

DESCRIPTION

SPUTTERING TARGET FOR PRODUCING HEAT-ASSISTED MAGNETIC RECORDING MEDIUM

TECHNICAL FIELD

[0001] The present invention relates to a sputtering target for producing a heat-assisted magnetic recording medium.

BACKGROUND ART

[0002] An increase in capacity is strongly required for hard disk devices, which are one type of the storage devices with an explosive increase in data amount in recent years. However, since it is difficult to satisfy a high signal noise ratio (SNR), a high thermal fluctuation resistance, and high ease of recording in the method for magnetic recording of current hard disk devices, it is becoming difficult to further increase the recording densities of recording media. In order to solve this problem, a method for heat-assisted magnetic recording has been proposed as a next-generation method for magnetic recording. In a method for heat-assisted magnetic recording, a magnetic recording medium is irradiated with near-field light from the magnetic head, and the coercive force of the region irradiated with the near-field light is locally reduced to write magnetic information. It is essential to use a granular magnetic material having a low fraction of in-plane oriented magnetic crystal grains, having high saturated magnetization (M_s) and having fine columnar magnetic crystal grains for improving the signal noise ratio (SNR) of a heat-assisted magnetic recording medium. In order to maintain the thermal fluctuation resistance, it is therefore necessary to increase the ratio between the magnetic energy and the thermal energy of a medium ($K_u V / kT$) and to increase K_u of each magnetic crystal grain. Here, K_u is the magnetic anisotropic constant of the magnetic crystal grains, V is the volume of the magnetic crystal grains, k is the Boltzmann constant, and T is absolute temperature.

[0003] For example, it has been reported that granular magnetic materials containing magnetic crystal grains of FePt alloy having an L1₀ crystal structure and grain boundary materials such as carbon (Non Patent Literature 1), MgO (Non Patent Literature 2), ZrO₂ (Non Patent Literature 3), and GeO₂ (Patent Literature 1) are used as heat-assisted magnetic recording media, and Ms·Ku greatly varies depending on the grain boundary material. The present inventors have reported that, in a CoPt-oxide granular magnetic material, Ms·Ku of a medium depends on the melting point of a grain boundary material (Non Patent Literature 4).

[0004] It has also been reported that magnetic crystal grains having high Ku are obtained using carbon (Non Patent Literature 1) besides an oxide (Non Patent Literature 5) as a grain boundary material of a FePt granular magnetic material until now. The present inventors have also reported about the saturated magnetization (Ms) of a FePt granular magnetic material that a FePt granular magnetic material having high Ms is obtained using a grain boundary material having a low melting point (Non Patent Literature 6). Furthermore, the present inventors have also reported that the fraction of in-plane oriented magnetic crystal grains greatly depends on a grain boundary material (Non Patent Literature 7).

[0005] The above-mentioned prior art literatures show that even though an oxide or carbon is used as a grain boundary material of magnetic crystal grains, it is difficult to obtain a FePt granular magnetic material having high saturated magnetization and having a low fraction of in-plane orientation. It has been reported that since, in a FePt granular magnetic material using an oxide and carbon as a grain boundary material, the oxide and the carbon as the grain boundary materials are dissolved in the FePt crystal grains, Ms decreases, and the fraction of in-plane oriented magnetic crystal grains increases (Non Patent Literatures 8 and 9).

CITATION LIST

PATENT LITERATURE

[0006]

PTL 1: Japanese Patent No. 6168066

NON PATENT LITERATURE

[0007]

NPL 1: A. Perumal, Y. K. Takahashi, and K. Hono, Appl. Phys. Exp., 1, 101301 (2008).

NPL 2: T. Suzuki and K. Ouchi, IEEE Trans. Magn. 37, 1283 (2001).

NPL 3: K. F. Dong, H. H. Li, Y. G. Peng, G. Ju, G. M. Chow, and J. S. Chen, Appl. Phys. Lett., 104, 192404 (2014).

NPL 4: K. K. Tham, R. Kushibiki, S. Hinata, and S. Saito, Jpn. J. Appl. Phys., 55, 07MC06 (2016).

NPL 5: T. Ono, T. Moriya, M. Hatayama, K. Tsumura, N. Kikuchi, S. Okamoto, O. Kitakami, and T. Shimatsu, Applied Physics Letters, 110, 022402(1-4), (2017).

NPL 6: T. Saito, K. K. Tham, R. Kushibiki, T. Ogawa, and S. Saito, Jpn. J. Appl. Phys., 59, 045501 (2020).

NPL 7: T. Saito, K. K. Tham, R. Kushibiki, T. Ogawa, and S. Saito, INTERMAG2021 Poster IP-02 (2021).

NPL 8: T. Shiroyama, T. Abe, Y. Takahashi, and K. Hono, IEEE Trans. Magn., 49, 3616 (2013).

NPL 9: J. Wang, H. Sepehri-Amin, H. Tajiri, T. Nakamura, K. Masuda, Y.K. Takahashi, T. Ina, T. Uruga, I. Suzuki, Y. Miura, K. Hono, Acta Mater., 166, 413 (2019).

NPL 10: T. Saito, K. K. Tham, R. Kushibiki, T. Ogawa, and S. Saito, INTERMAG2021 Poster IP-02 (2021).

SUMMARY OF INVENTION

TECHNICAL PROBLEM

[0008] An object of the present invention is to provide a sputtering target that enables producing a heat-assisted magnetic recording medium having high saturated magnetization and containing a small amount of in-plane oriented magnetic crystal grains.

SOLUTION TO PROBLEM

[0009] In order to reveal a granular magnetic material suitable for a heat-assisted magnetic recording medium having high M_s -Ku, the present inventors have produced FePt alloy sputtering targets having grain boundary materials with various melting points, layered thin films thereof on MgO grounds, examined the magnetic characteristics thereof, found that the use of a high melting point nitride as a grain boundary material of magnetic crystal grains enables increasing M_s of a granular magnetic material and reducing the fraction of in-plane oriented magnetic crystal grains as compared with using an oxide as the grain boundary material of magnetic crystal grains, and completed the present invention.

[0010] The present invention provides a sputtering target for producing a heat-assisted magnetic recording medium, characterized in including magnetic phases containing Fe and Pt and nitride non-magnetic phases selected from Cr_2N , VN, AlN, NbN, TaN, HfN, and any combination thereof.

