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(54) HOT DEFORMED MAGNET, AND A METHOD FOR PREPARING SAID HOT DEFORMED MAGNET

HEISSGEFORMTER MAGNET UND VERFAHREN ZUR HERSTELLUNG DES BESAGTEN HEISSGEFORMTEN MAGNETEN

AIMANT DÉFORMÉ À CHAUD ET PROCÉDÉ DE PRÉPARATION DUDIT AIMANT DÉFORMÉ À CHAUD

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(56) References cited:
CN-A- 102 189 266
CN-A- 102 436 887
CN-A- 102 610 347
CN-A- 102 693 799
CN-A- 106 448 986
FR-A1- 2 779 267
US-A- 5 211 766
US-A- 5 395 462
US-A1- 2013 093 552
US-A1- 2015 364 234

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Description

Technical Field

[0001] The present invention relates to a hot deformed magnet, as well as a method for preparing said hot deformed magnet.

Background Art

[0002] Generally, rare earth/iron/boron-based permanent magnet exhibits high remanence and coercivty, provides a high magnetic flux within a specific temperature range (for example -40 ~ 180 °C for EV/HEV traction motor), and makes the electric motor have superior performances, for example high power density, high torque density and high efficiency.

[0003] The coercivity is the magnitude of magnetic field at which the magnetization of a permanent magnet is reduced to zero. It stands for the ability of the permanent magnet to generate a magnetic flux against the demagnetization field and also the ability of the permanent magnet to generate a magnetic flux against the high working temperature.

[0004] The remanence represents the magnitude of the maximum magnetic flux which can be generated by the permanent magnet. It represents the ability of the permanent magnet to provide a magnetic moment. Normally a high remanence is favorable to render a permanent magnet thinner and lighter in case of a fixed magnetic moment, and consequently reduce the size and volume of an electric motor, which is desirable for many applications.

[0005] Coarsen grain regions are mainly generated at the original place of the magnetic powder particulate surfaces during the hot deformation. In the coarsen grain regions, the $RE_2F_{14}B$ grains are almost equiaxed instead of platelet, and often have a dimension of greater than 400 nm. These equiaxed large $RE_2F_{14}B$ grains exhibit a low magnetic orientation, a low ability against the demagnetization field, and consequently deteriorated magnetic properties. Due to the presence of coarsen grain regions, a remanence as high as 1.45 T or above normally can not be achieved for the conventional hot deformed magnets.

[0006] Although great efforts on the design of the alloy composition and the preparation method for the rare earth/iron/boron-based magnetic powders and hot deformed magnets have been made in the prior art, the issue of coarse equiaxed grains or coarsen grain regions is still not overcome for the known magnetic powders and hot deformed magnets

[0007] US 5 395 462 A and US 5 211 766 A show prior art examples of hot pressed NdFeB-based magnets. CN 106 448 986 A shows a cold pressed CeFeB-based magnet and FR 2 779 267 A1 a forged NdFeB-based magnet.

Summary of Invention

[0008] The object of the present invention is to provide a hot deformed magnet which has enhanced magnetic properties, especially enhanced remanence and coercivity, and almost has no coarse equiaxed grains with a diameter greater than 400 nm and consequently no coarse equiaxed grain regions in the microstructure.

[0009] Said object, according to one aspect, can be achieved by a hot deformed magnet having an alloy composition of the formula (1)

$$RE_xFe_{(100-x-y1-y2-z1-z2)}T_{y1}M_{y2}Cu_{z1}B_{z2} \qquad (1),$$

wherein

RE is one or more rare earth elements, such as La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Yb, and Lu, preferably Pr, Nd, Tb, and Dy;
T is one or more elements selected from the group consisting of Co, Al, Ga, Zr, Ti and Mo;
M is Nb and/or Ta;
Cu is copper;
B is boron;
the balance is Fe and inevitable impurities;
x is 13.0 ~ 15.0 at.%;
y1 is 1.2 ~ 10.0 at.%;
y2 is 0.1 ~ 0.8 at.%;
z1 is 0 ~ 0.5 at.%; and
z2 is 4.5 ~ 6.5 at.%.

[0010] Said object, according to another aspect, can be achieved by a method for preparing the hot deformed magnet

according to the present invention, said method including the following steps:

1) preparing magnetic powders by melt quenching from an ingot having an alloy composition of the formula (1)

$$RE_xFe_{(100-x-y1-y2-z1-z2)}T_{y1}M_{y2}Cu_{z1}B_{z2} \quad (1),$$

wherein

RE is one or more rare earth elements, such as La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Yb, and Lu, preferably Pr, Nd, Tb, and Dy;
T is one or more elements selected from the group consisting of Co, Al, Ga, Zr, Ti and Mo;
M is Nb and/or Ta;
Cu is copper;
B is boron;
the balance is Fe and inevitable impurities;
x is 13.0 ~ 15.0 at.%;
y1 is 1.2 ~ 10.0 at.%;
y2 is 0.1 ~ 0.8 at.%;
z1 is 0 ~ 0.5 at.%; and
z2 is 4.5 ~ 6.5 at.%;

2) pressing the magnetic powders prepared from step 1) to obtain a green body; and
3) hot deforming the green body prepared from step 2) to obtain the hot deformed magnet.

Brief Description of Drawings

[0011] Each aspect of the present invention will be illustrated in more detail in conjunction with the accompanying drawings, wherein :

Figure 1 shows the magnetization curves of the hot deformed magnets without Nb (a) (Example 1) and with about 0.2% of Nb (b) (Example 2);
Figure 2 shows the back-scattered SEM images of the hot deformed magnets without Nb (a) and (c) (Example 1) and with about 0.2% of Nb (b) and (d) (Example 2);
Figure 3 shows the BSE-SEM images of the hot deformed magnets without Nb (a) (Example 1) and with about 0.2% of Nb (b) (Example 2);
Figure 4 shows the STEM-EDS mapping of Nd and Nb of the hot deformed magnets with about 0.2% of Nb (a) (Example 2) and with about 0.6% of Nb (b) (Example 4).

