

Fe-Co-Based Alloy Target And Method For Producing The Same

The present invention relates to an Fe-Co-based alloy target and a method for producing the same, more particularly to an Fe-Co-based alloy target and a method thereof for perpendicular magnetic recording media.

Longitudinal magnetic recording (LMR) and perpendicular magnetic recording (PMR) are technologies for magnetic data storage, particularly hard disk drives (HDD). LMR aligns to the direction of magnetization horizontally in relation to the drive's spinning platter, while PMR aligns direction of magnetization perpendicularly in relation to the drive's spinning platter.

In the past, the hard disk drive industry focused on the LMR technology. In order to increase the storage capacity, the areal density — the number of bits that could be stored on a square centimeter of HDD — doubled every year. However, LMR had a limit of areal density of 100 gigabits per square inch (Gb/in²) to 200 Gb/in² because of the superparamagnetic effect. Therefore, PMR technology has emerged as a solution capable of recording more data onto each hard disk drive and enabling higher storage density.

Common perpendicular magnetic recording media comprise a substrate, a soft underlayer, a seed layer, an inter layer, a recording layer, a cover layer, a lubricating layer, etc. from bottom to top. The soft underlayer whose function is to increase a disk's write efficiency is sputtered from an iron-cobalt-based (Fe-Co-based) alloy target.

Nowadays, Fe-Co-based alloy targets are doped with transition elements such as tantalum (Ta), niobium (Nb), and molybdenum (Mo) in order to improve the bending strength. However, the addition of the transition

elements would significantly increase the percentage of the white phase of the Fe-Co-based alloy target. As shown in FIG. 1, when the 53Fe-29Co-18Ta alloy target with an aggregated white phase is sputtered to form an Fe-Co-based soft underlayer, nuclei are easily generated and thus form crystals on the surface of the Fe-Co-based soft underlayer. Therefore, the flatness of the Fe-Co-based soft underlayer is reduced.

When the surface roughness of the Fe-Co-based soft underlayer increases, the flatness of both the seed layer and the recording layer covering the Fe-Co-based soft underlayer is reduced. Therefore, the distance between a recording layer and a read/write head varies, resulting in increased signal-to-noise ratio and thus decreasing the storage capacity of perpendicular magnetic recording media.

To overcome the shortcomings, the objective of the present invention provides an Fe-Co-based alloy target, which not only maintains the bending strength but also mitigates growth and aggregation of the white phase of the Fe-Co-based alloy target. Therefore, an Fe-Co-based soft underlayer sputtered from the Fe-Co-based alloy target has excellent flatness.

Another objective of the present invention is to improve the flatness of a seed layer and/or a recording layer covering the Fe-Co-based soft underlayer, thus increasing the storage capacity of perpendicular magnetic recording media.

To achieve the aforementioned objectives, the present invention provides an Fe-Co-based alloy target, which consists of iron, cobalt, and first and second additives. The first additive is rhenium (Re), ruthenium (Ru), or

their combination, and the second additive is selected from the group consisting of tantalum, niobium, molybdenum, tungsten (W), chromium (Cr), boron (B), and any combination thereof. Based on a total amount of the Fe-Co-based alloy target, a total amount of the first additive is more than or equal to 2 atomic percent (at%) and less than or equal to 7 at%, and a total amount of the first and second additives is more than or equal to 27 at% and less than or equal to 35 at%. Herein, the total amount of the Fe-Co-based alloy target is directed to the sum of the amounts of iron, cobalt, the first additive, and the second additive.

By means of doping specific first and second additives into an Fe-Co-based alloy target and simultaneously controlling the total amount of the first additive as well as the total amount of the first and second additives, the bending strength of the Fe-Co-based alloy target is maintained, and the percentage of the white phase of the Fe-Co-based alloy target is also decreased. Therefore, the growth and aggregation of the white phase are effectively suppressed or mitigated, and thus nuclei or crystals generated on the surface of the Fe-Co-based soft underlayer are prevented, thereby improving the flatness of the Fe-Co-based soft underlayer as well as the seed layer and the recording layer covering thereon. When such Fe-Co-based soft underlayer is applied to perpendicular magnetic recording media, the surface roughness of the Fe-Co-based soft underlayer and/or the seed layer is reduced, so that both the signal-to-noise ratio and the storage capacity of perpendicular magnetic recording media can be improved.

Preferably, when the total amount of the first additive is more than or equal to 2 at% and less than or equal to 5 at%, the dilution of saturation

magnetization can be mitigated, thereby improving magnetic properties of the Fe-Co-based soft underlayer therefrom.

Preferably, the total amount of the first and second additives of the Fe-Co-based alloy target is more than or equal to 29 at% and less than or equal to 33 at%. When the total amount of the first and second additives is more than or equal to 29 at%, the Fe-Co-based alloy target can be sputtered to prepare an Fe-Co-based soft underlayer with reduced coercivity (H_c). When the total amount of the first and second additives is less than or equal to 33 at%, the dilution of saturation magnetization can also be mitigated, thereby improving magnetic properties of the Fe-Co-based soft underlayer therefrom.

