US 20080236171A1

(19) United States

(12) Patent Application Publication

(10) Pub. No.: US 2008/0236171 A1

(43) Pub. Date: Oct. 2, 2008

Saito et al.

(54) **MAGNETIC REFRIGERATING DEVICE AND MAGNETIC REFRIGERATING METHOD**

(75) Inventors: **Akiko Saito**, Kawasaki-shi (JP); **Tadahiko Kobayashi**, Yokohama-shi (JP); **Hideyuki Tsuji**, Yokohama-shi (JP); **Hideo Iwasaki**, Kawasaki-shi (JP); **Katsumi Hisano**, Matsudo-shi (JP); **Akihiro Koga**, Tokyo (JP); **Akihiro Kasahara**, Chiba-ken (JP); **Takuya Takahashi**, Tokyo (JP)

Correspondence Address:
OBLON, SPIVAK, MCCLELLAND MAIER & NEUSTADT, P.C.
1940 DUKE STREET
ALEXANDRIA, VA 22314 (US)

(73) Assignee: **KABUSHIKI KAISHA TOSHIBA**, Tokyo (JP)

(21) Appl. No.: **11/860,784**

(22) Filed: **Sep. 25, 2007**

(30) **Foreign Application Priority Data**

Sep. 28, 2006 (JP) P2006-265833

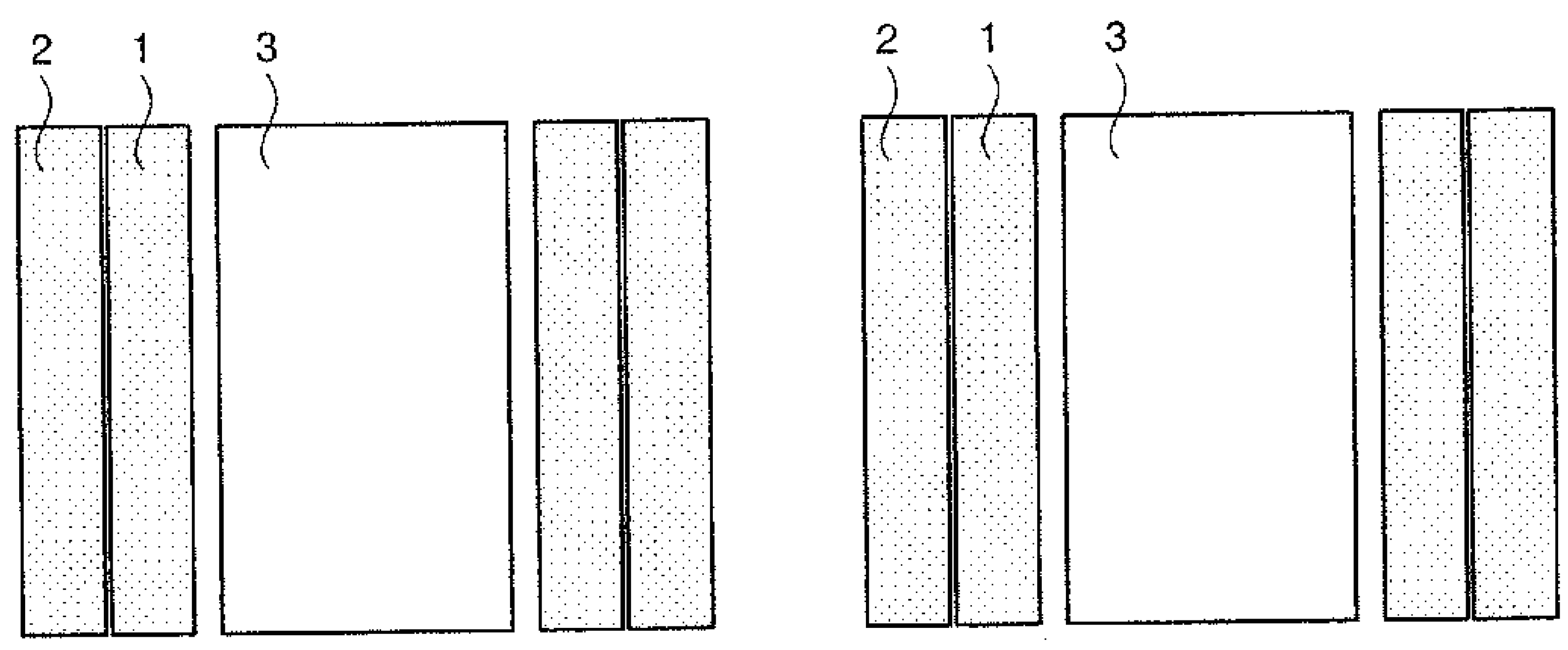
Publication Classification

(51) **Int. Cl.**
F25B 21/00 (2006.01)

