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(54) **METHOD AND APPARATUS FOR PRODUCING MAGNETIC POWDER**

VERFAHREN UND VORRICHTUNG ZUR HERSTELLUNG VON MAGNETPULVER

PROCÉDÉ ET APPAREIL DE PRODUCTION DE POUDRE MAGNÉTIQUE

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Description

TECHNICAL FIELD

[0001] The present invention relates to a method and apparatus for producing a magnetic powder, and, more particularly, to a method and apparatus for producing a magnetic powder that is suited for the manufacture of sintered magnets with favorable magnetic properties.

BACKGROUND ART

[0002] Permanent magnets (rare-earth magnets) made by sintering Nd-Fe-B-based magnetic powders, or the like, are beginning to find wider applications in recent years due to their favorable magnetic properties. In an effort to address environmental issues, the breadth of applications for magnets has expanded to household appliances, industrial equipment, electric vehicles, and wind power generation. Consequently, improvements in performance are being demanded of permanent magnets made by sintering such powders, e.g., Nd₂Fe₁₄B-based magnets, etc.

[0003] Magnitudes of remanence and coercivity may be cited as indices of magnet performance. By way of example, with respect to increasing the remanence of an Nd-Fe-B-based sintered magnet, this may be achieved by increasing the volume fraction of Nd₂Fe₁₄B compounds and improving the degree of crystalline orientation. To this end, various process improvements have been made to date.

[0004] On the other hand, with respect to increasing coercivity, this may be achieved through various approaches, such as methods that make crystal grains finer, methods that use alloys of compositions with an increased Nd amount, methods in which an effective element is added, and so forth. In particular, among these approaches, the most common method is to increase coercivity by using an alloy of a composition in which a portion of the Nd is substituted with Dy or Tb. Specifically, by substituting the Nd in an Nd₂Fe₁₄B compound with these elements, the anisotropy field of the compound increases, and coercivity consequently increases.

[0005] However, with respect to Dy, in addition to the fact that its consumption has far exceeded the natural abundance ratio of rare-earth elements, estimated buried amounts in currently commercially developed mineral deposits are limited, and its distribution is skewed globally even in regions where mineral deposits are found, the need for element strategies is now well recognized. With a view to increasing coercivity, Tb may be counted as a rare-earth element that produces effects similar to those of Dy. However, the abundance ratio of Tb is far lower than that of Dy. To date, the coercivity of Nd-Fe-B-based sintered magnets has already been improved dramatically as compared to what it was in the early stages of development through the addition of such trace elements, and through explorations of heat treatment conditions. Thus, in view of such improvement effects, reducing the amount of Dy or Tb added as a trace element has become unavoidable.

[0006] On the other hand, substitution by Dy or Tb reduces the saturation magnetic polarization of the compound. Therefore, insofar as coercivity is to be increased by the methods above, a drop in remanence is inevitable. Further, since Dy and Tb are expensive and scarce, using them as resources involves risks. As such, it is preferable that consumption be reduced as much as possible.

[0007] From such perspectives, there have been adopted methods in which Dy and Tb are concentrated only at or near the grain boundary of a magnet. By way of example, two-alloy methods have been proposed, where a powder obtained by pre-mixing a powder that contains more Dy or Tb than the main phase (Nd₂Fe₁₄B) with a powder that does not contain these elements is sintered (e.g., see Patent Document 1). In addition, as alternative methods, there have been proposed methods in which a fluoride of Dy or Tb is applied to the surface of a sintered magnet, and in which Dy and Tb are diffused at the grain boundary near the surface through a heat treatment (e.g., see Patent Document 2). JP 2005 203653 A (Patent Document 3) discloses a method for manufacturing a magnetic powder by coating an aerosolized hard magnetic phase powder with an aerosolized soft magnetic powder by using an apparatus with at least two aerosol chambers.

[0008] On the other hand, as methods in which Dy or Tb is concentrated at the grain boundary of a magnet, thereby reducing consumption thereof and causing its region to reach the center of a compacted magnet having a thickness of several mm, one may also contemplate methods in which a sintering powder is pre-coated with Dy or Tb.

Patent Document 1: JP Patent Application Publication (Kokai) No. 6-207203 A (1994)

Patent Document 2: JP Patent Application Publication (Kokai) No. 2006-303433 A

Patent Document 3: JP 2005 203653 A

SUMMARY OF THE INVENTION

Problems to be Solved by the Invention

- 5 **[0009]** However, the particle sizes of current hard magnetic powders for use in sintering with respect to rare-earth magnets are approximately 3 μm to 5 μm , and coating a magnetic powder evenly with these transition elements (transition metals), etc., with a thickness ranging from several nm to several tens of nm is extremely difficult.
- 10 **[0010]** By way of example, rare-earth metals are susceptible to reaction with moisture, and it is, in general, difficult to coat a powder (particles) with a rare-earth metal under wet conditions. In addition, magnetic powders on the order of 3 μm to 5 μm tend to aggregate with one another, thereby forming particles in which several tens of such magnetic powders are clustered. Thus, coating the surface of individual magnetic powders evenly with transition elements is not easy.
- 15 **[0011]** Even if one were to, taking the above into consideration, try to coat this hard magnetic powder with a metal, such as a transition metal, etc., in a dry system, given the nature of rare-earth metals and the fact that it is a fine powder with a particle size of 3 μm to 5 μm , it would be difficult to avoid surface oxidation of the hard magnetic powder. Further, compacting a sintered magnet using a magnetic powder whose surface is oxidized would result in lowered magnetic properties. In addition, even if conducted in a dry system, the above-discussed aggregation of the magnetic powder would be inevitable.
- 20 **[0012]** The present invention is made in view of the problems mentioned above. An object thereof is to provide a magnetic powder production method, according to claim 1, and magnetic powder production apparatus, according to claim 6, that are capable of improving the magnetic properties of a sintered magnet by coating the surface of a hard magnetic powder evenly with a metal, such as a transition metal, etc.

Means for Solving the Problems

- 25 **[0013]** In order to achieve the object above, the present inventors, through diligent examination, have focused on the thermophoresis phenomenon as a principle for depositing a metal, such as a transition metal, etc., on the surface of a hard magnetic powder, and have gained new insight that by utilizing this phenomenon, it is possible to deposit on the surface of a magnetic powder (to coat it with) a metal in small amounts and evenly.
- 30 **[0014]** The present invention is based on the above-mentioned new insight gained by the present inventors. A magnetic powder production method according to the present invention comprises: a step of aerosolizing a hard magnetic powder by means of an inert gas; a step of heating and vaporizing a metal under an inert gas atmosphere; and a step of depositing the vaporized metal on the surface of the aerosolized hard magnetic powder.
- 35 **[0015]** According to the present invention, an aerosol of a hard magnetic powder is generated, and the aerosolized hard magnetic powder is dispersed within an inert gas (aerosol). A metal vaporized under an inert gas atmosphere is then deposited on the surface of this dispersed magnetic powder. At this point, the vaporized metal, that is, the vapor particles of the metal, is/are of a higher temperature than the hard magnetic powder. Since there is a large temperature gradient between the hard magnetic powder and the vapor particles, the vapor particles, which are of a higher temperature than the hard magnetic powder, are subjected to a force (thermophoretic force) in such a manner as to be attracted towards the low-temperature hard magnetic powder. Vapor particles are consequently adsorbed to (they coat) the surface
- 40 of the magnetic powder densely and firmly. In addition, since the vaporized metal (vapor particles) is (are) several tens of nm, and thus smaller than the hard magnetic powder, it is possible to evenly deposit on the surface of the hard magnetic powder a small amount of vapor particles as compared to conventional methods.
- 45 **[0016]** The term "aerosol" in the context of the present invention refers to something in which a large amount of hard magnetic powder is suspended within a gas, and aerosolizing refers to causing a large amount of hard magnetic powder to be suspended within a gas. In addition, the term "hard magnetic powder" according to the present invention refers to a powder with which, after a magnetic field is applied, no magnetization remains when the magnetic field is removed, and which is for manufacturing permanent magnets. In contrast, a powder with which, after a magnetic field is applied, magnetization remains and a magnetized state is sustained even when the magnetic field is removed is a soft magnetic powder.
- 50 **[0017]** In addition, the inert gas may be such gasses as He, N₂, Ar, etc., and is not restricted in particular so long as it is for preventing the hard magnetic powder and the vaporized metal (vapor particles) from being oxidized.
- [0018]** In addition, so long as the vaporized metal may be deposited on the surface of the aerosolized hard magnetic powder, the deposition method thereof is not restricted in particular. However, with respect to the depositing step, it is preferable that the aerosolized hard magnetic powder and the vaporized metal be transported by being entrained in a
- 55 gas flow, and that the vaporized metal be made to collide with the aerosolized hard magnetic powder. It is preferable that the flow speed of the gas flow of the vaporized metal be made equal to or greater than the flow speed of the gas flow of the aerosolized hard magnetic powder.
- [0019]** As discussed above, according to the present invention, the vaporized metal (vapor particles) is (are) several

tens of nm. When these vapor particles are transported by being entrained in a gas flow, they are more readily accelerated as compared to the hard magnetic powder. It is thus possible to cause the vaporized metal to collide with the aerosolized hard magnetic powder with greater energy. Consequently, it is possible to deposit the vapor particles on the surface of the hard magnetic powder more firmly and densely. It is noted that "having an aerosolized hard magnetic powder entrained in a gas flow" in the context of the present invention refers to transporting the aerosol of the hard magnetic powder itself.

