

coercive force for the stabilization of their properties. It is generally noted in this connection that the iH_c of permanent magnets decreases with increases in temperature. For that reason, they will be demagnetized upon exposure to high temperatures, if their iH_c is low at room temperature. However, if iH_c is sufficiently high at room temperature, each demagnetization will then not substantially occur.

- 5 Ferrite or rare earth-cobalt magnets make use of additive elements or varied composition systems to obtain a high coercive force; however, there are generally drops of saturation magnetization and $(BH)_{max}$.

Summary of the disclosure

An essential object of the present invention is to provide novel permanent magnets and magnet
10 materials, from which the disadvantages of the prior art are substantially eliminated.

As a result of studies made of a number of systems for the purpose of preparing compound magnets based on R-Fe binary systems, which have a high Curie point and are stable at room temperature, it has already been found that FeBR and FeBRM base compounds are especially suited for the formation of magnets (Europ. Patent Application No. 83106573.5 filed on Jul 5, 1983).

- 15 A symbol R is here understood to indicate at least one of rare earth elements inclusive of Y and, preferably, refer to light rare earth elements such as Nd and Pr. B denotes boron, and M stands for at least one element selected from the group consisting of Al, Ti, V, Cr, Mn, Zr, Hf, Nb, Ta, Mo, Ge, Sb, Sn, Bi, Ni and W.

The FeBR magnets have a practically sufficient Curie point of as high as 300°C or more. In addition,
20 these magnets can be prepared by the powder metallurgical procedures that are alike applied to ferrite or rare earth-cobalt systems, but not successfully employed for R-Fe binary systems.

The FeBR base magnets can mainly use as R relatively abundant light rare earth elements such as Nd and Pr, do not necessarily contain expensive Co or Sm, and can show $(BH)_{max}$ of as high as 36 MGOe* or more that exceeds largely the highest $(BH)_{max}$ value (31 MGOe*) of the prior art rare earth-cobalt magnets.

- 25 It has further been found that the magnets based on these FeBR and FeBRM system compounds exhibit crystalline X-ray diffraction patterns that are sharply distinguished over those of the conventional amorphous strips or melt-quenched ribbons, and contain as the major phase a novel crystalline structure of the tetragonal system (Europ. Patent Application No. 83106573.5 filed on July 5, 1983).

In general, these FeBR and FeBRM base alloys have a Curie point ranging from about 300°C to 370°C,
30 and higher Curie points are obtained with permanent magnets prepared by substituting 50 at % or less of Co for the Fe of such systems. Such FeCoBR and FeCoBRM base magnets are disclosed in Europ. Patent Application No. 83107351.5 filed on July 26, 1983.

- More specifically, the present invention has for its object to increase the thermal properties, particularly iH_c while retaining a maximum energy product, $(BH)_{max}$, which is identical with, or larger
35 than, that obtained with the aforesaid FeCoBR and FeCoBRM base magnets.

According to the present invention, it is possible to markedly increase the iH_c of FeCoBR and FeCoBRM base magnets wherein as R light rare earth elements such as Nd and Pr are mainly used, while maintaining the $(BH)_{max}$ thereof at a high level, by incorporating thereto R_1 forming part of R, said R_1 representing at least one of rare earth elements selected from the group consisting of Dy, Tb, Gd, Ho, Er, Tm and Yb.
40 Namely R_1 is mainly comprised of heavy rare earth elements.

That is to say, the permanent magnets according to the present invention are as follows.

Magnetically anisotropic sintered permanent magnets are comprised of the FeCoBR system in which R represents the sum of R_1 and R_2 wherein:

- 45 R_1 is at least one of rare earth elements selected from the group consisting of Dy, Tb, Gd, Ho, Er, Tm and Yb, and

R_2 includes a total of 80 at % or more of Nd and/or Pr relative to the entire R_2 , and contains at least one of other rare earth elements exclusive of R_1 but inclusive of Y,

said system consisting essentially of, by atomic percent, 0.05 to 5% of R_1 , 12.5 to 20% of R, 4 to 20% of B, 0 (exclusive) to 35% of Co and the balance being Fe.

- 50 The other aspect of the present invention provides an anisotropic sintered permanent magnet of the FeCoBRM system.

Brief description of the drawings

Fig. 1 is a graph showing the relationship between the amount of Co and the Curie point, T_c , in one
55 example of the present invention wherein Fe is substituted with Co;

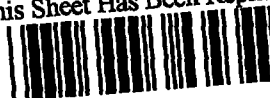
Fig. 2 is a graph showing the relationship between the amount of Dy, and iH_c and $(MG)_{max}$ in one example of the present invention wherein Nd is substituted with Dy, one element represented by R_1 ; and

Fig. 3 is a graph showing the demagnetization curves of typical example of the present invention.

- 60 Detailed description of the preferred embodiments

In the present disclosure % denotes atomic percent if not otherwise specified.

Magnetically anisotropic sintered permanent magnets comprise FeCoBRM systems in which R represents the sum of R_1 and R_2 , and M represents one or more additional elements added in amounts no
65 more than the values as specified below wherein:



R₁ is at least one of rare earth elements selected from the group consisting of Dy, Tb, Gd, Ho, Er, Tm and Yb,

R₂ includes a total of 80 at % relative to the entire R₂ or more of Nd and Pr and contains at least one of light rare earth elements exclusive of R₁ but inclusive of Y, and M is

5	3%	Ti,	3.3%	Zr,	3.3%	Hf,
	4.5%	Cr,	5%	Mn,	6%	Ni,
10	7%	Ta,	3.5%	Ge,	1.5%	Sn,
	1%	Sb,	5%	Bi,	5.2%	Mo,
	9%	Nb,	5%	Al,	5.5%	V, and
15	5%	W,				

said system essentially consisting of, by atomic percent, 0.05 to 5% of R₁, 12.5 to 20% of R, 4 to 20% of B, 0% < Co ≤ 35%, and the balance being Fe, provided that, when two or more additional elements M are included, the sum of M should be no more than the maximum value among those specified above of said elements M actually added. Further preferred embodiments are recited in the dependent claims.

