

Sputtering Target of Ruthenium-containing Alloy and Production Method Thereof

The present invention relates to a Ru-containing alloy sputtering target which is used for depositing an intermediate layer of magnetic media for use in hard disk drive and to a method for producing a Ru-containing alloy sputtering target.

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Hard disk drives used for storage of digital data typically comprise a substrate, such as a glass or aluminum substrate, with various materials deposited layer by layer on the substrate. Each of the materials deposited on the substrate serves a specific purpose so as to assist reading and writing data on the media. Each layer is typically deposited via physical vapor deposition techniques, also referred to as sputtering. Usually, the material of the deposited layers is provided from bulk components (i.e. sputtering targets).

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Current media architecture is referred to as “perpendicular magnetic recording” (PMR) due to the orientation of the magnetic recording bits in relation to the substrate and is composed of several layers such as Soft Magnetic Under Layer (SUL), Seed Layer (SL), Intermediate Layer (IL), multiple recording layers, cap layer, Carbon Overcoat (COC) and a lubrication layer. Each layer has a specific function in enabling the data to be stored and read.

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It is known that the magnetic recording layer can be a Co-containing oxide layer (e.g. a CoPt- or CoCrPt-based magnetic layer), and the intermediate layer can be a granular Ru-containing structure. The presence of intermediate layer can provide a template for well-isolated small grain microstructure as well as improvement of K_u by facilitating epitaxial growth in core grains of a magnetic recording layer. The intermediate layer composition may be adjusted to improve lattice parameters similar to a magnetic recording layer and to reduce interface strains caused by lattice mismatch between the magnetic recording layer and an underlying seed layer. The intermediate layer may be formed of Ru, RuCo and RuCoCr alloys. The grain core consists of the hcp Ru and the grain boundaries are made from magnetic materials having high permeability like RuCo or RuCoCr of the thin film. As like the other layers of the PMR device, such an intermediate layer is typically applied by sputtering.

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When a Ru alloy is to be used as a sputtering target material of a hard disk thin film media, in particular as an intermediate layer material, oxygen content should be kept very low level. In conventional technology, the oxygen content being less than 200 ppm is preferred. When sputtering is performed using a target with oxygen content of more than 200 ppm, there are

problems in that the quality of the deposited thin film will decrease which reduce SNR as well as epitaxial growth of the magnetic layer, and the generation of arcing and particles will become notable during sputtering. As a result, it was not possible to obtain a target material having the characteristics required for the PMR device. Arcing and generation of particles are problematic phenomena that may occur during a sputtering process and should be suppressed as much as possible. Furthermore, it would be desirable if a uniform and consistent sputtering is possible with the sputtering target, and the sputtered thin layer obtained from the sputtering process has a uniform composition.

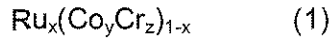
US 2009/0114535 A1 describes a Ru-containing alloy sputtering target having an oxygen content of 100 to 500 wt-ppm. To achieve a low oxygen content, the sputtering target is prepared by a powder metallurgical method wherein a Ru powder and a powder of a second metal which is tantalum are sintered. However, if the additive amount of tantalum is more than 20% in this patent example may form an intermetallic phase which will cause arcing and particle problems.

US 2007/0116592 A1 describes the preparation of a Ru-containing alloy sputtering target by a powder metallurgical process wherein metal powders are mixed to a preform which is then heated in a hydrogen atmosphere and subjected to hot isostatic pressing. Due to the treatment in a reducing atmosphere (i.e. hydrogen), the sputtering target can have an oxygen content of 200 ppm or less. However, this patent mentioned only hydrogen reduction effect to decrease the oxygen content. This patent did not evaluate multi-phase formation which will cause arcing and particle problems.

An object of the present invention is to provide a Ru-containing sputtering target which can be used for providing an intermediate layer to provide a uniform microstructure, and which shows low arcing and particle generation during the sputtering process.

