

TARGETS WITH HIGH PASS-THROUGH-FLUX MAGNETIC MATERIAL
SPUTTERING, METHOD OF MANUFACTURE AND HARD DISK OBTAINABLE
THEREOF

Field of the Invention

[01] The invention relates generally to the manufacturing of magnetic disks for hard disk drives and, more specifically, to sputter targets having a high-PTF for use in manufacturing the magnetic disks.

Background of the Invention

[02] A hard disk drive (HDD) stores and retrieves data on magnetic disks within the HDD. The surfaces of each magnetic disk are a laminate structure comprised of several different layers of magnetic and non-magnetic materials coated on an Al or glass-composite substrate. The resultant media layer provides the magnetic medium for read/write/erase cycles. The disk or disks are fixed to a rotating spindle and can spin at speeds sufficient to create a cushion of air on the disk surface. This cushion of air provides a bearing surface for an aerodynamically designed head to "fly" in very close proximity to media surfaces of the disks to access different locations.

[03] The HDD uses the head on each media surface to perform the write, erase and read functions on the disk. The head has two basic active components, and these components are the write element and the read sensor. The write element can basically be described as an electro-magnet that includes a coil wrapped around a pole structure. As electrical current is passed through the coil, the current induces a magnetic field into the pole structure. The pole structure includes a gap that physically presents itself to the media surface of the disk. When the magnetic field is induced into the pole structure, flux energy jumps the gap in the pole structure creating a field that projects out of the head device and onto the media surface. This write field causes a specific alignment of the magnetic domains in the media surface called a transition. Through elaborate encoding schemes, the HDD will "write" data patterns onto the media surfaces of the disk.

[04] The read sensor in the head accomplishes data retrieval, or reading. The read sensor is a magneto-resistive (MR) device that includes several layers of ferromagnetic and anti-ferromagnetic materials. As the read sensor is positioned over a written transition on the media, the sensor's MR effect creates a change in resistance proportional to the "sensed" field strength of the transition on the media surfaces. This change in resistance is electrically interpreted as a data bit and, through elaborate decoding schemes, is translated into data.

[05] Hard and soft magnetic materials are extensively used in the architecture of both media and head components of a HDD. Magnetic materials exhibit a hysteric behavior, and the magnetization of a ferromagnetic material increases with increasing applied magnetic field until saturation is achieved. After saturation has been achieved, the magnetization of the material remains relatively constant even with additional increases in applied field. After saturation, however, a decrease in the applied field to zero does not reduce the materials magnetization to zero. Instead, the magnetized material maintains a remnant field that is lower than the value of saturation magnetization. Ferromagnetic materials can thus be made into permanent magnets. For these reasons, ferromagnetic materials are chosen for long-term data storage applications (i.e., HDD).

[06] Ferromagnetic materials can be described as magnetically soft or hard. Typically, for data storage applications, high and low values of remnant magnetization are respectively associated with soft and hard magnetic materials. Ferromagnetic materials will alternatively be referred to as soft or hard magnetic materials.

[07] Typically for data storage applications, low and high values of magnetic coercivity are associated with soft and hard magnetic materials. Soft magnetic materials tend to have values of magnetic coercivity between several Oersteds to several hundred Oersteds, whereas hard magnetic materials have values of magnetic coercivity between several thousand to tens of thousand Oersteds. (For example, soft magnetic materials may have a coercivity ranging from 5-2000 and hard magnetic materials may have a coercivity ranging from 2000-100,000.

[08] A large portion of media and head components are manufactured using physical vapor deposition (PVD) or sputtering processes, specifically magnetron sputter deposition. PVD is a process that deposits thin films of material onto a substrate. The substrate is placed in close proximity to the material source (target) in a vacuum chamber, and the material

source is biased with a negative voltage (cathode) while the substrate is positively biased (anode). Predominantly neutral (uncharged) Ar gas is introduced into the sputter chamber, and the acceleration of a few incidental charged Ar ions and electrons towards the cathode and anode, respectively, results in collisions with the prevailing Ar gas cloud resulting in an escalation (avalanching) of the Ar ionization phenomena. The accelerating Ar ions collide with the target surface with sufficient energy to eject target surface atoms. The ejected target atoms traverse the space between target and substrate and deposit on the substrate. This process results in the atom-by-atom creation of thin films on the substrate.

[09] In magnetron sputtering, which is the predominant method employed in the data storage media industry, the ionization of Ar gas can be further enhanced by placing a magnetic array behind the target. The magnetic field, which must be of sufficient strength to transmit through the target, acts in conjunction with the prevailing electric field to focus electrons in a region near the target surface. This results in multiple and more efficient ionization by electrons of Ar atoms and improves the deposition rate of target atoms onto the substrate.

[10] Due to the magnetic nature of magnetic target alloys, however, there is considerable shunting of the applied magnetic field in the bulk of the target. This results in reduced target utilization due to focussing of the transmitted magnetic field in the erosion groove formed as a result of the shunting and an upper limit on operable magnetic target thickness due to the requirement of sufficient passage of magnetic flux through the bulk of the target to initiate the sputtering process. Both these effects are exacerbated with decreasing Pass-Through-Flux (PTF) capability. The presence of severe target erosion profiles also promotes a point source sputtering phenomena that can result in less than optimum deposited film thickness uniformity.