Detailed Description of Preferred Embodiments

[0012] Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. In case of conflict, the present specification, including definitions, will control.

[0013] When an amount, concentration, or other value or parameter is given as either a range, preferred range or a list of upper preferable values and lower preferable values, this is to be understood as specifically disclosing all ranges formed from any pair of any upper range limit or preferred value and any lower range limit or preferred value, regardless of whether ranges are separately disclosed. Where a range of numerical values is recited herein, unless otherwise stated, the range is intended to include the endpoints thereof, and all integers and fractions within the range.

[0014] The present invention, according to one aspect, relates to a hot deformed magnet having an alloy composition of the formula (1)

$$RE_xFe_{(100-x-y1-y2-z1-z2)}T_{y1}M_{y2}Cu_{z1}B_{z2} \quad (1),$$

wherein

RE is one or more rare earth elements, such as La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Yb, and Lu, preferably Pr, Nd, Tb, and Dy;
T is one or more elements selected from the group consisting of Co, Al, Ga, Zr, Ti and Mo;

M is Nb and/or Ta;
Cu is copper;
B is boron;
the balance is Fe and inevitable impurities;
x is 13.0 ~ 15.0 at.%;
y1 is 1.2 ~ 10.0 at.%;
y2 is 0.1 ~ 0.8 at.%;
z1 is 0 ~ 0.5 at.%; and
z2 is 4.5 ~ 6.5 at.%.

[0015] In accordance with an embodiment of the hot deformed magnet according to the present invention, the hot deformed magnet can contain a predominant magnetic phase and one or more grain boundary phases.

[0016] In particular, the predominant magnetic phase is the $RE_2Fe_{14}B$ phase having a tetragonal crystal structure. In the context of the present invention, the formula $RE_2Fe_{14}B$ as used herein includes all the compositions having the $RE_2Fe_{14}B$ tetragonal crystal structure, which may or may not include any other elements as stated above, as long as these other elements do not destroy the $RE_2Fe_{14}B$ tetragonal crystal structure.

[0017] On the other hand, the specific compositions and crystal structures of said one or more grain boundary phases are quite complicated. At least one of the grain boundary phases are believed to have a lower melting temperature and a greater proportion of rare earth element(s) than those of the predominant magnetic phase, and therefore, can also be called as RE-rich phase. Another grain boundary phase is believed to be present in form of nano-sized Nb-rich and/or Ta-rich precipitates.

[0018] In accordance with another embodiment of the hot deformed magnet according to the present invention, the hot deformed magnet can exhibit anisotropy with a $RE_2Fe_{14}B$ grain morphology in form of platelet. In particular, the hot deformed magnet can exhibit anisotropy with the crystallographic c-axes of the $RE_2Fe_{14}B$ grains aligned or orientated substantially parallel to one another. The crystallographic c-axes of the $RE_2Fe_{14}B$ grains in form of platelet are perpendicular to the major surfaces of the platelets and parallel to their smallest dimension. The preferred magnetic alignment direction of the $RE_2Fe_{14}B$ grains is along their crystallographic c-axes.

[0019] In accordance with another embodiment of the hot deformed magnet according to the present invention, the thickness of the platelet can be up to 200 nm, preferably 25 - 120 nm, more preferably 25 - 100 nm. In the context of the present invention, the thickness of the platelet shall be understood as its smallest dimension.

[0020] In accordance with another embodiment of the hot deformed magnet according to the present invention, the length of the platelet can be up to 1 μm, preferably 100 - 600 nm, more preferably 100 - 300 nm. In the context of the present invention, the length of the platelet shall be understood as its largest dimension.

[0021] In accordance with another embodiment of the hot deformed magnet according to the present invention, the hot deformed magnet almost has no coarse equiaxed grains with a diameter greater than 400 nm and consequently no coarse equiaxed grain regions in the microstructure.

[0022] The present invention, according to another aspect, relates to a method for preparing the hot deformed magnet according to the present invention, including the following steps:

1) preparing magnetic powders by melt quenching from an ingot having an alloy composition of the formula (1)

$$RE_xFe_{(100-x-y1-y2-z1-z2)}T_{y1}M_{y2}Cu_{z1}B_{z2} \qquad (1),$$

wherein

RE is one or more rare earth elements, such as La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Yb, and Lu, preferably Pr, Nd, Tb, and Dy;
T is one or more elements selected from the group consisting of Co, Al, Ga, Zr, Ti and Mo;
M is Nb and/or Ta;
Cu is copper;
B is boron;
the balance is Fe and inevitable impurities;
x is 13.0 ~ 15.0 at.%;
y1 is 1.2 ~ 10.0 at.%;
y2 is 0.1 ~ 0.8 at.%;
z1 is 0 ~ 0.5 at.%; and
z2 is 4.5 ~ 6.5 at.%;

2) pressing the magnetic powders prepared from step 1) to obtain a green body; and
3) hot deforming the green body prepared from step 2) to obtain the hot deformed magnet.

1) Preparation of magnetic powders

[0023] In step 1), magnetic powders can be prepared by melt quenching from an ingot having the alloy composition of the formula (1).

[0024] In accordance with an embodiment of the method according to the present invention, the ingot can be melted at a temperature of above 1000 °C, preferably 1000 ~ 1100 °C, preferably under a protect atmosphere, such as Argon, and then cast or injected onto a rotating wheel, such as a copper wheel, with a circumferential velocity of 10 ~ 40 m/s, so as to obtain melt-spun ribbons or magnetic powders. The cooling rate can be set according to the circumferential velocity of the rotating wheel and the amount of the molten metal cast or injected.

[0025] In accordance with another embodiment of the method according to the present invention, melt-spun ribbons can be directly obtained by melt quenching from the ingot, and preferably have a thickness of less than 50 μm. Then the melt-spun ribbons can be optionally crushed into magnetic powders preferably having a length of less than 200 μm.