The object is solved by a Ru-Co-Cr alloy sputtering target, wherein Co and Cr are present in the sputtering target in a combined amount (amount of Co + amount of Cr) of 80 at% or less, the balance being Ru and unavoidable impurities, and wherein the sputtering target has an oxygen content of less than 200 wt-ppm.

The alloy of which the sputtering target is made may also be described by the following formula (1):



5 wherein

x is ≥ 0.20 ;

$y + z = 1.0$

$0 < y * (1-x) < 0.80$;

$0 < z * (1-x) < 0.80$;

10 $y * (1-x) + z * (1-x) \leq 0.80$;

x is the atomic fraction of Ru in the Ru-Co-Cr alloy (at% of Ru: $100 * x$);

$y * (1-x)$ is the atomic fraction of Co in the Ru-Co-Cr alloy
(at% of Co: $100 * y * (1-x)$);

$z * (1-x)$ is the atomic fraction of Cr in the Ru-Co-Cr alloy

15 (at% of Cr: $100 * z * (1-x)$).

Preferably, the combined amount of Co and Cr in the sputtering target is in the range of from 5 at% to 80 at%, more preferably from 10 to 80 at%, even more preferably from 30 to 80 at% or from 45 to 80 at%.

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Preferably, Cr is present in the sputtering target (i.e. based on the total weight of the Ru-Co-Cr alloy sputtering target) in an amount of from 5 at% to less than 80 at%, more preferably from 10 at% to 50 at%.

25 If based on the combined amount of Cr and Co (i.e. total amount of Co + Cr in the Ru-Co-Cr alloy representing 100 at%), Cr can be present in an amount of e.g. from 10 at% to 90 at%, more preferably from 10 at% to 80 at% or from 20 at% to 70 at%. In other words, in formula (1), z can be e.g. from 0.10 to 0.90, more preferably from 0.10 to 0.80 or from 0.20 to 0.70.

30 Preferably, the sputtering target has an oxygen content of less than 160 wt-ppm, even more preferably less than 100 wt-ppm, or even less than 50 wt-ppm.

As will be described below in further detail, a Ru-Co-Cr alloy sputtering target having a very homogeneous microstructure can be obtained if the alloy is prepared by a cast process

35 including one or more vacuum melting steps. If the Ru-Co-Cr alloy is prepared by a powder

metallurgical process which includes sintering of Ru powder (or Ru-containing alloy powder) and Cr powder (or Cr-containing alloy powder), an intermetallic Cr-Ru phase can be formed in the form of high compositional fluctuation or even dispersed particles, thereby resulting in a microstructure of reduced homogeneity, as demonstrated by the Examples described further below.

Preferably, the Ru-Co-Cr alloy sputtering target has a fluctuation in composition, expressed as a standard deviation, for each of the elements Ru, Co and Cr of less than ± 5 at%, more preferably less than ± 2 at%.

The compositional fluctuation is determined by SEM-EDX analysis carried out at different locations on a polished surface of the sputtering target which is perpendicular to the sputtering direction. Five locations from x1000 magnification area are used for comparison. The distance between 2 neighbouring locations is more than 3000 μm , e.g. 5000 μm . Each location which is analyzed by SEM-EDX covers an area of 14400 μm^2 . For each location, the concentrations of Ru, Co, and Cr (in at%) are determined. Based on these measurements on 5 different locations, a mean concentration value (at%) and a standard deviation thereof are calculated for each element (i.e. Ru, Co, and Cr).

Preferably, Ru, Co and Cr of the Ru-Co-Cr alloy sputtering target are in solid solution state. Preferably, the Ru-Co-Cr alloy sputtering target is made of a single phase. The term "single phase" means that no second alloy phase (either as an intermetallic phase or as a newly precipitated phase) can be detected on a SEM image with x1000 magnification taken from a polished surface of the sputtering target which is perpendicular to the sputtering direction.

Preferably, the sputtering target does not contain a dispersed phase (e.g. a dispersed alloy phase) having a particle size of more than 5 μm . More preferably, the sputtering target does not contain a dispersed phase having a particle size of more than 3 μm . Even more preferably, no dispersed phase is present in the sputtering target of the present invention.