It is noted that the allowable limits of typical impurities to be included in the end products are preferred to be no higher than the following values by atomic percent:

25	2%	Cu,	2%	C,	2%	P,
	4%	Ca,	4%	Mg,	2%	O,
	5%	Si, and	2%	S.		

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It is noted, however, that the sum of impurities should be no more than 5%.

Such impurities are expected to be originally present in the starting material, or to come from the process of production, and the inclusion thereof in amounts exceeding the aforesaid limits would result in deterioration of properties. Among these impurities, Si serves both to increase Curie points and to improve corrosion resistance, but incurs decreases in iHc in an amount exceeding 5%. Ca and Mg may abundantly be contained in the R raw material, and has an effect upon increases in iHc. However, it is unpreferable to use Ca and Mg in larger amounts, since they deteriorate the corrosion resistance of the end products.

Having the composition as mentioned above, the permanent magnets show a coercive force, iHc, of as high as 10 kOe* or more, while they retain a maximum energy product, (BH)max, of 20 MGOe* or more.

The present invention will now be explained in detail.

As mentioned above, the FeBR base magnets possess high (BH)max, but their iHc was only similar to that of the Sm₂Co₁₇ type magnet which was typical one of the conventional high-performance magnets (5 to 10 kOe)*. This proves that the FeBR magnets are easily demagnetized upon exposure to strong demagnetizing fields or high temperatures, say, they are not well in stability. The iHc of magnets generally decreases with increases in temperature. For instance, the Sm₂Co₁₇ type magnets or the FeBR base magnets have a coercive force of barely 5 kOe* at 100°C (see Table 4).

Any magnets having such iHc cannot be used for magnetic disc actuators for computers or automobile motors, since they tend to be exposed to strong demagnetizing fields or high temperatures. To obtain even higher stability at elevated temperatures, it is required to increase Curie points and increase further iHc at temperatures near room temperature.

It is generally known that magnets having higher iHc are more stable even at temperatures near room temperature against deterioration with the lapse of time (changes with time) and physical disturbances such as impacting and contacting.

Based on the above-mentioned knowledge, further detailed studies were mainly focused on the FeCoBR componental systems. As a result, it has been found that a combination of at least one of rare earth elements Dy, Tb, Gd, Ho, Er, Tm and Yb with light rare earth elements such as Nd and Pr can provide a high coercive force that cannot possibly be obtained with the FeCoBR and FeCoBRM base magnets.

Furthermore, the componental systems according to the present invention have an effect upon not only increases in iHc but also improvements in the loop squareness of demagnetization curves, i.e., further increases in (BH)max. Various studies made to increase the iHc of the FeCoBR base magnets have revealed that the following procedures are effective.

(1) Increasing the amount of R or B, and (2) adding additional element(s) M.

However, it is recognized that increasing the amount of R or B serves to enhance iHc, but, as that amount increases, Br decreases with the values of (BH)max decreasing as a result.



It is also true that the additional element(s) M is effective to increase iH_c , but, as the amount of M increases, $(BH)_{max}$ drops again, thus not giving rise to any noticeable improvements.

In accordance with the permanent magnets of the present invention, an increase in iH_c by aging is remarkable owing to the inclusion of R_1 that is rare earth elements, especially heavy rare earth elements, the main use of Nd and/or Pr as R_2 , and the specific composition of R, B and Co. It is thus possible to increase iH_c without having an adverse influence upon the value of Br by aging the magnetically anisotropic sintered bodies comprising alloys having the specific composition as mentioned above. Besides, the loop squareness of demagnetization curves is improved, while $(BH)_{max}$ maintained at the same or higher level. It is noted in this connection that, when the composition of R, B and Co and the amount of Nd and/or Pr are within the specified ranges, iH_c of about 10 kOe* or higher is already reached prior to aging. Post-aging thus gives rise to a more favorable effect in combination with the incorporation of a given amount of R_1 into R.

That is to say, the present invention provides high-performance magnets which, while retaining $(BH)_{max}$ of 20 MGOe* or higher, combines T_c of about 310 to about 640°C with sufficient stability to be expressed in terms of iH_c of 10 kOe* or higher, and can find use in applications wider than those in which the conventional high-performance magnets have found use.

The maximum values of $(BH)_{max}$ and iH_c are 37.2 MGOe* (see No. 3 in Table 2 given later) and 16.8 kOe* (see No. 7 in Table 2), respectively.

In the permanent magnets according to the present invention, R represents the sum of R_1 and R_2 , and encompasses Y as well as rare earth elements Nd, Pr, La, Ce, Tb, Dy, Ho, Er, Eu, Sm, Gd, Pm, Tm, Yb and Lu. Out of these rare earth elements, at least one of seven elements Dy, Tb, Gd, Ho, Er, Tm and Yb is used as R_1 . R_2 represents rare earth elements except the above-mentioned seven elements and, especially, includes a sum of 80 at % or more of Nd and/or Pr in the entire R_2 , Nd and Pr being light rare earth elements.

The rare earth elements used as R may or may not be pure, and those containing impurities entrained inevitably in the process of production (other rare earth elements, Ca, Mg, Fe, Ti, Co, O, S and so on) may be used alike, as long as one has commercially access thereto. Also alloys of those rare earth elements with other componental elements such as Nd-Fe alloy, Pr-Fe alloy, Dy-Co alloy, Dy-Fe alloy or the like may be used.