[11] The PTF of a magnetic target is defined as the ratio of transmitted magnetic field to applied magnetic field. A PTF value of 100% is indicative of a non-magnetic material in which none of the applied field is shunted through the bulk of the target. The PTF of magnetic target materials is typically specified in the range of 0 to 100%, with the majority of commercially produced materials exhibiting values between 1 to 80%.

[12] There are several different techniques for measuring product PTF. One technique involves placing a 4.4 (± 0.4) kilogauss bar magnet in contact with one side of the target material and monitoring the transmitted field using an axial Hall probe in contact with the other side of the target material. The maximum value of the magnetic field transmitted through the bulk of the target divided by the applied field strength in the absence of the target between the magnet and probe (maintained at the same distance apart as when the target was between them) is defined as the PTF. PTF can be expressed as either a fraction or a percent. Another technique for measuring PTF involves using a horseshoe magnet and a transverse Hall probe. This technique, unless otherwise stated, has been used in obtaining the PTF values described in the present application. A more detailed description of the measurement technique itself can be found in ASTM Standard F 1761.

[13] The PTF measurement techniques are constructed to realistically approximate the applied magnetic flux occurring in an actual magnetron-sputtering machine. Therefore, PTF measurements correlate to a target material's performance during magnetron sputtering. Magnetic material PTF and permeability are not mutually exclusive. Rather, an inverse correlation typically exists between PTF and maximum permeability of magnetic materials. Values of material magnetic permeability can be very precisely determined by using vibrating-sample-magnetometer (VSM) techniques in accordance with ASTM Standard A 894-89. Descriptions of sample geometry and calculation of the appropriate demagnetization factors for permeability determination are also well known in the art, as described by Bozarth, *Ferromagnetism*, p. 846.

[14] Vacuum induction melting (VIM) processes have been used in the prior art to form both hard and soft ferromagnetic materials for use in targets. Although the prior art describes techniques for raising PTF in hard-magnetic materials typically used in the data storage industry, there is a notable absence in the prior art of high-PTF processing techniques for soft-magnetic materials, particularly as applied to magnetron sputtering thin-film electronic applications. Soft-magnetic materials used in magnetron sputtering applications in the data storage and electronics industry can broadly be described as comprising three alloy families: Co-based, Ni-based and Fe-based.

- [15] CoA - (Fe, Ta, Nb, Zr, B)B
- [16] NiA - (Fe, Nb, Cu, V, Cr, Mo) B
- [17] FeA - (Al, Si, Ta, B, C, Co, Cr, Ni, Ir, Rh, V) B

[18] For each of these families, one or more of alloying additions (shown in parentheses) can be added up to a total concentration not to exceed 60 atomic %. Thus, the subscript B ranges between 0 to 60 atomic % of one or more of the alloying additions described, and the subscript A constitutes the remainder such that A and B add up to a total of 100 atomic %.

[19] Through the use of conventional VIM techniques, soft-magnetic materials are formed having microscopic and macroscopic chemistries (or compositions) that are identical. VIM processing involves the casting of material inside a vacuum chamber. The starting materials, which are formulated to achieve desired alloy chemistry, are placed into a crucible composed of refractory material. The starting materials typically constitutes flakes, powders and alloy re-melt of the various constituent elements. A coil surrounds the crucible, and an alternating electrical current flows through the coil at a controlled frequency to create a voltage potential. The material in the crucible short circuits this potential and is subject to resistive heating via current flow. Once liquid, the material is poured (cast) into a metallic or ceramic mold and allowed to solidify and cool. The solid cast material is referred to as an ingot, and can be subjected to further thermo-mechanical processes, if necessary, to achieve material densification or specific microstructural properties. Thermo-mechanical processing typically constitutes various combinations of hot rolling, warm rolling, forging and annealing.

[20] As previously discussed, a problem with VIM processing of soft-magnetic materials is that a very low-PTF material is produced. The PTF values typically range from between 1% to 10%. PTF values greater than 10% are not achievable for target materials with thickness values between 3mm to 7mm. This is particularly true for the Ni and Fe-based soft-magnetic materials. For a select number of Co-based soft-magnetic alloys (typically not containing any Fe or Ni alloying additions), it is, however possible to achieve values of PTF in excess of 10%, (usually 20% to 50%), for the thickness ranges specified above using VIM techniques. There is, therefore, a need for a high-PTF soft-magnetic material and a method of manufacturing the same.

Summary of the Invention

[21] These and other needs are met by the present invention, which in accord with one aspect provides a target for use in a deposition apparatus. The target includes a first material phase having a first PTF and a second material phase having a second PTF higher than the first PTF. The second PTF is also higher than a PTF of a material having the same chemistry as the target. The chemistry of the target differs from chemistries of both the first and second material phases, and the chemistry of the target is that for a soft magnetic material. The target is formed by powder metallurgy.

[22] In certain aspects of the invention, the target has a thickness greater than 3 mm, a diameter greater than 50 mm, and a PTF of the target is greater than 5%. The PTF of the target can be greater than 20% when the chemistry of the target includes at least 40 atomic% of Fe or Ni and does not include Co. The PTF of the target can be greater than 50% when the chemistry of the target includes at least 40 atomic% of Co and does not include Fe and Ni.

