text{C}\% + \text{Si}\% + \text{P}\% + \text{Zn}\% + \text{Ga}\% + \text{Ge}\% + \text{Sn}\%$,

respectively.

[0012]

According to an embodiment of the present invention, it is preferable that, in the above-described alloy, the following formula (4):

(4) $0.25 \leq (\text{Nb}\% + \text{Ta}\%) / (\text{TAM} + \text{TNM}) \leq 1.00$

is satisfied.

[0013]

According to another embodiment of the present invention, it is preferable that in the above-described alloy, the following formulae (5) and/or (6):

(5) $0 \leq \text{Ti}\% + \text{Zr}\% + \text{Hf}\% + \text{B}\% / 2 \leq 5$

(6) $0 < \text{Cu}\% + \text{Sn}\% + \text{Zn}\% + \text{Ga}\% \leq 10$
are satisfied.

[0014]

According to another embodiment of the present invention, it is
5 preferable that

the above-described alloy consists of one or more
selected from the group consisting of Y, Ti, Zr, Hf, V, Nb, Ta, Cr,
Mo, W, Mn, Ni, Cu, Al, B, C, Si, P, Zn, Ga, Ge, and Sn, and the
balance Co and Fe; and

10 in at%, the following formulae (1) to (3):

(1) $0.50 \leq \text{Fe}\% / (\text{Fe}\% + \text{Co}\%) \leq 0.90$;

(2) $5 \leq \text{TAM} \leq 25$; and

(3) $15 \leq \text{TAM} + \text{TNM} \leq 25$

are satisfied,

15 with the proviso that TAM and TNM are:

$\text{TAM} = \text{Y}\% + \text{Ti}\% + \text{Zr}\% + \text{Hf}\% + \text{V}\% + \text{Nb}\% + \text{Ta}\% + \text{B}\% / 2$; and

$\text{TNM} = \text{Cr}\% + \text{Mo}\% + \text{W}\% + \text{Mn}\% + \text{Ni}\% / 3 + \text{Cu}\% / 3 + \text{Al}\% + \text{C}\% +$
 $\text{Si}\% + \text{P}\% + \text{Zn}\% + \text{Ga}\% + \text{Ge}\% + \text{Sn}\%$,
respectively.

20 [0015]

According to another embodiment of the present invention, it is
preferable that the above-described alloy has a saturation
magnetic flux density of more than 0.5 T and less than 1.1 T.

[0016]

25 According to another embodiment of the present invention,
there is provided a sputtering target material comprising the
alloy according to any of the above-described embodiments.

[0017]

As mentioned above, the present invention can provide a soft
30 magnetic amorphous alloy having a low saturation magnetic flux
density, in which the alloy has great immunity to an external
magnetic field in a multilayer film in which a nonmagnetic thin
film of Ru or the like is inserted between thin films of this alloy
films and is subjected to antiferromagnetic coupling; in addition,
35 a soft magnetic alloy for a magnetic recording medium with a
good rise of magnetization to an external magnetic field with

immunity or greater; and a sputtering target material for producing a thin film of this alloy. As described above, soft magnetic alloys in this application have not conventionally had the concept of positively aiming at low Bs. This idea is the most characteristic concept in the present invention.

[Brief Description of the Drawing]

[0018]

Fig. 1 is a schematic view of the magnetization curve of a multilayer film.

Fig. 2 is a view showing a correlation between Bs of a monolayer and Hbias of a multilayer film.

Fig. 3 is a view showing the influence of Ra of the monolayer and Hbias of the multilayer film on the sharpness of the rise of magnetization after Hbias.

[Description of Embodiments]

[0019]

The present invention will be specifically explained below. Unless otherwise specified, "%" means at%.

[0020]

The present invention relates to an alloy for a soft magnetic thin film layer in a magnetic recording medium, wherein

this alloy comprises one or more selected from the group consisting of Y, Ti, Zr, Hf, V, Nb, Ta, Cr, Mo, W, Mn, Ni, Cu, Al, B, C, Si, P, Zn, Ga, Ge, and Sn, and the balance Co and Fe, preferably consists essentially of these elements, more preferably consists of these elements. Moreover, in the alloy according to the present invention, in at%, the following formulae (1) to (3):

$$(1) 0.50 \leq \text{Fe}\% / (\text{Fe}\% + \text{Co}\%) \leq 0.90;$$

$$(2) 5 \leq \text{TAM} \leq 25; \text{ and}$$

$$(3) 15 \leq \text{TAM} + \text{TNM} \leq 25$$

are satisfied,

with the proviso that TAM and TNM are:

$$\text{TAM} = \text{Y}\% + \text{Ti}\% + \text{Zr}\% + \text{Hf}\% + \text{V}\% + \text{Nb}\% + \text{Ta}\% + \text{B}\% / 2; \text{ and}$$

$$\text{TNM} = \text{Cr}\% + \text{Mo}\% + \text{W}\% + \text{Mn}\% + \text{Ni}\% / 3 + \text{Cu}\% / 3 + \text{Al}\% + \text{C}\% + \text{Si}\% + \text{P}\% + \text{Zn}\% + \text{Ga}\% + \text{Ge}\% + \text{Sn}\%,$$

respectively.