The magnetization of a magnetic material increases as the strength of the externally applied magnetic field increases. In the present specification, the term “saturation magnetization” refers to the maximum magnetization of a magnetic material that can be magnetized under an external magnetic field.

In the present specification, the term “coercivity” refers to the magnetic-field strength necessary to demagnetize a material that is magnetized to saturation.

In the present specification, the term “bending strength” refers to the ultimate bending stress that can be applied on a sectional area of a sputtering target in such a way that the sputtering target can withstand before breaking.

In the present specification, when the first additive includes rhenium and ruthenium, the term “the total amount of the first additive” refers to the sum of the amount of rhenium and ruthenium; when the first additive includes either rhenium or ruthenium, the term “the total amount of the first additive”

refers to the individual amount of either rhenium or ruthenium.

Similarly, when the second additive includes multiple different elements, the term "the total amount of the second additive" refers to the sum of the amount of each individual element; in another aspect, when the second additive includes single element, the term "the total amount of the second additive" refers to the individual amount of the single element. For example, when the second additive includes tantalum, chromium, and boron, the total amount of the second additive is the sum of the amount of tantalum, chromium, and boron; in another aspect, when the second additive includes only tantalum, the total amount of the second additive is the individual amount of tantalum.

Further, in the present specification, the term "the total amount of the first and second additives" refers to the sum of the total amount of the first additive and the total amount of the second additive.

In accordance with the present invention, the bending strength of the Fe-Co-based alloy target is more than or equal to 1500 million pascals (MPa). Specifically, the bending strength of the Fe-Co-based alloy target is more than or equal to 1500 MPa and less than or equal to 3500 MPa; preferably, it is more than or equal to 2000 MPa and less than or equal to 3000 MPa; more preferably, it is more than or equal to 2500 MPa and less than or equal to 3000 MPa.

By means of controlling the total amount of the first additive as well as the total amount of the first and second additives, the number of maximum inscribed circles with a diameter more than 3 μm in the white phase, i.e., the rhenium-rich phase and/or the ruthenium-rich phase, is less than or equal to 5. Herein, with said composition, an aggregation of white phase in the

Fe-Co-based alloy target is significantly suppressed, so that the Fe-Co-based soft underlayer has improved flatness, thereby improving the flatness of the seed layer covering the Fe-Co-based soft underlayer.

Preferably, the diameter of each individual maximum inscribed circle in the white phase is less than or equal to 3 μm . In this embodiment, a maximum inscribed circle with a diameter of more than 3 μm was not found in the white phase, that is, the number of maximum inscribed circles with a diameter more than 3 μm in the white phase is zero.

In accordance with the present invention, the surface roughness of the seed layer formed on the Fe-Co-based soft underlayer of the present invention is less than 1.5 nanometers (nm); preferably, it is less than 1.3 nm; more preferably, it is less than 1.2 nm.

In accordance with the present invention, a method of producing the Fe-Co-based alloy target comprises:

mixing raw materials of iron, cobalt, and the first and second additives, and melting and casting the raw materials to obtain a prealloyed ingot, the first additive being rhenium, ruthenium, or their combination, and the second additive being selected from the group consisting of tantalum, niobium, molybdenum, tungsten, chromium, boron, and any combination thereof, wherein based on a total amount of the prealloyed ingot, a total amount of the first additive is more than or equal to 2 at% and less than or equal to 7 at%, and a total amount of the first and second additives is more than or equal to 27 at% and less than or equal to 35 at%;

processing the prealloyed ingot into prealloyed powder by gas

atomization; and

sintering the prealloyed powder at a temperature ranging from 600°C to 1200°C under a pressure ranging from 300 bar to 1800 bar to obtain the Fe-Co-based alloy target.

Herein, the total amount of the prealloyed ingot is directed to the sum of the amounts of raw materials of iron, cobalt, the first additive, and the second additive.

In accordance with the present invention, by using the method mentioned above, the bending strength of the produced Fe-Co-based alloy target is maintained, and the aggregation of white phase in the Fe-Co-based alloy target can also be suppressed. Therefore, crystals are not easy to form on the surface of the Fe-Co-based soft underlayer, so that the flatness of the Fe-Co-based soft underlayer as well as the flatness of the seed layer and the recording layer covering thereon is improved.

Preferably, the shape of the raw materials of iron, cobalt, the first and second additives can be, but not limited to, flaky, lumpy, or powdery.

Preferably, in the method of producing the Fe-Co-based alloy target, the temperature of melting and casting may range from 1300°C to 1800°C.

Preferably, in the method of producing the Fe-Co-based alloy target, the temperature of gas atomization may range from 1300°C to 1950°C; more preferably, it may range from 1400°C to 1900°C. In addition, the gas atomization may be performed in an argon environment or in a vacuum environment between 10^{-4} bar and 10^{-5} bar.

Preferably, in the method of producing the Fe-Co-based alloy target,

the particle size of the prealloyed powder may be less than or equal to 300 micrometers (μm); more preferably, it may be larger than or equal to 5 μm and less than or equal to 250 μm .

Preferably, in the method of producing the Fe-Co-based alloy target, the sintering temperature may range from 600°C to 1200°C, the sintering pressure may range from 300 bar to 1800 bar, and the sintering time may range from half an hour to 3 hours.