[23] In other aspects of the inventions, the average grain-size of the target is less than 500 microns or less than 200 microns. Also, the first and second phases are elemental phases or alloy phases. Alternatively, one of the first and second phases is an elemental phase and another of the first and second phases is an alloy phase. The target can have a density greater than 80% of theoretical or greater than 95% of theoretical.

[24] In another embodiment of the invention, a target for a deposition apparatus is formed by blending at least two different types of powders together and consolidating the powders with a powder metallurgy process to form a billet. The consolidation of the powders can be by isostatic pressing or uniaxial pressing. The target is then formed from the billet. The target includes a first material phase having a first PTF and a second material phase having a second PTF higher than the first PTF. The second PTF is also higher than a PTF of a material having the same chemistry as the target. The chemistry of the target is that for a soft magnetic material.

[25] In other aspects of the invention, the powders consist of elemental powders or alloy powders. Alternatively one of the powders is an elemental powder and another of the

powders is an alloy powder. The aggregate diameter of each of the powders is less than 500 microns or less than 200 microns.

[26] In still another embodiment of the invention, a method of forming a magnetic disk is provided. The method includes depositing material from a target onto a substrate of the magnetic disk. The target includes a first material phase having a first PTF and a second material phase having a second PTF higher than the first PTF. The chemistry of the target differs from chemistries of both the first and second material phases, and the chemistry of the target is that for a soft magnetic material. The target is formed by powder metallurgy.

[27] In yet another embodiment of the invention, a disk drive is provided. The disk drive includes a magnetic disk formed by depositing material from a target onto a substrate of the magnetic disk. The target includes a first material phase having a first PTF and a second material phase having a second PTF higher than the first PTF. The chemistry of the target differs from chemistries of both the first and second material phases, and the chemistry of the target is that for a soft magnetic material. The target is formed by powder metallurgy.

[28] Additional advantages of the present invention will become readily apparent to those skilled in this art from the following detailed description, wherein only an exemplary embodiment of the present invention is shown and described, simply by way of illustration of the best mode contemplated for carrying out the present invention. As will be realized, the present invention is capable of other and different embodiments, and its several details are capable of modifications in various obvious respects, all without departing from the invention. Accordingly, the drawings and description are to be regarded as illustrative in nature, and not as restrictive.

Brief Description of the Drawings

[29] Reference is made to the attached drawings, wherein elements having the same reference numeral designations represent like elements throughout, and wherein:

[30] Figure 1 is a flow chart of a process flow to form a high-PTF target in accordance with one aspect of the invention;

[31] Figure 2a illustrates the microstructure of a conventionally manufactured NiFeNb alloy;

[32] Figure 2b illustrates the microstructure of a high-PTF NiFeNb alloy manufactured in accordance with one aspect of the invention;

[33] Figure 3a illustrates the microstructure of a high-PTF FeAlSi alloy manufactured in accordance with one aspect of the invention using elemental phases; and

[34] Figure 3b illustrates the microstructure of a high-PTF FeAlSi alloy manufactured in accordance with one aspect of the invention using alloy phases.

Detailed Description of the Embodiments

[35] According to the invention, a method of manufacturing high-PTF soft-magnetic material is provided. The invention is also applicable to the manufacture of high-PTF hard magnetic materials. The invention is especially applicable to the manufacture of very brittle hard magnetic materials where PTF enhancement by use of standard wrought processing is difficult or impossible. In addition, novel sputtering targets formed by the high-PTF materials are also provided. Such sputtering targets can be used in PVD manufacturing processes of a magnetic disk. Furthermore, the sputtering targets can also be used to form a disk in a HDD.

[36] A high-PTF material according to aspects of the invention includes at least two different material phases (or types of grains). At least one of the material phases has a first PTF characteristic, and at least one of the other material phases has a PTF characteristic lower than the first PTF characteristic. The high-PTF material for a particular type of alloy can alternatively be defined as being macro-alloyed and micro-unalloyed (or partially micro-unalloyed). As defined, the chemistry (or composition) of individual grains of the high-PTF material can differ substantially from the chemistry of the aggregate composition of the high-PTF material. The individual grains, besides having different chemistries, can also have substantially different PTF characteristics. Furthermore, the PTF characteristic of at least one of the material phases (or type of grains) can be higher than the aggregate PTF characteristic of a conventionally-formed material for use in the body of a sputtering target.

[37] By providing at least two material phases with at least one the material phases having a higher PTF characteristic, the high-PTF material phase provides higher PTF flux paths for magnetic fields to pass through the body of the target. This effect is increased as the

percentage of higher PTF phase(s) within the body increases. The effect is also increased when the distribution of higher PTF phase or phases within the body is such that an uninterrupted high PTF flux path through the body is provided. The high PTF characteristics of the material can also be explained by the reduction or elimination of low PTF compound or solid solution phases in the microstructure of the body.

[38] The high-PTF material, therefore, macroscopically possesses the desired soft-magnetic phase chemistry, but microscopically is comprised of a combination of distinct elemental and/or alloy phases that do not possess the low-PTF characteristics of the aggregate composition. Because the PVD process (or magnetron sputtering), in which the high-PTF material can be used, is an atom-by-atom deposition process, the thin-film phase being deposited regains the equilibrium soft-magnetic phase chemistry macroscopically represented by the target material. Therefore, the high-PTF material allows for optimization of the magnetron sputter manufacturing process via target PTF maximization, while preserving the formation of the requisite soft-magnetic phase chemistry on the resultant thin-film device.