Whether or not the sputtering target contains a dispersed phase (i.e. a phase which is dispersed in the Ru-Co-Cr alloy in the form of discrete particles) can be determined on a SEM image with x1000 magnification taken from a polished surface of the sputtering target which is perpendicular to the sputtering direction. The size of dispersed particles can be determined on the SEM image by using a SEM image analyzer software. The particle size or diameter of a

particle is based on the projected area diameter which is the diameter of a sphere having the same projected area as the particle. The projected area diameter d of a particle can be related to the particle projected area A by

$$d = ((4 \times A) / \pi)^{1/2}$$

- 5 or $r = (A / \pi)^{1/2}$, wherein r is the circle radius (i.e. $0.5 \times d$)

The sputtering target can be in the form of a plate. However, other commonly known forms of sputtering targets, e.g. tubes, are possible as well.

- 10 Optionally, the sputtering target can be fixed on a supporting member, e.g. a backing plate or a backing tube.

- The present invention further relates to a process for preparing the Ru-Co-Cr alloy sputtering target as described above, wherein a metal starting material comprising Ru, Co and Cr is
15 provided, and the metal starting material is subjected to one or more vacuum melting steps, each vacuum melting step followed by a solidification step.

- As already mentioned above, it has been realized in the present invention that a Ru-Co-Cr alloy sputtering target having a very uniform microstructure can be obtained by using one or more
20 vacuum melting steps. Each vacuum melting step is followed by a solidification step which is typically carried out under vacuum or inert gas atmosphere, for example, argon. If needed, the solid alloy composition obtained after the final vacuum melting and solidification step can be subjected to a thermo-mechanical treatment (such as hot isostatic pressing or hot rolling) and/or a machining so as to obtain the final sputtering target.

- 25 The metal starting material can be in the form of two or more separate components, such as Ru or a Ru-based alloy, Co or a Co-based alloy, and Cr or a Cr-based alloy. These separate components can be separately introduced into the furnace where the vacuum melting is carried out. Alternatively, the two or more separate components can be mixed before they are
30 introduced into the furnace where the vacuum melting is carried out.

Alternatively, it is also possible that the metal starting composition comprises just one component.

Typically, the metal starting material contains Ru, Co and Cr in amount which substantially correspond to the amount of Ru, Co, and Cr in the Ru-Co-Cr alloy sputtering target. So, all the Ru, Co and Cr may already be introduced by the starting material which means normally that no additional Ru-, Co-, and/or Cr-containing material has to be added at a later stage of the process to balance the final composition.

As indicated above, the metal starting material is subjected to at least one vacuum melting step.

In the context of the present invention, the term "vacuum melting" typically refers to a pressure of 10^{-3} mbar or less, more preferably 10^{-5} mbar or less during the melting step.

Metallurgical vacuum melting methods are commonly known to the skilled person. Preferably, the one or more vacuum melting steps are a vacuum induction melting step, a vacuum arc remelting step, a vacuum electron beam melting step, or a combination of at least two of these vacuum melting steps. Appropriate conditions and devices for melting metals under vacuum by using e.g. a magnetic field (i.e. induction heating), an electron beam or an arc are generally known to the skilled person.

Typically, different from a sintering process wherein just the surface of the metal particles is melted, the entire material is melted during the vacuum melting step which results in uniform composition distribution.

Of course, if two or more vacuum melting steps are carried out, a solidification step follows each vacuum melting step. In other words, for each vacuum melting step, there is also a solidification step. If needed, the solid alloy material obtained after the final solidification step can be subjected to a machining step.

The second, third, etc. vacuum melting steps are also referred to as vacuum re-melting steps.

In the process of the present invention, just one vacuum melting step is already sufficient for obtaining a Ru-Co-Cr alloy sputtering target of high structural homogeneity. However, for further improving microstructure homogeneity and lower oxygen level, it can be preferred that two or more vacuum melting steps (i.e. an initial vacuum melting step and at least one vacuum re-melting step) are carried out.