In accordance with the present invention, sintering the prealloyed powder is performed by hot isostatic pressing (HIP), hot pressing (HP), or a combination of hot isostatic pressing and spark plasma sintering (SPS).

In one embodiment, when the sintering step is performed solely by HIP, the sintering temperature may range from 700°C to 1200°C, the sintering pressure may range from 1200 bar to 1700 bar, and the sintering time may range from half an hour to 3 hours. In one embodiment, when the sintering step is performed solely by HP, the sintering temperature may range from 900°C to 1100°C, the sintering pressure may range from 300 bar to 400 bar, and the sintering time may range from half an hour to 3 hours. In another embodiment, when the sintering step is performed by combined SPS and HIP, the sintering temperature may range from 600°C to 1000°C, the sintering pressure may range from 300 bar to 1800 bar, and the sintering time may range from half an hour to 3 hours.

Preferably, in the method of producing the Fe-Co-based alloy target, the sintering step is performed by combining SPS and HIP.

Other objectives, advantages and novel features of the invention will

become more apparent from the following detailed description when taken in conjunction with the accompanying drawings.

In the drawings:

FIG. 1 is a scanning electron microscopy (SEM) image showing the metallographic structure of a conventional Fe-Co-based alloy target.

FIG. 2 is an SEM image showing the metallographic structure of a Fe-Co-based alloy target of Comparative Example 2, wherein the marked circles refer to maximum inscribed circles with a diameter greater than 3 μm in the white phase.

FIG. 3 is an SEM image showing the metallographic structure of a Fe-Co-based alloy target of Example 1.

FIG. 4 illustrates two spots in FIG. 3 selected to be analyzed by an energy dispersive X-ray spectrometer (EDS or EDX) to identify the composition of the white and the black phases of the Fe-Co-based alloy target of Example 1.

FIG. 5 illustrates two spots in FIG. 2 selected to be analyzed by EDS to identify the composition of the white and the black phases of the Fe-Co-based alloy target of Comparative Example 2.

FIG. 6 is an atomic force microscope (AFM) image of a seed layer covering the Fe-Co-based soft underlayer sputtered from the Fe-Co-based alloy target of Example 1, which shows the surface roughness of the seed layer.

FIG. 7 is an AFM image of a seed layer covering the Fe-Co-based soft underlayer sputtered from the Fe-Co-based alloy target of Comparative Example 2, which shows the surface roughness of the seed layer.

In order to verify how the composition of an Fe-Co-based alloy target of the present invention influences the flatness of the Fe-Co-based soft underlayer as well as the flatness of the seed layer formed thereon, several Fe-Co-based alloy targets with different compositions are exemplified below to illustrate the implementation of the present invention. The person skilled in the art can easily realize the advantages and effects of the present invention in accordance with the contents of the specification. Various modifications and variations could be made in order to practice or apply the present invention without departing from the spirit and scope of the invention.

Examples 1 to 10 and Comparative Examples 1 to 14: Fe-Co-based alloy targets

The Fe-Co-based alloy targets of Examples 1 to 10 and Comparative Examples 1 to 14 were produced by the following method.

First, appropriate amounts of raw materials of iron with a purity of 3N5 (99.95%), cobalt with a purity of 3N5, rhenium with a purity of 3N (99.9%), ruthenium with a purity of 3N5, tantalum with a purity of 3N5, niobium with a purity of 3N, molybdenum with a purity of 3N5, tungsten with a purity of 3N5, chromium with a purity of 3N5, and boron with a purity of 2N4 (99.4%) were provided for the preparation of the Fe-Co-based alloy targets with the composition as described in Table 1 below. Herein, rhenium, ruthenium, or their combination was adopted as a first additive, which was expressed as M1 in Table 1, and tantalum, niobium, molybdenum, tungsten, chromium, boron, or any combination thereof was adopted as a second additive, which was expressed as M2 in Table 1. In Table 1, the amount of the composition of the

Fe-Co-based alloy targets was expressed in atomic percent (at%).

Next, the raw materials of iron, cobalt, and the first and second additives were put into a crucible, and molten and cast in an induction melting furnace to obtain a prealloyed ingot.

Subsequently, the prealloyed ingot was atomized into Fe-Co-based alloy powder by using gas atomizer at 1400°C to 1900°C under an argon atmosphere. The Fe-Co-based alloy powder was screened by a 60-mesh sieve to obtain the Fe-Co-based alloy powder with average particle size less than or equal to 250 μm .