[39] The invention is not limited as to the manner in which the at least two material phases of the high-PTF material is provided as described herein. For example, this structure can also be provided by mechanical joining of the different phases, (i.e., make the target of one phase, and mechanically embed chips of the other phase in the matrix). Another method for providing the high-PTF material is known as powder metallurgy. Powder metallurgy and powder metallurgy derivatives are well known in the art of material processing, and the invention is not limited as to a particular variation. During the powder metallurgy process, the body is formed using elemental and/or alloy powders, which are processed at conditions that promote densification of the resultant product. This process is accomplished without complete interdiffusion and reaction of the elemental and/or alloy powders such that at least one high-PTF phase is provided and the amount of low-PTF phases is reduced.

[40] One exemplary method of using powder metallurgy is illustrated in Fig. 1. In step 10, the powder parameters of the raw materials are selected to promote homogeneous blending of the elemental and/or alloy powders and to optimize final product properties. Examples of powder parameters include size, distribution, morphology and purity. Although not limited

in this manner, in certain aspects of the invention, the aggregate diameters of the powders are less than 200 micrometers, and in other aspects, the aggregate diameters of the powders are less than 500 micrometers.

[41] After the powders are received in step 20, the powders are blended together in step 30. Numerous techniques exist that can be used to efficiently blend and homogenize elemental powders. In some cases, mechanical pre-alloying can also be used. Examples of techniques to blend and homogenize the powders include ball milling, v-blending, tubular blending, and attritor milling.

[42] In step 40, following the blending process, the powders can be canned in preparation for consolidation. For example, a container is filled with the powder, evacuated under heat to ensure the removal of any moisture or trapped gasses present, and then sealed. Although the geometry of the container is not limited in any manner, the container can possess a near-net shape geometry with respect to the final material configuration. The encapsulated material can be consolidated via uniaxial or isostatic pressing. Although not limited in this manner, the temperatures can range from ambient temperature to about 1500°C.

[43] In step 50, the blended powders can be subject to consolidation, for example, via Hot-Isostatic-Pressing (HIP). A HIP unit is typically a cylindrical pressure vessel large enough to house one or more containers. The inner walls of the vessel can be lined with resistance heating elements, and the pressure can be controlled by the introduction of inert gas within the container. The consolidation of the blended powders can also use hot/warm uniaxial or isostatic pressing. Multi step uniaxial/isostatic pressing at different temperatures (including room) and at different pressures (with ramp-rate control for both temperature and pressure) may be utilized depending on the alloy system and powder specifics under consideration.

[44] Depending upon the complexity of the cycle, total hold times during uniaxial/isostatic pressing typically vary from about 1 to about 12 hours. For data storage soft-magnetic materials, pressures of about 5 to about 40 ksi (preferably 10-20 ksi) at temperatures between about 500° to about 1500°C (preferably 600-900°C), are typically employed to ensure densities greater than about 98% of theoretical although in other aspects of the invention densities greater than 80% of theoretical can be provided. High density advantageously ensures that material micro arching and defect generation does not compromise data storage

media yields during a PVD manufacturing process. In at least one aspect of the invention, the hold times are between about 2 to about 6 hours at temperatures between about 400°C and about 1000°C and at pressures between about 10 and about 20 ksi.

[45] Consolidation can also be facilitated by roll compaction of the previously described container or can, or by sintering of the alloy and/or elemental powders without the application of an applied pressure. After consolidation, the billet can be further thermo-mechanically processed to achieve further optimization of properties, such as PTF. For example, straight warm-rolling a rectangular billet, or cylindrical target section at temperatures less than 800°C for reduction ratios in excess of 2%, preferably between 5% to 20%, can promote noticeable improvements in target PTF.

[46] In step 60, after consolidation, the solid material form (billet) is removed from the encapsulation can, and a slice of the billet can then be sent to be tested as to various properties of the billet. As with VIM processing, the billet can be subjected to optional thermo-mechanical processing to further manipulate the microstructural and macro-magnetic properties of the target. Also, in steps 70, 80, and 90, the final shape and size of the sputter targets can be formed, for example, by processes such as grind, waterjet, mill, and lathe. In step 100, the target can be cleaned and subjected to a final inspection.

[47] Some soft-magnetic materials are optimally manufactured using blended elemental powders, while others use alloy powders. Although not limited in this manner, alloy powders are typically fabricated using gas atomization. In gas atomization, VIM processing can be employed to generate molten metal that is poured through a nozzle and atomized by a stream of inert gas. The atomized material spheroidizes and rapidly cools to form an alloy powder aggregate. Another method of fabricating alloy powders is to conventionally cast an ingot of the target material, crush it, and sieve it to yield powders of the desired size and morphology.