In an exemplary embodiment, the metal starting material is subjected to one or more vacuum induction melting steps, and subsequently to one or more vacuum arc remelting steps.

- 5 According to another exemplary embodiment, the metal starting material is subjected to one or more vacuum induction melting steps, and subsequently to one or more vacuum electron beam remelting steps.

10 The solidification step can be carried out under vacuum. Optionally, it is also possible that the solidification is at least partially accomplished under non-vacuum conditions (e.g. at atmospheric pressure), preferably in an inert gas atmosphere.

The average cooling rate (i.e. $(T_{\text{melt}} - T_{\text{solidified alloy}}) / \text{time needed for cooling down from } T_{\text{melt}} \text{ to } T_{\text{solidified alloy}}$) of the one or more solidification steps can vary over a broad range. Just as an
 15 example, the average cooling rate during the solidification can be less than 50°C/min, more preferably less than 25°C/min, or less than 15°C/min, or even less than 5°C/min.

The process comprises a final vacuum melting step, followed by a final solidification step. In a preferred embodiment, the average cooling rate in the final solidification step is less than
 20 15°C/min, more preferably less than 5°C/min. Of course, if the process comprises just one vacuum melting step, followed by a first solidification step, said first solidification step would then automatically represent the final solidification step.

For accomplishing a low average cooling rate, the final solidification step is preferably carried
 25 out in a graphite mold. Optionally, the graphite mold is covered by a thermal insulator material such as a ceramic fiber material (e.g. ceramic fiber wool, in particular alumina wool, alumina silicate wool, or similar materials). Such graphite molds are known and commercially available. It is also possible that a mold can be heated by any given heating machine (e.g. direct / indirect electric resistance heating or induction heating).

30 If needed, the solid alloy material obtained after the final solidification step can be subjected to a machining step. The steps typically carried out for machining a solid alloy composition to a final sputtering target are commonly known to the skilled person. Machining to the final sputtering target may include e.g. cutting the solid alloy composition to its final dimensions and polishing a
 35 surface of the solid alloy composition.

Optionally, the solid alloy material obtained after the final solidification step, and/or the sputtering target (obtained after the machining treatment) can be subjected to a thermo-mechanical treatment (such as hot isostatic pressing or hot rolling) to increase mechanical properties and/or to improve compositional uniformity.

The present invention will now be described in further detail by the following Examples.

Examples

If not stated otherwise, the microstructure of the sputtering targets of the present invention was analyzed as follows:

To investigate the localized compositional fluctuation and to confirm a single phase alloy, the SEM device (JEOL JSM-6610LV) equipped with EDX (Oxford INCA x-act) is used. A surface of the sputtering target which is perpendicular to the sputtering direction was polished by conventional metallurgical analysis method. A SEM image with x1000 magnification was taken from the polished surface of the sputtering target.

The compositional fluctuation is determined by SEM-EDX analysis carried out at different locations on a polished surface of the sputtering target which is perpendicular to the sputtering direction. Five locations from x1000 magnification area are used for comparison. The distance between 2 neighbouring locations is 5000 μm . Each location which is analyzed by SEM-EDX covers an area of 14400 μm^2 . For each location, the concentrations of Ru, Co, and Cr (in at%) are determined. Based on these measurements at 5 different locations, a mean concentration value (at%) and a standard deviation thereof are calculated for each element (i.e. Ru, Co, and Cr).

Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) is used to measure the target's overall composition.

Oxygen content is measured by GAS analyzer (Eltra ONH-2000) via inert gas fusion in an impulse furnace.

If dispersed particles can be detected on the SEM image, an image analyzer software (Image J 2.0) was used for determining particle size.