[0026] In accordance with another embodiment of the method according to the present invention, the magnetic powders or the melt-spun ribbons can be crystalline or even amorphous, or have crystallitic grains with a grain size of less than 50 nm, in each case according to the cooling rate.

2) Pressing

[0027] In step 2), the magnetic powders prepared from step 1) can be pressed to obtain a green body.

[0028] In accordance with another embodiment of the method according to the present invention, the magnetic powders prepared from step 1) can be cold pressed at room temperature, wherein the pressure and the duration of the cold pressing are not particularly limited and can be selected in such a way to reach up to 70% or even more of the saturated density, for example 50 ~ 400 MPa and 1 ~ 5 seconds; and then hot pressed to obtain the green body, wherein the temperature of the hot pressing is not particularly limited, for example 550 ~ 850 °C, preferably 600 ~ 700 °C, and can be selected in such a way not to liquefy the predominant magnetic phase, but liquefy the grain boundary phase sufficiently, otherwise the densification might be insufficient and even cracks might be initiated and propagated in the green body; the pressure of the hot pressing is not particularly limited, for example 20 ~ 200 MPa, preferably 20 ~ 100 MPa, and can be selected in such a way to reach the full densification; the duration of the hot pressing is not particularly limited, for example 10 ~ 240 seconds, and can be selected in such a way to reach the full densification, but shall not be too long to cause abnormal growth of the $RE_4Fe_{14}B$ grains and consequently deteriorate the microstructure of the green body; and the atmosphere of the hot pressing is not particularly limited, for example an inert gas protected atmosphere, an oxidation atmosphere, a reduction atmosphere, and vacuum, preferably vacuum.

3) Hot deformation

[0029] In step 3), the green body prepared from step 2) can be hot deformed to obtain the hot deformed magnet.

[0030] In accordance with another embodiment of the method according to the present invention, the green body prepared from step 2) can be hot deformed, for example by extrusion, or die up-setting, so as to reshape the green body into the predetermined shape and geometry, such as cylinder, rectangular block or segment, and simultaneously align the crystallographic c-axes of the $RE_2Fe_{14}B$ grains to the predetermined direction, and finally obtain the hot deformed magnet, wherein the temperature of the hot deformation is not particularly limited, for example 750 ~ 850 °C, preferably 780 ~ 820 °C, and can be selected in such a way to subject the green body to a plastic deformation, but not initiate and propagate cracks in the green body; the pressure of the hot deformation is not particularly limited, for example 20 ~ 250 MPa, preferably 20 ~ 200 MPa; and the atmosphere of the hot deformation is not particularly limited, for example an inert gas protected atmosphere, a reduction atmosphere, vacuum or a low oxidation atmosphere.

[0031] The anisotropy of the $RE_2Fe_{14}B$ grains can be achieved based on such a mechanism that the $RE_2Fe_{14}B$ grains can rotate during the hot deformation under pressure with the help of the grain boundary phase liquefied at the hot deformation temperature, so that the crystallographic c-axes of the $RE_2Fe_{14}B$ grains can be aligned or orientated substantially parallel to one another. The crystallographic c-axes of the $RE_2Fe_{14}B$ grains in form of platelet are perpendicular to the major surfaces of the platelets and parallel to their smallest dimension. The preferred magnetic alignment direction of the $RE_2Fe_{14}B$ grains is along their crystallographic c-axes.

[0032] In accordance with another embodiment of the method according to the present invention, the hot deformed magnet can be further processed by thermal annealing, grain boundary diffusion or other post treatment under cold or warm conditions.

Examples

1) Preparation of magnetic powders

[0033] Raw materials according to the alloy compositions as listed in Table 1 were melted under Argon at a temperature of above 1000 °C until homogeneous, and cast into ingots. The ingots were melted again under Argon at a temperature of above 1000 °C, and then injected onto a copper wheel with a circumferential velocity of 20 m/s to obtain melt-spun ribbons. Then the melt-spun ribbons were crushed into magnetic powders having a length of less than 200 μm.

Table 1 Alloy compositions according to Examples 1 ~ 19 (all in at.%)

Example	Nd	Fe	Co	B	Al	Ga	Nb	Cu
1	12.83	75.97	4.5	5.31	0.43	0.53	0	0
2	12.59	75.67	4.5	5.44	0.67	0.52	0.21	0
3	12.9	75.21	4.49	5.52	0.55	0.51	0.4	0
4	13.09	74.87	4.49	5.56	0.48	0.52	0.64	0
5	13.41	75.42	4.33	5.3	0.31	0.51	0.22	0.19
6	14.42	75.33	4.5	5.22	0	0.53	0	0
7	14.42	75.13	4.5	5.22	0	0.53	0.2	0
8	14.42	74.93	4.5	5.22	0	0.53	0.4	0
9	14.42	74.73	4.5	5.22	0	0.53	0.6	0
10	14.42	74.93	4.5	5.22	0	0.53	0.2	0.2
11	13.64	75.29	4.51	5.58	0.4	0.54	0	0
12	13.52	75.13	4.48	5.51	0.5	0.53	0.2	0
13	13.5	74.99	4.51	5.54	0.5	0.52	0.41	0
14	13.56	74.74	4.5	5.58	0.5	0.53	0.61	0
15	14.15	75.11	4.5	5.09	0.3	0.52	0.17	0.19
16	13	75.54	4.48	5.4	0.63	0.52	0.21	0
17	13.03	75.17	4.49	5.38	0.57	0.51	0.4	0
18	12.88	75.14	4.49	5.47	0.51	0.51	0.66	0
19	13	75.85	4.07	5.34	0.34	0.52	0.25	0.19

2) Pressing

[0034] The magnetic powders prepared from step 1) were cold pressed at room temperature for about 5 seconds to reach at least 70% of the saturated density, and then hot pressed under vacuum at about 700 °C and about 100 MPa for about 120 seconds to obtain green bodies.