[0011] It is preferable that the magnetic phases be contained at 50% by vol. or more and 80% by vol. or less, and the nitride non-magnetic phases be contained at 20% by vol. or more and 50% by vol. or less.

[0012] It is preferable that the magnetic phases consist of Pt at 40% by mol or more and 60% by mol or less, and contain Fe and incidental impurities as the remainder.

[0013] Alternatively, the magnetic phases may consist of Pt at 40% by mol or more and 60% by mol or less, one or more selected from Si, Ti, Cr, B, V, Nb, Ta, Ru, Mn, Zn, Mo, W, Ge, Au, Ag, and Cu at more than 0% by mol and 10% by mol or less, and Fe and incidental impurities as the remainder.

[0014] The present invention provides a sputtering target for producing a heat-assisted magnetic recording medium, characterized by including magnetic phases containing Fe and Pt, nitride non-magnetic phases selected from Cr_2N , VN, AlN, NbN, TaN, HfN, and any combination thereof, and C non-magnetic phases consisting of carbon.

[0015] It is preferable that the sputtering target include the magnetic phases at 50% by vol. or more and 80% by vol. or less, the nitride non-magnetic phases at 10% by vol. or more and

50% by vol. or less, and the C non-magnetic phases at more than 0% by vol. and 10% by vol. or less, and the total of the nitride non-magnetic phases and the C non-magnetic phases be 20% by vol. or more and 50% by vol. or less.

[0016] It is preferable that the magnetic phases consist of Pt at 40% by mol or more and 60% by mol or less and Fe and incidental impurities as the remainder.

[0017] Alternatively, the magnetic phases may consist of Pt at 40% by mol or more and 60% by mol or less, one or more selected from Si, Ti, Cr, B, V, Nb, Ta, Ru, Mn, Zn, Mo, W, Ge, Au, Ag, and Cu at more than 0% by mol and 10% by mol or less, and Fe and incidental impurities as the remainder.

ADVANTAGEOUS EFFECTS OF INVENTION

[0018] A sputtering target of the present invention enables producing a heat-assisted magnetic recording medium having high saturated magnetization and having a small amount of in-plane oriented magnetic crystal grains.

BRIEF DESCRIPTION OF DRAWINGS

[0019]

Fig. 1 is a schematic conceptual diagram showing one example of a layered structure of a heat-assisted magnetic recording medium produced with a sputtering target of the present invention.

Fig. 2 is the magnetization curves of FePt-nitride granular thin films.

Fig. 3 is graphs showing the relationships between the saturated magnetizations M_s and the melting points of FePt-nitride granular thin films and FePt-oxide granular thin films.

Fig. 4 is a graph showing the relationships the magnetic anisotropic constants K_u and the melting points of FePt-nitride granular thin films and FePt-oxide granular thin films.

Fig. 5 is the in-plane X-ray diffraction profiles of FePt-nitride granular thin films and FePt-oxide granular thin films.

Fig. 6 is a graph showing the relationship between the fractions of in-plane orientation and

the melting points of FePt-nitride granular thin films and FePt-oxide granular thin films.

Fig. 7 is a graph showing the relationships between the crystal grain sizes and the melting points of FePt-nitride granular thin films and FePt-oxide granular thin films.

Fig. 8 is a graph showing the relationships between the saturated magnetizations M_s and L_{40}/K_u of Examples and Comparative Examples.

DESCRIPTION OF EMBODIMENTS

[0020] Although the present invention will be described with reference to the attached drawings in detail hereinafter, the present invention is not limited to these.

[0021] Fig. 1 outlines one example of a layered structure of a heat-assisted magnetic recording medium produced with a sputtering target of the present invention. The heat-assisted magnetic recording medium shown in Fig. 1 is formed by layering a CoW layer ($\text{Co}_{60}\text{W}_{40}$ (80 nm)) for improving heat resistance, a underlayer (MgO (5 nm)), a magnetic layer containing an alloy having L_{10} crystal structure (FePt-nitride (5 nm)), and a protective layer (C (7 nm)) on a substrate (glass N105Z) sequentially in this order. The heat-assisted magnetic recording medium shown in Fig. 1 is formed by layering the CoW layer and the MgO underlayer on the glass substrate, forming a magnetic layer of FePt-nitride with a sputtering target of the present invention on the MgO underlayer, and forming the C protective layer on the FePt-nitride layer. Each layer of the heat-assisted magnetic recording medium is formed by sputtering targets corresponding to each layer.

[0022] The present invention provides a sputtering target that enables producing a heat-assisted magnetic recording medium having high saturated magnetization and containing a small amount of in-plane oriented magnetic crystal grains.

[0023] [First embodiment]

A sputtering target of a first embodiment of the present invention is characterized by including magnetic phases containing Fe and Pt and nitride non-magnetic phases selected from Cr_2N , VN , AlN , NbN , TaN , HfN , and any combination thereof, and is suitable for producing a heat-assisted magnetic recording medium.

[0024] The sputtering target of the present invention include the magnetic phases preferably at 50% by vol. or more and 80% by vol. or less and more preferably at 52.5% by vol. or more and 77.5% by vol. or less. If the content fraction of the magnetic phases is in the above-mentioned range, increasing the crystal magnetic anisotropic constant K_u of magnetic crystal grains in the granular magnetic film formed with the sputtering target enables adjusting the magnetism.

[0025] As the nitride constituting the nitride non-magnetic phases, a high melting point nitride selected from Cr_2N , VN, AlN, NbN, TaN, HfN, and any combination thereof can be suitably used. It has been confirmed that although the heat-assisted magnetic recording medium produced with the sputtering target containing these nitrides has a high melting point, the heat-assisted magnetic recording medium exhibits a high saturated magnetization, M_s , of 420 emu/cm^3 or more as described below. Since VN, AlN, NbN, TaN, HfN, and Cr_2N enable reducing the fraction of in-plane oriented magnetic crystal grains in the magnetic layer of the heat-assisted magnetic recording medium formed with the sputtering target of the present invention, VN, AlN, NbN, TaN, HfN, and Cr_2N are particularly preferable.