[0021]

The present invention will be explained in detail below.

[0022]

5 First, each Hbias of soft magnetic films with various compositions was evaluated in order to examine the influence of the composition of each soft magnetic film on Hbias, and it was thus found that the level of Hbias varies depending not only on the level of Bs, but also on $\text{Fe}\% / (\text{Fe}\% + \text{Co}\%)$. In other words,
10 it was found that even in the case of a soft magnetic film having a Bs of more than 0.5 T and less than 1.1 T, which is comparatively lower than that of each of conventional examples, high Hbias can be obtained by the predetermined range of $\text{Fe}\% / (\text{Fe}\% + \text{Co}\%)$.

15 [0023]

Then, the rise of magnetization due to an applied magnetic field greater than or equal to Hbias was examined, and it was thus found that among the addition elements other than Fe and Co, more Nb and Ta, less Ti, Zr, Hf, and B, and addition of small
20 amounts of Cu, Sn, Zn, and Ga have an influence on the rise. Accordingly, it was found that the effect of showing a sharp rise of magnetization while having high Hbias can be additionally obtained by setting these addition elements to the predetermined amounts.

25 [0024]

Based on such new findings, unlike the required characteristics of a conventional alloy for a soft magnetic film for use in a perpendicular magnetic recording medium, there was found a soft magnetic alloy showing great Hbias while having
30 comparatively low Bs and, in addition, showing a sharp rise of magnetization under an applied magnetic field greater than or equal to Hbias while having high Hbias. Compatibility between high resistance to an external noise magnetic field and high recording density due to suppression of blurred writing, which
35 was conventionally difficult, was thus enabled to accomplish the present invention. The reasons of the limitations of the alloy of

the present invention will be explained below.

[0025]

(a) $0.50 \leq \text{Fe}\% / (\text{Fe}\% + \text{Co}\%) \leq 0.90$

Fe and Co are elements for imparting minimal magnetization
 5 necessary for stabilizing the magnetization of a recording film,
 and the behaviors of Bs and $\text{Fe}\% / (\text{Fe}\% + \text{Co}\%)$ are shown in
 so-called Slater-Pauling curve or the like. Furthermore,
 $\text{Fe}\% / (\text{Fe}\% + \text{Co}\%)$ is also an important factor for providing high
 Hbias even at comparatively low Bs. When $\text{Fe}\% / (\text{Fe}\% + \text{Co}\%)$ is
 10 less than 0.50, Hbias is lowered when compared to a soft
 magnetic film having similar Bs and $\text{Fe}\% / (\text{Fe}\% + \text{Co}\%)$ of 0.50 or
 more. Although the detailed cause of this phenomenon is
 unclear, Bs of a soft magnetic film and an interlayer interaction
 due to the 3d electron orbits of magnetic elements are
 15 considered to be involved in AFC coupling, and it is presumed
 that the AFC coupling is influenced by a change in the
 interaction depending on a ratio between Fe and Co. When
 $\text{Fe}\% / (\text{Fe}\% + \text{Co}\%)$ is more than 0.90, Bs is significantly
 decreased, resulting in insufficient Hbias. In addition, the
 20 preferable range of $\text{Fe}\% / (\text{Fe}\% + \text{Co}\%)$ is 0.55 or more and 0.85
 or less, more preferably 0.60 or more and 0.80 or less.

[0026]

(b) $5 \leq \text{TAM} \leq 25$ and $15 \leq \text{TAM} + \text{TNM} \leq 25$

The effects of the elements other than Fe and Co are
 25 summarized as follows. Ti, Zr, Hf, and B are elements that lead
 to promotion of amorphization and reduction in Bs, and that
 allow the rise of magnetization to be greatly gentle. B can be
 treated as $\text{B}\% / 2$ in TAM because of having the effect of reducing
 Bs and enhancing an amorphous property that is about 1/2
 30 compared to those of Ti, Zr, and Hf. However, since B in a
 sputtering target material generates a particularly hard
 compound (e.g., borides), which makes it necessary to decrease
 a processing speed in machining, B is preferably added with
 other elements classified as TAM, rather than added separately.
 35 In view of this, $(\text{B}/2) / \text{TAM}$ is preferably 0.8 or less, more
 preferably 0.5 or less.