[0020] It is preferable that the metal to be deposited on the hard magnetic powder for use in a magnetic powder production method of the present invention be a transition metal or an alloyed metal thereof. Rare-earth metals (4f transition elements) are Dy, Tb, or Pr. Since these rare-earth metals are elements with higher anisotropy fields as compared to other metals, a magnet manufactured therefrom provides for improved magnetic properties. The metal to be deposited is an alloyed metal of Nd and Dy, Tb, or Pr. Such alloyed metals melt more readily at the grain boundary as compared to Dy, Tb, and Pr on their own.

[0021] In addition, besides the above, examples of the metal to be deposited include Al, Cu, Zn, In, Si, P, S, Ti, V, Cr, Mn, Ni, Co, Ga, Ge, Zr, Nb, Mo, Pd, Ag, Cd, Sn, Sb, Hf, Ta, W, or alloyed metals thereof, etc. Of the above, highly anisotropic metals, or nonmagnetic metals are generally preferable, with Al and Cu being more preferable. Both Al and Cu, when being sintered into a magnet, melt readily, and form a low-melting point eutectic alloy with an Nd-rich phase, and are capable of improving wettability at the grain boundary, and of causing magnetic discontinuity. They are thus capable of improving magnetic properties.

[0022] In this case, so long as the hard magnetic powder is one with which a permanent magnet may be manufactured by sintering, the powder is not limited to any type in particular, an example of which might be an $R_2Tm_{14}(B,C)_1$ -based magnetic powder (where R is a rare-earth metal, Tm a transition metal excluding rare-earth metals, etc.). Examples of rare-earth metals include Sc, Y, La, Ce, Pr, Sm, Eu, Gd, Ho, Er, Yb, Lu and Nd. In addition, examples of other transition metals, etc., excluding rare-earth metals include Al, Cu, Zn, In, Si, P, S, Ti, V, Cr, Mn, Ni, Co, Ga, Ge, Zr, Nb, Mo, Pd, Ag, Cd, Sn, Sb, Hf, Ta, W, etc. The hard magnetic powder is preferably an Nd-Fe-B-based magnetic powder. According to the present invention, such a magnetic powder has, as compared to other combinations, high coercivity, and is superior in terms of magnetic properties. A magnetic powder thus produced is suited for use as a magnet through sintering.

[0023] For the present invention, a magnetic powder production apparatus that is suited for the production of the magnetic powder discussed above is disclosed below. A magnetic powder production apparatus according to the present invention comprises: an aerosol chamber in which a hard magnetic powder is aerosolized by means of an inert gas; a vapor generation chamber in which a metal is heated and vaporized under an inert gas atmosphere; a deposition part that deposits the vaporized metal on the surface of the aerosolized hard magnetic powder; and a discharge chamber in which the hard magnetic powder on which the metal has been deposited is discharged.

[0024] With the present invention, it is possible to aerosolize a hard magnetic powder in the aerosol chamber by means of an inert gas, while on the other hand heating and vaporizing a metal in the vapor generation chamber under an inert gas atmosphere. Further, it is possible to deposit the vaporized metal on the surface of the aerosolized hard magnetic powder at the deposition part, and to discharge in the discharge chamber the hard magnetic powder on which the metal has been deposited. In so doing, through the above-discussed thermophoretic phenomenon, it is possible to have the vaporized metal evenly adsorbed to the surface of the hard magnetic powder dispersed in the aerosol.

[0025] With respect to a magnetic powder production apparatus according to the present invention, as long as the deposition part thereof is capable of depositing the vaporized metal on the surface of the aerosolized hard magnetic powder, its device configuration is not restricted in any particular way.

[0026] However, it is preferable that a magnetic powder production apparatus according to the present invention be such that the deposition part comprises a main transport pipe connected to the aerosol chamber and an auxiliary transport pipe connected to the vapor generation chamber, wherein the auxiliary transport pipe is connected with the main transport pipe in such a manner that the vaporized metal is able to deposit on the hard magnetic powder.

[0027] With the present invention, it is possible to transport the aerosolized hard magnetic powder towards the discharge chamber through the main transport pipe by having it entrained in a gas flow (to transport the aerosol itself towards the discharge chamber), and to transport the vaporized metal (vapor particles) towards the discharge chamber through the auxiliary transport pipe by having it (them) entrained in a gas flow. In addition, since the auxiliary transport pipe is connected with the main transport pipe in such a manner that the vapor particles are able to deposit on the hard magnetic powder, it is possible to cause the vapor particles to collide with the aerosolized hard magnetic powder. Further, it is also possible to make the flow speed of the gas flow for the vapor particles equal to or greater than the flow speed of the gas flow for the aerosolized hard magnetic powder. It is thus possible to deposit the vapor particles on the surface of the hard magnetic powder more firmly and densely.

[0028] In addition, while there are no particular limitations on the number of vapor generation chambers, it is preferable that a magnetic powder production apparatus according to the present invention comprise the vapor generation chamber and the auxiliary transport pipe connected to the vapor generation chamber in plural numbers, and that the plurality of auxiliary transport pipes be connected to the outer circumference of the main transport pipe at regular intervals.

[0029] With the present invention, by virtue of the fact that there are a plurality of pairs each comprising a vapor generation chamber and an auxiliary transport pipe, and of the fact that the auxiliary transport pipes are each connected to the outer circumference of the main transport pipe at regular intervals, it is possible to deposit, evenly and without any irregularity, the vapor particles on the surface of the hard magnetic powder contained in the aerosol that travels

(flies) through the main transport pipe. In addition, since different metals may be vaporized in the plurality of vapor generation chambers, it is possible to produce a multifunctional magnetic powder.

[0030] In addition, it is preferable that a magnetic powder production apparatus according to the present invention comprise a pipe heating part that heats the auxiliary transport pipe. With the present invention, since the auxiliary transport pipe is heated by the pipe heating part, it is possible to prevent the vapor particles from depositing and accumulating on the inner wall surface of the transport pipe.

[0031] In addition, the aerosol chamber and vapor generation chamber of the above-mentioned production apparatus according to the present invention are each provided with a feed pipe for feeding the inert gas. It is preferable that the feed pipe be provided with an oxygen removal device that removes the oxygen contained in the inert gas. With the present invention, by reducing the oxygen concentration contained in the inert gas, it is possible to suppress oxidation of the hard magnetic powder and vapor particles. With respect to the vapor particles, this is particularly favorable since vapor particles of rare-earth metals are prone to oxidation.

Effects of the Invention

[0032] With the present invention, by evenly coating the surface of a hard magnetic powder with a metal, such as a transition metal, etc., it is possible to improve the magnetic properties of a sintered magnet in which this powder is used.

BRIEF DESCRIPTION OF THE DRAWINGS

[0033]

Figure 1 is an overall configuration diagram of a magnetic powder production apparatus according to the first embodiment.

Figure 2 is a schematic diagram of a magnetic powder produced by a magnetic powder production method according to the first embodiment.

Figure 3 is a diagram illustrating a thermophoresis phenomenon with respect to a method of producing the magnetic powder shown in Figure 2.

Figure 4 shows diagrams illustrating a magnetic powder production apparatus according to the second embodiment, where (a) is an overall configuration diagram of a magnetic powder production apparatus, (b) an enlarged view of the b part shown in (a), and (c) an A-A' sectional view of (b).

Figure 5 is a chart representing the relationship between Dy content and coercivity with respect to Examples 1 and 2 as well as Comparative Examples 1 to 3.

Figure 6 is a chart representing the relationship between Dy content and maximum energy product with respect to Examples 1 and 2 as well as Comparative Examples 1 to 3.

List of Reference Numerals

[0034]

11... hard magnetic powder supply, 12... powder feeding pipe, 13a... oxygen removal device, 13b... oxygen removal device, 16... inert gas pipe, 17... inert gas pipe, 18... cooling unit, 20... aerosol chamber, 21... aerosol generation part, 21a... discharge opening, 25... evacuation pipe, 30... vapor generation chamber, 32... metal melting furnace, 33... heating device, 40... deposition part, 40A... deposition part, 41... main transport pipe, 42... auxiliary transport pipe, 44... transport pipe heater, 45: merging part, 45A... merging part, 48... transport pipe, 49... nozzle part, 50... discharge chamber, 53: receiver part, 58... inert gas pipe, 100... magnetic powder production apparatus, 100A... magnetic powder production apparatus, AG... aerosol, P... hard magnetic powder, PV... magnetic powder, V... vapor particle (vaporized metal)

BEST MODES FOR CARRYING OUT THE INVENTION

[0035] A magnetic powder production apparatus according to the present invention, and a magnetic powder production method using this production apparatus are described below with reference to the drawings based on two embodiments.

[0036] Figure 1 is an overall configuration diagram of a magnetic powder production apparatus according to the first

embodiment for favorably performing a magnetic powder production method according to the present invention. Figure 2 is a schematic diagram of a magnetic powder produced by a magnetic powder production method according to the first embodiment.

[0037] As shown in Figure 1, a magnetic powder production apparatus 100 according to the present embodiment comprises at least an aerosol chamber 20, a vapor generation chamber 30, a deposition part 40, and a discharge chamber 50.

[0038] The aerosol chamber 20 is a chamber for aerosolizing a hard magnetic powder by means of an inert gas. In order to feed a hard magnetic powder P into the chamber, the aerosol chamber 20 is connected, via a powder feeding pipe 12, to a hard magnetic powder supply 11 comprising a grinder, such as a jet mill, etc., and an air classifier.