[0026] The sputtering target of the present invention includes the nitride non-magnetic phases preferably at 20% by vol. or more and 50% by vol. or less, more preferably at 22.5% by vol. or more and 47.5% by vol. or less, and further preferably at 25% by vol. or more and 45% by vol. or less. If the content fraction of the nitride non-magnetic phases is in the above-mentioned range, the nitride particles satisfactorily function as the grain boundary material of the magnetic crystal grains in the granular magnetic film formed with the sputtering target, and can suppress the contact between adjacent magnetic crystal grains.

[0027] The magnetic phases consist of an alloy containing Fe and Pt. Fe and Pt become magnetic crystal grains (fine magnets) having $L1_0$ crystal structure in the granular magnetic thin film formed by sputtering.

[0028] Fe is a ferromagnetic metal element, and plays a central role in the formation of the magnetic crystal grains in the granular magnetic thin film. The content fraction of Fe in the

magnetic layer of the sputtering target of the present invention is preferably 40% by mol or more and 60% by mol or less and more preferably 45% by mol or more and 55% by mol or less from the viewpoint of increasing the crystal magnetic anisotropic constant K_u of the magnetic crystal grains in the granular magnetic thin film formed by sputtering, and maintaining the magnetism.

[0029] Pt has the function of reducing the magnetic moment of the FePt alloy, and plays a role of adjusting the magnetic intensity of the magnetic crystal grains. The content fraction of Pt in the magnetic layer of the sputtering target of the present invention is preferably 40% by mol or more and 60% by mol or less and more preferably 45% by mol or more and 55% by mol or less from the viewpoint of increasing the crystal magnetic anisotropic constant K_u of the magnetic crystal grains in the granular magnetic thin film formed by sputtering, and adjusting the magnetism.

[0030] As long as the magnetic characteristics of the formed heat-assisted magnetic recording medium are not deteriorated, the sputtering target of the present invention can contain an additional element in the magnetic layer. Suitable examples of the additional element include one or more selected from Si, Ti, Cr, B, V, Nb, Ta, Ru, Mn, Zn, Mo, W, Ge, Au, Ag, and Cu. The content of the additional element in the magnetic layer is preferably 0% by mol or more and 10% by mol or less and more preferably 0% by mol or more and 7.5% by mol or less.

[0031] Suitable examples of the alloy constituting the magnetic phases of the sputtering target of the present invention include FePt, FePtSi, FePtTi, FePtCr, FePtB, FePtV, FePtNb, FePtTa, FePtRu, FePtMn, FePtZn, FePtMo, FePtW, FePtGe, FePtAu, FePtAg, FePtCu, FePtSiCu, FePtTiCu, FePtCrCu, FePtBCu, FePtVCu, FePtNbCu, FePtTaCu, FePtRuCu, FePtMnCu, FePtZnCu, FePtMoCu, FePtWCu, FePtGeCu, FePtAuCu, FePtAgCu, FePtSiAgCu, FePtTiAgCu, FePtCrAgCu, FePtBAgCu, FePtVAgCu, FePtNbAgCu, FePtTaAgCu, FePtRuAgCu, FePtMnAgCu, FePtZnAgCu, FePtMoAgCu, FePtWAgCu, FePtGeAgCu, and FePtAuAgCu.

[0032] Although the cross-sectional texture of the sputtering target of the present invention

is not particularly limited, the cross-sectional texture is preferably a structure in which the magnetic phases and the nitride non-magnetic phases are finely dispersed in each other. Troubles such as nodules and particles less likely occur during the sputtering by forming such a fine cross-sectional texture.

[0033] For example, the sputtering target of the present invention can be produced as follows.

[0034] Raw material powders the particle sizes of which are adjusted to a predetermined value or less (for example, 106 μm or less) are weighed so that the raw material powders have a predetermined designed composition to prepare FePt powder. If the magnetic phases contain an additional element, alloy powder containing the additional element is prepared. Hereinafter, the alloy will be described as FePt alloy in the description of the production method also in the case where the additional element is contained.

[0035] Nitride powder is added to the FePt alloy powder, and the mixture is stirred and mixed with a ball mill to prepare mixed powder for pressure sintering in which the nitride powder is finely dispersed in the FePt alloy powder. The nitride powder is added at 20% by vol. or more and 50% by vol. or less, preferably at 22.5% by vol. or more and 47.5% by vol. or less, and more preferably at 25% by vol. or more and 45% by vol. or less with respect to the total amount of the mixed powder for pressure sintering.

[0036] For example, the mixed powder for pressure sintering is subjected to pressure sintering and molded by vacuum hot pressing to produce a sputtering target. The sintering condition preferably includes the sintering temperature of from 800°C to 1300°C, the sintering pressure of from 30 MPa to 200 MPa, and the holding time of from 1 hour to 4 hours. Since the mixed powder for pressure sintering is stirred and mixed with the ball mill, and the FePt alloy powder and the nitride powder are finely dispersed in each other, troubles such as nodules and particles less likely occur during sputtering using the sputtering target obtained by the present production method. The method for subjecting the mixed powder for pressure sintering is not particularly limited, and may be a method other than vacuum hot pressing. For example, HIP or the like may be used.

[0037] The FePt powder to be used at the time of preparing the mixed powder for the pressure sintering is not limited to the alloy powder, and the metal powders may be used. In this case, the metal powders and the nitride powder can be mixed and dispersed with a ball mill or the like to prepare the mixed powder for the pressure sintering.

[0038] [Second embodiment]

A sputtering target of a second embodiment of the present invention is characterized by including magnetic phases containing Fe and Pt, nitride non-magnetic phases selected from Cr₂N, VN, AlN, NbN, TaN, HfN, and any combination thereof, and C non-magnetic phases consisting of carbon, and is suitable for producing a heat-assisted magnetic recording medium.

[0039] The sputtering target of the present invention includes the magnetic phases preferably at 50% by vol. or more and 80% by vol. or less and more preferably at 52.5% by vol. or more and 77.5% by vol. or less. If the content fraction of the magnetic phases is in the above-mentioned range, the crystal magnetic anisotropic constant Ku of the magnetic crystal grains in the granular magnetic film formed with the sputtering target can be increased and the magnetism thereof can be adjusted.