3) Hot deformation

[0035] The green bodies prepared from step 2) were hot deformed by extrusion under vacuum at about 800 °C and about 180 MPa to obtain hot deformed magnets.

Evaluation of magnetic properties

[0036] Figure 1 shows the magnetization curves of the hot deformed magnets without Nb (a) (Example 1) and with about 0.2% of Nb (b) (Example 2). The magnetic properties of the hot deformed magnets prepared according to Examples 1 ~ 5 are listed in Table 2.

Table 2 Magnetic properties of the magnets according to Examples 1 ~ 5

Example	Nd (at.%)	Fe (at. %)	Co (at. %)	B (at. %)	Al (at. %)	Ga (at.%)	Nb (at. %)	Cu (at. %)	Remanence (μ_0Mr)	Coercivity (μ_0Hcj)
1	12.83	75.97	4.5	5.31	0.43	0.53	0	0	1.48	0.77
2	12.59	75.67	4.5	5.44	0.67	0.52	0.21	0	1.54	1.08
3	12.9	75.21	4.49	5.52	0.55	0.51	0.4	0	1.51	1.12
4	13.09	74.87	4.49	5.56	0.48	0.52	0.64	0	1.38	1.21
5	13.41	75.42	4.33	5.3	0.31	0.51	0.22	0.19	1.38	1.22

[0037] The hot deformed magnets prepared according to Examples 1 ~ 5 exhibit very high remanences, for example 1.54 T as the highest and a corresponding anisotropy of 0.96, wherein the anisotropy is represented as the ratio of the remanence to the saturation magnetic flux density of 1.6 T.

[0038] It is also apparent from Table 2 that the remanence has been increased from 1.48 T (no Nb) to 1.54 T (about 0.2% of Nb), and the coercivity also has been enhanced from 0.77 T (no Nb) to 1.08 T (about 0.2% of Nb).

Evaluation of microstructure

[0039] Figure 2 shows the back-scattered SEM images of the hot deformed magnets without Nb (a) and (c) (Example 1) and with about 0.2% of Nb (b) and (d) (Example 2).

[0040] It is apparent from Figure 2 that the formation of coarsen grains or coarsen grain regions in the microstructure of the hot deformed magnets has been suppressed by adding small amount of Nb. A microstructure almost having no coarse equiaxed grains with a diameter greater than 400 nm and consequently no coarse equiaxed grain regions is favorable for the magnetic properties of the hot deformed magnets.

[0041] It is also apparent from Figure 2 that the platelet-shaped morphology of the $RE_2Fe_{14}B$ grains has been optimized by adding Nb. In particular, both the grain size and the aspect ratio of the $RE_2Fe_{14}B$ grains have been reduced, which is beneficial to enhance the coercivity and the thermal stability of the coericivty of the hot deformed magnets. In the context of the present invention, the aspect ratio of the platelet shall be understood as the ratio of the length to the thickness of the platelet.

[0042] Figure 3 shows the BSE-SEM images of the hot deformed magnets without Nb (a) (Example 1) and with about 0.2% of Nb (b) (Example 2). It is apparent from Figure 3 that both the grain size and the aspect ratio of the $RE_2Fe_{14}B$ grains have been reduced.

[0043] Figure 4 shows the STEM-EDS mapping of Nd and Nb of the hot deformed magnets with about 0.2% of Nb (a) (Example 2) and with about 0.6% of Nb (b) (Example 4).

[0044] It is apparent from the Nb mapping in the microstructure of the hot deformed magnets that Nb mainly forms nano-sized Nb-rich precipitates at the grain boundary and slightly segregates inside the $RE_2Fe_{14}B$ grains.

[0045] Potential applications of the hot deformed magnet according to the present invention include, but are not limited to, electric motor for automotives, power tools, home appliances, drive & control, and others.

Claims

1. A hot deformed magnet having an alloy composition of the formula (1)

$$RE_xFe_{(100-x-y1-y2-z1-z2)}T_{y1}M_{y2}Cu_{z1}B_{z2} \qquad (1),$$

wherein

RE is one or more rare earth elements, such as La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Yb, and Lu, preferably Pr, Nd, Tb, and Dy;
T is one or more elements selected from the group consisting of Co, Al, Ga, Zr, Ti and Mo;
M is Nb and/or Ta;
Cu is copper;

B is boron;
the balance is Fe and inevitable impurities;
x is 13.0 ~ 15.0 at.%;
y1 is 1.2 ~ 10.0 at.%;
y2 is 0.1 ~ 0.8 at.%;
z1 is 0 ~ 0.5 at.%; and
z2 is 4.5 ~ 6.5 at.%.

2. The hot deformed magnet of claim 1, **characterized in that** the hot deformed magnet exhibits anisotropy with a $RE_2Fe_{14}B$ grain morphology in form of platelet.

3. The hot deformed magnet of claim 2, **characterized in that** the thickness of the platelet is up to 200 nm, preferably 25 - 120 nm, more preferably 25 - 100 nm.

4. The hot deformed magnet of claim 2 or 3, **characterized in that** the length of the platelet is up to 1 μm, preferably 100 - 600 nm, more preferably 100 - 300 nm.

5. The hot deformed magnet of any one of claims 1 to 4, **characterized in that** the hot deformed magnet almost has no coarse equiaxed grains with a diameter greater than 400 nm and consequently no coarse equiaxed grain regions in the microstructure.