After that, the screened Fe-Co-based alloy powder was uniformly filled into a mold, and then sintered at a sintering temperature ranging from 600°C to 1200°C under a sintering pressure varied from 300 bar to 1800 bar for half an hour to 3 hours to obtain a sintered body. Herein, the sintering step could be conducted by HIP, HP, or a combination of HIP and SPS. As shown in Table 1 below, the screened Fe-Co-based alloy powders of Examples 1 to 6 and Comparative Examples 1 to 7 were separately sintered by only HIP, wherein the lower temperature limit of HIP of Examples 1 to 6 was 700°C, and the lower temperature limit of HIP of Comparative Examples 1 to 7 was 600°C. For Examples 7 to 8 and Comparative Examples 8 to 11, the screened Fe-Co-based alloy powders were separately sintered by only HP with a lower temperature limit of 900°C. The screened Fe-Co-based alloy powders of Examples 9 to 10 and Comparative Examples 12 to 14 were separately sintered by combining SPS and HIP, wherein the lower temperature limit of a combination of SPS and HIP of Examples 9 to 10 and Comparative Examples

12 to 14 was 600 °C. The upper limits of sintering temperature and sintering pressure of Examples 1 to 10 and Comparative Examples 1 to 14 were shown in Table 1 below.

Finally, the sintered bodies of Examples 1 to 10 and Comparative Examples 1 to 14 were each machined by a wire cutting machine and a computer numerical control (CNC) lathe to obtain a disc-shaped Fe-Co-based alloy target with a diameter of 76 mm and a thickness of 4 mm.

The composition of the Fe-Co-based alloy targets of Examples 1 to 10 and Comparative Examples 1 to 14 was expressed by a formula “aFe-bCo-c1Re-c2Ru-d1Ta-d2Nb-d3Mo-d4W-d5Cr-d6B”, wherein the unit of “a”, “b”, “c1”, “c2”, “d1”, “d2”, “d3”, “d4”, “d5”, and “d6” was atomic percent (at%). In the formula, “a” represented the amount of iron atoms contained in total atoms of the Fe-Co-based alloy target, “b” represented the amount of cobalt atoms contained in total atoms of the Fe-Co-based alloy target, “c1” and “c2” respectively represented the amount of rhenium atoms contained in total atoms of the Fe-Co-based alloy target and the amount of ruthenium atoms contained in total atoms of the Fe-Co-based alloy target, and “d1”, “d2”, “d3”, “d4”, “d5”, and “d6” respectively represented the amount of tantalum atoms, the amount of niobium atoms, the amount of molybdenum atoms, the amount of tungsten atoms, the amount of chromium atoms, and the amount of boron atoms contained in total atoms of the Fe-Co-based alloy target. In the formula above, the sum of c1 and c2 represented the total amount of the first additive, and the sum of d1 to d6 represented the total amount of the second additive.

In the present specification, the term “the total amount of the first

additive” is the sum of c1 and c2; the term “the total amount of the second additive” is the sum of d1, d2, d3, d4, d5, and d6; the term “the total amount of the first and second additives” is the sum of c1, c2, d1, d2, d3, d4, d5, and d6.

As shown in Table 1 below, the difference between the Fe-Co-based alloy targets of Examples 1 to 10 and the Fe-Co-based alloy targets of Comparative Examples 1 to 14 was the composition. The composition of the Fe-Co-based alloy targets of Examples 1 to 10 simultaneously meets the following criteria:

- (1) the Fe-Co-based alloy target consists of iron, cobalt, the first additive, and the second additive;
- (2) the first additive is rhenium, ruthenium, or their combination;
- (3) the second additive is selected from the group consisting of tantalum, niobium, molybdenum, tungsten, chromium, boron, and any combination thereof;
- (4) the total amount of the first additive is more than or equal to 2 at% and less than or equal to 7 at%; and
- (5) the total amount of the first and second additives is more than or equal to 27 at% and less than or equal to 35 at%.

In contrast, the Fe-Co-based alloy target of Comparative Example 8 did not contain any first additive, so the composition thereof didn't meet the criteria (1), (2), and (4). Although the Fe-Co-based alloy targets of Comparative Examples 1, 4, 5, 7, 9, 13, and 14 contained the first additive, i.e., at least one of rhenium and ruthenium, the total amount of the first additive was not within the range from 2 at% to 7 at%, thus failing to meet the criterion (4).

Further, the total amount of the first and second additives of each of the Fe-Co-based alloy targets of Comparative Examples 1 to 3, 6, 10 to 12, and 14 was not within the range from 27 at% to 35 at%, so the composition thereof failed to meet the criterion (5).

Table 1: The composition, sintering method, parameters, and characteristics of the Fe-Co-based alloy targets of Examples 1 to 10 and

Comparative Examples 1 to 14, wherein the unit of composition is atomic percent (at%)

Sample No.	Fe	Co	M1		M2							M1 & M2	sintering method	maximum sintering temperature (°C)	maximum sintering pressure (bar)	bending strength (MPa)	No. of max inscribed circles with a diameter more than 3 μm in the white phase
			Re	Ru	Ta	Nb	Mo	W	Cr	B							
Example 1	46	23	2	0	5	0	0	0	11	13	2	31	HIP	900	1500	2257	0
Example 2	14	57	5	0	0	11	8	5	0	0	5	29	HIP	800	1400	2022	5
Example 3	19.5	45.5	7	0	4	0	0	0	11	13	7	35	HIP	700	1700	2554	0
Example 4	32.5	32.5	0	2	12	0	0	10	11	0	2	35	HIP	1200	1300	2098	4
Example 5	24	49	0	2	4	0	0	0	11	10	2	27	HIP	850	1650	2463	0
Example 6	44	29	0	7	0	9	9	2	0	0	7	27	HIP	900	1600	2172	3
Example 7	44	23	0	4	5	0	0	0	11	13	4	33	HP	1000	400	2896	2
Example 8	58	15	0	4	0	4	7	0	0	12	4	27	HP	1100	350	2301	3
Example 9	29	44	2	0	0	6	0	7	5	7	2	27	SPS&HIP	950	1800	2262	0
Example 10	48	21	3	2	5	0	6	8	7	0	5	31	SPS&HIP	1000	1550	2243	3
Comparative Example 1	48	32	1	0	19	0	0	0	0	0	1	20	HIP	600	1800	658	14
Comparative Example 2	52	28	2	0	18	0	0	0	0	0	2	20	HIP	1000	1400	724	14