[0040] As the nitride constituting the nitride non-magnetic phases, a high melting point nitride selected from Cr₂N, VN, AlN, NbN, TaN, HfN, and any combination thereof can be suitably used. It has been confirmed that although the heat-assisted magnetic recording medium produced with the sputtering target containing these nitrides has a high melting point, the heat-assisted magnetic recording medium exhibits a high saturated magnetization, Ms, of 540 emu/cm³ or more as described below. Since VN, AlN, NbN, TaN, HfN, and Cr₂N enable reducing the fraction of in-plane oriented magnetic crystal grains in the magnetic layer of the heat-assisted magnetic recording medium formed with the sputtering target of the present invention, VN, AlN, NbN, TaN, HfN, and Cr₂N are particularly preferable.

[0041] The sputtering target of the present invention includes the nitride non-magnetic phases and the C non-magnetic phases preferably at 20% by vol. or more and 50% by vol. or

less, more preferably at 22.5% by vol. or more and 47.5% by vol. or less, and further preferably at 25% by vol. or more and 45% by vol. or less in total. If the content fraction of the non-magnetic phases is in the above-mentioned range, the nitride particles and the C particles satisfactorily function as the grain boundary material of the magnetic crystal grains in the granular magnetic film formed with the sputtering target, and enable suppressing the contact between adjacent magnetic crystal grains.

[0042] The content fraction of the nitride non-magnetic phases is preferably 10% by vol. or more and 50% by vol. or less, more preferably 12.5% by vol. or more and 47.5% by vol. or less, and further preferably 15% by vol. or more and 45% by vol. or less in the sputtering target. The content fraction of the C non-magnetic phases is preferably more than 0% by vol. and 10% by vol. or less, more preferably more than 0% by vol. and 9% by vol. or less, and further preferably more than 0% by vol. and 8% by vol. or less in the sputtering target.

[0043] Since the magnetic phases of the sputtering target of the second embodiment is the same as those of the first embodiment, the description is omitted.

[0044] Although the cross-sectional texture of the sputtering target of the present invention is not particularly limited, the cross-sectional texture is preferably a texture in which the magnetic phases, the nitride non-magnetic phases, and the C non-magnetic phases are finely dispersed in each other. Troubles such as nodules and particles less likely occur during the sputtering by forming the cross-sectional texture into such a fine texture.

[0045] For example, the sputtering target of the present invention can be produced as follows.

[0046] Raw material powders the particle sizes of which are adjusted to a predetermined value or less (for example, 106 μm or less) are weighed so that the raw material powders have a designed composition to prepare FePt powder. If the magnetic phases contain an additional element, alloy powder containing the additional element is prepared. Hereinafter, the alloy will be described as FePt alloy in the description of the production method also in the case where the additional element is contained.

[0047] Nitride powder and C powder are added to the FePt alloy powder, and the mixture is

stirred and mixed with a ball mill to prepare mixed powder for pressure sintering in which the nitride powder and the C powder are finely dispersed in the FePt alloy powder. The nitride powder is added at 10% by vol. or more and 50% by vol. or less, preferably at 12.5% by vol. or more and 47.5% by vol. or less, and more preferably at 15% by vol. or more and 45% by vol. or less with respect to the total amount of the mixed powder for pressure sintering. The C powder is added at more than 0% by vol. and 10% by vol. or less, preferably at more than 0% by vol. and 9% by vol. or less, and more preferably at more than 0% by vol. and 8% by vol. or less with respect to the total amount of the mixed powder for pressure sintering. The addition is however performed so that the total of the nitride powder and the C powder is 20% by vol. or more and 50% by vol. or less, preferably 22.5% by vol. or more and 47.5% by vol. or less, and more preferably 25% by vol. or more and 45% by vol. or less with respect to the total amount of the mixture powder for pressure sintering.

[0048] For example, the mixed powder for pressure sintering is subjected to pressure sintering and molded by vacuum hot pressing to produce the sputtering target. The sintering condition preferably includes the sintering temperature of from 800°C to 1300°C, the sintering pressure of from 30 MPa to 200 MPa, and the holding time of from 1 hour to 4 hours. The mixed powder for pressure sintering is stirred and mixed with a ball mill, and the FePt alloy powder, the nitride powder, and the C powder are finely dispersed in each other, and troubles such as the generation of nodules and particles therefore less likely occur during sputtering using the sputtering target obtained by the present production method. The method for subjecting the mixed powder for pressure sintering is not particularly limited, and may be a method other than vacuum hot pressing. For example, HIP or the like may be used.

[0049] The FePt powder to be used at the time of preparing the mixed powder for the pressure sintering is not limited to the alloy powder, and the metal powders may be used. In this case, the metal powders, the nitride powder, and the C powder can be mixed and dispersed with a ball mill to prepare mixed powder for pressure sintering.

EXAMPLES

[0050] Hereinafter, the present invention will be further described using Examples and Comparative Examples.

Each metal powder was first classified with a 150-mesh sieve to prepare 50 Fe-50 Pt alloy powder having a particle size of 106 μm or less. The metals were specifically weighed so that the alloy powder had a composition of Fe: 50% by mol and Pt: 50% by mol.

[0051] Powders of non-magnetic materials shown in Tables 1 to 4 were added to the 50 Fe-50 Pt alloy powder, the mixture was mixed for dispersion with a ball mill so as to prepare (Fe₅₀ Pt₅₀)-non-magnetic phases shown in Tables 1 to 4, and mixed powders for the pressure sintering containing different non-magnetic materials were obtained. The prepared mixed powders for pressure sintering were then subjected to hot pressing under the vacuum conditions to produce FePt-non-magnetic phases sputtering targets.

[0052] A CoW layer was formed to a thickness of 80 nm on a glass substrate by DC magnetron sputtering under the conditions of 500 W and an argon gas atmosphere at 0.6 Pa. A MgO underlayer was subsequently formed to a thickness of 5 nm by RF magnetron sputtering under the conditions of 500 W and an argon gas atmosphere at 4 Pa. The CoW layer and the MgO underlayer were formed at room temperature. A granular magnetic thin film of FePt-non-magnetic material was formed to a predetermined film thickness on the MgO underlayer with each sputtering target of FePt-non-magnetic phase by DC magnetron sputtering under the conditions of 100 W and an argon gas atmosphere at 8 Pa. The substrate was heated to 550°C during the formation of the granular magnetic thin film of FePt-non-magnetic material. A C protective layer was formed to a thickness of 7 nm on the granular magnetic thin film by DC magnetron sputtering under the conditions of 300 W and an argon gas atmosphere at 0.6 Pa to produce a heat-assisted magnetic recording medium.