6. A method for preparing the hot deformed magnet of any one of claims 1 to 5, said method including the following steps:

1) preparing magnetic powders by melt quenching from an ingot having an alloy composition of the formula (1)

$$RE_xFe_{(100-x-y1-y2-z1-z2)}T_{y1}M_{y2}Cu_{z1}B_{z2} \quad (1),$$

wherein

RE is one or more rare earth elements, such as La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Yb, and Lu, preferably Pr, Nd, Tb, and Dy;
T is one or more elements selected from the group consisting of Co, Al, Ga, Zr, Ti and Mo;
M is Nb and/or Ta;
Cu is copper;
B is boron;
the balance is Fe and inevitable impurities;
x is 13.0 ~ 15.0 at.%;
y1 is 1.2 ~ 10.0 at.%;
y2 is 0.1 ~ 0.8 at.%;
z1 is 0 ~ 0.5 at.%; and
z2 is 4.5 ~ 6.5 at.%;

2) pressing the magnetic powders prepared from step 1) to obtain a green body; and
3) hot deforming the green body prepared from step 2) to obtain the hot deformed magnet.

7. The method of claim 6, **characterized in that** in step 1), the ingot is melted at a temperature of above 1000 °C, preferably 1000 ~ 1100 °C, and then cast or injected onto a rotating wheel with a circumferential velocity of 10 ~ 40 m/s.

8. The method of claim 6 or 7, **characterized in that** in step 2), the magnetic powders prepared from step 1) are cold pressed, and then hot pressed at a temperature of 550 ~ 850 °C, preferably 600 ~ 700 °C, under a pressure of 20 ~ 200 MPa, preferably 20 ~ 100 MPa, so as to obtain the green body.

9. The method of any one of claims 6 to 8, **characterized in that** in step 3), the green body prepared from step 2) is hot deformed at a temperature of 750 ~ 850 °C, preferably 780 ~ 820 °C, under a pressure of 20 ~ 250 MPa, preferably 20 ~ 200 MPa, so as to obtain the hot deformed magnet.

Patentansprüche

1. Heißverformter Magnet, der eine Legierung der Formel (1)

$$RE_xFe_{(100-x-y1-y2-z1-z2)}T_{y1}M_{y2}Cu_{z1}B_{z2} \quad (1),$$

aufweist, wobei

RE für ein oder mehrere Seltenerdelemente wie La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Yb und Lu, vorzugsweise Pr, Nd, Tb und Dy, steht;
T für ein oder mehrere aus der Gruppe bestehend aus Co, Al, Ga, Zr, Ti und Mo ausgewählte Elemente steht;
M für Nb und/oder Ta steht;
Cu für Kupfer steht;
B für Bor steht;
der Rest Fe und unvermeidbare Verunreinigungen ist;
x 13,0 ~ 15,0 Atom-% beträgt;
y1 1,2 ~ 10,0 Atom-% beträgt;
y2 0,1 ~ 0,8 Atom-% beträgt;
z1 0 ~ 0,5 Atom-% beträgt; und
z2 4,5 - 6,5 Atom-% beträgt.

2. Heißverformter Magnet nach Anspruch 1, **dadurch gekennzeichnet, dass** der heißverformte Magnet eine Anisotropie mit einer $RE_2Fe_{14}B$-Kornmorphologie in Plättchenform aufweist.

3. Heißverformter Magnet nach Anspruch 2, **dadurch gekennzeichnet, dass** die Dicke des Plättchens bis zu 200 nm, vorzugsweise 25 ~ 120 nm, weiter bevorzugt 25 ~ 100 nm, beträgt.

4. Heißverformter Magnet nach Anspruch 2 oder 3, **dadurch gekennzeichnet, dass** die Länge des Plättchens bis zu 1 pm, vorzugsweise 100 ~ 600 nm, weiter bevorzugt 100 ~ 300 nm, beträgt.

5. Heißverformter Magnet nach einem der Ansprüche 1 bis 4, **dadurch gekennzeichnet, dass** der heißverformte Magnet fast keine groben gleichachsigen Körner mit einem Durchmesser von mehr als 400 nm und folglich keine Bereiche von grobem gleichachsigen Korn in der Mikrostruktur aufweist.

6. Verfahren zur Herstellung des heißverformten Magneten nach einem der Ansprüche 1 bis 5, wobei das Verfahren die folgenden Schritte einschließt:

1) Herstellen eines magnetischen Pulvers durch Abschrecken einer aus einem Barren stammenden Schmelze, die eine Legierungszusammensetzung der Formel (1)

$$RE_xFe_{(100-x-y1-y2-z1-z2)}T_{y1}M_{y2}Cu_{z1}B_{z2} \quad (1),$$

aufweist, wobei

RE für ein oder mehrere Seltenerdelemente wie La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Yb und Lu, vorzugsweise Pr, Nd, Tb und Dy, steht;
T für ein oder mehrere aus der Gruppe bestehend aus Co, Al, Ga, Zr, Ti und Mo ausgewählte Elemente steht;
M für Nb und/oder Ta steht;
Cu für Kupfer steht;
B für Bor steht;
der Rest Fe und unvermeidbare Verunreinigungen ist;
x 13,0 ~ 15,0 Atom-% beträgt;
y1 1,2 ~ 10,0 Atom-% beträgt;
y2 0,1 ~ 0,8 Atom-% beträgt;
z1 0 ~ 0,5 Atom-% beträgt; und
z2 4,5 - 6,5 Atom-% beträgt;

2) Pressen des in Schritt 1) hergestellten magnetischen Pulvers zum Erhalt eines Grünkörpers; und

3) Heißverformen des in Schritt 2) hergestellten Grünkörpers zum Erhalt des heißverformten Magneten.

7. Verfahren nach Anspruch 6, **dadurch gekennzeichnet, dass** der Barren in Schritt 1) bei einer Temperatur von oberhalb von 1000 °C, vorzugsweise 1000 - 1100 °C, geschmolzen wird und dann auf ein umlaufendes Rad mit einer Umfangsgeschwindigkeit von 10 ~ 40 m/s gegossen oder gespritzt wird.

8. Verfahren nach Anspruch 6 oder 7, **dadurch gekennzeichnet, dass** die in Schritt 1) hergestellten magnetischen Pulver in Schritt 2) kaltgepresst werden und dann bei einer Temperatur von 550 ~ 850 °C, vorzugsweise 600 ~ 700 °C, bei einem Druck von 20 ~ 200 MPa, vorzugsweise 20 ~ 100 MPa, zum Erhalt des Grünkörpers heißgepresst werden.