Inventive Example 1 (IE1): 24.95Ru-50.15Co-24.90Cr-alloy sputtering target via vacuum melting

In Inventive Example 1, a sputtering target made of an alloy containing about 24.95 at% Ru, 50.15 at% Co, and 24.90 at% Cr was prepared as follows:

A Ru-Co-Cr alloy raw material containing nominal composition of Co: 50at %, Cr: 25 at %, and remainder being Ru and unavoidable impurities was subject to vacuum induction melting. The raw materials were melted under the pressure of less than 10^{-4} mbar. The resulting product was cast using a graphite mold, which is covered by alumina wool to reduce heat conductivity to out of the mold, at a temperature between melting point and melting point+100° C. Subsequently, the ingot was hot isostatic pressed at 1375° C for 3 hours with 196.5 MPa, and additionally machined to obtain a target.

The final sputtering target had a very low oxygen content of 91 wt-ppm. The oxygen content values of all Inventive and Comparative Examples are summarized further below in Table 7.

A SEM image at 1000 x magnification is shown in Figure 1. Elemental mapping images are shown in Figure 2a (for Cr), 2b (for Ru), and 2c (for Co). As can be seen from Figures 1 and 2a-c, a very homogeneous alloy structure was obtained. No separate intermetallic phase and no dispersed particles were detected in the SEM image.

No dispersed phase larger than 3 μm was formed.

The very uniform structure was confirmed by elemental area analysis of Ru, Co, and Cr via SEM-EDX, comparing the Ru, Co and Cr concentrations of 5 locations and determining a standard deviation for each element, as described above. The Ru-Co-Cr alloy sputtering target had a fluctuation in composition, expressed as a standard deviation, for each of the elements Ru, Co and Cr of less than ± 1 at%. The results are summarized in Table 1.

Table 1: Compositional fluctuations determined via SEM-EDX

	Ru (at%)	Co (at%)	Cr (at%)	Total
Location 1	25.58	49.72	24.7	100
Location 2	24.31	51.11	24.58	100
Location 3	25.64	49.65	24.71	100
Location 4	24.38	50.82	24.8	100
Location 5	25.04	49.98	24.98	100
Mean	24.99	50.26	24.75	100
Std. deviation	0.63	0.67	0.15	

5 Inventive Example 2 (IE2): 30.33Ru-49.51Co-20.16Cr-alloy sputtering target via vacuum melting

In Inventive Example 2, a sputtering target made of an alloy containing about 30.33 at% Ru, 49.51 at% Co, and 20.16 at% Cr was prepared as follows:

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A Ru-Co-Cr alloy raw material containing nominal composition of Co: 50at %, Cr: 20 at %, and remainder being Ru and unavoidable impurities was subject to vacuum induction melting. The raw materials were melted under the pressure of less than 10^{-4} mbar. The resulting product was cast using a graphite mold, which is covered by alumina wool to reduce heat conductivity to out of the mold, at a temperature between melting point and melting point+100° C. Subsequently, the ingot was hot isostatic pressed at 1375° C for 3 hours with 196.5 MPa, and additionally machined to obtain a target.

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The final sputtering target had a low oxygen content of 44 ppm.

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A SEM image at 1000 x magnification is shown in Figure 3. Elemental mapping images are shown in Figure 4a (for Cr), 4b (for Ru), and 4c (for Co). As can be seen from Figures 3 and 4a-c, a very homogeneous alloy structure was obtained. No separate intermetallic phase and no dispersed particles were detected in the SEM image.

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The very uniform structure was confirmed by elemental area analysis of Ru, Co, and Cr via SEM-EDX, comparing the Ru, Co and Cr concentrations of 5 locations and determining a

standard deviation for each element, as described above. The Ru-Co-Cr alloy sputtering target had a fluctuation in composition, expressed as a standard deviation, for each of the elements Ru, Co and Cr of less than ± 1 at%. The results are summarized in Table 2.