Comparative Example 3	18	43	7	0	0	9	9	0	6	8	7	39	HIP	1200	1350	1359	18
Comparative Example 4	13	53	0	8	6	6	0	0	6	8	8	34	HIP	1000	1750	1331	23
Comparative Example 5	40	33	0.5	0.5	0	8	0	10	8	0	1	27	HIP	1100	1700	1131	23
Comparative Example 6	43	21	2	3	0	10.5	0	9.5	0	11	5	36	HIP	800	1650	1218	28
Comparative Example 7	17.5	52.5	5	4	0	0	7	8	0	6	9	30	HIP	1150	1600	1294	17
Comparative Example 8	44	23	0	0	0	0	0	8	12	13	0	33	HP	1050	500	1467	31
Comparative Example 9	26	39	1	0	11	0	0	10	13	0	1	35	HP	1200	300	981	27
Comparative Example 10	50.7	27.3	0	4	18	0	0	0	0	0	4	22	HP	1050	450	580	15
Comparative Example 11	26	48	0	6	18	0	2	0	0	0	6	26	HP	1050	550	491	17
Comparative Example 12	43	19	2	0	14	0	0	8	6	8	2	38	SPS&HIP	950	1500	796	29
Comparative Example 13	35.5	35.5	0	1	10.5	0	10	0	3.5	4	1	29	SPS&HIP	1000	1600	1054	25
Comparative Example 14	59	15	8	0	0	6	5	0	7	0	8	26	SPS&HIP	900	1550	1202	19

Examples 1A to 10A and Comparative Examples 1A to 14A:**Fe-Co-based soft underlayer**

The Fe-Co-based alloy targets of Examples 1 to 10 and Comparative Examples 1 to 14 were respectively put into a magnetron sputtering machine to respectively form a Fe-Co-based soft underlayer with a thickness of 80 nm on a 10 mm*10 mm glass substrate for each of Examples 1A to 10A and Comparative Examples 1A to 14A (argon flow rate: 30 standard cubic centimeter per minute (sccm), pressure: 10 mTorr, and sputtering power: 90 watts (W)).

Examples 1B to 10B and Comparative Examples 1B to 14B: seed layer

The same nickel-tungsten (Ni-W) target was sputtered to respectively form a seed layer with a thickness of 40 nm on each of the Fe-Co-based soft underlayers of Examples 1A to 10A and Comparative Examples 1A to 14A (argon flow rate: 30 sccm, pressure: 3 mTorr, and sputtering power: 45 W) as Examples 1B to 10B and Comparative Examples 1B to 14B. Herein, the composition of the Ni-W target was expressed by “92Ni-8W”, that is, based on the total atoms of the Ni-W target, the amount of the nickel atoms was 92 at% and the amount of the tungsten atoms was 8 at%.

Test Example 1: bending strength of the Fe-Co-based alloy target

The bending strength of the Fe-Co-based alloy targets of Examples 1 to 10 and Comparative Examples 1 to 14 was measured by a four-point bending tester. The unit of bending strength was MPa, and the results were listed in Table 1.

As can be seen from Table 1, the bending strength of each of the Fe-Co-based alloy targets of Examples 1 to 10 was larger than 1500 MPa; preferably, larger than 2000 MPa; more preferably, parts of those were larger than 2500 MPa.

In contrast, since the composition of the Fe-Co-based alloy targets of Comparative Examples 1 to 14 failed to meet all of the above criteria (1) to (5) simultaneously, the bending strength of each of the Fe-Co-based alloy targets of Comparative Examples 1 to 14 was less than 1500 MPa; particularly, the bending strength of the Fe-Co-based alloy targets of Comparative Examples 1, 2, and 9 to 12 was less than 1000 MPa; more particularly, the bending strength of the Fe-Co-based alloy target of Comparative Example 11 was even less than 500 MPa.

From the above test results, it is understood that the Fe-Co-based alloy target produced by the method of the present invention has excellent bending strength.

Test Example 2: metallographic microstructure of the Fe-Co-based alloy target

This test example aims to observe metallographic microstructures of the Fe-Co-based alloy targets to analyze the number of maximum inscribed circles with a diameter more than 3 μm in the white phase. Further, the composition of the white and black phases is identified by EDS.

First, a 10 mm*10 mm sample was taken from each of the disc-shaped Fe-Co-based alloy targets of Examples 1 to 10 and Comparative Examples 1 to 14 at its half-radius ($r/2$).