9. Verfahren nach einem der Ansprüche 6 bis 8, **dadurch gekennzeichnet, dass** der in Schritt 2) hergestellte Grünkörper in Schritt 3) bei einer Temperatur von 750 ~ 850 °C, vorzugsweise 780 ~ ~ 820 °C, bei einem Druck von 20 ~ 250 MPa, vorzugsweise 20 ~ 200 MPa, zum Erhalt des heißverformten Magneten heißverformt wird.

Revendications

1. Aimant déformé à chaud possédant une composition d'alliage de la formule (1)

$$RE_xFe_{(100-x-y1-y2-z1-z2)}T_{y1}M_{y2}Cu_{z1}B_{z2} \quad (1),$$

RE étant un ou plusieurs éléments des terres rares, tels que La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Yb, et Lu, préférablement Pr, Nd, Tb, et Dy ;
T étant un ou plusieurs éléments choisis dans le groupe constitué par Co, Al, Ga, Zr, Ti et Mo ;
M étant Nb et/ou Ta ;
Cu étant le cuivre ;
B étant le bore ;
le reste étant Fe et des impuretés inévitables ;
x étant 13,0 à 15,0 % at. ;
y1 étant 1,2 à 10,0 % at. ;
y2 étant 0,1 à 0,8 % at. ;
z1 étant 0 à 0,5 % at. ; et
z2 étant 4,5 à 6,5 % at..

2. Aimant déformé à chaud selon la revendication 1, **caractérisé en ce que** l'aimant déformé à chaud présente une anisotropie avec une morphologie de grain de $RE_2Fe_{14}B$ sous forme de plaquette.

3. Aimant déformé à chaud selon la revendication 2, **caractérisé en ce que** l'épaisseur de la plaquette va jusqu'à 200 nm, préférablement 25 à 120 nm, plus préférablement 25 à 100 nm.

4. Aimant déformé à chaud selon la revendication 2 ou 3, **caractérisé en ce que** la longueur de la plaquette va jusqu'à 1 pm, préférablement 100 à 600 nm, plus préférablement 100 à 300 nm.

5. Aimant déformé à chaud selon l'une quelconque des revendications 1 à 4, **caractérisé en ce que** l'aimant déformé à chaud ne possède presque aucun grain équiaxial grossier doté d'un diamètre supérieur à 400 nm et par conséquent en aucune région de grain équiaxial grossier dans la microstructure.

6. Procédé pour la préparation de l'aimant déformé à chaud selon l'une quelconque des revendications 1 à 5, ledit procédé comportant les étapes suivantes :

1) préparation de poudres magnétiques par trempe de masse fondue d'un lingot possédant une composition d'alliage de la formule (1)

$$RE_xFe_{(100-x-y1-y2-z1-z2)}T_{y1}M_{y2}Cu_{z1}B_{z2} \quad (1),$$

RE étant un ou plusieurs éléments des terres rares, tels que La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er,

Yb, et Lu, préférablement Pr, Nd, Tb, et Dy ;
T étant un ou plusieurs éléments choisis dans le groupe constitué par Co, Al, Ga, Zr, Ti et Mo ;
M étant Nb et/ou Ta ;
Cu étant le cuivre ;
B étant le bore ;
le reste étant Fe et des impuretés inévitables ;
x étant 13,0 à 15,0 % at. ;
y1 étant 1,2 à 10,0 % at. ;
y2 étant 0,1 à 0,8 % at. ;
z1 étant 0 à 0,5 % at. ; et
z2 étant 4,5 à 6,5 % at. ;

2) compression des poudres magnétiques préparées de l'étape 1) pour obtenir un corps vert; et
3) déformation à chaud du corps vert préparé de l'étape 2) pour obtenir l'aimant déformé à chaud.

7. Procédé selon la revendication 6, **caractérisé en ce que** dans l'étape 1), le lingot est fondu à une température supérieure à 1 000 °C, préférablement de 1 000 à 1 100 °C, et ensuite coulé ou injecté sur une roue rotative dotée d'une vitesse circonférentielle de 10 à 40 m/s.

8. Procédé selon la revendication 6 ou 7, **caractérisé en ce que** dans l'étape 2), les poudres magnétiques préparées de l'étape 1) sont comprimées à froid, et ensuite comprimées à chaud à une température de 550 à 850 °C, préférablement 600 à 700 °C, sous une pression de 20 à 200 MPa, préférablement 20 à 100 MPa, de manière à obtenir le corps vert.

9. Procédé selon l'une quelconque des revendications 6 à 8, **caractérisé en ce que** dans l'étape 3), le corps vert préparé de l'étape 2) est déformé à chaud à une température de 750 à 850 °C, préférablement 780 à 820 °C, sous une pression de 20 à 250 MPa, préférablement de 20 à 200 MPa, de manière à obtenir l'aimant déformé à chaud.