[0039] In addition, the aerosol chamber 20 comprises, in the lower part of the chamber, an aerosol generation part 21 that aerosolizes the hard magnetic powder P fed into the chamber, that is, it generates an aerosol of the hard magnetic powder P. The aerosol generation part 21 is connected to an inert gas pipe 16. For the purpose of aerosolizing the hard magnetic powder, a plurality of discharge openings 21a so positioned as to enable the discharging of an inert gas G3 towards the base part inside the chamber are formed in the aerosol generation part 21. The aerosol generation part 21 may be, by way of example, of a mechanism that might be used in aerosol deposition techniques, examples of which may include a mechanism that stirs the hard magnetic powder P with the inert gas G3, a mechanism that agitates the container containing the hard magnetic powder P, and so forth.

[0040] In addition, to the inert gas pipe 16 are connected an oxygen removal device 13a that removes the oxygen gas contained in the inert gas G3, and a gas cooling unit 18 that cools the inert gas G3. Further, an inert gas pipe 17 that replaces the gas inside the chamber with an inert gas G2 is connected to the aerosol chamber 20. An oxygen removal device 13b that removes the oxygen gas contained in the inert gas G2 is similarly connected to the inert gas pipe 17.

[0041] In addition, the interior of this aerosol chamber 20 is so designed as to be pressurized by this inert gas G2 to a pressure that is higher (but no greater than 120,000 Pa) than that of the later-discussed discharge chamber 50. By virtue of the differential pressure between the aerosol chamber 20 and the discharge chamber 50, it is possible to transport the aerosolized hard magnetic powder inside the aerosol chamber 20 to the discharge chamber 50. In addition, the inert gasses G2 and G3 fed into the aerosol chamber 20 are such gasses as He, N₂, Ar, etc., and it is preferable that the purity of these gasses be 99.999 % or above.

[0042] It is noted that the oxygen concentration within those gasses should preferably be kept at or below at least 1.0×10^{-6} atm O₂ in partial pressure. The lower this partial pressure is, the better it is, and bringing it to or below 1.0×10^{-7} atm O₂ via the oxygen removal device 13a or 13b is effective. If and as required, the oxygen concentration may be brought down to 1.0×10^{-30} atm O₂.

[0043] On the other hand, the upper part of the aerosol chamber 20 is connected to a main transport pipe 41, which forms part of the later-discussed deposition part 40. This main transport pipe 41 is a pipe that transports the aerosolized hard magnetic powder P.

[0044] The vapor generation chamber 30 is a chamber for heating and vaporizing a metal, examples of which include rare-earth metals, such as Dy, Tb, Pr, etc., and other transition metals, etc. Here, Dy is used for the rare-earth metal. In addition, the vapor generation chamber 30 comprises a metal melting furnace 32, and a heating device 33 that heats and melts the metal inside the metal melting furnace 32. As long as this heating device 33 is capable of melting the metal inside the metal melting furnace 32, it is not limited to any particular system. By way of example, its heating method may include heat radiation melting, high-frequency melting, arc melting, laser-heated melting, electron beam melting, etc.

[0045] In addition, as with the aerosol chamber 20, the vapor generation chamber 30 is pressurized to a pressure greater than that of the later-discussed discharge chamber 50 by means of the inert gas G2. In addition, it is so designed as to be pressurized to a pressure that is equal to or greater than the pressure of the aerosol chamber 20. In order to maintain such a pressure, there may be provided a shutter for making the interior of the aerosol chamber 20 a sealed space.

[0046] Thus, by virtue of the differential pressure between the vapor generation chamber 30 and the discharge chamber 50, the vaporized metal inside the vapor generation chamber 30 may be transported to the discharge chamber 50. In addition, since the pressure is made equal to or greater than that of the aerosol chamber, the flying speed of the vaporized metal (vapor particles) V flying inside an auxiliary transport pipe 42 may be made faster than the flying speed of the hard magnetic powder P flying inside the main transport pipe 41. By consequently causing the vapor particles V to collide strongly with the hard magnetic powder P at a merging part 45, the surface of the hard magnetic powder P may be coated with firmer vapor particles V. It is noted that the pressure in the vapor generation chamber 30 is an inert gas atmosphere of or below 120,000 Pa, and it is preferable that the oxygen concentration within that gas be held at or below at least 1.0×10^{-8} atm O₂ in partial pressure.

[0047] In addition, the aerosol chamber 20 and the vapor generation chamber 30 are connected to an evacuation system including a vacuum pump via an evacuation pipe 25. The gasses inside the aerosol chamber 20 and the vapor generation chamber 30 may thus be readily replaced with the inert gas G2.

[0048] The deposition part 40 is a part where the vaporized metal V is deposited on the surface of the aerosolized

hard magnetic powder P. The deposition part 40 comprises the main transport pipe 41, which is connected to the upper part of the aerosol chamber 20, and the auxiliary transport pipe 42, which is connected to the upper part of the vapor generation chamber 30. Further, the deposition part 40 forms the merging part 45, which is communicably connected to the auxiliary transport pipe 42 and the main transport pipe 41 in such a manner that the vaporized metal V is able to deposit on the hard magnetic powder P. In addition, further downstream of the merging part 45, there is formed a nozzle part 49 which extends into the discharge chamber 50 through the lower part thereof.

[0049] The discharge chamber 50 is a chamber into which a hard magnetic powder (magnetic powder) PV on which a metal has been deposited is discharged (sprayed). Here, the discharge chamber 50, as discussed above, is of such a size that the magnetic powder PV would fall naturally without colliding with the inner wall surface of the chamber due to the differential pressures with respect to the aerosol chamber 20 and the vapor generation chamber 30. In addition, a receiver part 53 for receiving the fallen magnetic powder PV is provided in the discharge chamber 50.

[0050] Further, as with the aerosol chamber 20 and the vapor generation chamber 30, the discharge chamber 50 is connected to an evacuation system via the evacuation pipe 25. It is preferable that the discharge chamber 50 be thus made a vacuum of or below 1.0×10^{-6} atm. In addition, as with the aerosol chamber 20 and the vapor generation chamber 30, the interior of the chamber may be made an inert gas atmosphere, in which case having the inert gas be of an oxygen concentration of or below 1.0×10^{-7} atm O_2 would be effective. Further, in order to recycle the inert gas, the discharge chamber 50 is connected to a gas circulation system via a gas circulation pipe 54.

[0051] A method of producing the magnetic powder PV using such a magnetic powder production apparatus 100 is presented below. First, the interiors of the aerosol chamber 20 and the vapor generation chamber 30 are evacuated, and an inert gas is introduced into these chambers via the oxygen removal device 13b, thereby having the interiors of these chambers be inert gas atmospheres. At this point, the pressure inside the aerosol chamber 20 and the vapor generation chamber 30 is held at or below 120,000 Pa, the oxygen concentration at or below 1.0×10^{-7} to 10^{-8} atm O_2 , and the pressure within the vapor generation chamber 30 equal to or greater than the pressure within the aerosol chamber 20. On the other hand, the interior of the discharge chamber 50 is evacuated and brought down to a pressure lower than those of the aerosol chamber 20 and the vapor generation chamber 30. In so doing, if the chambers are each equipped with a shutter, these are utilized to create the intended pressure.

[0052] Next, from the hard magnetic powder supply 11, such as a jet mill, etc., and via the powder feeding pipe 12, the Nd-Fe-B-based ($Nd_2Fe_{14}B$) hard magnetic powder P, whose average particle size has been classified within the range of $1 \mu m$ to $10 \mu m$, is fed into the aerosol chamber 20. On the other hand, after the oxygen gas contained in the inert gas G3 is removed with the oxygen removal device 13a, the inert gas G3 is cooled by the gas cooling unit 18 to a temperature around $20^\circ C$, and this cooled inert gas G3 is introduced to the aerosol generation part 21.

[0053] Thus, through the plurality of discharge openings 21a in the aerosol generation part 21, the cooled inert gas G3 is discharged towards the base part of the aerosol chamber 20, and the hard magnetic powder P at the base part is agitated and stirred, while at the same time being suspended within the aerosol chamber 20, and an aerosol of magnetic particles is thus generated (the hard magnetic powder P is aerosolized). On the other hand, Dy, which is a rare-earth metal and is disposed within the metal melting furnace 32 within the vapor generation chamber 30, is heated and vaporized with the heating device 33.

[0054] The aerosolized hard magnetic powder P is transported within the main transport pipe 41 towards the discharge chamber 50 due to the differential pressure relative to the discharge chamber 50. In addition, the vaporized metal (vapor particles) V is (are) similarly transported within the auxiliary transport pipe 42 towards the discharge chamber 50.

[0055] Specifically, the aerosolized hard magnetic powder P is entrained in a gas flow and transported towards the discharge chamber 50 (the aerosol itself is transported towards the discharge chamber 50) via the main transport pipe 41. The vapor particles V are entrained in a gas flow and transported towards the discharge chamber 50 via the auxiliary transport pipe 42. Then, since the auxiliary transport pipe 42 is connected with the main transport pipe 41 in such a manner that the vapor particles V are able to deposit on the hard magnetic powder P, it is possible to cause the vapor particles V to collide with the hard magnetic powder P at the merging part 45 of the deposition part.

[0056] Here, the aerosolized hard magnetic powder P has been cooled by the cooling unit 18, while on the other hand the vapor particles V have been heated and vaporized. Thus, as shown in the schematic diagram in Figure 2, due to thermophoresis, it is possible to deposit on the surface of the hard magnetic powder P, which has been classified into the range of $1 \mu m$ to $10 \mu m$, the vapor particles V of sizes ranging from approximately 1 nm to 100 nm.