[0053] The magnetic characteristics of the produced heat-assisted magnetic recording medium were measured with a SQUID-VSM (Max7T) and a PPMS torque magnetometer (Max9T). The fine texture of the produced heat-assisted magnetic recording medium was observed with an XRD.

[0054] Fig. 2 shows the magnetization curves of the FePt-nitride granular thin films (film thickness: 5 nm) produced with the sputtering targets of the present invention, containing specific high melting point nitrides as the non-magnetic phases. As reference, the magnetization curves of the FePt-nitride granular thin films produced with the sputtering targets containing Si_3N_4 , BN, or TiN as the nitride of the non-magnetic phase are shown together. When only the magnetization curves are compared, the magnetization curves of the thin films containing specific high melting point nitrides to be used in the present invention are inferior to the magnetization curve of the thin film containing Si_3N_4 , BN, or TiN. As described below, it was, however, able to be confirmed that the sputtering target of the present invention, containing the specific high melting point nitride, enables producing a heat-assisted magnetic recording medium having higher saturated magnetization, M_s , and containing a smaller amount of in-plane oriented magnetic crystal grains than the sputtering target containing Si_3N_4 , BN, or TiN.

[0055] Table 1 and Fig. 3 show the relationships between the saturated magnetizations M_s and the melting points of the FePt-nitride granular thin films (film thickness: 5 nm) produced with the sputtering targets containing the high melting point nitrides as the non-magnetic phases. Fig. 3 also shows the relationships between the saturated magnetizations M_s and the melting points of FePt-oxide granular thin films produced with sputtering targets containing oxides as non-magnetic phases and the relationships between the saturated magnetizations M_s and the melting points of the FePt-nitride granular thin films produced with sputtering targets containing Si_3N_4 , TiN, or BN as non-magnetic phases for comparison. It is found that as the melting point increases, the saturated magnetization M_s decreases regardless of whether the non-magnetic phases are an oxide or a nitride; but the FePt-nitride granular thin films produced with the sputtering targets containing the nitrides as the non-magnetic phases have higher saturated magnetizations, M_s , than the FePt-oxide granular thin films produced with the sputtering targets containing the oxides as the non-magnetic phases in the case where the melting points thereof are equivalent. It is believed that some of the grain boundary materials having high melting point is partially dissolved in the crystal grains

of FePt, and as the melting point increases, the saturated magnetization M_s therefore decreases. In the case where the melting points thereof are the same, the FePt-nitride granular thin films have higher saturated magnetizations, M_s , than the FePt-oxide granular thin films, and it can therefore be said that it is preferable to use the nitrides as the grain boundary materials.

[0056] [Table 1]

Table 1 Relationships between melting points and M_s of FePt-oxides and FePt-nitrides

Designed composition	Melting point of oxide or nitride (°C)	M_s (emu/cm ³)
(Fe ₅₀ Pt ₅₀)-30vol%B ₂ O ₃	450	755
(Fe ₅₀ Pt ₅₀)-30vol%SnO	1080	710
(Fe ₅₀ Pt ₅₀)-30vol%GeO ₂	1115	640
(Fe ₅₀ Pt ₅₀)-30vol%WO ₃	1473	661
(Fe ₅₀ Pt ₅₀)-30vol%Nb ₂ O ₅	1512	617
(Fe ₅₀ Pt ₅₀)-30vol%SiO ₂	1723	585
(Fe ₅₀ Pt ₅₀)-30vol%TiO ₂	1857	586
(Fe ₅₀ Pt ₅₀)-30vol%Y ₂ O ₃	2425	557
(Fe ₅₀ Pt ₅₀)-30vol%Zr ₂ O	2715	577
(Fe ₅₀ Pt ₅₀)-30vol%C	3500	497
(Fe ₅₀ Pt ₅₀)-30vol%Si ₃ N ₄	1900	668
(Fe ₅₀ Pt ₅₀)-30vol%TiN	2930	599
(Fe ₅₀ Pt ₅₀)-30vol%BN	2973	571
(Fe ₅₀ Pt ₅₀)-30vol%Cr ₂ N	1650	710
(Fe ₅₀ Pt ₅₀)-30vol%VN	2050	676
(Fe ₅₀ Pt ₅₀)-30vol%AlN	2200	630
(Fe ₅₀ Pt ₅₀)-30vol%NbN	2573	604
(Fe ₅₀ Pt ₅₀)-30vol%TaN	3090	603
(Fe ₅₀ Pt ₅₀)-30vol%HfN	3305	570

[0057] Table 2 and Fig. 4 show the relationships between the magnetic anisotropic constants K_u and the melting points of the FePt-nitride granular thin films and the FePt-oxide granular thin films. The magnetic anisotropic constants K_u of the FePt-nitride granular thin films (film thickness: 5 nm) produced with the sputtering target of the present invention, containing the specific nitrides as the non-magnetic phases, are in the range of 2.89 to 5.86×10^6 erg/cm³, but the magnetic anisotropic constants K_u of the FePt-oxide granular thin films produced with the sputtering targets containing the oxides as the non-magnetic phases (film thickness: 5 nm) greatly vary from 4.99×10^6 erg/cm³ to 1.99×10^7 erg/cm³. The magnetic anisotropic constants K_u of the FePt-nitride granular thin films (film thickness: 5 nm)

produced with the sputtering targets containing Si_3N_4 , TiN , or BN are $3.73 \times 10^6 \text{ erg/cm}^3$ to $1.52 \times 10^7 \text{ erg/cm}^3$, and are larger than the magnetic anisotropic constants K_u of the FePt-nitride granular thin films produced with the sputtering targets of the present invention having equivalent melting points. It is found that the magnetic anisotropic constants K_u of the FePt-nitride granular thin films produced with the sputtering targets containing the nitrides as the non-magnetic phases do not depend on the melting points of the nitrides.