[0027]

Y, V, Cr, Mo, and W are elements that lead to reduction in Bs and also allow the rise of magnetization to be slightly gentle. Y and V also contribute to promotion of amorphization. Nb and Ta are important elements that lead to promotion of amorphization and reduction in Bs, as well as having the effect of making the rise of magnetization to be sharp. Mn, Al, Si, Ge, and P are elements that lead to reduction in Bs and allow the rise of magnetization to be slightly gentle. Ni and Cu are elements that lead to a low decrease in Bs, and Cu is an element that has the effect of making the rise of magnetization to be sharp when added in a small amount, but slightly reduces the rise of magnetization when added in a large amount.

[0028]

Ni and Cu can be treated as Ni%/3 and Cu%/3 in TNM because of showing a decrease in Bs of about 1/3 compared to the other elements classified as TAM and TNM. Ga, Sn, and Zn are elements that lead to reduction in Bs and have the effect of making the rise of magnetization to be sharp when added in a small amount, but allow the rise of magnetization to be slightly gentle when added in a large amount. As described above, all the elements have the effect of reducing Bs, and some of the elements have the effect of improving an amorphous property and influence the rise of magnetization. The alloy according to the present invention is obtained by optimizing the addition amounts of the elements.

[0029]

TAM of less than 5 results in an insufficient amorphous property, while TAM of more than 25 results in low Bs and insufficient Hbias. Accordingly, TAM is 5 or more and 25 or less, preferably 7 or more and 23 or less, more preferably 9 or more and less than 20. Since Nb and Ta produce a brittle intermetallic compound with Fe and Co in a sputtering target material, it is necessary to decrease a processing speed to prevent cracking and chipping in machining, when only Nb or/and Ta are added as TAM. In consideration of this, it is preferable that TAM is

less than 20, when only Nb or/and Ta are added as TAM.

[0030]

TAM+TNM of less than 15 increases Bs, resulting in a gentle rise of magnetization, although H_{bias} is increased. TAM+TNM of more than 25 results in low Bs and low H_{bias}. Accordingly, TAM+TNM is 15 or more and 25 or less, preferably 17 or more and 23 or less, more preferably 18 or more and 21 or less.

[0031]

(c) $0.25 \leq (\text{Nb}\% + \text{Ta}\%) / (\text{TAM} + \text{TNM}) \leq 1.00$

Although Nb and Ta are important elements that have the additional effect of making the rise of magnetization to be sharp in this alloy as described above, this effect is not obtained when $(\text{Nb}\% + \text{Ta}\%) / (\text{TAM} + \text{TNM})$ is less than 0.25. Since the addition amounts of Nb and Ta are also included in TAM, the upper limit of $(\text{Nb}\% + \text{Ta}\%) / (\text{TAM} + \text{TNM})$ is necessarily 1.00. Accordingly, $(\text{Nb}\% + \text{Ta}\%) / (\text{TAM} + \text{TNM})$ is 0.25 or more and 1.00 or less, preferably 0.40 or more and less than 1.00, more preferably 0.60 or more and less than 1.00.

[0032]

(d) $0 \leq \text{Ti}\% + \text{Zr}\% + \text{Hf}\% + \text{B}\% / 2 \leq 5$ and $0 < \text{Cu}\% + \text{Sn}\% + \text{Zn}\% + \text{Ga}\% \leq 10$

Since Ti, Zr, Hf, and B are elements that allow the rise of magnetization to be greatly gentle in this alloy as described above, a sharper rise of magnetization is provided as an additional effect by strictly defining the upper limit of the total amount thereof. When $\text{Ti}\% + \text{Zr}\% + \text{Hf}\% + \text{B}\% / 2$ is more than 5, the effect of making the rise of magnetization to be sharp is not obtained. Accordingly, $\text{Ti}\% + \text{Zr}\% + \text{Hf}\% + \text{B}\% / 2$ is 0 or more and 5 or less, preferably 3 or less, more preferably 0.