[0057] Specifically, as shown in Figure 3, under a condition where the hard magnetic powder P is suspended within a gas, the vapor particles V, due to their thermophoresis, collide with the hard magnetic powder P. In particular, since there is a large temperature gradient between this hard magnetic powder P and the vapor particles V, the vapor particles V, which are higher in temperature than the hard magnetic powder P, are subjected to a force (thermophoretic force) in such a manner that they are attracted towards the low-temperature hard magnetic powder P. Consequently, the vapor particles V are deposited on (coat) the surface of the hard magnetic powder P in a dense and firm manner.

[0058] Further, the aerosolized hard magnetic powder P is of a particle size on the order of several μm , and the vapor particles V are of a particle size on the order of several tens of nm. Since the vapor particles V are thus smaller compared

to the hard magnetic powder P, they are readily entrained in the gas flow and accelerated. In other words, due to the above-discussed differential pressures among the respective chambers and due to the sizes of the particles, the flying speed of the vapor particles V is faster than the flying speed of the hard magnetic powder P. As a result, it is possible to densely and firmly deposit the vapor particles V on the surface of the hard magnetic powder P. Thus, the vapor particles V are deposited on the surface of the hard magnetic powder P as shown in Figure 2.

[0059] Thus, the hard magnetic powder PV on which the vapor particles V have been deposited (the hard magnetic powder coated with Dy particles) is discharged into the discharge chamber 50 via the nozzle part 49, and the magnetic powder PV and the vapor particles V accumulate on the receiver part 53. These are then classified using an air classifier, thus obtaining only the magnetic powder PV.

[0060] The magnetic powder PV thus obtained (the hard magnetic powder coated with Dy particles) is compacted within a magnetic field at a predetermined pressure while being oriented. Subsequently, this compact is sintered in a sintering furnace under an inert gas atmosphere, and thereafter subjected to a predetermined heat treatment to manufacture a magnet. With a magnet thus obtained, it is possible to attain greater coercivity compared to conventional magnets by merely using a small amount of rare-earth metal, such as Dy, etc., as compared to what has been conventional.

[0061] Figure 4 is a figure illustrating a magnetic powder production apparatus according to the second embodiment, where (a) is an overall configuration diagram of a magnetic powder production apparatus, (b) an enlarged view of the b part shown in (a), and (c) an A-A' sectional view of (b). A production apparatus according to the second embodiment differs from an apparatus according to the first embodiment mainly in that a plurality of vapor generation chambers are provided, and in the configuration of the deposition part connected to these vapor generation chambers. In other words, it differs in that it comprises a plurality of pairs each comprising a vapor generation chamber and an auxiliary transport pipe. Only the points where it differs from the first embodiment are described below.

[0062] As shown in Figure 4, a magnetic powder production apparatus 100A according to the second embodiment comprises three vapor generation chambers 30, 30, 30. Each vapor generation chamber 30 is of a similar structure to that of the vapor generation chamber indicated in the first embodiment. The auxiliary transport pipe 42 of a deposition part 40A is connected to the upper part of the vapor generation chamber 30. Each auxiliary transport pipe 42 is connected with the main transport pipe 41 at a merging part 45A in such a manner that the vaporized metal V is able to deposit on the hard magnetic powder P.

[0063] In addition, the three auxiliary transport pipes 42 are connected to the outer circumference of the main transport pipe 41 at regular intervals at the merging part 45A. By thus having the auxiliary transport pipes 42 connected to the outer circumference of the main transport pipe 41 at regular intervals at the merging part 45A, it is possible to deposit the vapor particles V evenly and without any irregularity on the surface of the hard magnetic powder P contained in an aerosol AG that travels (flies) through the main transport pipe 41.

[0064] Further, transport pipe heaters (pipe heating parts) 44 are provided on the auxiliary transport pipes 42 of the deposition part 40A that transport the vaporized metal (vapor particles V) and on the transport pipe (a portion of the main transport pipe) that transports the magnetic powder PV on which the vapor particles V have been deposited. By heating these pipes with these transport pipe heaters 44, it is possible to prevent the vapor particles V from depositing and accumulating on the inner wall surfaces of these transport pipes.

[0065] In the present embodiment, an inert gas pipe 58 that replaces the gas inside the chamber with the inert gas G2 is connected to the discharge chamber 50. The oxygen removal device 13b that removes the oxygen gas contained in the inert gas G2 is similarly connected to the inert gas pipe 58. It is thus possible to fill the interior of the discharge chamber 50 with an inert gas.

Examples

[0066] A magnetic powder production method of the present invention is described below based on examples. The examples indicated below are examples where magnetic powders are produced using the magnetic powder apparatus presented in the first embodiment shown in Figure 1.

(Example 1)

[0067] After Nd, Al, Fe and Cu, each of a purity of 99.5 % or above, and ferroboron were high-frequency melted within an Ar gas atmosphere, a strip cast of an alloy was produced, the alloy comprising 13.5 atomic % of Nd, 0.5 atomic % of Al, 0.3 atomic % of Cu, 5.8 atomic percent of B, with the remainder being Fe and incidental impurities. After subjecting this alloy to hydrogen absorption at 0.1 MPa, a hydrogen desorption treatment was performed at 520°C. After cooling, it was sifted to produce an Nd-Fe-B-based magnetic coarse powder (hard magnetic coarse powder) of or below 50 mesh.

[0068] Thereafter, it was ground to an average particle size of 4.2 μm with a jet mill, and this hard magnetic coarse powder was powder fed to an aerosol chamber of an Ar gas of 1.0×10^{-6} atm. It is noted that the gas within the aerosol chamber was evacuated, and the interior of the chamber was made a vacuum of 1.0×10^{-11} atm in advance, after which

the residual gas inside the chamber was replaced with an Ar gas whose oxygen concentration was lowered to a concentration of 1.0×10^{-11} atm O_2 with a zirconia oxygen pump. Then, while holding the pressure inside this chamber at 1.0×10^{-6} atm, an Ar gas, which had been so prepared as to have a gas temperature of 20°C by means of a cooling unit, was used as an aerosol gas. Then, the Nd-Fe-B-based magnetic powder inside the chamber was agitated and stirred to aerosolize the Nd-Fe-B-based magnetic powder (to generate an aerosol of Nd-Fe-B-based magnetic particles).

[0069] On the other hand, as with the aerosol chamber, the interior of the vapor generation chamber was also made a vacuum of 1.0×10^{-11} atm, after which it was replaced with an Ar gas whose O_2 concentration had been lowered to a concentration of 1.0×10^{-11} atm O_2 by a zirconia oxygen pump, and the pressure inside the chamber was made to be 1.0×10^{-5} atm.

[0070] Then, Dy of 99.9 % purity placed inside a carbon crucible was melted at 1077°C through high-frequency melting by means of a high-frequency heating device to generate a Dy vapor (Dy nano vapor particles: average particle size 20 nm). Here, the melting point of Dy under a pressure environment of 1.0×10^{-5} atm is 844°C.

[0071] It is noted that the temperature of at least the inner wall of the auxiliary transport pipe from the vapor generation chamber up to the deposition part (the region up to where the vapor metal is deposited) shown in Figure 1 was heated so as to be at or above 844°C using the heater shown in Figure 1. This is to prevent the Dy nano vapor particles from depositing and accumulating on the inner wall surfaces of the auxiliary transport pipe and the merging part.

[0072] Further, after being similarly evacuated to 1.0×10^{-11} atm, the discharge chamber also had its interior replaced with an Ar gas whose O_2 concentration had been lowered to a concentration of 1.0×10^{-11} atm O_2 by a zirconia oxygen pump, and its internal pressure was made to be 1.0×10^{-7} atm.

[0073] Under such conditions, the shutters cutting off communication among the aerosol chamber, the vapor chamber and the discharge chamber are opened. At this point, the hard magnetic powder in the aerosol chamber flies inside the main transport pipe towards the discharge chamber due to the differential pressure between the aerosol chamber and the discharge chamber. On the other hand, the Dy nano vapor particles of the vapor generation chamber also fly inside the auxiliary transport pipe towards the discharge chamber due to the differential pressure between the vapor generation chamber and the discharge chamber.

[0074] In so doing, due to thermophoresis, the Dy nano vapor particles collide with or adsorb to the hard magnetic powder, which is of a lower temperature compared thereto, and are deposited so as to cover the surface of the hard magnetic powder.

[0075] Further, as discussed in the description for Figure 2 discussed above, in the present example, the Nd-Fe-B-based magnetic powder has an average particle size of 4.2 μ m, and the Dy nano vapor particles are around 20 nm. Since its diameter is of a size that is around 200-fold, the vapor particles are more readily entrained in the gas flow and more readily accelerated. Then, when differential pressures are set for the respective chambers discussed above and the particle sizes are taken into account, the flying speed of the Dy nano vapor particles at the time of collision and until they reach the discharge chamber is faster than the flying speed of the Nd-Fe-B-based magnetic powder, and it is inferred that the relative speed would be 100 m/s or greater. Due to such a relative speed, the Dy nano vapor particles are densely deposited on and coat the surface of the Nd-Fe-B-based magnetic powder.

[0076] The hard magnetic powder (magnetic powder) on which the Dy nano vapor particles were thus deposited were discharged into the discharge chamber via the nozzle part and cooled, and the Dy nano vapor particles deposited on the hard magnetic powder were taken to be Dy nano particles. The magnetic powder and the Dy nano particles that were not deposited on the magnetic powder accumulated on the receiver part within the discharge chamber, and these were classified with an air classifier to obtain only the magnetic powder.