[0058] [Table 2]

Table 2 Relationships between melting points and K_u of FePt-oxides and FePt-nitrides

Designed composition	Melting point of oxide or nitride ($^{\circ}\text{C}$)	K_u (erg/cm^3)
(Fe ₅₀ Pt ₅₀)-30vol%B ₂ O ₃	450	9.04×10^6
(Fe ₅₀ Pt ₅₀)-30vol%SnO	1080	1.99×10^7
(Fe ₅₀ Pt ₅₀)-30vol%GeO ₂	1115	1.72×10^7
(Fe ₅₀ Pt ₅₀)-30vol%WO ₃	1473	7.59×10^6
(Fe ₅₀ Pt ₅₀)-30vol%Nb ₂ O ₅	1512	7.43×10^6
(Fe ₅₀ Pt ₅₀)-30vol%SiO ₂	1723	1.55×10^7
(Fe ₅₀ Pt ₅₀)-30vol%TiO ₂	1857	6.20×10^6
(Fe ₅₀ Pt ₅₀)-30vol%Y ₂ O ₃	2425	1.28×10^7
(Fe ₅₀ Pt ₅₀)-30vol%Zr ₂ O	2715	4.99×10^6
(Fe ₅₀ Pt ₅₀)-30vol%C	3500	1.52×10^7
(Fe ₅₀ Pt ₅₀)-30vol%Si ₃ N ₄	1900	8.17×10^6
(Fe ₅₀ Pt ₅₀)-30vol%TiN	2930	3.73×10^6
(Fe ₅₀ Pt ₅₀)-30vol%BN	2973	1.35×10^7
(Fe ₅₀ Pt ₅₀)-30vol%Cr ₂ N	1650	3.58×10^6
(Fe ₅₀ Pt ₅₀)-30vol%VN	2050	5.86×10^6
(Fe ₅₀ Pt ₅₀)-30vol%AlN	2200	5.16×10^6
(Fe ₅₀ Pt ₅₀)-30vol%NbN	2573	3.24×10^6
(Fe ₅₀ Pt ₅₀)-30vol%TaN	3090	3.61×10^6
(Fe ₅₀ Pt ₅₀)-30vol%HfN	3305	2.89×10^6

[0059] Fig. 5 shows the in-plane X-ray diffraction profiles of the FePt-nitride granular thin films and FePt-oxide granular thin films. In any granular thin film (film thickness: 5 nm), the diffraction lines of FePt (110), (200), and (220) are observed at diffraction angles of around 33°, around 47°, and around 69°, respectively, and it is found that the magnetic crystal grains are preferentially in-plane oriented. An intense diffraction line of FePt (001) is observed in the oxide granular thin films, but a diffraction line of FePt (001) is scarcely observed in the nitride granular thin films near a diffraction angle of 24°. It is found that the

FePt-nitride granular thin films produced with the sputtering target containing the nitrides as the non-magnetic phases have fewer in-plane components than the FePt-oxide granular thin films produced with the sputtering targets containing the oxides as the non-magnetic phases. [0060] Table 3 and Fig. 6 show the relationships between the fractions of in-plane orientation and the melting points of the FePt-nitride granular thin films (film thickness: 5 nm) and FePt-oxide granular thin films (film thickness: 5 nm). It has been reported that the fraction of in-plane oriented magnetic crystal grains can be quantitatively indicated with an index determined by normalizing the harmonic component (L_{40} component) analyzed from the torque curve by the perpendicular magnetic anisotropic energy (magnetic anisotropic constant: K_u) (Non Patent Literature 10). As the value of L_{40}/K_u decreases, the fraction of in-plane orientation decreases, and more preferable as the heat-assisted magnetic recording medium. As shown in Fig. 6, it is found that the fraction of in-plane orientation is lower in the FePt-nitride granular thin films produced with the sputtering targets of the present invention, containing the specific nitrides as the non-magnetic phases, than in the FePt-oxide granular thin films produced with the sputtering targets containing the oxides as the non-magnetic phases. It can be said from Fig. 6 that, in the heat-assisted magnetic recording media produced with the sputtering targets containing VN, AlN, NbN, TaN, HfN, and Cr_2N as the nitrides, L_{40}/K_u are 0.1 or less, and the fractions of in-plane oriented magnetic crystal grains are lower and therefore more preferable than those in the heat-assisted magnetic recording media produced with the sputtering targets containing BN, TiN and Si_3N_4 as the nitrides. It is found that the fractions of in-plane orientation in the FePt-nitride granular thin films produced with the sputtering targets containing the nitrides as the non-magnetic phases do not depend on the melting points of the nitrides.

[0061] [Table 3]

Table 3 L_{40}/K_u of FePt-nitrides and FePt-oxides

Designed composition	Melting point of oxide or nitride (°C)	L_{40}/K_u
(Fe ₅₀ Pt ₅₀)-30vol%B ₂ O ₃	450	0.23
(Fe ₅₀ Pt ₅₀)-30vol%SnO	1080	0.27
(Fe ₅₀ Pt ₅₀)-30vol%GeO ₂	1115	0.21
(Fe ₅₀ Pt ₅₀)-30vol%WO ₃	1473	0.34
(Fe ₅₀ Pt ₅₀)-30vol%Nb ₂ O ₅	1512	0.45
(Fe ₅₀ Pt ₅₀)-30vol%SiO ₂	1723	0.35
(Fe ₅₀ Pt ₅₀)-30vol%TiO ₂	1857	0.45
(Fe ₅₀ Pt ₅₀)-30vol%Y ₂ O ₃	2425	0.25
(Fe ₅₀ Pt ₅₀)-30vol%Zr ₂ O	2715	0.49
(Fe ₅₀ Pt ₅₀)-30vol%Si ₃ N ₄	1900	0.17
(Fe ₅₀ Pt ₅₀)-30vol%TiN	2930	0.15
(Fe ₅₀ Pt ₅₀)-30vol%BN	2973	0.18
(Fe ₅₀ Pt ₅₀)-30vol%C	3500	0.25
(Fe ₅₀ Pt ₅₀)-30vol%Cr ₂ N	1650	0.02
(Fe ₅₀ Pt ₅₀)-30vol%VN	2050	0.09
(Fe ₅₀ Pt ₅₀)-30vol%AlN	2200	0.10
(Fe ₅₀ Pt ₅₀)-30vol%NbN	2573	0.05
(Fe ₅₀ Pt ₅₀)-30vol%TaN	3090	0.05
(Fe ₅₀ Pt ₅₀)-30vol%HfN	3305	0.03

[0062] Table 4 and Fig. 7 show the crystal grain sizes (GD) of the FePt-nitride granular thin films (film thickness: 5 nm) and the FePt-oxide granular thin films (film thickness: 5 nm).