[0033]

Since Cu, Sn, Zn, and Ga are the elements that have the additional effect of making the rise of magnetization to be sharp when added in a small amount in this alloy as described above, a sharper rise of magnetization is provided by positively adding a small amount of these elements. However, when $\text{Cu}\% + \text{Sn}\% + \text{Zn}\% + \text{Ga}\%$ is more than 10, this effect is not

obtained. Accordingly, $Cu\%+Sn\%+Zn\%+Ga\%$ is more than 0 and 10 or less, preferably 1 or more and 8 or less, more preferably 2 or more and 6 or less. Even when only any one of these formulae is satisfied, the additional effect of making the
5 rise of magnetization to be sharp is obtained.

[0034]

Various elements have an influence on the rise of magnetization as well as an influence on Bs as described above; although its detailed cause is unclear, the following is presumed. It is seen
10 that the surface roughness of a sputtered film in a soft magnetic alloy tends to influence the sharpness of the rise of magnetization to an applied magnetic field greater than or equal to Hbias. It is considered that AFC coupling in an interface between a soft magnetic film and an Ru film cannot endure a
15 large applied magnetic field and flux reversal occurs in the phenomenon of the rise of magnetization due to an external magnetic field greater than or equal to Hbias; when the surface of the soft magnetic film is rough and concave portions and convex portions exist on the interface between the both films, a
20 site in which flux reversal early occurs and a site in which flux reversal slowly occurs can locally coexist.

[0035]

When discordance of flux reversal behaviors occurs in sites as described above, the rise of magnetization becomes gentle on
25 an overall film. Therefore, it is considered that there is a correlation between the surface roughness of a sputtered film and the sharpness of the rise of magnetization. Furthermore, it is presumed that a free volume and an excess free volume as an amorphous alloy can affect the influence of the addition
30 elements on the surface roughness of the sputtered film. Both of these volumes are volumes corresponding to gaps between atoms in the amorphous alloy, and it is considered that when the volumes are large, atoms do not densely gather in the alloy, and the surface roughness is thus increased in terms of an
35 atomic size level in the sputtered film.

[0036]

It is suggested that the stability of an amorphous state can relate to the both volumes; however, in the present invention, Ti, Zr, Hf, and B, which allow the rise of magnetization to be greatly gentle, are elements that particularly stabilize an amorphous state, while Cu, Ga, Sn, and Zn, which make the rise of magnetization to be sharp when added in a small amount, are elements that deteriorate amorphous properties. Furthermore, Nb and Ta, which are important elements that make the rise of magnetization to be sharp, are elements having the low effect of promoting amorphization when compared to Ti, Zr, Hf, and B.

[Examples]

[0037]

The present invention is specifically explained below with reference to Examples.

[0038]

A soft magnetic alloy powder with the composition shown in Table 1 was produced by a gas atomization method. A molten base material, which was 25 kg, was induction-melted in Ar with a reduced pressure, an alloy molten metal was tapped from a nozzle having a diameter of 8 mm, and just thereafter, a high-pressure Ar gas was sprayed to perform atomization. The powder was classified into 500 μm or less and used as a raw powder for HIP molding (hot isostatic press). A carbon steel can having a diameter of 200 mm and a length of 10 mm was filled with the raw powder, then subjected to vacuum deaeration, and sealed to produce a billet for HIP molding. The billet filled with the powder was HIP-molded under conditions of a temperature of 1100°C, a pressure of 120 MPa, and a retention time of 2 hours. Then, a soft magnetic alloy sputtering target material having a diameter of 95 mm and a thickness of 2 mm was produced from the molded body. A soft magnetic thin film was produced using the sputtering target material made of the soft magnetic alloy. Further, a commercially available sputtering target material made of an Ru metal was used for producing a Ru thin film.

[0039]

The inside of a chamber was evacuated to 1×10^{-4} Pa or less, Ar gas with a purity of 99.99% was charged at 0.6 Pa, and sputtering was performed. First, the soft magnetic alloy thin film (lower soft magnetic layer) of 20 nm was formed on a cleaned glass substrate, the Ru film of 0.8 nm was formed thereon, and the soft magnetic alloy thin film (upper soft magnetic layer) of 20 nm which was the same as the above-mentioned film was further formed thereon, to produce a multilayer film. The same alloy was used in the upper and lower soft magnetic films in the multilayer films in all the examples and comparative examples. A monolayer in which only the lower soft magnetic layer was formed was also produced for evaluating the Bs, crystal structure, and surface roughness of the soft magnetic film.