[0077] The thus obtained hard magnetic powder coated with the Dy nano particles was compacted in a mold at a pressure of 100 MPa while being oriented within a $15 \times 10^3/4\pi$ kA/m (15 kOe) magnetic field under an Ar gas atmosphere of 1.0×10^{-11} atm O_2 . This compact was subsequently placed within a sintering furnace under an Ar gas atmosphere of 1.0×10^{-11} atm O_2 , and was sintered for two hours at 1067°C. Further, a heat treatment was performed with the treatment conditions of 820°C and five hours, and a heat treatment was subsequently performed at 520°C for 1.5 hours to produce a magnet block.

[0078] After processing this magnet block to the dimensions $5 \times 5 \times 2$ mm by means of a diamond cutter, magnetic measurements were taken with a BH tracer (VSM (Lake Shore 7400)). What was measured was remanence Br, coercivity Hcj, and maximum energy product (BH)max. The results thereof are shown in Table 1, as well as Figures 5 and 6.

(Example 2)

[0079] A magnet block was produced in a manner similar to Example 1. The only difference with respect to Example 1 is that after Nd, Al, Fe, Cu and Dy, each of a purity of 99.5 % or above, and ferroboration were high-frequency melted within an Ar gas atmosphere, a strip cast of an alloy was produced, the alloy comprising 11.5 atomic % of Nd, 5.0 atomic % of Dy, 0.5 atomic % of Al, 0.3 atomic % of Cu, and 5.8 atomic % of B with the remainder comprising Fe and incidental impurities. Then, as in Example 1, remanence Br, coercivity Hcj, and maximum energy product (BH)max were measured

with respect to the magnetic block thus produced. The results thereof are shown in Table 1, as well as Figures 5 and 6.

(Comparative Example 1)

[0080] A magnetic block was produced in a manner similar to Example 1. The difference with respect to Example 1 is that Dy vapor particles were not deposited. Specifically, by grinding to an average particle size of 4.2 μm with a jet mill, and sintering this hard magnetic powder after compacting under the same conditions as Example 1, a magnetic block was produced. Then, as in Example 1, remanence Br, coercivity Hcj, and maximum energy product (BH)max were measured with respect to the magnetic block thus produced. The results thereof are shown in Table 1, as well as Figures 5 and 6.

(Comparative Example 2)

[0081] A magnetic block was produced in a manner similar to Example 2. The difference with respect to example 2 is that Dy vapor particles were not deposited. Specifically, by grinding to an average particle size of 4.2 μm with a jet mill, and sintering this hard magnetic powder after compacting under the same conditions as Example 2, a magnetic block was produced. Then, as in Example 1, remanence Br, coercivity Hcj, and maximum energy product (BH)max were measured with respect to the magnetic block thus produced. The results thereof are shown in Table 1, as well as Figures 5 and 6.

(Comparative Example 3)

[0082] A magnetic block was produced in a manner similar to Example 1. The difference with respect to Example 1 is that Dy vapor particles were not deposited, and the Dy surface diffusion method indicated below was used instead. Specifically, after grinding to an average particle size of 4.2 μm with a jet mill, this hard magnetic powder was compacted under the same conditions as Example 1.

[0083] The thus obtained hard magnetic powder coated with Dy nano particles was compacted in a mold at a pressure of 100 MPa while being oriented in a $15 \times 10^3/4\pi$ kA/m (15 kOe) magnetic field under an Ar gas atmosphere of 1.0×10^{-11} atm O_2 . This compact was subsequently placed in a sintering furnace under an Ar gas atmosphere of 1.0×10^{-11} atm O_2 , and was sintered for two hours at 1067°C. A magnet block was processed into a magnet with the dimensions $5 \times 5 \times 2$ mm by means of a diamond cutter.

[0084] The magnet was subsequently immersed, while applying ultrasonic waves, for 30 seconds in a turbid solution in which dysprosium fluoride with an average particle size of 10 μm was mixed with ethanol at a mass fraction of 50 %, and placed in a vacuum desiccator where it was dried for 30 minutes at room temperature under an evacuated atmosphere created by a rotary pump. Further, with respect to the magnet coated with dysprosium fluoride, a heat treatment was performed in an Ar gas atmosphere at 800°C for 10 hours, and an aging treatment was further performed at 510°C for an hour. It was then cooled rapidly and a magnet was produced. Then, as in Example 1, remanence Br, coercivity Hcj, and maximum energy product (BH)max were measured with respect to the magnetic block thus produced. The results thereof are shown in Table 1, as well as Figures 5 and 6.

[Table 1]

	Remanence Br (T)	Coercivity Hcj (kA/m)	Maximum Energy Product (BH)Max (kJ/m ³)	Dy Content (mass %)
Example 1	1.41	2000	400	0.8
Example 2	1.35	2400	410	5.8
Comp. Ex. 1	1.42	1100	385	0
Comp. Ex. 2	1.36	1750	395	5
Comp. Ex. 3	1.42	1800	390	0.2

(Results and Discussion)

[0085] As compared to those of Comparative Examples 1 through 3, the magnets of Example 1 and Example 2 were high in coercivity and had large maximum energy products. It is speculated that this is due to the fact that Dy is evenly and densely located at the grain boundary of particles comprising a magnetic powder. In addition, the magnet of Com-

parative Example 2 was low in coercivity and had a small maximum energy product despite the fact that it has a greater Dy content as compared to the magnet of Example 1. It is speculated that this is due to the fact that there is no Dy at the grain boundary. In addition, it is speculated that the magnet of Comparative Example 3 was lower in coercivity and had a smaller maximum energy product than the magnet of Example 1 because Dy is not sufficiently diffused to the interior.

[0086] Embodiments of the present invention have been described above in detail using the drawings.

Claims

1. A magnetic powder production method comprising:

a step of aerosolizing a hard magnetic powder by means of an inert gas;
a step of generating, by heating and melting a metal in a melting furnace under an inert gas atmosphere, vapor particles vaporized from a portion of the melted metal; and

a step of depositing the vapor particles on the surface of the aerosolized hard magnetic powder, wherein in the depositing step, the aerosolized hard magnetic powder is transported by being entrained in a gas flow, while the vapor particles are transported, by being entrained in a gas flow, at a faster speed than the hard magnetic powder entrained in the gas flow, and the vapor particles are deposited on the surface of the aerosolized hard magnetic powder by merging the gas flow of the vapor particles with the gas flow of the hard magnetic powder, wherein

the hard magnetic powder is $R_2Tm_{14}(B,C)_1$ -based magnetic powder, where R is a rare-earth metal selected from Sc, Y, La, Ce, Pr, Sm, Eu, Gd, Ho, Er, Yb, Lu and Nd, and Tm is a transition metal excluding rare-earth metals selected from Al, Cu, Zn, In, Si, P, S, Ti, V, Cr, Mn, Ni, Co, Ga, Ge, Zr, Nb, Mo, Pd, Ag, Cd, Sn, Sb, Hf, Ta, W and Fe; and

the metal to be deposited on the hard magnetic powder is a rare-earth metal selected from Pr, Dy, Tb and Nd or an alloyed metal thereof or a transition metal selected from Al, Cu, Zn, In, Si, P, S, Ti, V, Cr, Mn, Ni, Co, Ga, Ge, Zr, Nb, Mo, Pd, Ag, Cd, Sn, Sb, Hf, Ta and W or an alloyed metal thereof.

2. The magnetic powder production method according to claim 1, wherein, in the depositing step, the vapor particles are deposited on the surface of the aerosolized hard magnetic powder by merging the gas flows of the vapor particles with the gas flow of the hard magnetic powder at positions of regular intervals around the gas flow in which the aerosolized hard magnetic powder is entrained.

3. The magnetic powder production method according to claim 1 or 2, wherein the metal is Dy, Tb or Pr.

4. The magnetic powder production method according to claim 1 or 2, wherein the metal is Al or Cu.

5. The magnetic powder production method according to any one of claims 1 to 4, wherein the hard magnetic powder is an Nd-Fe-B-based magnetic powder.

6. A magnetic powder production apparatus comprising:

an aerosol chamber in which a hard magnetic powder is aerosolized by means of an inert gas;
a vapor generation chamber including a melting furnace in which a metal is heated and melted under an inert gas atmosphere, wherein, through the melting of the metal in the melting furnace, vapor particles vaporized from a portion of the melted metal are generated;

a deposition part in which the vapor particles are deposited on the surface of the aerosolized hard magnetic powder; and

a discharge chamber into which the hard magnetic powder on which the vapor particles have been deposited is discharged, wherein

the deposition part comprises a main transport pipe, which is connected to the aerosol chamber so as to transport the hard magnetic powder by having it entrained in a gas flow, and an auxiliary transport pipe, which is connected to the vapor generation chamber so as to transport the vapor particles, by having them entrained in a gas flow, at a faster speed than the hard magnetic powder entrained in the gas flow, and

the auxiliary transport pipe is connected with the main transport pipe so that the gas flow of the vapor particles merges with the gas flow of the hard magnetic powder, wherein

the hard magnetic powder is $R_2Tm_{14}(B,C)_1$ -based magnetic powder, where R is a rare-earth metal selected from Sc, Y, La, Ce, Pr, Sm, Eu, Gd, Ho, Er, Yb, Lu and Nd, and Tm is a transition metal excluding rare-earth

metals selected from Al, Cu, Zn, In, Si, P, S, Ti, V, Cr, Mn, Ni, Co, Ga, Ge, Zr, Nb, Mo, Pd, Ag, Cd, Sn, Sb, Hf, Ta, W and Fe; and

the metal to be deposited on the hard magnetic powder is a rare-earth metal selected from Pr, Dy, Tb and Nd or an alloyed metal thereof or a transition metal selected from Al, Cu, Zn, In, Si, P, S, Ti, V, Cr, Mn, Ni, Co, Ga, Ge, Zr, Nb, Mo, Pd, Ag, Cd, Sn, Sb, Hf, Ta and W or an alloyed metal thereof.