As boron (B), pure- or ferro-boron may be used, including those containing as impurities Al, Si, C and so on.

When composed of 0.05—5 at % R_1 , 12.5—20 at % R representing the sum of R_1+R_2 , 4—20 at % B, $0\% < Co \leq 35\%$ and the balance being Fe, the permanent magnets according to the present invention show a high coercive force (iH_c) on the order of no less than about 10 kOe*, a high maximum energy product $((BH)_{max})$ on the order of no less than 20 MGOe* and a residual magnetic flux density (Br) on the order of no less than 9 kG*.

The composition of 0.2—3 at % R_1 , 13—19 at % R, 5—11 at % B, $0\% < Co \leq 23\%$ and the balance being Fe are preferable in that they show $(BH)_{max}$ of 29 MGOe* or more.

As R_1 particular preference is given to Dy and Tb.

The reason for placing the lower limit of R upon 12.5 at % is that, when the amount of R is below that limit, Fe participates in the alloy compounds based on the present systems, and causes a sharp drop of coercive force. The reason for placing the upper limit of R upon 20 at % is that, although a coercive force of no less than 10 kOe* is obtained even in an amount exceeding 20 at %, yet Br drops to such a degree that the required $(BH)_{max}$ of no less than 20 MGOe* is not attained.

Referring now to the amount of R_1 forming part of R, H_c increases even by the substitution of barely 0.2% R_1 for R, as will be understood from No. 2 in Table 2. The loop squareness of demagnetization curves is also improved with increases in $(BH)_{max}$. The lower limit of R_1 is placed upon 0.05 at %, taking into account the effects upon increases in both iH_c and $(BH)_{max}$ (see Fig. 2). As the amount of R_1 increases, iH_c increases (Nos. 2 to 7 in Table 2), and $(BH)_{max}$ decreases bit by bit after showing a peak at 0.4 at %. However, for example, even 3 at % addition gives $(BH)_{max}$ of 29 MGOe* or higher (see Fig. 2).

In applications for which stability is especially needed, the higher the iH_c , say, the more the amount of R_1 , the better the results will be. However, the elements constituting R_1 are contained in rare earth ores to only a slight extent, and very expensive. This is the reason why the upper limit of R_1 is fixed at 5 at %. When the amount of B is 4 at % or less, iH_c decreases to 10 kOe* or less. Like R, B serves to increase iH_c , as its amount increases, but there is a drop of Br. To give $(BH)_{max}$ of 20 MGOe* or more the amount of B should be no more than 20 at %.

Because of the inclusion of Co in an amount of no more than 35 at %, the permanent magnets of the present invention have improved temperature-depending properties while maintaining $(BH)_{max}$ at a high level. It is generally observed that, as the amount of Co incorporated in Fe-alloys increases, some Fe alloys increase proportionally in Curie point, while another decrease in that point. Difficulty is thus involved in the anticipation of the effect created by Co addition.

When the Fe of FeBR systems is partially substituted with Co, the Curie point increases gradually with increases in the amount of Co added, as will be appreciated from Fig. 1. Co is effective for an increase in Curie point even in a slight amount of, e.g., 1 at %, and gives alloys having any Curie point which ranges from about 310 to about 640°C depending upon the amount to be added. When Fe is substituted with Co,



iHc tends to drop with increases in the amount of Co, but (BH)max increases slightly at the outset due to the improved loop rectangularity of demagnetization curves.

When the amount of Co is 25 at % or below, it contributes to an increase in Curie point without having a substantial influence upon other magnetic properties, particularly (BH)max. Especially, Co serves to maintain said other magnetic properties at the same or higher level in amounts of 23 at % or below.

When the amount of Co exceeds 25 at %, there is a drop of (BH)max. When the amount of Co increases to 35 at % or higher, (BH)max decreases to 20 MGOe* or below. The incorporation of Co in an amount of 5 at % or more also causes the coefficient of temperature dependence of Br (referred to as the thermal coefficient of Br) to be on the order of about 0.1 %/°C or less.

The FeCoBR base magnets of the present invention were magnetized at normal temperature, and exposed to an atmosphere of 100°C to determine their irreversible loss of magnetic flux which was found to be only slight compared with that of the $\text{Sm}_2\text{Co}_{17}$ magnets or the FeBR magnet free from R₁. This indicates that stability is considerably improved.

As far as Co is concerned, parallel discussions hold for the FeCoBRM systems, and as far as an increase in Curie point is concerned, similar tendencies are essentially observed, although that increase varies more or less depending upon the type of M.

The additional element(s) M serves to increase iHc and improve the loop squareness of demagnetization. However, as the amount of M increases, Br decreases. Br of 9 kG* or more is thus needed to obtain (BH)max of 20 MGOe* or more. This is the reason why the upper limits of M to be added are fixed as mentioned in the foregoing. When two or more additional elements M are included, the sum of M should be no more than the maximum value among those specified in the foregoing of said elements M actually added. For instance, when Ti, Ni and Nb are added, the sum of these elements is no more than 9 at %, the upper limit of Nb. Preferable as M are V, Nb, Ta, Mo, W, Cr and Al. It is noted that, except some M such as Sb or Sn, the amount of M is preferably within about 2 at %.