5 Table 2: Compositional fluctuations determined via SEM-EDX

	Ru (at%)	Co (at%)	Cr (at%)	Total
Location 1	29.38	51.38	19.24	100
Location 2	30.84	50.01	19.15	100
Location 3	29.54	49.69	20.77	100
Location 4	30.38	49.82	19.8	100
Location 5	30.14	49.94	19.92	100
Mean	30.06	50.17	19.78	100
Std. deviation	0.60	0.69	0.65	

Inventive Example 3 (IE3): 35.11Ru-24.84Co-40.05Cr-alloy sputtering target via vacuum melting

10 In Inventive Example 3, a sputtering target made of an alloy containing about 35.11 at% Ru, 24.84 at% Co, and 40.05 at% Cr was prepared as follows:

A Ru-Co-Cr alloy raw material containing nominal composition of Co: 25at %, Cr: 40 at %, and remainder being Ru and unavoidable impurities was subject to vacuum induction melting. The raw materials were melted under the pressure of less than 10^{-4} mbar. The resulting product was cast using a graphite mold, which is covered by alumina wool to reduce heat conductivity to out of the mold, at a temperature between melting point and melting point+100° C. Subsequently, the ingot was hot isostatic pressed at 1375° C for 3 hours with 196.5 MPa, and additionally machined to obtain a target.

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The final sputtering target had a low oxygen content of 116 ppm.

A SEM image at 1000 x magnification is shown in Figure 5. Elemental mapping images are shown in Figure 6a (for Cr), 6b (for Ru), and 6c (for Co). As can be seen from Figures 5 and 6a-c, a very homogeneous alloy structure was obtained. No separate intermetallic phase and no dispersed particles were detected in the SEM image.

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The very uniform structure was confirmed by elemental area analysis of Ru, Co, and Cr via SEM-EDX, comparing the Ru, Co and Cr concentrations of 5 locations and determining a standard deviation for each element, as described above. The Ru-Co-Cr alloy sputtering target had a fluctuation in composition, expressed as a standard deviation, for each of the elements Ru, Co and Cr of less than ± 0.5 at%. The results are summarized in Table 3.

Table 3: Compositional fluctuations determined via SEM-EDX

	Ru (at%)	Co (at%)	Cr (at%)	Total
Location 1	36.05	24.31	39.64	100
Location 2	35.97	24.84	39.19	100
Location 3	35.51	25.31	39.18	100
Location 4	35.2	24.93	39.87	100
Location 5	36.01	24.84	39.15	100
Mean	35.75	24.85	39.41	100
Std. deviation	0.38	0.36	0.33	

Inventive Example 4 (IE4): 49.80Ru-24.95Co-25.25Cr-alloy sputtering target via vacuum melting

In Inventive Example 4, a sputtering target made of an alloy containing about 49.80 at% Ru, 24.95 at% Co, and 25.25 at% Cr was prepared as follows:

A Ru-Co-Cr alloy raw material containing nominal composition of Co: 25at %, Cr: 25 at %, and remainder being Ru and unavoidable impurities was subject to vacuum induction melting. The raw materials were melted under the pressure of less than 10^{-4} mbar. The resulting product was cast using a graphite mold, which is covered by alumina wool to reduce heat conductivity to out of the mold, at a temperature between melting point and melting point+100° C. Subsequently, the ingot was hot isostatic pressed at 1375° C for 3 hours with 196.5 MPa, and additionally machined to obtain a target.

The final sputtering target had a low oxygen content of 138 ppm.

A SEM image at 1000 x magnification is shown in Figure 7. Elemental mapping images are shown in Figure 8a (for Cr), 8b (for Ru), and 8c (for Co). As can be seen from Figures 7 and 8a-

c, a very homogeneous alloy structure was obtained. No separate intermetallic phase and no dispersed particles were detected in the SEM image.

The very uniform structure was confirmed by elemental area analysis of Ru, Co, and Cr via SEM-EDX, comparing the Ru, Co and Cr concentrations of 5 locations and determining a standard deviation for each element, as described above. The Ru-Co-Cr alloy sputtering target had a fluctuation in composition, expressed as a standard deviation, for each of the elements Ru, Co and Cr of not more than ± 0.5 at%. The results are summarized in Table 4.