Next, the metallographic microstructures of the samples were each observed by SEM (manufacturer: HITACHI, model: SE-3400) at 1000x magnification, and five metallographic images were taken for the observation of five different regions of each individual sample.

Subsequently, the five metallographic images of each individual sample were analyzed with a commercially-available image analysis software Image-Pro-Plus. Fifty spots in the white phase were selected arbitrarily in each of the metallographic images, and every spot was analyzed with the built-in measurement "Diameter (max)" on Image-Pro-Plus as follows. For the outline of each selected spot, report the length of the longest line joining two outline points and passing through the centroid, which is defined as the diameter of the maximum inscribed circle of the spot, and draw a maximum inscribed circle if the diameter thereof is more than 3 μm . Then, the number of the maximum inscribed circles for each of the five metallographic images was counted, and the maximal number of each individual sample was listed in Table 1 as the result for this test sample.

FIG. 2 is a metallographic image of the Fe-Co-based alloy target of Comparative Example 2. In Fig. 2, fifty spots in the white phase were selected arbitrarily and analyzed with the built-in measurement "Diameter (max)" on Image-Pro-Plus as mentioned above. Then, the number of the maximum inscribed circles with a diameter more than 3 μm was counted. The marked circles in FIG. 2 refer to maximum inscribed circles with a diameter greater than 3 μm for the selected fifty spots in the white phase, and the number of the circles is 14.

FIG. 3 is a metallographic image of the Fe-Co-based alloy target of Example 1. Likewise, in FIG. 3, fifty spots in the white phase were selected arbitrarily and analyzed with the built-in measurement "Diameter (max)" on Image-Pro-Plus as mentioned above. Since the diameter of the maximum inscribed circle of each of the fifty spots was less than 3 μm , the number of the maximum inscribed circles with a diameter of more than 3 μm in the white phase of Example 1 is zero.

Further, the composition of the white and black phases of the Fe-Co-based alloy targets was analyzed by EDS. For the Fe-Co-based alloy target of Example 1, one spot marked "+1" in the white phase and the other spot marked "+2" in the black phase as shown in FIG. 4 were analyzed by EDS to identify their composition. Likewise, for the Fe-Co-based alloy target of Comparative Example 2, one spot marked "+A" in the white phase and the other spot marked "+B" in the black phase as shown in FIG. 5 were analyzed by EDS to identify the composition of the white and black phases. The results of composition were shown in Table 2 below.

Table 2: The composition of the white phase and black phase of Example 1 and Comparative Example 2, wherein the unit of the amount of each element is atomic percent (at%).

	spots	phases	Fe	Co	Re	Ta	Cr	B
Example 1	+1	White	38.6	24.5	3.3	26.8	6.8	—
	+2	Black	57.8	30.8	1.8	2.0	7.6	—

Comparative	+A	White	45.0	28.3	2.3	24.4	—	—
Example 2	+B	Black	67.8	29.7	—	2.5	—	—

[Note: In Example 1, since atomic mass of boron is small, boron could not be detected in neither the white phase nor the black phase.]

As shown in Table 2, for Comparative Example 2, rhenium was not detected in the black phase, while it was detected in the white phase. Further, for Example 1, the amount of rhenium in the white phase was much higher than that in the black phase. Therefore, the white phase is called a rhenium-rich phase.

As listed in Table 1, the number of maximum inscribed circles with a diameter more than 3 μm in the white phase of the Fe-Co-based alloy targets of Examples 1 to 10 is less than or equal to 5. Particularly, in each of the Fe-Co-based alloy targets of Examples 1, 3, 5, and 9, a maximum inscribed circle with a diameter of more than 3 μm was not found in the white phase. Therefore, the number of maximum inscribed circles with a diameter more than 3 μm in the white phase of each of the Fe-Co-based alloy targets of Examples 1, 3, 5, and 9 is zero.

However, since the composition of the Fe-Co-based alloy targets of Comparative Examples 1 to 14 fails to simultaneously meet the above-mentioned criteria (1) to (5), the number of maximum inscribed circles with a diameter more than 3 μm in the white phase of each of them is more than 10; particularly, the number of maximum inscribed circles with a diameter more than 3 μm in the white phase of each of Comparative Examples 4 to 6, 8

to 9, and 12 to 13 is more than 20; more particularly, the number of maximum inscribed circles with a diameter more than 3 μm in the white phase of Comparative Example 8 is more than 30.

From the above test results, the number of maximum inscribed circles with a diameter more than 3 μm in the white phase of the Fe-Co-based alloy target of the present invention is only 5 or less.

Test Example 3: surface roughness of the seed layers

The surface roughness of the seed layers of Examples 1B to 10B and Comparative Examples 1B to 14B was measured by an atomic force microscope (manufacturer: Veeco, model: DI-3100). The unit of surface roughness was nanometer (nm), and the results were listed in Table 3 below.