The permanent magnets of the present invention are obtained as sintered bodies. It is then important that the sintered bodies, either based on FeCoBR or FeCoBRM, have a mean crystal grain size of 1 to 100 μm , preferably 2 to 40 μm more preferably about 3 to 10 μm . Sintering can be carried out at a temperature of 900 to 1200°C. Aging following sintering can be carried out at a temperature between 350°C and the sintering temperature, preferably between 450 and 800°C. The alloy powders for sintering have appropriately a mean particle size of 0.3 to 80 μm , preferably 1 to 40 μm , more preferably 2—20 μm . Sintering conditions, etc. are disclosed in a parallel Europ. Patent application to be assigned to the same assignee with this application based on Japanese Patent Application Nos. 58-88373 and 58-90039.

The embodiments and effects of the present invention will now be explained with reference to examples, which are given for the purpose of illustration alone, and are not intended to limit the scope of the present invention.

Samples were prepared by the following steps (purity is given by weight).

(1) Alloys were melted by high-frequency melting and cast in a water-cooled copper mold. As the starting materials for Fe, B and R use was made of 99.9% electrolytic iron, ferrobore alloys of 19.38% B, 5.32% Al, 0.74% Si, 0.03% C and the balance Fe, and a rare earth element or elements having a purity of 99.7% or higher with the impurities being mainly other rare earth elements, respectively.

(2) Pulverization: The castings were coarsely ground in a stamp mill until they passed through a 0.43 mm (−35-mesh) sieve, and then finely pulverized in a ball mill for 3 hours to 3—10 μm .

(3) The resultant powders were aligned in a magnetic field of 10 kOe* and compacted under a pressure of 1471 bar (1.5 t/cm²).

(4) The resultant compacts were sintered at 1000—1200°C for one hour in an argon atmosphere and, thereafter, allowed to cool.

The samples were processed, polished, and tested to determine their magnet properties in accordance with the procedures for measuring the magnet properties of electromagnets.

Example 1

Prepared were alloys containing as R a number of combinations of Nd with other rare earth elements, from which magnets were obtained by the above-mentioned steps. The results are shown in Table 1. It has been found that, among the rare earth elements R, there are certain elements R₁ such as Dy, Tb, Ho and so on, which have a marked effect on improvements in iHc, as seen from Nos. 11 to 14. Comparison examples are marked. It has also been recognized from Table 1 that the coefficient of temperature dependence of Br is decreased to 0.01%/°C or below by the inclusion of Co in an amount of 5 at % or higher.

Example 2

In accordance with the foregoing procedures, magnets were obtained using light rare earth elements, mainly Nd and Pr, in combination with the rare earth elements, which were chosen in a wider select than as mentioned in Example 1 and applied in considerably varied amounts. To increase further iHc, heat treatment was applied at 600 to 700°C for two hours in an argon atmosphere. The results are set forth in Table 2.

In Table 2, No. *1 is a comparison example wherein only Nd was used as the rare earth element. Nos. 2



to 7 are examples wherein Dy was replaced for Nd. iH_c increases gradually with increases in the amount of Dy, and $(BH)_{max}$ reaches a maximum value when the amount of Dy is about 0.4 at %. See also Fig. 2.

Fig. 2 indicates that Dy begins to affect iH_c from 0.05 at %, and enhance its effect from 0.1 to 0.3 at % (this will become apparent if the abscissa of Fig. 2 is rewritten in terms of a logarithmic scale). Although Gd (No. 11), Ho (No. 10), Tb (No. 12), Er (No. 13), Yb (No. 14), etc. have a similar effect, yet a considerably large effect on increases in iH_c is obtained with Dy and Tb. The elements represented by R_1 , other than Dy and Tb, also give iH_c exceeding largely 10 kOe* and high $(BH)_{max}$. Any magnets materials having $(BH)_{max}$ of as high as 30 MGOe* or higher which can provide such a high iH_c have not been found until now. $(BH)_{max}$ of 20 MGOe* or more is also obtained by replacing Pr for Nd (No. 15), or allowing (Nd plus Pr) to amount to 80% or more of R_2 .

Fig. 3 shows a demagnetization curve of 0.8% Dy (No. 8 in Table 1) having typical iH_c , from which it is recognized that iH_c is sufficiently high compared with that of the Fe-B-Nd base sample (No. 1 in Table 1).

Example 3

As the additional elements M use was made of Ti, Mo, Bi, Mn, Sb, Ni, Ta, Sn and Ge, each having a purity of 99%, W having a purity of 98%, Al having a purity of 99.9%, Hf having a purity of 95%, ferrovandium (serving as V) containing 81.2% of V, ferroniobium (serving as Nb) containing 67.6% of Nb, ferrochromium (serving as Cr) containing 61.9% of Cr and ferrozirconium (serving as Zr) containing 75.5% of Zr, wherein the purity is given by weight percent.

The starting materials were alloyed and sintered in accordance with the foregoing procedures, followed by aging at 500—700°C. The results are shown in Table 3.

It has been ascertained that the FeCoBRM base alloys prepared by adding the additional elements M to the FeCoBR base systems have also sufficiently high iH_c . A demagnetization curve of No. 1 in Table 3 is shown as a curve 3 in Fig. 3.