7. The magnetic powder production apparatus according to claim 6, wherein the production apparatus comprises the vapor generation chamber and the auxiliary transport pipe connected to the vapor generation chamber in plural numbers, and the plurality of auxiliary transport pipes are connected to the outer circumference of the main transport pipe at regular intervals.
8. The magnetic powder production apparatus according to claim 6 or 7, further comprising a pipe heating part that heats the auxiliary transport pipe.
9. The magnetic powder production apparatus according to any one of claims 6, 7 and 8, wherein the aerosol chamber and the vapor generation chamber are provided with a feed pipe for feeding the inert gas, and the feed pipe is provided with an oxygen removal device that removes oxygen contained in the inert gas.

Patentansprüche

1. Magnetpulverproduktionsverfahren, aufweisend:

einen Schritt des Aerosolierens eines harten Magnetpulvers durch ein Inertgas;
einen Schritt des Erzeugens, durch Erwärmen und Schmelzen eines Metalls in einem Schmelzofen unter einer Inertgasatmosphäre, von Dampfpartikeln, die aus einem Abschnitt des geschmolzenen Metalls verdampft werden; und
einen Schritt des Absetzens der Dampfpartikel auf der Oberfläche des aerosolisierten harten Magnetpulvers, wobei
bei dem Absetzschritt das aerosolisierte harte Magnetpulver dadurch transportiert wird, dass es in einem Gasstrom mitgenommen wird, während die Dampfpartikel transportiert werden, indem sie bei einer höheren Geschwindigkeit in einem Gasstrom mitgenommen werden als das harte Magnetpulver, das in dem Gasstrom mitgenommen wird, und wobei die Dampfpartikel auf der Oberfläche des aerosolisierten harten Magnetpulvers abgesetzt werden, indem der Gasstrom der Dampfpartikel mit dem Gasstrom des harten Magnetpulvers vermischt wird, wobei das harte Magnetpulver ein $R_2Tm_{14}(B,C)_1$ -basiertes Magnetpulver ist, wobei R ein Seltenerdmetall ist, das aus Sc, Y, La, Ce, Pr, Sm, Eu, Gd, Ho, Er, Yb, Lu und Nd ausgewählt ist, und Tm ein Übergangsmetall ist, das Seltenerdmetalle ausschließt, das aus Al, Cu, Zn, In, Si, P, S, Ti, V, Cr, Mn, Ni, Co, Ga, Ge, Zr, Nb, Mo, Pd, Ag, Cd, Sn, Sb, Hf, Ta, W und Fe ausgewählt ist; und
das Metall, das auf dem harten Magnetpulver abgesetzt werden soll, ein Seltenerdmetall ist, das aus Pr, Dy, Tb und Nd oder einem Legierungsmetall derselben ausgewählt ist, oder ein Übergangsmetall ist, das aus Al, Cu, Zn, In, Si, P, S, Ti, V, Cr, Mn, Ni, Co, Ga, Ge, Zr, Nb, Mo, Pd, Ag, Cd, Sn, Sb, Hf, Ta und W oder einem Legierungsmetall derselben ausgewählt ist.

2. Magnetpulverproduktionsverfahren nach Anspruch 1, wobei in dem Absetzschritt die Dampfpartikel auf der Oberfläche des aerosolisierten harten Magnetpulvers abgesetzt werden, indem die Gasströme der Dampfpartikel mit dem Gasstrom des harten Magnetpulvers an Positionen mit regelmäßigen Intervallen um den Gasstrom, in dem das aerosolisierte harte Magnetpulver mitgenommen wird, vermischt werden.

3. Magnetpulverproduktionsverfahren nach Anspruch 1 oder 2, wobei das Metall Dy, Tb oder Pr ist.

4. Magnetpulverproduktionsverfahren nach Anspruch 1 oder 2, wobei das Metall Al oder Cu ist.

5. Magnetpulverproduktionsverfahren nach einem der Ansprüche 1 bis 4, wobei das harte Magnetpulver ein Nd-Fe-B-basiertes Magnetpulver ist.

6. Magnetpulverproduktionsvorrichtung, aufweisend:

eine Aerosolkammer, in der ein hartes Magnetpulver durch ein Inertgas aerosolisiert wird;
 eine Dampferzeugungskammer, die einen Schmelzofen beinhaltet, in dem ein Metall unter einer Inertgasatmosphäre erwärmt und geschmolzen wird, wobei durch das Schmelzen des Metalls in dem Schmelzofen Dampfpartikel, die aus einem Abschnitt des geschmolzenen Metalls verdampft werden, erzeugt werden;
 einen Absetzteil, in dem die Dampfpartikel auf der Oberfläche des aerosolisierten harten Magnetpulvers abgesetzt werden; und
 eine Ausstoßkammer, in die das harte Magnetpulver, auf dem die Dampfpartikel abgesetzt werden, ausgestoßen wird, wobei
 der Absetzteil eine Haupttransportleitung, die mit der Aerosolkammer verbunden ist, so dass das harte Magnetpulver transportiert wird, indem es in einem Gasstrom mitgenommen wird, und eine Hilfstransportleitung, die mit der Dampferzeugungskammer verbunden ist, so dass die Dampfpartikel transportiert werden, indem sie in einem Gasstrom mit einer höheren Geschwindigkeit als der des harten Magnetpulvers, das in dem Gasstrom mitgenommen wird, mitgenommen werden, aufweist, und
 die Hilfstransportleitung mit der Haupttransportleitung verbunden ist, so dass der Gasstrom der Dampfpartikel mit dem Gasstrom des harten Magnetpulvers vermischt wird, wobei
 das harte Magnetpulver ein $R_2Tm_{14}(B,C)_1$ -basiertes Magnetpulver ist, wobei R ein Seltenerdmetall ist, das aus Sc, Y, La, Ce, Pr, Sm, Eu, Gd, Ho, Er, Yb, Lu und Nd ausgewählt ist, und Tm ein Übergangsmetall ist, das Seltenerdmetalle ausschließt, das aus Al, Cu, Zn, In, Si, P, S, Ti, V, Cr, Mn, Ni, Co, Ga, Ge, Zr, Nb, Mo, Pd, Ag, Cd, Sn, Sb, Hf, Ta, W und Fe ausgewählt ist; und
 das Metall, das auf dem harten Magnetpulver abgesetzt werden soll, ein Seltenerdmetall ist, das aus Pr, Dy, Tb und Nd oder einem Legierungsmetall derselben ausgewählt ist, oder ein Übergangsmetall, das aus Al, Cu, Zn, In, Si, P, S, Ti, V, Cr, Mn, Ni, Co, Ga, Ge, Zr, Nb, Mo, Pd, Ag, Cd, Sn, Sb, Hf, Ta und W oder einem Legierungsmetall derselben ausgewählt ist.

7. Magnetpulverproduktionsvorrichtung nach Anspruch 6, wobei die Produktionsvorrichtung die Dampferzeugungskammer und die Hilfstransportleitung, die mit der Dampferzeugungskammer verbunden ist, mehrfach aufweist, und die Mehrzahl an Hilfstransportleitungen mit dem äußeren Umfang der Haupttransportleitung in regelmäßigen Intervallen verbunden ist.
8. Magnetpulverproduktionsvorrichtung nach Anspruch 6 oder 7, ferner aufweisend einen Leitungsheizteil, der die Hilfstransportleitung heizt.
9. Magnetpulverproduktionsvorrichtung nach einem der Ansprüche 6, 7 und 8, wobei die Aerosolkammer und die Dampferzeugungskammer mit einer Zuführleitung zum Zuführen des Inertgases versehen sind, und die Zuführleitung mit einer Sauerstoffentfernungsvorrichtung versehen ist, die Sauerstoff, der in dem Inertgas enthalten ist, entfernt.

Revendications

1. Procédé de production de poudre magnétique comprenant :

une étape d'aérosolisation d'une poudre magnétique dure au moyen d'un gaz inerte ;
 une étape de production, par chauffage et fusion d'un métal dans un four de fusion sous une atmosphère de gaz inerte, de particules de vapeur vaporisées à partir d'une portion du métal fondu ; et
 une étape de dépôt des particules de vapeur sur la surface de la poudre magnétique dure aérosolisée, où dans l'étape de dépôt, la poudre magnétique dure aérosolisée est transportée en étant entraînée dans un écoulement de gaz, alors que les particules de vapeur sont transportées, en étant entraînées dans un écoulement de gaz, à une vitesse plus grande que la poudre magnétique dure entraînée dans l'écoulement de gaz, et les particules de vapeur sont déposées sur la surface de la poudre magnétique dure aérosolisée en combinant l'écoulement de gaz des particules de vapeur avec l'écoulement de gaz de la poudre magnétique dure, où la poudre magnétique dure est une poudre magnétique à base de $R_2Tm_{14}(B,C)_1$, où R est un métal de terres rares choisi parmi Sc, Y, La, Ce, Pr, Sm, Eu, Gd, Ho, Er, Yb, Lu et Nd, et Tm est un métal de transition excluant les métaux de terres rares choisi parmi Al, Cu, Zn, In, Si, P, S, Ti, V, Cr, Mn, Ni, Co, Ga, Ge, Zr, Nb, Mo, Pd, Ag, Cd, Sn, Sb, Hf, Ta, W et Fe ; et
 le métal à déposer sur la poudre magnétique dure est un métal de terres rares choisi parmi Pr, Dy, Tb et Nd ou un métal allié de ceux-ci ou un métal de transition choisi parmi Al, Cu, Zn, In, Si, P, S, Ti, V, Cr, Mn, Ni, Co,

Ga, Ge, Zr, Nb, Mo, Pd, Ag, Cd, Sn, Sb, Hf, Ta et W ou un métal allié de ceux-ci.