Table 4: Compositional fluctuations determined via SEM-EDX

	Ru (at%)	Co (at%)	Cr (at%)	Total
Location 1	50.11	25.2	24.69	100
Location 2	50.16	25.23	24.61	100
Location 3	50.68	24.42	24.9	100
Location 4	50.75	24.21	25.04	100
Location 5	50.23	24.3	25.47	100
Mean	50.39	24.67	24.94	100
Std. deviation	0.30	0.50	0.34	

Inventive Example 5 (IE5): 50.16Ru-24.87Co-24.96Cr-alloy sputtering target via vacuum melting and vacuum arc remelting

In Inventive Example 5, a sputtering target made of an alloy containing about 50.16 at% Ru, 24.87 at% Co, and 24.96 at% Cr was prepared as follows:

A Ru-Co-Cr alloy raw material containing nominal composition of Co: 25at %, Cr: 25 at %, and remainder being Ru and unavoidable impurities was subject to vacuum induction melting. The raw materials were melted under the pressure of less than 10^{-4} mbar. The ingot was cast using a graphite mold, which is covered by alumina wool to reduce heat conductivity to out of the mold, at a temperature between melting point and melting point+100° C. Then, the ingot is proceed to the 2nd melting process with Vacuum Arc Remelting (VAR) methods. The ingot which is used as an electrode is attached to an upper ram. Furnace walls enclose furnace chamber are water-cooled which is common in this art. Furnace has a hollow cylinder configuration and the inside is evacuated with vacuum level. The electrode melting rate is 1.53 kg / min. The melt is solidified in a water-cooled copper mold. After melting, the ingot was

cooled in the furnace for 3 hours. Subsequently, the ingot was hot isostatic pressed at 1375° C for 3 hours with 196.5 MPa, and additionally machined to obtain a target.

The final sputtering target had a low oxygen content of 22 ppm.

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A SEM image at 1000 x magnification is shown in Figure 9. Elemental mapping images are shown in Figure 10a (for Cr), 10b (for Ru), and 10c (for Co). As can be seen from Figures 9 and 10a-c, a very homogeneous alloy structure was obtained. No separate intermetallic phase and no dispersed particles were detected in the SEM image.

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The very uniform structure was confirmed by elemental area analysis of Ru, Co, and Cr via SEM-EDX, comparing the Ru, Co and Cr concentrations of 5 locations and determining a standard deviation for each element, as described above. The Ru-Co-Cr alloy sputtering target had a fluctuation in composition, expressed as a standard deviation, for each of the elements Ru, Co and Cr of less than ± 0.5 at%. The results are summarized in Table 5.

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Table 5: Compositional fluctuations determined via SEM-EDX

	Ru (at%)	Co (at%)	Cr (at%)	Total
Location 1	50.11	25.75	24.14	100
Location 2	50.55	25.45	24	100
Location 3	50.47	24.8	24.73	100
Location 4	50.24	25.12	24.64	100
Location 5	49.95	25.09	24.96	100
Mean	50.26	25.24	24.49	100
Std. deviation	0.25	0.37	0.41	

20 **Comparative Example 1 (CE1): 49.93Ru-25.11Co-24.97Cr-alloy sputtering target via powder metallurgy**

In Comparative Example 1, a sputtering target made of an alloy containing about 49.93 at% Ru, 25.11 at% Co, and 24.97 at% Cr (i.e. a composition which corresponds to the one of Inventive Example 4) was prepared by powder metallurgical process steps as follows:

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A Ru-75Co at% powder having a grain size of less than 45 μm , a Cr powder having a grain size of less than 44 μm , and a Ru powder having an grain size of less than 15 μm were prepared as raw material powders. These powders were weighed at weight proportions of 29.59 wt % of the Ru-75Co powder, 16.61 wt % of the Cr powder, and 53.81 wt % of the Ru powder to obtain a target having a nominal composition of Ru-25Co-25Cr at%. Subsequently, the Ru-75Co powder, the Cr powder, and the Ru powder were placed in a blend machine for 2 hours for mixing. The resulting powder mixture was charged in a graphite mold and was hot-pressed in a vacuum atmosphere under conditions of a temperature of 1285° C., a retention time of 10 minutes, and a pressure of 35 MPa to obtain a sintered compact. The sintered compact was ground with a surface grinder to obtain a disk-shaped.