It should be noted that since the seed layers of Examples 1B to 10B and Comparative Examples 1B to 14B were respectively formed on each of the Fe-Co-based soft underlayers of Examples 1A to 10A and Comparative Examples 1A to 14A by the same sputtering method, the surface roughness of the Fe-Co-based soft underlayers of Examples 1A to 10A and Comparative Examples 1A to 14A could be respectively obtained by measuring the surface roughness of the seed layers of Examples 1B to 10B and Comparative Examples 1B to 14B.

For example, by using the atomic force microscope, the values of the surface roughness of Example 1B and Comparative Example 2B were 1.26 nm and 1.68 nm, respectively, as shown in FIG. 6 and FIG. 7.

As can be seen from Table 3, the surface roughness of the seed layers of Examples 1B to 10B was less than 1.35 nm, while the surface roughness of

the seed layers of Comparative Examples 1B to 14B was greater than 1.65 nm.

Therefore, it can be known that the Fe-Co-based soft underlayer sputtered from the Fe-Co-based alloy target of the present invention has a superior flat surface, resulting in that the seed layer covering the Fe-Co-based soft underlayer also has improved flatness.

Table 3: the characteristics of the Fe-Co-based alloy targets of Examples 1 to 10 and Comparative Examples 1 to 14 and the surface roughness of the seed layers of Examples 1B to 10B and Comparative Examples 1B to 14B

Fe-Co-based alloy target			Seed layer	
Sample No.	Bending strength (MPa)	No. of max inscribed circles with a diameter more than 3 μm in the white phase	Sample No.	Surface roughness (nm)
Example 1	2257	0	Example 1B	1.26
Example 2	2022	5	Example 2B	1.29
Example 3	2554	0	Example 3B	1.2
Example 4	2098	4	Example 4B	1.32
Example 5	2463	0	Example 5B	1.23
Example 6	2172	3	Example 6B	1.28
Example 7	2896	2	Example 7B	1.02
Example 8	2301	3	Example 8B	1.27
Example 9	2262	0	Example 9B	1.15
Example 10	2243	3	Example 10B	1.22
Comparative Example 1	658	14	Comparative Example 1B	1.69
Comparative Example 2	724	14	Comparative Example 2B	1.68
Comparative Example 3	1359	18	Comparative Example 3B	1.71
Comparative Example 4	1331	23	Comparative Example 4B	1.8
Comparative Example 5	1131	23	Comparative Example 5B	1.84
Comparative Example 6	1218	28	Comparative Example 6B	2

Comparative Example 7	1294	17	Comparative Example 7B	1.73
Comparative Example 8	1467	31	Comparative Example 8B	2.17
Comparative Example 9	981	27	Comparative Example 9B	1.89
Comparative Example 10	580	15	Comparative Example 10B	1.7
Comparative Example 11	491	17	Comparative Example 11B	1.72
Comparative Example 12	796	29	Comparative Example 12B	1.94
Comparative Example 13	1054	25	Comparative Example 13B	1.85
Comparative Example 14	1202	19	Comparative Example 14B	1.83

As shown in Table 3, the Fe-Co-based alloy targets of Examples 1 to 10, whose composition meets the above criteria (1) to (5), all have high bending strength, and the number of maximum inscribed circles with a diameter more than 3 μm in the white phase is less than or equal to 5, which means the growth and aggregation of the white phase are effectively suppressed or mitigated. Therefore, the surface roughness of the seed layers of Examples 1B to 10B is less than 1.35 nm, which indicates improved flatness. In contrast, since the composition of the Fe-Co-based alloy targets of Comparative Examples 1 to 14 failed to meet the above criteria (1) to (5) simultaneously, the Fe-Co-based alloy targets have low bending strength, and the number of maximum inscribed circles with a diameter more than 3 μm in the white phase is more than 14, which means nuclei from aggregation of white phase occur in the Fe-Co-based alloy targets. Therefore, the surface roughness of the seed layers of Comparative Examples 1B to 14B is more than 1.65 nm, which indicates poor flatness.

After further studying the composition of the Fe-Co-based alloy target of Comparative Example 8, it does not contain any first additive, which means the composition thereof does not meet the criteria (1), (2), and (4), such that the bending strength thereof is less than 1500 MPa. Further, the number of maximum inscribed circles with a diameter more than 3 μm in the white phase is more than 30, resulting in the surface roughness of the seed layer of Comparative Example 8B up to 2.17 nm. Therefore, the Fe-Co-based soft underlayer sputtered from the Fe-Co-based alloy target of Comparative Example 8 lacks sufficient flatness.

In addition, since the composition of the Fe-Co-based alloy targets of Comparative Examples 1, 4, 5, 7, 9, 13, and 14 fails to meet the criterion (4), i.e., the total amount of the first additive thereof is not within the range from 2 at% to 7 at%, the bending strength thereof is less than 1500 MPa. Further, the number of maximum inscribed circles with a diameter more than 3 μm in the white phase is more than 10, and thus the surface roughness of the seed layers of Comparative Examples 1B, 4B, 5B, 7B, 9B, 13B, and 14B is more than 1.65 nm. It is noted that even though the composition of Fe-Co-based alloy targets of Comparative Examples 4, 5, 7, 9 and 13 meets the criteria (1) to (3) and (5), the growth and aggregation of the white phase are not effectively suppressed as long as the composition fails to meet the criterion (4). Therefore, the Fe-Co-based soft underlayers sputtered from the Fe-Co-based alloy targets of Comparative Examples 4, 5, 7, 9 and 13 also lack sufficient flatness.