[0040]

The monolayer film produced in such a manner was used as a sample, and Bs, a crystal structure, and an arithmetic mean roughness Ra (surface roughness) were evaluated using VSM (sample-vibration-type magnetic-flux meter), X-ray diffraction, and AFM (atomic force microscope), respectively. For the crystal structure, an amorphous state was evaluated as "good," a case in which a microcrystal was partially observed in an amorphous state was evaluated as "fair," and a crystal was evaluated as "poor." Hbias and the sharpness of the rise of magnetization were further evaluated with the multilayer film. These results are as shown in Table 2.

[0041]

Figure 1 is a schematic view of the magnetization curve of the multilayer film. As shown in this view, Hbias was evaluated by an applied magnetic field at the time of the rise of the magnetization of the multilayer film, and the sharpness of the rise of the magnetization was evaluated by a ratio between an applied magnetic field (Hsat) in which the magnetization of the multilayer film was saturated and Hbias, i.e., Hsat/Hbias. Figure 1(a) shows an example in which Hbias is high and the

rise of magnetization is sharp, while Figure 1(b) shows an example in which H_{bias} is low and the rise of magnetization is gentle. In other words, this value that is low and closer to 1 shows a sharper rise of magnetization. This value of less than 1.2 was evaluated as "A," this value of 1.2 or more and less than 1.4 was evaluated as "B," this value of 1.4 or more and less than 1.8 was evaluated as "C," and this value of 1.8 or more was evaluated as "D."

[0042]

10 [Table 1]

Table 1

No.	Alloy Composition (at%)																								TAM	TNM	Fe/(Fe+Co)	TAM+TNM	(Nb+Ta)/(TAM+TNM)	Ti+Zr+Hf+B/2	Cu+Sn+Zn+Ga
	Co	Fe	Y	Ti	Zr	Hf	V	Nb	Ta	Cr	Mo	W	Mn	Ni	Cu	Al	B	C	Si	P	Zn	Ga	Ge	Sn							
1	27	50	0	4	0	0	3	1	3	4	0	0	0	0	0	0	8	0	0	0	0	0	0	0	15	4	0.65	19	0.21	8	0
2	16	65	3	0	6	0	6	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	15	4	0.80	19	0.00	6	0
3	22	52	0	8	0	0	0	2	0	0	4	0	0	0	12	0	0	0	0	0	0	0	0	0	10	8	0.70	18	0.11	8	12
4	34	50	0	0	7	0	0	0	1	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	8	0.60	16	0.06	7	0
5	42	42	0	1	0	7	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0.50	16	0.00	8	0
6	31	46	0	0	6	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	11	12	0.60	23	0.22	6	12
7	29	53	0	0	10	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18	0	0.65	18	0.00	10	0
8	40	41	1	0	6	0	0	0	8	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	4	0.51	19	0.42	6	0
9	24	57	0	8	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19	0	0.70	19	0.58	8	0
10	25	57	0	0	5	5	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18	0	0.70	18	0.44	10	0
11	33	49	0	0	6	0	0	0	8	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	16	0	0.60	16	0.50	8	0
12	22	53	0	0	6	0	0	0	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25	0	0.71	25	0.76	6	0
13	35	42	0	0	0	0	0	15	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	2	15	4	0.55	19	0.79	0	2
14	32	49	0	0	0	2	11	2	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	15	4	0.60	19	0.11	2	0
15	24	57	0	0	2	3	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	12	0	0	5	14	0.70	19	0.00	5	12
16	24	56	0	0	0	2	0	4	0	0	0	0	6	0	0	0	2	0	6	0	0	0	0	0	7	12	0.70	19	0.21	3	0
17	24	57	0	0	0	2	0	0	7	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	9	10	0.70	19	0.37	2	0
18	23	52	0	10	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	5	0	0	5	15	10	0.69	25	0.20	10	10
19	23	54	2	4	0	4	0	5	0	0	0	0	0	0	3	5	0	0	0	0	0	0	0	0	15	6	0.70	21	0.24	8	3
20	24	55	0	0	0	0	0	7	8	0	0	0	0	0	0	0	0	0	0	3	3	0	0	0	15	6	0.70	21	0.71	0	3
21	25	57	2	2	1	0	3	3	4	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	15	3	0.70	18	0.39	3	0
22	24	55	0	0	0	0	0	6	5	0	0	0	0	0	0	0	8	0	0	0	0	2	0	0	15	2	0.70	17	0.65	4	2
23	26	59	0	0	5	0	7	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0	0.69	15	0.20	5	0
24	24	57	0	0	0	0	0	0	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19	0	0.70	19	1.00	0	0
25	24	57	0	0	0	5	8	0	5	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	18	1	0.70	19	0.26	5	0
26	20	61	0	1	0	0	0	10	4	0	0	2	0	0	0	0	0	0	0	0	0	2	0	2	15	4	0.75	19	0.74	1	0
27	12	69	0	0	0	0	0	0	15	0	2	0	0	0	0	0	0	0	0	0	0	0	2	0	15	4	0.85	19	0.79	0	0
28	8	73	0	0	0	0	11	2	2	2	0	0	0	0	0	0	0	0	2	0	0	0	0	0	15	4	0.90	19	0.21	0	0
29	57	24	1	0	6	0	0	0	8	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	4	0.30	19	0.42	6	0
30	49	32	1	0	6	0	0	0	8	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	4	0.40	19	0.42	6	0
31	45	36	1	0	6	0	0	0	8	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	4	0.44	19	0.42	6	0
32	4	77	0	0	0	0	11	2	2	2	0	0	0	0	0	0	0	0	2	0	0	0	0	0	15	4	0.95	19	0.21	0	0
33	0	81	0	0	0	0	11	2	2	2	0	0	0	0	0	0	0	0	2	0	0	0	0	0	15	4	1.00	19	0.21	0	0
34	22	50	0	8	0	0	0	12	0	4	0	0	4	0	0	0	0	0	0	0	0	0	0	0	20	8	0.69	28	0.43	8	0
35	21	49	0	10	0	0	0	0	5	0	0	5	0	0	0	0	0	0	0	0	5	0	0	5	15	15	0.70	30	0.17	10	10
36	22	50	0	8	0	0	0	18	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	26	2	0.69	28	0.64	8	0
37	26	60	0	0	5	0	6	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	0	0.70	14	0.21	5	0
38	24	57	0	0	2	2	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	12	0	0	4	15	0.70	19	0.00	4	12
39	55	37	0	0	5	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0.40	8	0.38	5	0