The grain sizes are measured by formula (1).

[0063] [Formula 1]

$$GD = \frac{0.9\lambda}{\beta \cos \theta_{\chi}} \quad (1)$$

wherein λ is the wavelength of the radiation source of the X-ray diffractometer, namely 0.1542 nm, β is the full width at half maximum of the diffraction peak of FePt (200), and θ_{χ} is the diffraction angle at the diffraction peak of FePt (200).

[0064] [Table 4]

Table 4 Crystal grain sizes (GD) of FePt-nitride granular thin films and FePt-oxide granular thin films

Designed composition	Melting point of oxide or nitride (°C)	GD (nm)
(Fe ₅₀ Pt ₅₀)-30vol%B ₂ O ₃	450	4.5
(Fe ₅₀ Pt ₅₀)-30vol%MoO ₃	795	3.9
(Fe ₅₀ Pt ₅₀)-30vol%SnO	1080	7.8
(Fe ₅₀ Pt ₅₀)-30vol%GeO ₂	1115	6.2
(Fe ₅₀ Pt ₅₀)-30vol%SiO ₂	1723	5.8
(Fe ₅₀ Pt ₅₀)-30vol%TiO ₂	1857	4.2
(Fe ₅₀ Pt ₅₀)-30vol%MnO	1945	7.1
(Fe ₅₀ Pt ₅₀)-30vol%Y ₂ O ₃	2425	5.9
(Fe ₅₀ Pt ₅₀)-30vol%C	3500	5.5
(Fe ₅₀ Pt ₅₀)-30vol%TiN	2930	4.1
(Fe ₅₀ Pt ₅₀)-30vol%BN	2973	5.7
(Fe ₅₀ Pt ₅₀)-30vol%Si ₃ N ₄	1900	7.6
(Fe ₅₀ Pt ₅₀)-30vol%Cr ₂ N	1650	3.3
(Fe ₅₀ Pt ₅₀)-30vol%VN	2050	4.0
(Fe ₅₀ Pt ₅₀)-30vol%AlN	2200	4.2
(Fe ₅₀ Pt ₅₀)-30vol%NbN	2573	3.1
(Fe ₅₀ Pt ₅₀)-30vol%TaN	3090	4.0
(Fe ₅₀ Pt ₅₀)-30vol%HfN	3305	3.1

[0065] Fig. 7 reveals that the FePt-nitrides produced with the sputtering targets containing the nitrides as the non-magnetic phases tend to have smaller grain sizes than the FePt-oxides produced with the sputtering targets containing the oxides as the non-magnetic phases, but the grain sizes do not depend on the melting points.

[0066] Heat-assisted magnetic recording media were produced with the sputtering targets in the same way except that the compositions were changed into the designed compositions shown in Tables 5 to 6. Tables 5 to 6 and Fig. 8 show the relationships between the saturated magnetizations M_s and L_{40}/K_u of the heat-assisted magnetic recording media produced with the sputtering targets of Examples and Comparative Example. It is found that although in Comparative Examples L_{40}/K_u exceed 0.10, in all Examples L_{40}/K_u are 0.10 or less, and the fractions of in-plane orientation are low. In comparison between Examples 14 to 17, in which the contents of the same nitride NbN are varied, Table 5 reveals that as the content of the nitride increases, L_{40}/K_u decreases, but the saturated magnetization M_s also decreases; and if the content of the nitride is set to 20% by vol. to 40% by vol., L_{40}/K_u is low, the saturated magnetization M_s is 500 emu/cm³ or more, and the balance between the two becomes the optimal. It is found that in Examples 18 to 21, containing the

additional elements besides Fe and Pt in the magnetic phases, the saturated magnetizations M_s decrease, and L_{40}/K_u slightly increase as compared with Example 4, not containing any additional element; but the balance between the saturated magnetization M_s and L_{40}/K_u is maintained in the optimal range of 500 emu/cm³ or more, 0.10 or less. Furthermore, it is found in comparison between Examples 22 to 25, in which the ratios between Fe and Pt of the magnetic phases are varied, that in the range of 40% by mol or more and 60% by mol or less, the saturated magnetization M_s increases as Pt decreases while L_{40}/K_u is maintained at 0.10 or less.

[0067] [Table 5]

Table 5 Designed compositions, saturated magnetizations M_s , and L_{40}/K_u of Examples

	Designed composition	Melting point of oxide or nitride (°C)	M_s emu/cm ³	L_{40}/K_u
Example 01	(Fe ₅₀ Pt ₅₀)-30vol%Cr ₂ N	1650	710	0.02
Example 02	(Fe ₅₀ Pt ₅₀)-30vol%VN	2050	676	0.09
Example 03	(Fe ₅₀ Pt ₅₀)-30vol%AlN	2200	630	0.10
Example 04	(Fe ₅₀ Pt ₅₀)-30vol%NbN	2573	604	0.05
Example 05	(Fe ₅₀ Pt ₅₀)-30vol%Ta ₂ N	3090	603	0.05
Example 06	(Fe ₅₀ Pt ₅₀)-30vol%HfN	3305	570	0.03
Example 07	(Fe ₅₀ Pt ₅₀)-25vol%Cr ₂ N-5vol%C	-	695	0.02
Example 08	(Fe ₅₀ Pt ₅₀)-25vol%VN-5vol%C	-	657	0.08
Example 09	(Fe ₅₀ Pt ₅₀)-25vol%AlN-5vol%C	-	612	0.09
Example 10	(Fe ₅₀ Pt ₅₀)-25vol%NbN-5vol%C	-	589	0.04
Example 11	(Fe ₅₀ Pt ₅₀)-20vol%NbN-10vol%C	-	559	0.04
Example 12	(Fe ₅₀ Pt ₅₀)-25vol%Ta ₂ N-5vol%C	-	581	0.04
Example 13	(Fe ₅₀ Pt ₅₀)-25vol%HfN-5vol%C	-	545	0.03
Example 14	(Fe ₅₀ Pt ₅₀)-10vol%NbN	2573	785	0.09
Example 15	(Fe ₅₀ Pt ₅₀)-20vol%NbN	2573	690	0.07
Example 16	(Fe ₅₀ Pt ₅₀)-40vol%NbN	2573	512	0.04
Example 17	(Fe ₅₀ Pt ₅₀)-50vol%NbN	2573	427	0.03
Example 18	(Fe ₄₅ Pt ₄₅ Ag ₁₀)-30vol%NbN	2573	545	0.07
Example 19	(Fe ₄₅ Pt ₄₅ Au ₁₀)-30vol%NbN	2573	551	0.07
Example 20	(Fe ₄₅ Pt ₄₅ Cu ₁₀)-30vol%NbN	2573	543	0.06
Example 21	(Fe _{47.5} Pt _{47.5} Cu ₅)-30vol%NbN	2573	572	0.06
Example 22	(Fe ₄₅ Pt ₅₅)-30vol%NbN	2573	542	0.07
Example 23	(Fe ₄₀ Pt ₆₀)-30vol%NbN	2573	487	0.10
Example 24	(Fe ₅₅ Pt ₄₅)-30vol%NbN	2573	667	0.08
Example 25	(Fe ₆₀ Pt ₄₀)-30vol%NbN	2573	723	0.10