Further, since the composition of the Fe-Co-based alloy targets of Comparative Examples 1 to 3, 6, 10 to 12 and 14 fails to meet the criterion (5),

i.e., the total amount of the first and second additives thereof is not within the range from 27 at% to 35 at%, the bending strength thereof is less than 1500 MPa. Further, the number of maximum inscribed circles with a diameter more than 3 μm in the white phase is more than 10, and thus the surface roughness of the seed layers of Comparative Examples 1B to 3B, 6B, 10B to 12B and 14B is more than 1.65 nm. It is noted that even though the composition of Fe-Co-based alloy targets of Comparative Examples 2, 3, 6 to 10 and 12 meets the criteria (1) to (4), the growth and aggregation of the white phase are not effectively suppressed as long as the composition fails to meet the criterion (5). Therefore, the Fe-Co-based soft underlayers sputtered from the Fe-Co-based alloy targets of Comparative Examples 2, 3, 6 to 10 and 12 also lack sufficient flatness.

It is known from the above test results that if the number of maximum inscribed circles with a diameter more than 3 μm in the white phase of an Fe-Co-based alloy target is less than or equal to 5, the Fe-Co-based soft underlayer sputtered therefrom has a superior flat surface, thereby improving the flatness of the seed layer on the Fe-Co-based soft underlayer. In contrast, if the number of maximum inscribed circles with a diameter more than 3 μm in the white phase is more than 5, the Fe-Co-based soft underlayer sputtered therefrom has a rougher surface, resulting in the seed layer covering the Fe-Co-based soft underlayer having insufficient surface flatness.

From the above test results, the Fe-Co-based alloy target of the present invention has high bending strength. In addition, the growth and aggregation of the white phase of the Fe-Co-based alloy target are effectively suppressed, and

thus nuclei and crystals from the nuclei generated on the surface of the Fe-Co-based soft underlayer are suppressed and even prevented, thereby improving the flatness of the Fe-Co-based soft underlayer as well as the flatness of the seed layer and the recording layer covering thereon.

Even though numerous characteristics and advantages of the present invention have been set forth in the foregoing description, together with details of the structure and features of the invention, the disclosure is illustrative only. Changes may be made in the details, especially in matters of shape, size, and arrangement of parts within the principles of the invention to the full extent indicated by the broad general meaning of the terms in which the appended claims are expressed.

Claims

1. An Fe-Co-based alloy target, which consists of iron, cobalt, and first and second additives, the first additive being rhenium, ruthenium, or their combination, and the second additive being selected from the group consisting of tantalum, niobium, molybdenum, tungsten, chromium, boron, and any combination thereof; wherein based on a total amount of the Fe-Co-based alloy target, a total amount of the first additive is more than or equal to 2 atomic percent and less than or equal to 7 atomic percent, and a total amount of the first and second additives is more than or equal to 27 atomic percent and less than or equal to 35 atomic percent.
2. The Fe-Co-based alloy target as claimed in claim 1, wherein the Fe-Co-based alloy target contains a white phase, and the number of maximum inscribed circles with a diameter more than 3 μm in the white phase is less than or equal to 5.
3. The Fe-Co-based alloy target as claimed in claim 1, wherein the Fe-Co-based alloy target contains a white phase, and each of the maximum inscribed circles in the white phase has a diameter of less than or equal to 3 micrometers.
4. The Fe-Co-based alloy target as claimed in claim 1, wherein the bending strength of the Fe-Co-based alloy target is more than or equal to 1500 million pascals.
5. The Fe-Co-based alloy target as claimed in claim 1, wherein the total amount of the first additive is more than or equal to 2 atomic percent and less than or equal to 5 atomic percent.

6. The Fe-Co-based alloy target as claimed in claim 1, wherein the total amount of the first and second additives is more than or equal to 29 atomic percent and less than or equal to 33 atomic percent.

7. A method of producing the Fe-Co-based alloy target as claimed in any one of claims 1 to 6, comprising the following steps:

mixing raw materials of iron, cobalt, and the first and second additives, and melting and casting the raw materials to obtain a prealloyed ingot, the first additive being rhenium, ruthenium, or their combination, and the second additive being selected from the group consisting of tantalum, niobium, molybdenum, tungsten, chromium, boron, and any combination thereof, wherein based on a total amount of the prealloyed ingot, a total amount of the first additive is more than or equal to 2 atomic percent and less than or equal to 7 atomic percent, and a total amount of the first and second additives is more than or equal to 27 atomic percent and less than or equal to 35 atomic percent;

processing the prealloyed ingot into prealloyed powder by gas atomization; and

sintering the prealloyed powder at a temperature ranging from 600°C to 1200°C under a pressure ranging from 300 bar to 1800 bar to obtain the Fe-Co-based alloy target.

8. The method as claimed in claim 7, wherein sintering the prealloyed powder is performed by hot isostatic pressing, hot pressing, or a combination of hot isostatic pressing and spark plasma sintering.