NOTE 1: The underlined figures fall outside the scope of the present invention.

Present Invention Examples

Comparative Examples

[0043]
[Table 2]

Table 2

No.	Bs (T)	Crystal Structure	Ra (nm)	Hbias (A/m)	Rise of Magnetization	
1	0.96	Good	0.8	6560	C	Present Invention Examples
2	0.72	Good	0.8	5600	C	
3	0.94	Good	0.9	6300	C	
4	1.09	Good	1.0	7010	C	
5	1.09	Good	0.9	7020	C	
6	0.72	Good	0.9	5310	C	
7	0.96	Good	0.8	6600	C	
8	0.90	Good	0.6	5600	B	
9	0.90	Good	0.5	6240	B	
10	0.94	Good	0.5	6520	B	
11	1.08	Good	0.5	6650	B	
12	0.65	Good	0.5	5020	B	
13	0.93	Good	0.1	6000	A	
14	0.95	Good	0.3	6400	B	
15	0.92	Fair	0.3	6480	B	
16	0.91	Good	0.3	6480	B	
17	0.90	Good	0.2	6560	A	
18	0.67	Good	0.3	5520	B	
19	0.74	Good	0.3	5680	B	
20	0.84	Good	0.1	6160	A	
21	0.89	Good	0.2	6400	A	
22	1.01	Good	0.1	6880	B	
23	1.09	Good	0.3	7040	C	
24	0.88	Good	0.2	6320	A	
25	0.89	Good	0.2	6240	A	
26	0.85	Good	0.2	6080	A	
27	0.69	Good	0.2	5200	A	
28	0.58	Good	0.3	4750	B	
29	0.80	Good	0.6	3120	B	Comparative Examples
30	0.84	Good	0.5	3360	B	
31	0.86	Good	0.6	3840	B	
32	0.48	Good	0.3	3600	B	
33	0.47	Good	0.3	3120	B	
34	0.49	Good	0.6	3840	B	
35	0.49	Good	0.3	3600	B	
36	0.48	Good	0.6	3760	B	
37	1.14	Good	0.3	7200	D	
38	0.89	Poor	1.6	6600	D	
39	1.57	Good	0.3	6350	B	

As shown in Table 1 and Table 2, Nos. 1 to 28 are present invention examples, while Nos. 29 to 39 are comparative examples.