[48] As previously discussed, good densification is desirable to minimize defect generation during the PVD process. The scale and crystal structure of the blended phases can also have an impact on media properties by impacting the angle of atomic ejection during the PVD process. Material design paradigms can be developed on an individual basis for specific applications. For example, with Ni-Fe soft-magnetic alloys in the GMR read sensor

(read-component of data storage head device), oxygen impurity content can be advantageously minimized to mitigate adverse compromise of the GMR effect. In contrast, oxygen content in the range of several thousand ppm may be beneficial in the same Ni-Fe alloy that is used as a part of a data-storage media device. In the media application, oxygen impurity content may serve to positively impact the wetting characteristics between the soft-magnetic film and seed-layer (i.e. Ti, Ru, Pt, etc.) to promote beneficial media performance effects associated with grain-size refinement.

[49] Although not limited to the characteristics described below, a target formed from the inventive methodology can possess the following magnetic and microstructural characteristics. The data described is for cylindrical targets with thickness between 3 to 7 mm and diameters between 50 to 200 mm. However, the general applicability of the data is not constrained by these target dimensional ranges. The PTF can exceed 5%, as measured using the ASTM technique, and a preferred range of PTF is between 20% and 70%. For Co-based alloys with no Fe or Ni alloying additions, the preferred PTF range can be further increased to be between 50% and 90%. The average particle-size and grain-size can typically be less than 500 microns, and preferably less than 200 microns. The microstructure of target constitutes an assembly of elemental phases, an assembly of alloy phases, or some combination of elemental and alloy phases. Typically, interdiffusion between the different phases will be kept to a minimum to avoid the formation of the equilibrium low-PTF soft-magnetic phase. However, in certain situation, limited interdiffusion can be engineered to improve phase cohesion (such as for reasons of ductility), or to impact the macromagnetic properties of the target for reasons other than PTF maximization. The targets typically have densities greater than 80% of theoretical, and preferably greater than 95% of theoretical.

[50] By increasing the PTF of the target, a less severe erosion profile can be provided during sputtering of the target. This increases target material utilization and subsequently contributes to a reduction in material cost. A higher PTF also enables the use of thicker targets, which reduce the frequency that the target is changed during thin-film device manufacture, and the reduction in apparatus downtime caused by frequent target changes can reduce component manufacturing costs. Also, increasing target material PTF has the added

benefit of increasing deposited film thickness uniformity by reducing point source sputtering phenomena.

Example 1

[51] For comparative purposes, targets using a Ni-15.6Fe-3.2Nb alloy were manufactured using both conventional processing and processing according to aspects of the invention, as previously discussed.

Target Formed by Conventional Process

[52] The conventionally formed targets were formed using vacuum induction melting of an ingot of the specified alloy chemistry. The ingot was then roll-processed to form a plate at temperatures between 900 and 1200°C. The rolling process was conducted to ensure a fine dynamically recrystallized grain morphology and full material densification. The net reduction ratio exceeded 60% where the reduction ratio = ((ingot thickness – plate thickness)/ingot thickness). A cylindrically-shaped target having a thickness of 5 mm and a diameter of 180 mm was machined from the rolled plate.

[53] The PTF of the conventionally formed target was measured at four equally spaced locations (one measurement per quadrant) and at a radial position halfway between the center of the target and the outer diameter using the previously-described ASTM measurement technique. The microstructure of the conventionally formed target, as characterized by crystallite grain-size, was measured using standard optical metallographic techniques known in the art. The microstructure of the conventional formed target using a Ni-15.6Fe-3.2Nb alloy is illustrated in Fig. 2A. The results of the PTF and grain-size measurements are as follows:

[54] Average PTF = 1%
 Average grain-size = 45 micrometers

[55] Although conventional processing can form a target with a moderately fine-grained microstructure, which is very desirable for optimum deposited film thickness uniformity, the macro-magnetic PTF is very low. Under achievable cathode-voltage and gas-pressure

conditions in the sputter chamber for magnetron sputtering, the PVD process can usually only be initiated when the PTF values of the target exceed 20% to 30%. Thus, the conventionally formed target will unlikely fire and sputter in a stable manner at a thickness of 5 mm. Although a thinner target will be more likely to fire and sputter in a stable manner, reducing the target thickness further has a detrimental impact on production through-put and costs during HDD component manufacturing. This results in the higher frequency of target changes during manufacturing to account for a reduced amount of material available for sputtering.

Target Formed by Process According to the Invention

[56] The manufacturing of the Ni-15.6Fe-3.2Nb target with the process according to the invention involved using elemental Ni, Fe and Nb powders, each having an average diameter less than 150 micrometers. The powders were blended to achieve homogeneous mixing, encapsulated, evacuated, and hot-isostatic-pressed at between about 600 and about 900°C at a pressure between about 10 and about 20 ksi for hold times between about 2 to about 6 hours. After hot-isostatic-pressing, the fully consolidated or fully dense material was machined to yield a cylindrically-shaped target having a thickness of 5 mm and a diameter of 180 mm.