Fig. 1

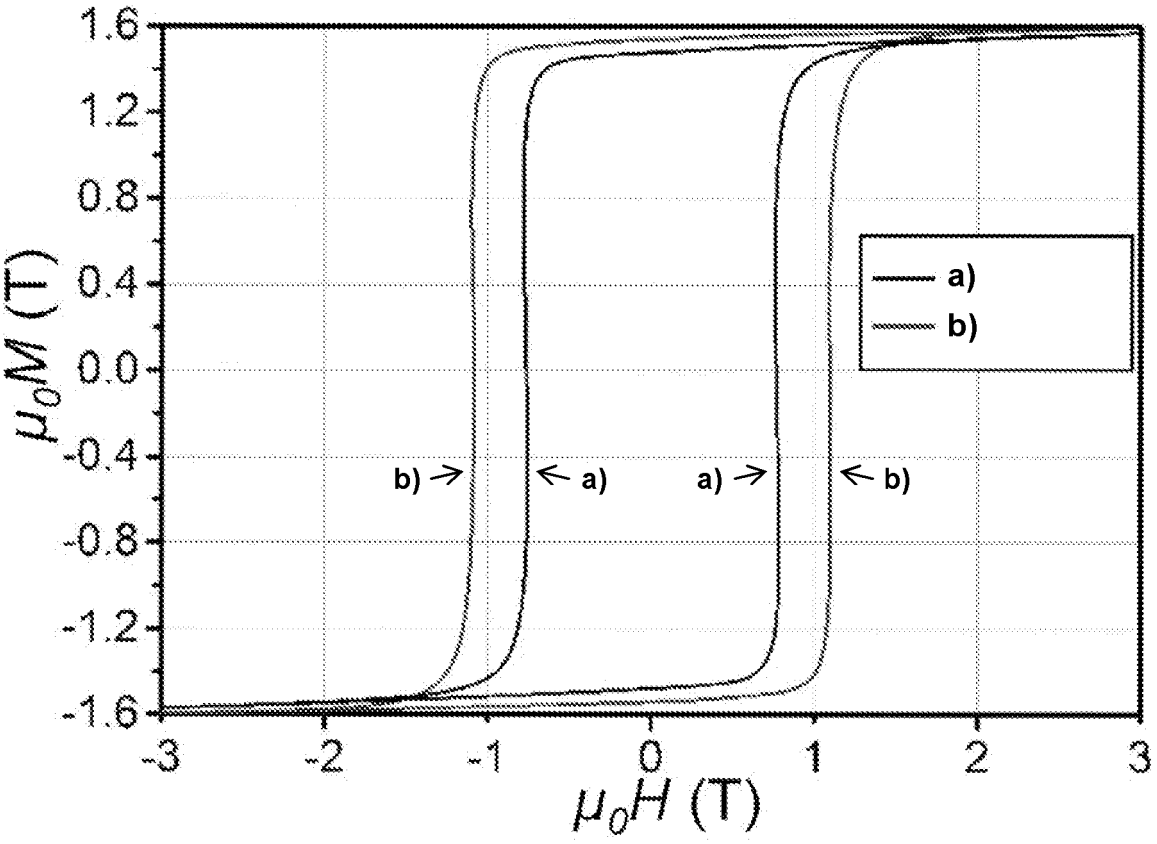


Fig. 2

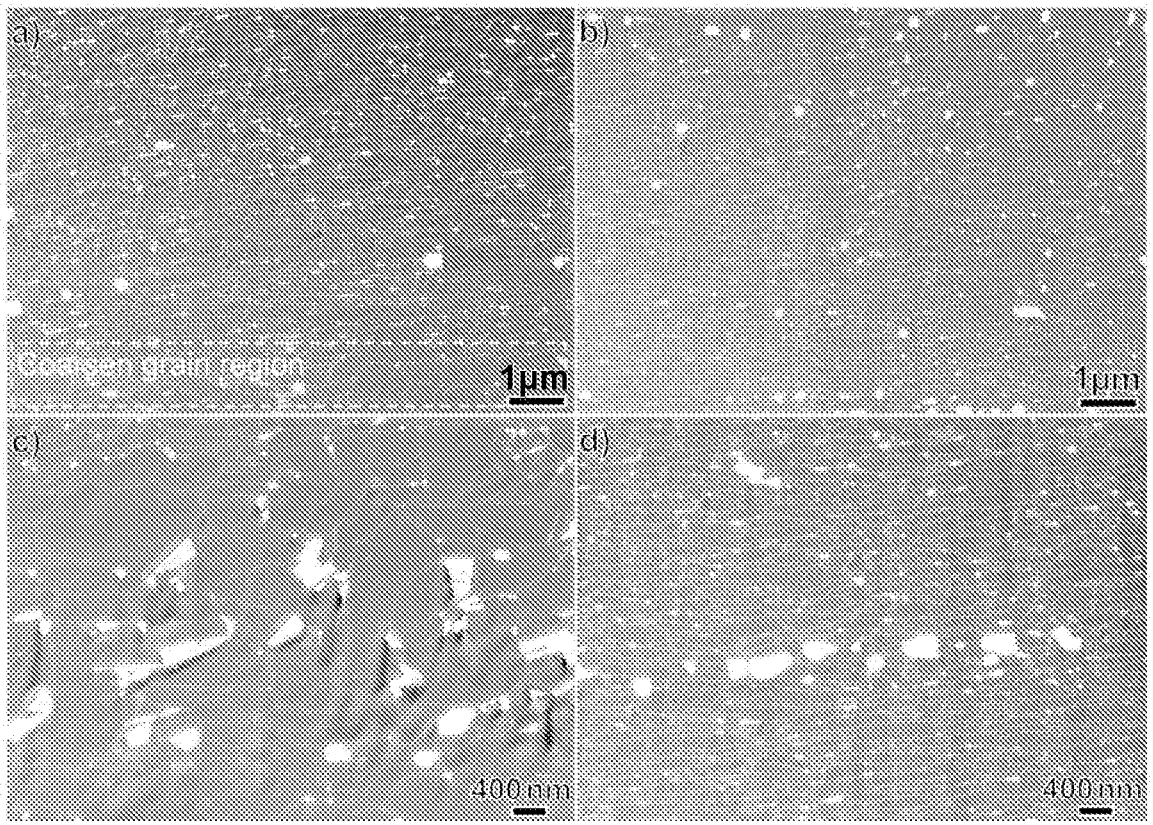


Fig. 3

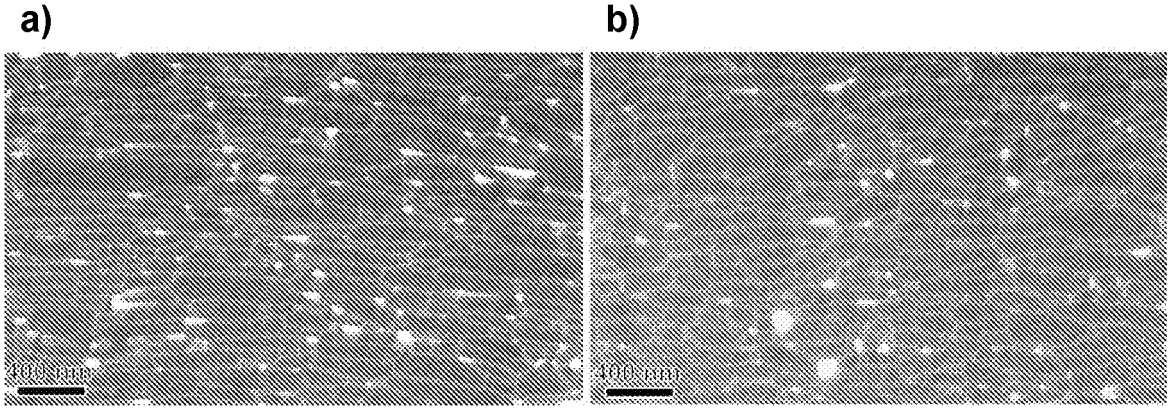
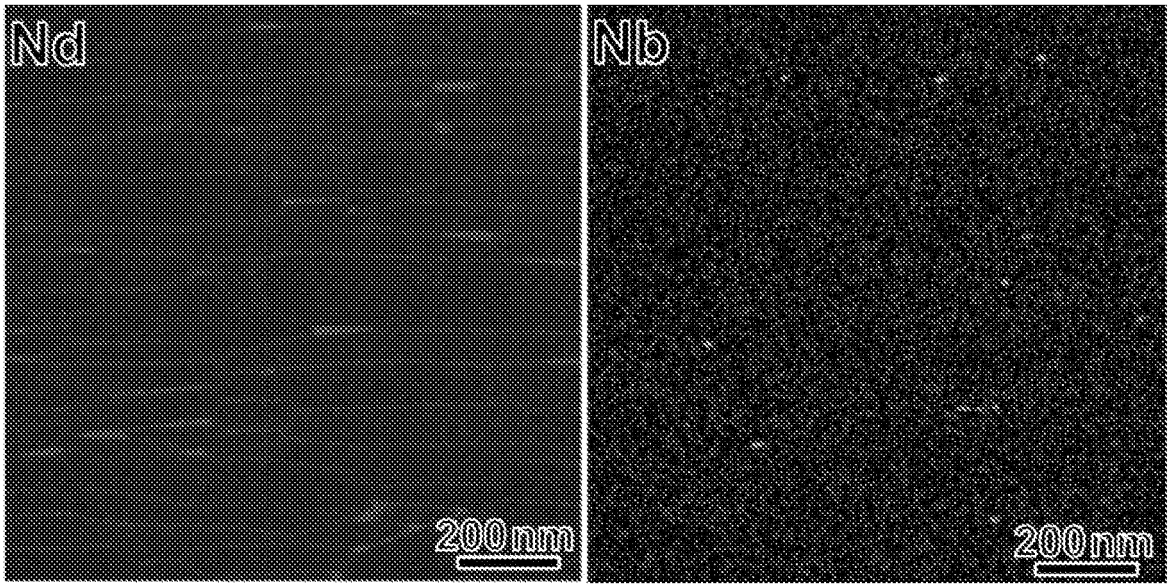