[0044]

Figure 2 is a view in which the results of Table 2 are plotted for

Hbias of the multilayer film on the vertical axis and Bs of the monolayer on the horizontal axis. As shown in the ellipse with a solid line in this view, it is found that high Bs is necessary for obtaining high Hbias. Each of the data in the ellipse with a solid line has $\text{Fe}\% / (\text{Fe}\% + \text{Co}\%)$ within a range of 0.5 to 0.9. In contrast, Comparative Example Nos. 29 to 31 located below the ellipse with a solid line in Figure 2 show Bs equivalent to the data in the ellipse with a solid line, but show low Hbias values due to $\text{Fe}\% / (\text{Fe}\% + \text{Co}\%)$ being less than 0.5. In other words, high Hbias is obtained even at comparatively low Bs by adjusting $\text{Fe}\% / (\text{Fe}\% + \text{Co}\%)$ to be 0.50 to 0.90.

[0045]

In contrast, Comparative Example Nos. 32 to 36 located in the ellipse with a dotted line, which is in the lower left of Figure 2, show significantly low Bs and therefore also show low Hbias. Further, Comparative Example No. 39 has a composition, in which $\text{Fe}\% / (\text{Fe}\% + \text{Co}\%)$ is as low as 0.4 and TAM+TNM is less than 15, and which is a composition of high Bs, frequent in the conventional art. This composition is shown in the plot located on the right side of the ellipse with a solid line in Figure 2, significantly high Bs is required for obtaining high Hbias equivalent to the composition in the ellipse with a solid line, and such a composition causes so-called "blurred writing."

[0046]

Figure 3 is a view in which the results of Table 2 are plotted for Hbias of the multilayer film on the vertical axis and Ra of the monolayer on the horizontal axis, in which the mark of the plot is changed according to the sharpness of the rise of the magnetization of the multilayer film at the time of applying an external magnetic field greater than or equal to Hbias. From this view, it is found that the rise of the magnetization is deteriorated when the surface roughness (Ra) of the monolayer is high, even in the case of the multilayer films having equivalent Hbias.

[0047]

Each of comparative example data shown in Table 2 is explained.

Comparative Example Nos. 29 to 31 do not show high Hbias although having Bs of 0.80 to 0.86 T, because each of the $\text{Fe}\% / (\text{Fe}\% + \text{Co}\%)$ value is low. Since Comparative Example Nos. 32 and 33 show excessively high $\text{Fe}\% / (\text{Fe}\% + \text{Co}\%)$ values, Comparative Example Nos. 34 and 35 show high TAM+TNM, and Comparative Example No. 36 shows high TAM and high TAM+TNM, each example shows significantly low Bs and does not show high Hbias.

[0048]

Comparative Example No. 37 shows a gentle rise of magnetization to an external magnetic field with more than Hbias, although showing high Bs and high Hbias because of showing low TAM+TNM. Comparative Example No. 38 shows low TAM, is crystalline, shows high Ra due to concave portions and convex portions on a monolayer film surface caused by crystal grains, and shows a gentle rise of magnetization to an external magnetic field with more than Hbias. Comparative Example No. 39 shows only Hbias of which the level is equivalent to that of each working example, although showing significantly high Bs because the $\text{Fe}\% / (\text{Fe}\% + \text{Co}\%)$ value and TAM+TNM are low, and such a composition with significantly high Bs causes so-called "blurred writing."

[0049]

It is found that compared to these examples, Example Nos. 1 to 28 have Bs of less than 1.1 T, which is lower than that of the conventional art, but have high Hbias, since all the examples are within the scope of the present invention, and further show a sharp rise of magnetization to an applied magnetic field with more than Hbias. Such a composition enables compatibility between resistance to high external noise magnetic field and suppression of blurred writing due to excessively high Bs. Example Nos. 8 to 12 also show the additional effects of lower roughness (Ra) of a monolayer film and a sharper rise of magnetization when compared to those in Example Nos. 1 to 7, because $(\text{Nb}\% + \text{Ta}\%) / (\text{TAM} + \text{TNM})$ is within the range of 0.5 to 1.0.

[0050]

Furthermore, Example Nos. 13 to 28 also show the additional effects of lower roughness (Ra) of a monolayer and a sharper rise of magnetization when compared to those in Example Nos. 1 to 7, because $Ti\%+Zr\%+Hf\%+B\%/2$ is 5 or less and/or $Cu\%+Sn\%+Zn\%+Ga\%$ is more than 0 and not more than 10. It is found that Example No. 23 has a rise of magnetization equivalent to those of Example Nos. 1 to 7, because $Ti\%+Zr\%+Hf\%+B\%/2$ is 5 or less while its Hbias is the highest in the examples.

[0051]

As described above, the present invention shows the excellent effect of being capable of providing an alloy for a soft magnetic film layer having a low saturation magnetic flux density and a sputtering target material that enable compatibility between high resistance to an external magnetic field and high recording density due to suppression of "blurred writing," because the alloy has high Hbias even at comparatively low Bs while having minimum Bs for stabilizing the magnetization of a recording film, and further having a sharp rise of magnetization as an additional effect.