[57] The PTF of the target was measured at four equally spaced locations (one measurement per quadrant) and at a radial position halfway between the center of the target and the outer diameter using the previously-described ASTM measurement technique, which was identical to the method used to measure the PTF of the conventionally formed target. The microstructure of the conventionally formed target, as characterized by crystallite grain-size, was measured using scanning electron microscopy (SEM) techniques. The microstructure of the conventional formed target using a Ni-15.6Fe-3.2Nb alloy is illustrated in Fig. 2B. The SEM was utilized for improved contrast capability to show the multi-elemental phases of the target. The results of the PTF and grain-size measurements are as follows:

[58] Average PTF = 32%
 Average grain size = 13 micrometers

[59] The process according to the invention formed a target having a very fine grain-size, which can be important for obtaining good deposited film thickness uniformity, and the grain-size of the target formed by the process according to the invention is considerably finer than that of the target formed by conventionally processing. Furthermore, in contrast to the conventionally formed target, which had a PTF of 1%, the PTF of the target formed by the process according to the invention is significantly higher at 32%. Thus, the target formed by the process according to the invention can fire and sputter in a stable manner at a thickness of 5 mm. The use of the target formed by the process according to the invention can therefore be used during HDD component manufacturing, and therefore, results in a less pronounced sputter erosion groove, greater uniformity of deposited film thickness, and better overall material utilization.

[60] The processing technique according to the invention yields higher values of target PTF than that of the conventional technique, in part, because the blended elemental/alloy phases typically possess higher individual values of PTF than the compound/alloy phase. Thus, an applied magnetic field will find more available "higher-PTF" flux paths through the blended elemental/alloy phases than through a conventional single-phase having a uniformly low-PTF. Ni and Fe individually exhibit higher values of PTF than the combined Ni-Fe soft-magnetic phase. Furthermore, since Nb is not noticeably magnetic (paramagnetic) at operable PVD temperatures, Nb exhibits excellent high-PTF characteristics (PTF = 100%). Thus, the elemental combination and consolidation of Ni, Fe and Nb to form an elementally blended target possessing a nominal Ni-15.6Fe-3.2Nb composition possess a higher PTF value than a conventionally formed target having a single Ni-15.6Fe-3.2Nb soft-magnetic phase.

Example 2

[61] For comparative purposes, targets using Fe-30.5Co-11B, Fe-9.7Al-16.5Si and Ni-19Fe alloys (in atomic %) were manufactured using both conventional processing and processing according to an aspect of the invention.

Target Formed by Conventional Process

[62] For the Fe-30.5Co-11B and Ni-19Fe alloys, targets were formed using vacuum induction melting of an ingot of the specified alloy chemistry. The ingot was then roll-processed to form a plate at temperatures between 900 and 1200°C. The rolling process was conducted to ensure a fine dynamically recrystallized grain morphology and full material densification. The net reduction ratio exceeded 60% where the reduction ratio = ((ingot thickness – plate thickness)/ingot thickness). A cylindrically-shaped target having a thickness of 5 mm and a diameter of 180 mm was machined from the rolled plate.

[63] Due to the excessive brittleness of the Fe-9.7Al-16.5Si material, this material could not be roll-processed after vacuum induction melting. Thus, for this material, the target was machined from the as-cast ingot, and this is a conventional practice for manufacturing a target from this particular material. The cooling rate after conventional casting of Fe-9.7Al-16.5Si product was closely controlled to insure that the as-cast ingot did not catastrophically fracture.

[64] The PTF of the conventionally formed target was measured at four equally spaced locations (one measurement per quadrant) and at a radial position halfway between the center of the target and the outer diameter using the previously-described ASTM measurement technique.

Target Formed by Process According to the Invention

[65] The manufacturing of the Fe-30.5Co-11B target with the process according to the invention involved using elemental Fe, Co and B powders, each having an average diameter less than 150 micrometers. The powders were blended to achieve homogeneous mixing, encapsulated, evacuated, and hot-isostatic-pressed at between about 700 and about 1200°C at a pressure between about 12 and about 25 ksi for hold times between about 2 to about 6 hours. After hot-isostatic-pressing, the fully consolidated or fully dense material was machined to yield a cylindrically-shaped target having a thickness of 5 mm and a diameter of 180mm.

[66] The manufacture of the Ni-19Fe target using the process according to the invention involved using elemental Ni and Fe powders, each having an average diameter less than 150

micrometers. The powders were blended to achieve homogeneous mixing, encapsulated, evacuated, and hot-isostatic-pressed at between about 700 and about 1200°C at a pressure between about 12 and about 25 ksi for hold times between about 2 to about 6 hours. After hot-isostatic-pressing, the fully consolidated or fully dense material was machined to yield a cylindrically-shaped target having a thickness of 5 mm and a diameter of 180 mm.

[67] The manufacture of the Fe-9.7Al-16.5Si target using the process according to the invention involved using elemental Fe, Al and Si powders, each having an average diameter less than 150 micrometers. The powders were blended to achieve homogeneous mixing, encapsulated, evacuated, and hot-isostatic-pressed at between about 300 and about 600°C at a pressure between about 15 and about 30 ksi for hold times between about 4 to about 8 hours. After hot-isostatic-pressing, the fully consolidated or fully dense material was machined to yield a cylindrically-shaped target having a thickness of 5 mm and a diameter of 180 mm.

[68] The PTF of the target was measured at four equally spaced locations (one measurement per quadrant) and at a radial position halfway between the center of the target and the outer diameter using the previously-described ASTM measurement technique, which was identical to the method used to measure the PTF of conventionally formed targets.

[69] Table 1 below shows the significant increase in PTF from the conventionally formed targets to targets formed using the process according to the invention.