TABLE 1

No.	Alloy composition (at %)	Thermal coefficient of Br (%/°C)	iH_c (kOe)*	Br (kG)*	$(BH)_{max}$ (MGOe)*
*1	Fe-8B-15Nd	0.14	11.4	12.3	34.0
*2	Fe-10Co-8B-15Nd	0.09	10.6	11.9	33.1
*3	Fe-8B-14.2Nd-0.8Dy	0.14	16.1	12.0	34.2
*4	Fe-10Co-14Nd-1Dy	—	0	0	0
*5	Fe-10Co-10B-5Nd-1Dy	—	<5	<5	<5
*6	Fe-10Co-17B-28Nd-2Dy	—	16.2	5.0	<5
7	Fe-10Co-8B-13.2Nd-0.8Dy	0.09	14.4	11.8	34.0
8	Fe-20Co-8B-13.2Nd-0.8Dy	0.08	15.8	11.9	33.5
9	Fe-30Co-8B-13.2Nd-0.8Dy	0.07	10.8	11.7	32.2
*10	Fe-40Co-8B-13.2Nd-0.8Dy	0.07	7.6	10.8	20.3
11	Fe-5Co-8B-13.5Nd-1Dy	0.10	14.8	12.0	33.8
12	Fe-10Co-7B-7Pr-7Nd-2La-0.5Ho	0.10	13.2	9.8	21.3
13	Fe-10Co-7B-13Pr-2La-1Tb	0.10	12.1	10.2	22.5
14	Fe-10Co-7B-14Nd-1Gd-0.5Yb	0.09	14.3	10.9	26.0

*10e<0,0796 —
kA
m

1G=10⁻⁴ Tesla
1 MGOe=7,96 kJ/m³

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TABLE 2

No.	Alloy composition (at%)	iHc (kOe)*	(BH) max (MGOe)*
*1	Fe-5Co-8B-15Nd	11.1	33.4
2	Fe-5Co-8B-14.8Nd-0.2Dy	11.6	35.8
3	Fe-5Co-8B-14.6Nd-0.4Dy	12.0	37.2
4	Fe-5Co-8B-14.2Nd-0.8Dy	13.9	33.8
5	Fe-5Co-8B-13.8Nd-1.2Dy	14.9	31.9
6	Fe-5Co-8B-13.5Nd-1.5Dy	15.7	30.7
7	Fe-5Co-8B-12Nd-3Dy	16.8	29.4
8	Fe-10Co-7B-13.5Nd-1.5Dy	13.9	32.7
9	Fe-20Co-7B-13.5Nd-1.5Dy	12.2	29.0
10	Fe-10Co-8B-14Nd-1Ho	12.4	33.6
11	Fe-10Co-8B-14Nd-1Gd	11.4	31.8
12	Fe-10Co-8B-14Nd-1Tb	14.6	33.6
13	Fe-10Co-8B-14Nd-1Er	12.8	30.3
14	Fe-10Co-8B-14Nd-1Yb	11.6	34.1
15	Fe-8Co-8B-14Pr-1Dy	14.2	22.8
16	Fe-10Co-11Nd-2La-1Dy-1Gd	12.7	24.5

$$*1Oe = 0,0796 \frac{kA}{m}$$

$$1MGOe = 7,96 \text{ kJ/cm}^3$$

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TABLE 3

No.	Alloy composition (at%)	iHc (kOe)*	(BH) max (MGOe)*
1	Fe-10Co-7B-13.5Nd-1.5Dy-1Nb	12.8	34.5
2	Fe-20Co-7B-13.5Nd-1.5Dy-1Nb	11.1	30.5
3	Fe-10Co-7B-13.5Nd-1.5Dy-4Nb	12.2	26.8
4	Fe-10Co-8B-13.5Nd-1.5Dy-1W	13.8	32.2
5	Fe-10Co-8B-13.5Nd-1.5Dy-1Al	14.1	30.8
6	Fe-10Co-8B-13.5Nd-1.5Dy-1Ti	11.6	28.7
7	Fe-10Co-8B-13.5Nd-1.5Dy-1V	12.6	28.8
8	Fe-10Co-8B-13.5Nd-1.5Dy-1Ta	12.1	31.2
9	Fe-10Co-8B-13.5Nd-1.5Dy-1Cr	12.7	28.3
10	Fe-10Co-8B-13.5Nd-1.5Dy-1Mo	13.3	31.1
11	Fe-10Co-8B-13.5Nd-1.5Dy-1Mn	12.5	28.2
12	Fe-10Co-8B-13.5Nd-1.5Dy-1Ni	10.8	28.6
13	Fe-10Co-8B-13.5Nd-1.5Dy-1Ge	11.3	27.3
14	Fe-10Co-8B-13.5Nd-1.5Dy-1Sn	14.6	21.5
15	Fe-10Co-8B-13.5Nd-1.5Dy-Sb	10.1	22.4
16	Fe-10Co-8B-13.5Nd-1.5Dy-1Bi	11.8	27.5
17	Fe-10Co-8B-13.5Nd-1.5Dy-1Zr	10.8	28.6

$$*10e=0,0796 \frac{kA}{m}$$

$$1MGOe=7,96 \text{ kJ/cm}^3$$

TABLE 4

	Room temp. (22°C)		100°C	
	iHc (kOe)*	(BH) max (MGOe)*	iHc (kOe)*	(BH) max (MGOe)*
R.Co (2—17 type) magnet	6.2	29.3	5.2	26.4
Fe-8B-15Nd	11.4	34.0	5.6	26.8