The final sputtering target had an oxygen content of 322 ppm, which is significantly higher than the oxygen content obtained in the Inventive Examples.

A SEM image at 1000 x magnification is shown in Figure 11. Elemental mapping images are shown in Figure 12a (for Cr), 12b (for Ru), and 12c (for Co). As can be seen from Figures 11 and 12a-c, the microstructure is not homogeneous and some dispersed particles are located inside the intermetallic area.

The structure of low homogeneity was confirmed by elemental area analysis of Ru, Co, and Cr via SEM-EDX, comparing the Ru, Co and Cr concentrations of 5 locations and determining a standard deviation for each element, as described above. The Ru-Co-Cr alloy sputtering target had a fluctuation in composition, expressed as a standard deviation, for each of the elements Ru, Co and Cr of more than ± 7 at%. The results are summarized in Table 6.

Table 6: Compositional fluctuations determined via SEM-EDX

	Ru (at%)	Co (at%)	Cr (at%)	Total
Location 1	47.63	34.06	18.31	100
Location 2	49.88	25.1	25.02	100
Location 3	55.01	24.8	20.19	100
Location 4	23.45	17.94	58.61	100
Location 5	42.67	36.09	21.24	100
Mean	43.73	27.60	28.67	100
Std. deviation	12.17	7.44	16.91	

The oxygen content values of Inventive Examples 1-6 and Comparative Example 1 are summarized in Table 7.

Table 7: Oxygen content of the sputtering targets

Examples	Oxygen (ppm)
Inventive Example 1	91
Inventive Example 2	44
Inventive Example 3	116
Inventive Example 4	138
Inventive Example 5	22
Comparative Example 1	322

Patent Claims

1. A Ru-Co-Cr alloy sputtering target, wherein Co and Cr are present in the sputtering target in a combined amount of 80 at% or less, the balance being Ru and unavoidable impurities; and wherein the sputtering target has an oxygen content of less than 200 wt-ppm.
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2. The sputtering target according to claim 1, having an oxygen content of less than 160 ppm.
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3. The sputtering target according to claim 1 or 2, wherein Cr is present in the sputtering target in an amount of from 5 at% to less than 80 at%.
4. The sputtering target according to one of the preceding claims, wherein the amount of Cr, based on the total amount of Co and Cr in the sputtering target, is from 10 at% to 90 at%.
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5. The sputtering target according to one of the preceding claims, wherein no intermetallic phase is present in the sputtering target.
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6. The sputtering target according to one of the preceding claims, wherein the sputtering target has a fluctuation in composition for each of the elements Ru, Co and Cr of less than +/- 5 at%.
7. The sputtering target according to one of the preceding claims, wherein the sputtering target is made of a single Ru-Co-Cr alloy phase.
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8. A process for preparing the Ru-Co-Cr alloy sputtering target of one of the claims 1 to 7, wherein a metal starting material comprising Ru, Co and Cr is subjected to one or more vacuum melting steps, each vacuum melting step followed by a solidification step.
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9. The process according to claim 8, wherein the vacuum melting step is a vacuum induction melting step, a vacuum arc remelting step, or a vacuum electron beam melting step, or a combination of at least two of these vacuum melting steps.
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10. The process according to claim 8 or 9, comprising two or more vacuum melting steps.
11. The process according to one of the claims 9 to 10, comprising at least one vacuum induction melting step, and subsequently at least one vacuum arc remelting step or at least one vacuum electron beam remelting step.
12. The process according to one of the claims 8 to 11, comprising a final vacuum melting step followed by a final solidification step, wherein the final solidification step has an average cooling rate of less than 15°C/min.