[0068] [Table 6]

Table 6 Designed compositions, saturated magnetizations Ms, and L_{40}/K_u of Comparative

Examples				
	Designed composition	Melting point of oxide or nitride (°C)	Ms emu/cm ³	L_{40}/K_u
Comparative Example 01	(Fe ₅₀ Pt ₅₀)-30vol%B ₂ O ₃	450	755	0.23
Comparative Example 02	(Fe ₅₀ Pt ₅₀)-30vol%SnO	1080	710	0.27
Comparative Example 03	(Fe ₅₀ Pt ₅₀)-30vol%GeO ₂	1115	640	0.21
Comparative Example 04	(Fe ₅₀ Pt ₅₀)-30vol%WO ₃	1473	661	0.34
Comparative Example 05	(Fe ₅₀ Pt ₅₀)-30vol%Nb ₂ O ₅	1512	617	0.45
Comparative Example 06	(Fe ₅₀ Pt ₅₀)-30vol%SiO ₂	1723	585	0.35
Comparative Example 07	(Fe ₅₀ Pt ₅₀)-30vol%TiO ₂	1857	586	0.45
Comparative Example 08	(Fe ₅₀ Pt ₅₀)-30vol%Y ₂ O ₃	2425	557	0.25
Comparative Example 09	(Fe ₅₀ Pt ₅₀)-30vol%Zr ₂ O	2715	577	0.49
Comparative Example 10	(Fe ₅₀ Pt ₅₀)-30vol%C	3500	497	0.25
Comparative Example 11	(Fe ₅₀ Pt ₅₀)-30vol%Si ₃ N ₄	1900	668	0.17
Comparative Example 12	(Fe ₅₀ Pt ₅₀)-30vol%TiN	2930	599	0.15
Comparative Example 13	(Fe ₅₀ Pt ₅₀)-30vol%BN	2973	571	0.18
Comparative Example 14	(Fe ₅₀ Pt ₅₀)-25vol%BN-5vol%C	-	540	0.17

[0069] As mentioned above, it is found that the FePt-nitride sputtering targets of the present invention including the nitride non-magnetic phases consisting of the specific nitrides, or the FePt-nitride sputtering targets including the nitride non-magnetic phases consisting of the specific nitrides and C non-magnetic phases consisting of carbon enable producing the granular magnetic thin films of the heat-assisted magnetic recording media having high saturated magnetizations and containing small amounts of in-plane oriented magnetic crystal grains.

CLAIMS

1. A sputtering target for producing a heat-assisted magnetic recording medium, comprising:
 - magnetic phases containing Fe and Pt and
 - nitride non-magnetic phases selected from Cr₂N, VN, AlN, NbN, TaN, HfN, and any combination thereof.
2. The sputtering target according to claim 1, comprising:
 - the magnetic phases at 50% by vol. or more and 80% by vol. or less and
 - the nitride non-magnetic phases at 20% by vol. or more and 50% by vol. or less.
3. The sputtering target according to claim 1 or 2, wherein the magnetic phases consist of Pt at 40% by mol or more and 60% by mol or less and Fe and incidental impurities as the remainder.
4. The sputtering target according to claim 1 or 2, wherein the magnetic phases consist of Pt at 40% by mol or more and 60% by mol or less, one or more selected from Si, Ti, Cr, B, V, Nb, Ta, Ru, Mn, Zn, Mo, W, Ge, Au, Ag, and Cu at more than 0% by mol and 10% by mol or less, and Fe and incidental impurities as the remainder.
5. A sputtering target for producing a heat-assisted magnetic recording medium, comprising:
 - magnetic phases comprising Fe and Pt;
 - nitride non-magnetic phases selected from Cr₂N, VN, AlN, NbN, TaN, HfN, and any combination thereof; and
 - C non-magnetic phases consisting of carbon.
6. The sputtering target according to claim 5, comprising:
 - the magnetic phases at 50% by vol. or more and 80% by vol. or less;
 - the total of the nitride non-magnetic phases and the C non-magnetic phases at 20% by vol. or more and 50% by vol. or less,
 - wherein the nitride non-magnetic phases are 10% by vol. or more and 50% by vol.

or less, and

wherein the C non-magnetic phases are more than 0% by vol. and 10% by vol. or less.

7. The sputtering target according to claim 5 or 6, wherein the magnetic phases consist of Pt at 40% by mol or more and 60% by mol or less and Fe and incidental impurities as the remainder.

8. The sputtering target according to claim 5 or 6, wherein the magnetic phases consist of Pt at 40% by mol or more and 60% by mol or less, one or more selected from Si, Ti, Cr, B, V, Nb, Ta, Ru, Mn, Zn, Mo, W, Ge, Au, Ag, and Cu at more than 0% by mol and 10% by mol or less, and Fe and incidental impurities as the remainder.