$$1 \text{ kOe}=79.6 \frac{kA}{m}$$

$$1 \text{ MGOe}=7.96 \text{ kJ/cm}^3$$

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Claims

1. A magnetically anisotropic sintered permanent magnet of the FeCoBR system in which R represents the sum of R_1 and R_2 wherein:
- 5 R_1 is at least one of rare earth elements selected from the group consisting of Dy, Tb, Gd, Ho, Er, Tm and Yb, and
- R_2 consists of a total of 80 at% or more of Nd and/or Pr relative to the entire R_2 , and the balance of at least one of other rare earth elements exclusive of R_1 but inclusive of Y,
- 10 said system consisting essentially of, by atomic percent, 0.05 to 5% of R_1 , 12.5 to 20% of R, 4 to 20% of B, $0\% < \text{Co} \leq 35\%$, and the balance being Fe.
2. A magnetically anisotropic sintered permanent magnet of the FeCoBRM system in which R represents the sum of R_1 and R_2 wherein:
- R_1 is at least one of rear earth elements selected from the group consisting of Dy, Tb, Gd, Ho, Er, Tm and Yb,
- 15 R_2 consists of a total of 80 at% or more of Nd and/or Pr relative to the entire R_2 , and the balance of at least one of other rare earth elements exclusive of R_1 but inclusive of Y, and
- M represents additional elements M as specified hereinbelow,
- said system consisting essentially of, by atomic percent, 0.05 to 5% of R_1 , 12.5 to 20% of R, 4 to 20% of B, $0\% < \text{Co} \leq 35\%$, at least one of the additional elements M in the amount of no more than the values as
- 20 specified hereinbelow, and the balance being Fe
- M being:
- | | | | | | |
|---------|-----|------|-----|------|--------|
| 3% | Ti, | 3.3% | Zr, | 3.3% | Hf, |
| 25 4.5% | Cr, | 5% | Mn, | 6% | Ni, |
| 7% | Ta, | 3.5% | Ge, | 1.5% | Sn, |
| 1% | Sb, | 5% | Bi, | 5.2% | Mo, |
| 30 9% | Nb, | 5% | Al, | 5.5% | V, and |
| 5% | W, | | | | |
- 35 provided that, when two or more additional elements M are included, the sum of M should be no more than the maximum value among those specified above of said elements M actually added.
3. A permanent magnet as defined in Claim 1 or 2, wherein, by atomic percent, R_1 is 0.2—3%, R is 13—19%, B is 5—11%, and Co is no more than 23%.
4. A permanent magnet as defined in Claim 1 or 2, wherein R_1 comprises Dy and/or Tb.
- 40 5. A permanent magnet as defined in Claim 1 or 2, wherein R_1 is Dy.
6. A permanent magnet as defined in Claim 1 or 2, wherein R_1 is 0.2 at % or more.
7. A permanent magnet as defined in Claim 1 or 2, wherein R_1 is about 0.4 at%.
8. A permanent magnet as defined in Claim 1 or 2, wherein R_1 is about 1.5 at%.
9. A permanent magnet as defined in Claim 2, wherein the additional elements M comprises one or
- 45 more selected from the group consisting of V, Nb, Ta, Mo, W, Cr and Al.
10. A permanent magnet as defined in Claim 8, wherein M is no more than about 2 at%.
11. A permanent magnet as defined in Claim 1 or 2, which has been subjected to aging after sintering at a temperature between 350°C and the sintering temperature.
12. A permanent magnet as defined in Claim 1 or 2, which has a maximum energy product (BH) max of
- 50 160 kJ/cm³ (20 MGOe) or more.
13. A permanent magnet as defined in Claim 3, which has a maximum energy product (BH) max of 230 kJ/m³ (29 MGOe) or more.
14. A permanent magnet as defined in Claim 1 or 2, which has an intrinsic coercive force iH_c of 800 kA/m (10 kOe) or more.
- 55 15. A permanent magnet as defined in Claim 1 or 2, wherein Co is no more than 25 at%.
16. A permanent magnet as defined in Claim 1 or 2, wherein Co is 5 at% or more.
17. A permanent magnet as defined in Claim 14, wherein the temperature coefficient of Br is about 0.1%/°C or less.
18. A permanent magnet as defined in Claim 1 or 2, which has a Curie point of 310°C or higher.
- 60 19. A permanent magnet as defined in Claim 11, which has an intrinsic coercive force iH_c of 960 kA/m (12 kOe) or more.
20. A permanent magnet as defined in Claim 19, which has iH_c of 1100 kA/m (14 kOe) or more.
21. A permanent magnet as defined in Claim 8, which has iH_c of 1100 kA/m (14 kOe) or more.
22. A permanent magnet as defined in Claim 1 or 2, which has a maximum energy product (BH) max of
- 65 200 kJ/cm³ (25 MGOe) or more.

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23. A permanent magnet as defined in Claim 13, which has a (BH) max of 250 kJ/m³ (32 MGOe) or more.
 24. A permanent magnet as defined in Claim 23, which has a (BH) max of 280 kJ/m³ (35 MGOe) or more.
 25. A permanent magnet as defined in Claim 7, which has a (BH) max of 250 kJ/m³ (32 MGOe) or more.
 26. A permanent magnet as defined in Claim 7, which has a (BH) max of 280 kJ/m³ (35 MGOe) or more.
 5 27. A permanent magnet as defined in Claim 1 or 2, in which Si is present up to 5 at%.

Patentansprüche

1. Magnetisch anisotroper, gesinterter Permanentmagnet des Systems FeCoBR, worin R die Summe
 10 aus R₁ und R₂ darstellt, von denen
 R₁ mindestens eines der Seltenerdmetalle Dy, Tb, Gd, Ho, Er, Tm und Yb bedeutet, sowie
 R₂ zu insgesamt 80 oder mehr Atom-% aus Nd und/oder Pr, bezogen auf das gesamte R₂, und
 hinsichtlich des Restes aus mindestens einem anderen Seltenerdmetall, ausgenommen R₁, jedoch
 einschließlich Y, besteht,
 15 wobei das genannte System im wesentlichen aus 0,05 bis 5 Atom-% R₁, 12,5 bis 20 Atom-% R, 4 bis 20
 Atom-% B, 0 Atom-% <CO ≤ 35 Atom-%, sowie Rest Fe besteht.
 2. Magnetisch anisotroper, gesinterter Permanentmagnet des Systems FeCoBRM, worin R die Summe
 aus R₁ und R₂ darstellt, von denen
 R₁ mindestens eines der Seltenerdmetalle Dy, Tb, Gd, Ho, Er, Tm und Yb bedeutet.
 20 R₂ zu insgesamt 80 oder mehr Atom-% aus Nd und/oder Pr, bezogen auf das gesamte R₂, und
 hinsichtlich des Restes aus mindestens einem anderen Seltenerdmetall, ausgenommen R₁, jedoch
 einschließlich Y, besteht und M zusätzliche Elemente gemäß nachfolgender Angabe bedeutet, wobei das
 System im wesentlichen aus 0,05 bis 5 Atom-% R₁, 12,5 bis 20 Atom-% R, 4 bis 20 Atom-% B, 0
 Atom-% <Co ≤ 35 Atom-%, mindestens einem der zusätzlichen Elemente M in einer die nachfolgenden
 25 Atom-%-Werte nicht überschreitenden Menge sowie hinsichtlich des Restes aus Eisen besteht, wobei für M