2. Procédé de production de poudre magnétique selon la revendication 1, où, dans l'étape de dépôt, les particules de vapeur sont déposées sur la surface de la poudre magnétique dure aérosolisée en combinant les écoulements de gaz des particules de vapeur avec l'écoulement de gaz de la poudre magnétique dure à des positions d'intervalles réguliers autour de l'écoulement de gaz dans lequel la poudre magnétique dure aérosolisée est entraînée.

3. Procédé de production de poudre magnétique selon la revendication 1 ou 2, où le métal est Dy, Tb ou Pr.

4. Procédé de production de poudre magnétique selon la revendication 1 ou 2, où le métal est Al ou Cu.

5. Procédé de production de poudre magnétique selon l'une quelconque des revendications 1 à 4, où la poudre magnétique dure est une poudre magnétique à base de Nd-Fe-B.

6. Appareil de production de poudre magnétique comprenant :

une chambre d'aérosol dans laquelle une poudre magnétique dure est aérosolisée au moyen d'un gaz inerte ;
une chambre de production de vapeur incluant un four de fusion dans lequel un métal est chauffé et fondu sous une atmosphère de gaz inerte, où, par la fusion du métal dans le four de fusion, des particules de vapeur vaporisées à partir d'une portion du métal fondu sont produites ;

une partie de dépôt dans laquelle les particules de vapeur sont déposées sur la surface de la poudre magnétique dure aérosolisée ; et

une chambre de décharge dans laquelle la poudre magnétique dure sur laquelle les particules de vapeur ont été déposées est déchargée, où

la partie de dépôt comprend un tuyau de transport principal, qui est connecté à la chambre d'aérosol afin de transporter la poudre magnétique dure en l'ayant entraîné dans un écoulement de gaz, et un tuyau de transport auxiliaire, qui est connecté à la chambre de production de vapeur afin de transporter les particules de vapeur, en les ayant entraîné dans un écoulement de gaz, à une vitesse supérieure à la poudre magnétique dure entraînée dans l'écoulement de gaz, et

le tuyau de transport auxiliaire est connecté avec le tuyau de transport principal de sorte que l'écoulement de gaz des particules de vapeur se combine à l'écoulement de gaz de la poudre magnétique dure, où

la poudre magnétique dure est une poudre magnétique à base de $R_2Tm_{14}(B,C)_1$, où R est un métal de terres rares choisi parmi Sc, Y, La, Ce, Pr, Sm, Eu, Gd, Ho, Er, Yb, Lu et Nd, et Tm est un métal de transition excluant les métaux de terres rares choisi parmi Al, Cu, Zn, In, Si, P, S, Ti, V, Cr, Mn, Ni, Co, Ga, Ge, Zr, Nb, Mo, Pd, Ag, Cd, Sn, Sb, Hf, Ta, W et Fe ; et

le métal à déposer sur la poudre magnétique dure est un métal de terres rares choisi parmi Pr, Dy, Tb et Nd ou un métal allié de ceux-ci ou un métal de transition choisi parmi Al, Cu, Zn, In, Si, P, S, Ti, V, Cr, Mn, Ni, Co, Ga, Ge, Zr, Nb, Mo, Pd, Ag, Cd, Sn, Sb, Hf, Ta et W ou un métal allié de ceux-ci.

7. Appareil de production de poudre magnétique selon la revendication 6, où l'appareil de production comprend la chambre de production de vapeur et le tuyau de transport auxiliaire connecté à la chambre de production de vapeur en plusieurs nombres, et les plusieurs tuyaux de transport auxiliaire sont connectés à la circonférence externe du tuyau de transport principal à des intervalles réguliers.

8. Appareil de production de poudre magnétique selon la revendication 6 ou 7, comprenant de plus une partie de chauffage de tuyau qui chauffe le tuyau de transport auxiliaire.

9. Appareil de production de poudre magnétique selon l'une quelconque des revendications 6, 7 et 8, où la chambre d'aérosol et la chambre de production de vapeur sont munies d'un tuyau d'alimentation pour introduire le gaz inerte, et le tuyau d'alimentation est muni d'un dispositif d'élimination d'oxygène qui élimine l'oxygène contenu dans le gaz inerte.