Claims

1. An alloy for a soft magnetic thin film layer in a magnetic recording medium, wherein

the alloy comprises one or more selected from the group consisting of Y, Ti, Zr, Hf, V, Cr, Mo, W, Mn, Ni, Cu, Al, B, C, Si, P, Zn, Ga, Ge, and Sn, and the balance Co and Fe; and

in at%, the following formulae (1) to (4) and (X):

$$(1) 0.65 \leq \text{Fe}\% / (\text{Fe}\% + \text{Co}\%) \leq 0.80;$$

$$(2) 5 \leq \text{TAM} \leq 25;$$

$$(3) 15 \leq \text{TAM} + \text{TNM} \leq 25;$$

$$(4) (\text{Nb}\% + \text{Ta}\%) / (\text{TAM} + \text{TNM}) = 0; \text{ and}$$

$$(X) (\text{B}/2) / \text{TAM} \leq 0.8,$$

are satisfied,

with the proviso that TAM and TNM are:

$$\text{TAM} = \text{Y}\% + \text{Ti}\% + \text{Zr}\% + \text{Hf}\% + \text{V}\% + \text{B}\% / 2; \text{ and}$$

$$\text{TNM} = \text{Cr}\% + \text{Mo}\% + \text{W}\% + \text{Mn}\% + \text{Ni}\% / 3 + \text{Cu}\% / 3 + \text{Al}\% + \text{C}\% + \text{Si}\% + \text{P}\% + \text{Zn}\% + \text{Ga}\% + \text{Ge}\% + \text{Sn}\%,$$

respectively, and

with the proviso that the following compositions (A) to (E) are excluded:

(A) a composition consisting of Co, Fe, Zr, B, W, V, Mn, and C, wherein the total content of Co and Fe is 83 at.%, the ratio of the Co content to the Fe content (Co:Fe) is 35:65, the content of Zr is 8 at.%, the content of B is 1 at.%, the content of W is 5 at.%, the content of V is 1 at.%, the content of Mn is 1 at.%, and the content of C is 1 at.%;

(B) a composition consisting of Co, Fe, Zr, B, V, Mo, and Ge, wherein the total content of Co and Fe is 84 at.%, the ratio of the Co content to the Fe content (Co:Fe) is 35:65, the content of Zr is 8 at.%, the content of B is 1 at.%, the content of V is 5 at.%, the content of Mo is 1 at.%, and the content of Ge is 1 at.%;

(C) a composition consisting of Co, Fe, Zr, W, and Mo, wherein the total content of Co and Fe is 83 at.%, the ratio of the Co content to the Fe content (Co:Fe) is 35:65, the content of Zr is 8 at.%, the content of W is 8 at.%, and the content of Mo is 1 at.%;

(D) a composition consisting of Co, Fe, Zr, V, Mn, and P, wherein the total content of Co and Fe is 83 at.%, the ratio of the Co content to the Fe content (Co:Fe) is 35:65, the content of Zr is 8 at.%, the content of V is 4 at.%, the content of Mn is 4 at.%, and the content of P is 1 at.%; and

(E) a composition consisting of Co, Fe, Zr, W, Al, Cr, and Si, wherein the total content of Co and Fe is 80 at.%, the ratio of the Co content to the Fe content (Co:Fe) is 35:65, the content of Zr is 8 at.%, the content of W is 3 at.%, the content of Al is 3 at.%, the content of Cr is 3 at.%, and the content of Si is 3 at.%.

2. The alloy according to claim 1, wherein the following formulae (5) and/or (6):

$$(5) 0 \leq \text{Ti}\% + \text{Zr}\% + \text{Hf}\% + \text{B}\% / 2 \leq 5$$

$$(6) 0 < \text{Cu}\% + \text{Sn}\% + \text{Zn}\% + \text{Ga}\% \leq 10$$

are satisfied.

3. The alloy according to claim 1 or 2, wherein

the alloy consists of one or more selected from the group consisting of Y, Ti, Zr, Hf, V, Cr, Mo, W, Mn, Ni, Cu, Al, B, C, Si, P, Zn, Ga, Ge, and Sn, and the balance Co and Fe.

4. The alloy according to any one of claims 1 to 3, wherein the alloy has a saturation magnetic flux density of more than 0.5 T and less than 1.1 T.

5. A sputtering target material for producing a soft magnetic thin film comprising the alloy according to any one of claims 1 to 4.