Table 1

Chemistry (atomic %)	PTF (Conventional)	PTF (New)
Fe-30.5Co-11B	2%	20%
Fe-9.7Al-16.5Si	4%	49%
Ni-19Fe	1%	22%

[70] As previously stated in Example 1, a target formed from the process according to the invention and having a higher PTF value will reduce thin-film manufacturing costs by maximizing material utilization of the target. The less severe erosion groove associated with higher-PTF values promotes greater utilization of available material, and the greater possible thickness of the target promotes longer target utilization and, therefore, less frequent target changes in the sputter tool. Furthermore, the less severe erosion groove geometry associated with the high-PTF targets enhances the uniformity of deposited film-thickness.

[71] The Fe-9.7Al-16.5Si alloy is an example of why targets formed with the process according to the invention yield higher-PTF values. Al and Si are non-magnetic elemental phases at operable PVD temperatures. Thus, a significant portion of the target's microstructure possesses non-magnetic elemental phases that allows for more available higher-PTF flux paths for magnetic fields to pass through the body of the target. In contrast, the entire microstructure of the conventionally formed target consists of a low-PTF Fe-9.7Al-16.5Si soft-magnetic compound phase.

[72] The same rationale applies to the other two alloys found in Table 1. With Ni-19Fe, both Ni and Fe are soft-magnetic elemental phases; however, the individual values of PTF for Ni and Fe are higher than that of the Ni-19Fe compound phase. Thus, targets with multiple phases formed by the process according to the invention have a higher aggregate PTF than the conventionally formed single-phase targets.

Example 3

[73] The targets formed discussed in previous examples using the process according to the invention were all manufactured using elemental powder phases. However, these targets can also be formed with a blend of elemental/alloy or alloy/alloy phases. For example, the Fe-30.5Co-11B alloy of Example 2 can be manufactured using individual Fe, Co and B elemental phases, or alternatively, by using an elemental Fe phase in conjunction with a Co-B alloy phase. The Co-B alloy phase can be formed, for example, by gas-atomization, melting, or crushing. Similarly, the Fe-9.7Al-16.5Si target formed using the process according to the invention can comprise of individual Fe, Al and Si elemental phases or a combination of an elemental-Al and a Fe-Si phase.

[74] Although not limited to the reasons described below, there are many reasons to engage in complex element/alloy phase blending during using the process according to the invention. Different elemental and alloy phases have different impurity characteristics; and thus, the flexibility of combining elemental and alloy phases together to form a nominal composition provides an improved ability to microstructurally design specific target impurity profiles to enhance thin-film performance characteristics.

[75] For example, as previously noted, oxygen is potentially a beneficial impurity in soft-magnetic materials for data storage media applications. In contrast, oxygen needs to be minimized in data storage GMR sensor applications. However, by custom-designing impurity profiles using element/alloy phase blending, targets can be provided that use the process according to the invention and include all of the benefits associated with the process.

[76] Another reason for complex element/alloy phase blending is that some of the elemental-phase additions to soft-magnetic alloys are electrically insulating (i.e., B, C, Si). These insulative elemental phases, when embedded in a conductive metallic matrix, may promote micro-arching and material "spitting" onto the thin film device being fabricated. Spitting is an undesirable defect-generating phenomenon in the PVD manufacture of thin-film devices. However, alloying of the insulating phases can mitigate the phenomenon of spitting during PVD processing.

[77] For example, the formation of a Fe-9.7Al-16.5Si target using the process according to the invention can use an elemental Al phase in combination with a Fe-Si phase. This combination can result in thin-film yield improvement during the PVD fabrication process. For this particular chemistry, the Si is distributed in a Fe matrix in a much more refined format (substitutionally, interstitially or precipitately) and is, therefore, less likely to exhibit micro-arching and spitting characteristics during a magnetron PVD process.

[78] A SEM micrograph of a Fe-9.7Al-16.5Si target manufactured by the process according to the invention using Fe, Al and Si elemental phases is shown in Fig. 3A. Fig. 3B is a SEM micrograph of a Fe-9.7Al-16.5Si target manufactured by the process according to the invention using an Fe elemental-phase blended with gas-atomized Fe-Al and Fe-Si alloy-phases. For both processes, the powders were blended to achieve homogeneous mixing, encapsulated, evacuated, and hot-isostatic-pressed at between about 300 and about 600°C at a

pressure between about 15 and about 30 ksi for hold times between about 4 to about 8 hours. After hot-isostatic-pressing, the fully consolidated or fully dense material was machined to yield a cylindrically-shaped target having a thickness of 5 mm and a diameter of 180 mm. The PTF of the targets were measured at four equally spaced locations (one measurement per quadrant) and at a radial position halfway between the center of the target and the outer diameter using the previously-described ASTM measurement technique. The PTF of the elemental/alloy blend is 35% and is slightly lower than that of the PTF of 49% for the pure elemental blend.

Example 4

[79] For comparative purposes, targets using a Co-4Nb-5Zr alloy (in atomic %) were manufactured using both conventional processing and processing according to an aspect of the invention. It is known that Co-based soft-magnetic alloys, with no Fe or Ni alloying additions, exhibit the highest PTF capability using either conventional processing or processing according to the invention.