	3%	Ti,	3,3%	Zr,	3,3%	Hf,	
	4,5%	Cr,	5%	Mn,	6%	Ni,	
	7%	Ta,	3,5%	Ge,	1,5%	Sn,	
30	1%	Sb,	5%	Bi,	5,2%	Mo,	
	9%	Nb,	5%	Al,	5,5%	V,	und
	5%	W					

gilt, mit der Maßgabe, daß für den Fall, daß zwei oder mehr zusätzliche Elemente M vorliegen, die Summe
 35 von M nicht über dem Maximalwert liegen soll, der für die oben erwähnten und tatsächlich eingesetzten
 Elemente M angegeben ist.

3. Permanentmagnet nach Anspruch 1 oder 2, worin R₁ 0,2 bis 3 Atom-%, R 13 bis 19 Atom-%, B 5 bis
 11 Atom-% und Co nicht mehr als 23 Atom-% betragen.
 4. Permanentmagnet nach Anspruch 1 oder 2, worin R₁ Dy und/oder Tb umfaßt.
 40 5. Permanentmagnet nach Anspruch 1 oder 2, worin R₁ Dy bedeutet.
 6. Permanentmagnet nach Anspruch 1 oder 2, worin R₁ 0,2 oder mehr Atom-% beträgt.
 7. Permanentmagnet nach Anspruch 1 oder 2, worin R₁ etwa 0,4 Atom-% beträgt.
 8. Permanentmagnet nach Anspruch 1 oder 2, worin R₁ etwa 1,5 Atom-% beträgt.
 9. Permanentmagnet nach Anspruch 2, worin die zusätzlichen Elemente M eines oder mehrere der
 45 Elemente V, Nb, Ta, Mo, W, Cr und Al bedeuten.
 10. Permanentmagnet nach Anspruch 8, worin M nicht mehr als etwa 2 Atom-% beträgt.
 11. Permanentmagnet nach Anspruch 1 oder 2, der nach dem Sintern einer Alterung bei einer
 Temperatur zwischen 350°C und der Sintertemperatur unterworfen worden ist.
 12. Permanentmagnet nach Anspruch 1 oder 2, der ein maximales Energieprodukt (BH)max von 160
 50 kJ/m³ (20 MGOe) oder mehr aufweist.
 13. Permanentmagnet nach Anspruch 3, der ein maximales Energieprodukt (BH)max von 230 kJ/m³ (20
 MGOe) oder mehr aufweist.
 14. Permanentmagnet nach Anspruch 1 oder 2, der eine Induktionskoerzitivkraft iH_c von 800 kA/m (10
 kOe) oder mehr aufweist.
 55 15. Permanentmagnet nach Anspruch 1 oder 2, worin Co in einer Menge von nicht mehr als 25 Atom-%
 vorliegt.
 16. Permanentmagnet nach Anspruch 1 oder 2, worin Co in einer Menge von 5 Atom-% oder mehr
 vorliegt.
 17. Permanentmagnet nach Anspruch 14, worin der Temperaturkoeffizient von Br etwa 0,1%/°C
 60 oder weniger beträgt.
 18. Permanentmagnet nach Anspruch 1 oder 2, der einen Curie-Punkt von 310°C oder höher aufweist.
 19. Permanentmagnet nach Anspruch 11, der eine Induktionskoerzitivkraft iH_c von 960 kA/m (12 kOe)
 oder mehr aufweist.
 20. Permanentmagnet nach Anspruch 19, der eine Induktionskoerzitivkraft iH_c von 1100 kA/m (14 kOe)
 65 oder mehr aufweist.



21. Permanentmagnet nach Anspruch 8, der eine Induktionskoerzitivkraft iH_c von 1100 kA/m (14 kOe) oder mehr aufweist.
22. Permanentmagnet nach Anspruch 1 oder 2, der ein maximales Energieprodukt $(BH)_{max}$ von 200 kJ/m³ (25 MGOe) oder mehr aufweist.
23. Permanentmagnet nach Anspruch 13, der ein maximales Energieprodukt $(BH)_{max}$ von 250 kJ/m³ (32 MGOe) oder mehr aufweist.
24. Permanentmagnet nach Anspruch 23, der ein maximales Energieprodukt $(BH)_{max}$ von 280 kJ/m³ (35 MGOe) oder mehr aufweist.
25. Permanentmagnet nach Anspruch 7, der ein maximales Energieprodukt $(BH)_{max}$ von 250 kJ/m³ (32 MGOe) oder mehr aufweist.
26. Permanentmagnet nach Anspruch 7, der ein maximales Energieprodukt $(BH)_{max}$ von 280 kJ/m³ (35 MGOe) oder mehr aufweist.
27. Permanentmagnet nach Anspruch 1 oder 2, worin Si in einer Menge von bis zu 5 Atom-% vorliegt.