FIG. 1

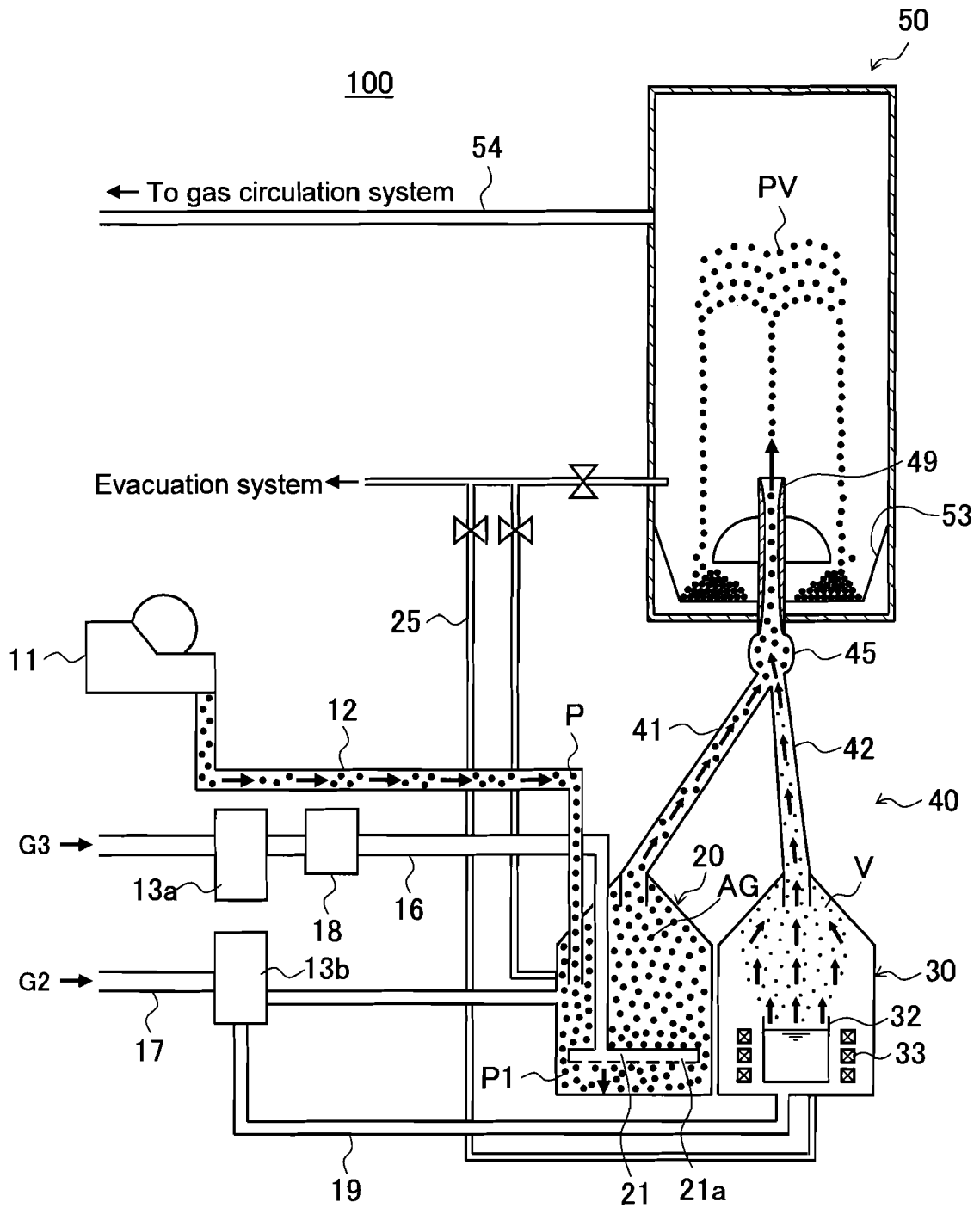


FIG. 2

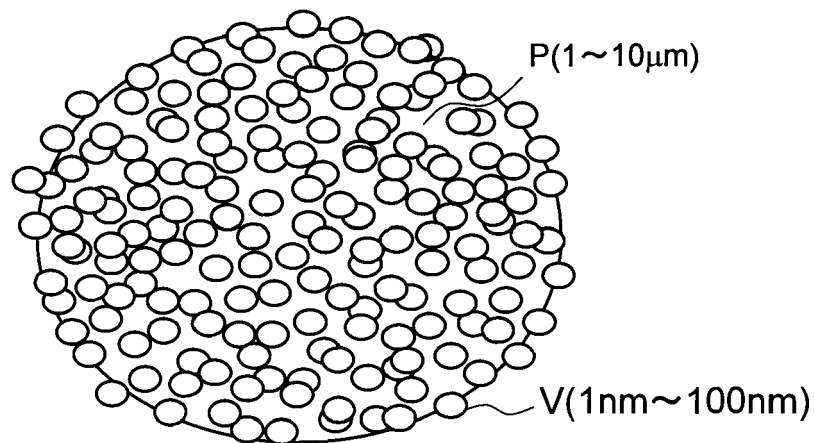


FIG. 3

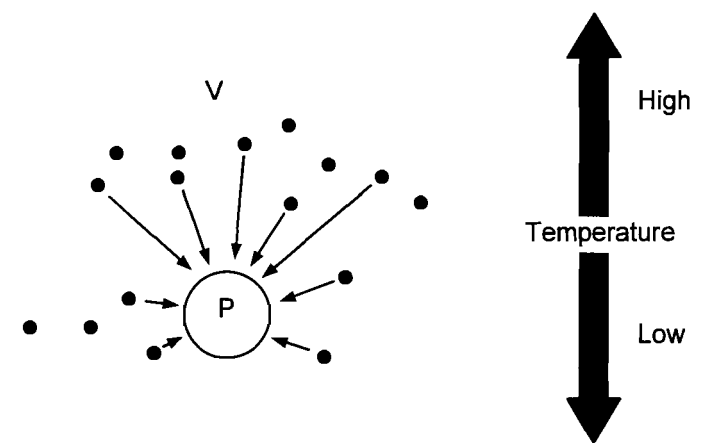


FIG. 4

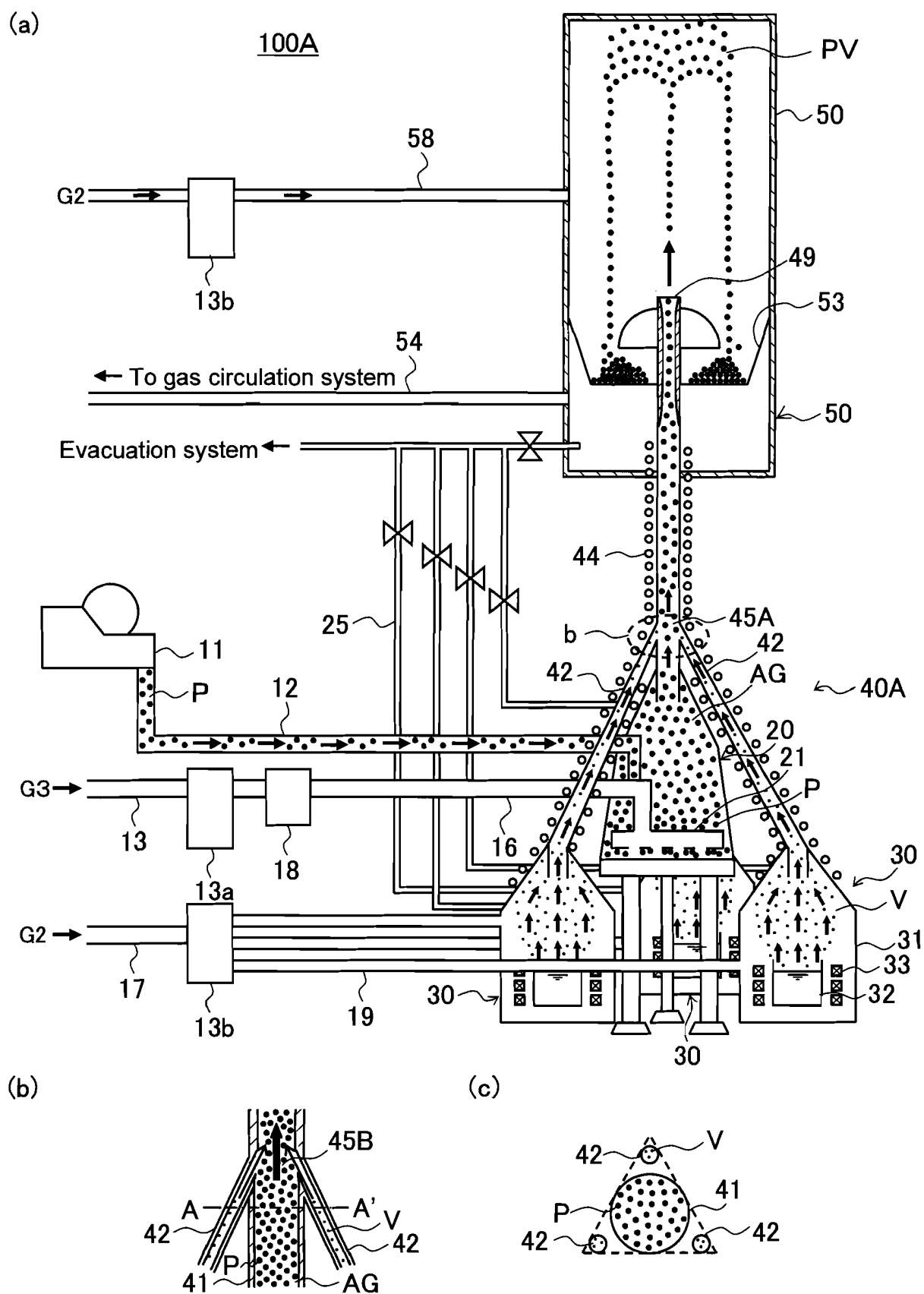


FIG. 5

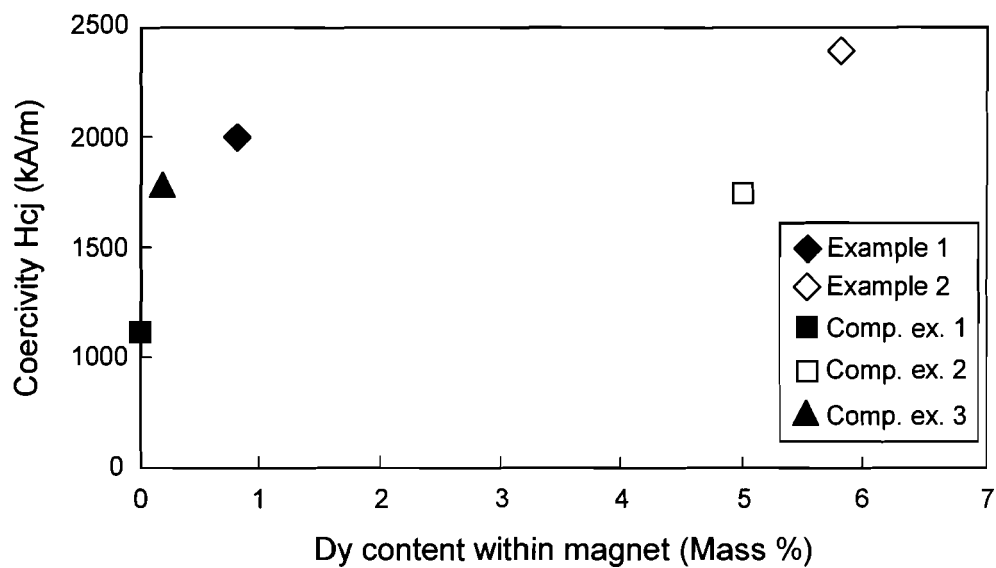
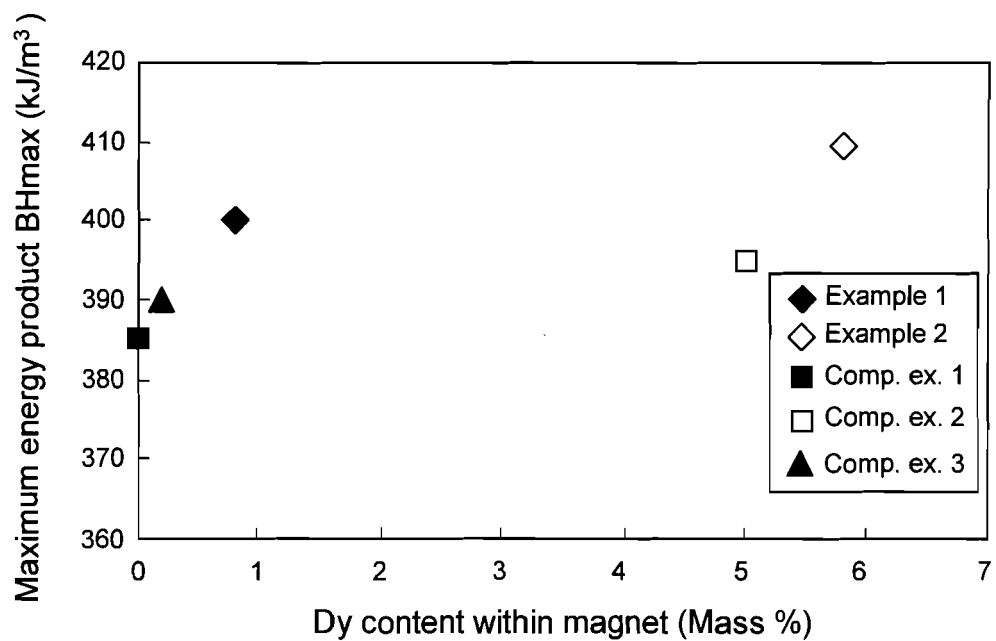


FIG. 6



REFERENCES CITED IN THE DESCRIPTION

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