Target Formed by Conventional Process

[80] The conventionally formed targets were formed using vacuum induction melting of an ingot of the specified alloy chemistry. The ingot was then roll-processed to form a plate at temperatures between 950 and 1200°C. The rolling process was conducted to ensure a fine dynamically recrystallized grain morphology and full material densification. The net reduction ratio exceeded 60% where the reduction ration = ((ingot thickness – plate thickness)/ingot thickness). In a subsequent step, the hot-rolled plate was thermo-mechanically processed as described in U.S. Patent No. 6,123,783, to Bartholomeusz, et al., incorporated herein by reference. A cylindrically-shaped target having a thickness of 5 mm and a diameter of 180 mm was then machined from the thermo-mechanically processed plate.

[81] The PTF of the conventionally formed target was measured at four equally spaced locations (one measurement per quadrant) and at a radial position halfway between the center of the target and the outer diameter using the previously-described ASTM measurement technique.

Target Formed by Process According to the Invention

[82] The manufacture of the Co-4Nb-5Zr target with the process according to the invention involved using elemental Co, Nb and Zr powders, each having an average diameter less than 150 micrometers. The powders were blended to achieve homogeneous mixing, encapsulated, evacuated, and hot-isostatic-pressed at between about 800 and about 1400°C at a pressure between about 5 and about 15 ksi for hold times between about 1 to about 4 hours. After hot-isostatic-pressing, the fully consolidated or fully dense material was thermo-mechanically processed as described in U.S. Patent No. 6,123,783, to Bartholomeusz, et al. A cylindrically-shaped target having a thickness of 5 mm and a diameter of 180 mm was then machined from the thermo-mechanically processed plate.

[83] The PTF of the target was measured at four equally spaced locations (one measurement per quadrant) and at a radial position halfway between the center of the target and the outer diameter using the previously-described ASTM measurement technique, which was identical to the method used to measure the PTF of conventionally formed target.

[84] The PTF values of the conventionally formed target and the target manufactured by the process according to the invention are 39% and 56%, respectively. The PTF value of 39% indicates that even conventionally formed Co-based soft-magnetic materials (not containing Fe or Ni as alloying additions) can exhibit reasonably high values of PTF. However, as previously demonstrated, forming the targets with the process according to the invention still results in significantly enhanced PTF performance of the alloy under consideration. This example further demonstrates that PTF enhancing techniques applied to Co and Ni based materials are also effective in enhancing the PTF of the elemental Co and Ni constituent phases contained within a target formed using the process according to the invention.

[85] In the examples discussed above, the PTF test and geometries of the targets have been maintained as consistently as possible because the absolute PTF value of soft-magnetic materials can exhibit a dependency on the relative geometry between target and magnet and the nominal strength of the magnet utilized. Therefore, although the absolute values of PTF for targets formed using the conventional process and the process according to the invention

can vary as a function of the method utilized to measure PTF, targets manufactured using the process according to the invention have higher values of PTF than targets formed using identical alloys but by conventional processing.

[86] As an example, two targets of Ni-19Fe were manufactured using identical processes with the first target being 6 mm thick with a 76 mm diameter and the second target also being 6 mm thick but with a 152 mm diameter. For both targets, a 4.4 kilogauss magnet, possessing a 6.5 mm by 26mm cross section, was placed in contact with the center of one face of each target. An axial Hall probe was then placed at the center of the opposite face. The PTF measured values for the 76 mm and 152 mm diameter targets were respectively 30% and 15%. Thus, this test demonstrates that a target (76 mm) with a smaller relative amount of soft-magnetic target material can be saturated by an applied magnetic field to yield a higher net PTF.

[87] In another test using the 152 mm target, the target was placed on an actual PVD magnetron cathode. At target-to-cathode distances of 10 and 15 mm, the maximum PTF on the opposing face of the 152 mm target was measured at 60% and 20%, respectively. Thus, this test demonstrates the impact of applied magnetic field strength on the net PTF of soft-magnetic materials.

[88] The present invention can be practiced by employing conventional materials, methodology and equipment. Accordingly, the details of such materials, equipment and methodology are not set forth herein in detail. In the previous descriptions, numerous specific details are set forth, such as specific materials, structures, chemicals, processes, etc., in order to provide a thorough understanding of the present invention. However, it should be recognized that the present invention can be practiced without resorting to the details specifically set forth. In other instances, well known processing structures have not been described in detail, in order not to unnecessarily obscure the present invention.

[89] Only an exemplary aspect of the present invention and but a few examples of its versatility are shown and described in the present disclosure. It is to be understood that the present invention is capable of use in various other combinations and environments and is capable of changes or modifications within the scope of the inventive concept as expressed herein.

What is Claimed Is:

1. A disk drive, comprising:

a magnetic disk; wherein

the magnetic disk is formed by depositing material from a target onto a substrate of the magnetic disk, the target includes a first material phase having a first PTF and a second material phase having a second PTF, the second PTF higher than the first PTF.

2. The disk drive according to claim 1, wherein the target has a chemistry differing from chemistries of both the first and second material phases.

3. The disk drive according to claim 1, wherein a chemistry of the target is that for a soft magnetic material.

4. The method according to claim 1, wherein the target is formed by powder metallurgy.