15 Revendications

1. Aimant permanent fritté magnétiquement anisotrope du système FeCoBR dans lequel R représente la somme de R_1 et R_2 , où:
- R_1 est au moins l'une des terre rares choisies dans le groupe constitué de Dy, Tb, Gd, Ho, Er, Tm et Yb, et
- R_2 est constitué d'un total de 80% ou plus de Nd et/ou de Pr par rapport à la totalité de R_2 , et le reste d'au moins une autre terre rare à l'exclusion de R_1 , mais comprenant Y, ledit système étant constitué essentiellement, en pourcentage atomique, de 0,05 à 5% de R_1 , 12,5 à 20% de R, 4 à 20% de B, de 0% < Co ≤ 35%, et le reste étant du Fe.
2. Aimant permanent fritté magnétique anisotrope du système FeCoBRM dans lequel R représente la somme de R_1 et R_2 , où:
- R_1 est au moins l'une des terres rares choisies dans le groupe constitué de Dy, Tb, Gd, Ho, Er, Tm et Yb, R_2 est constitué d'un total de 80% ou plus de Nd et/ou de Pr par rapport à la totalité de R_2 , et le reste d'au moins une autre terre rare à l'exclusion de R_1 , mais comprenant Y, et
- M représente des éléments additionnels M tels que spécifiés ci-dessous, ledit système étant constitué essentiellement, en pourcentage atomique, de 0,05 à 5% de R_1 , 12,5 à 20% de R, 4 à 20% de B, 0% < Co ≤ 35% d'au moins l'un des éléments additionnels M en quantité ne dépassant pas les valeurs telles que spécifiées ci-dessous, de le reste étant du Fe, M étant:

3%	Ti,	3,3%	Zr,	3,3%	Hf,
4,5%	Cr,	5%	Mn,	6%	Ni,
7%	Ta,	3,5%	Ge,	1,5%	Sn,
1%	Sb,	5%	Bi,	5,2%	Mo,
9%	Nb,	5%	Al,	5,5%	V,
5%	W,				et

pourvu que, lorsque deux éléments additionnels M, ou plus, sont incorporés, la somme de M ne soit pas supérieure à la valeur maximale faisant partie de celles spécifiées ci-dessus desdits éléments M réellement ajoutés.

3. Aimant permanent selon la revendication 1 ou 2, dans lequel, en pourcentage atomique, R_1 est de 0,2—3%, R est de 13—19%, B est de 5—11% et Co ne dépasse pas 23%.
4. Aimant permanent selon la revendication 1 ou 2, dans lequel R_1 comprend Dy et/ou Tb.
5. Aimant permanent selon la revendication 1 ou 2, dans lequel R_1 est Dy.
6. Aimant permanent selon la revendication 1 ou 2, dans lequel R_1 est de 0,2% ou plus.
7. Aimant permanent selon la revendication 1 ou 2, dans lequel R_1 est d'environ 0,4%.
8. Aimant permanent selon la revendication 1 ou 2, dans lequel R_1 est d'environ 1,5%.
9. Aimant permanent selon la revendication 2, dans lequel les éléments additionnels M comprennent un ou plusieurs éléments choisis dans le groupe constitué de V, Nb, Ta, Mo, W, Cr et Al.
10. Aimant permanent selon la revendication 8, dans lequel M ne dépasse pas environ 2%.
11. Aimant permanent selon la revendication 1 ou 2, qui a été soumis à un vieillissement après frittage à une température comprise entre 350°C et la température de frittage.
12. Aimant permanent selon la revendication 1 ou 2, qui possède un produit d'énergie maximale $(BH)_{max}$ de 160 kJ/m³ (20 MGOe) ou plus.
13. Aimant permanent selon la revendication 3, qui possède un produit d'énergie maximale $(BH)_{max}$ de 230 kJ/m³ (29 MGOe) ou plus.
14. Aimant permanent selon la revendication 1 ou 2, qui possède une force coercitive intrinsèque iH_c de 800 kA/m (10 kOe) ou plus.
15. Aimant permanent selon la revendication 1 ou 2, dans lequel Co ne dépasse pas 25%.
16. Aimant permanent selon la revendication 1 ou 2, dans lequel Co est de 5% ou plus.



17. Aimant permanent selon la revendication 14, dans lequel le coefficient de température de Br est d'environ 0,1%/°C ou moins.
18. Aimant permanent selon la revendication 1 ou 2, qui possède un point de Curie de 310°C ou plus.
19. Aimant permanent selon la revendication 11, qui possède une force coercitive intrinsèque iHc de 5 960 kA/m (12 kOe) ou plus.
20. Aimant permanent selon la revendication 19, qui possède une valeur iHc de 1100 kA/m (14 kOe) ou plus.
21. Aimant permanent selon la revendication 8, qui possède une valeur iHc de 1100 kA/m (14 kOe) ou plus.
- 10 22. Aimant permanent selon la revendication 1 ou 2, qui possède un produit d'énergie maximale (BH)max de 200 kJ/m³ (25 MGOe) ou plus.
23. Aimant permanent selon la revendication 13, qui possède une valeur (BH)max de 250 kJ/m³ (32 MGOe) ou plus.
24. Aimant permanent selon la revendication 23, qui possède une valeur (BH)max de 280 kJ/m³ (35 15 MGOe) ou plus.
25. Aimant permanent selon la revendication 7, qui possède une valeur (BH)max de 250 kJ/m³ (32 MGOe) ou plus.
26. Aimant permanent selon la revendication 7, qui possède une valeur (BH)max de 280 kJ/m³ (35 MGOe) ou plus.
- 20 27. Aimant permanent selon la revendication 1 ou 2, dans lequel Si est présent jusqu'à 5%.

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