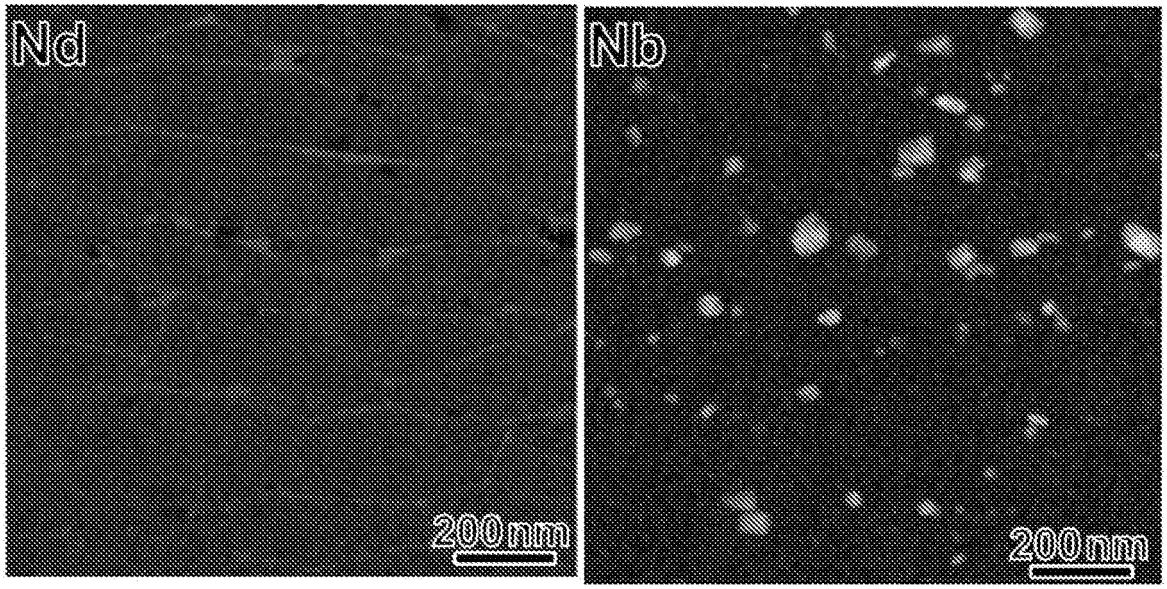


Fig. 4

a)



b)



REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- US 5395462 A **[0007]**
- US 5211766 A **[0007]**
- CN 106448986 A **[0007]**
- FR 2779267 A1 **[0007]**