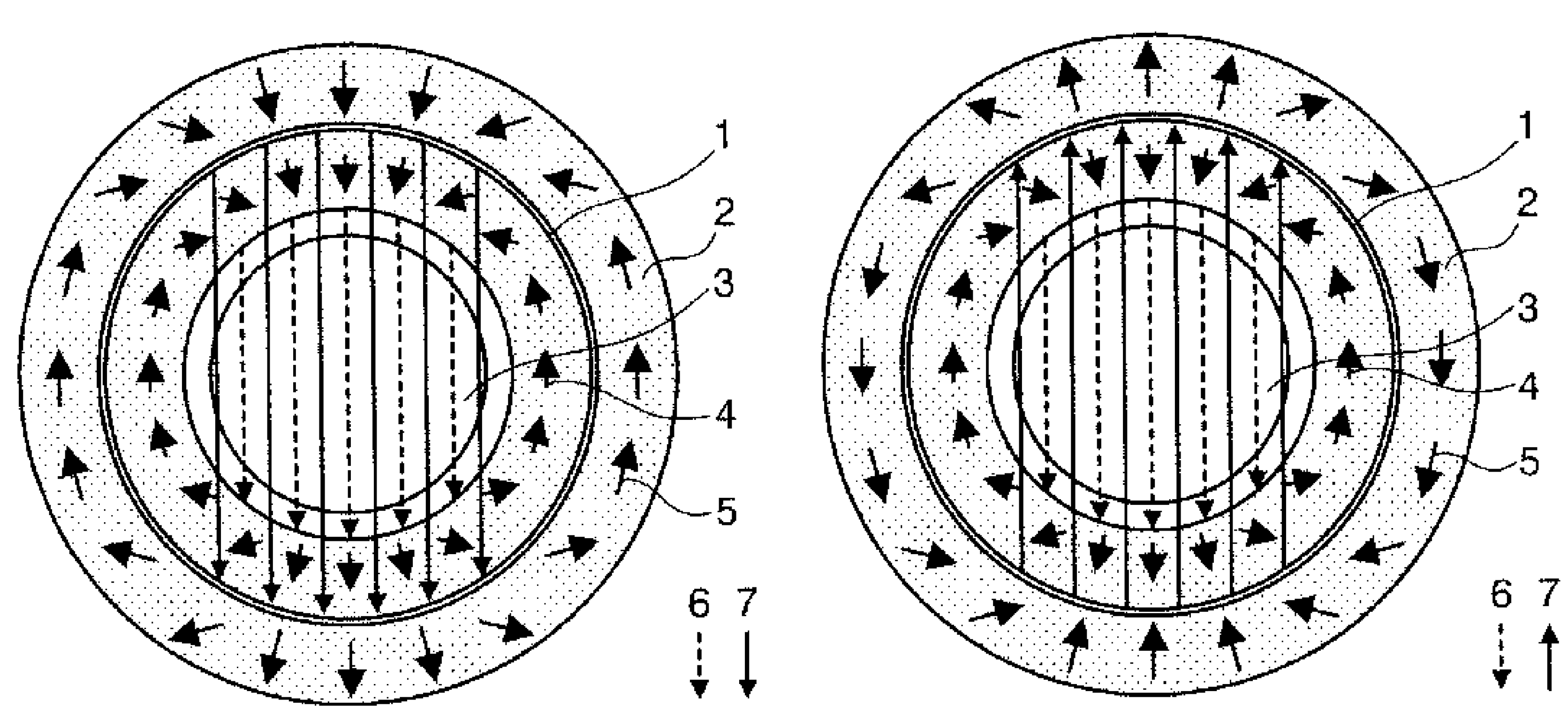
(52) **U.S. Cl.** **62/3.1**

(57) **ABSTRACT**

A magnetic refrigerating device includes: at least one set of double-structured Halbach type magnet including a ring-shaped inner Halbach type magnet and a ring-shaped outer Halbach type magnet which are coaxially arranged one another so that a magnetic field generated by the inner Halbach type magnet is superimposed with a magnetic field generated by the outer Halbach type magnet; a magnetic refrigerant or a magnetic refrigeration working chamber including the magnetic refrigerant therein disposed in a bore space of the inner Halbach type magnet; and a rotating mechanism to rotate the outer Halbach type magnet while the inner Halbach type magnet is stationed.



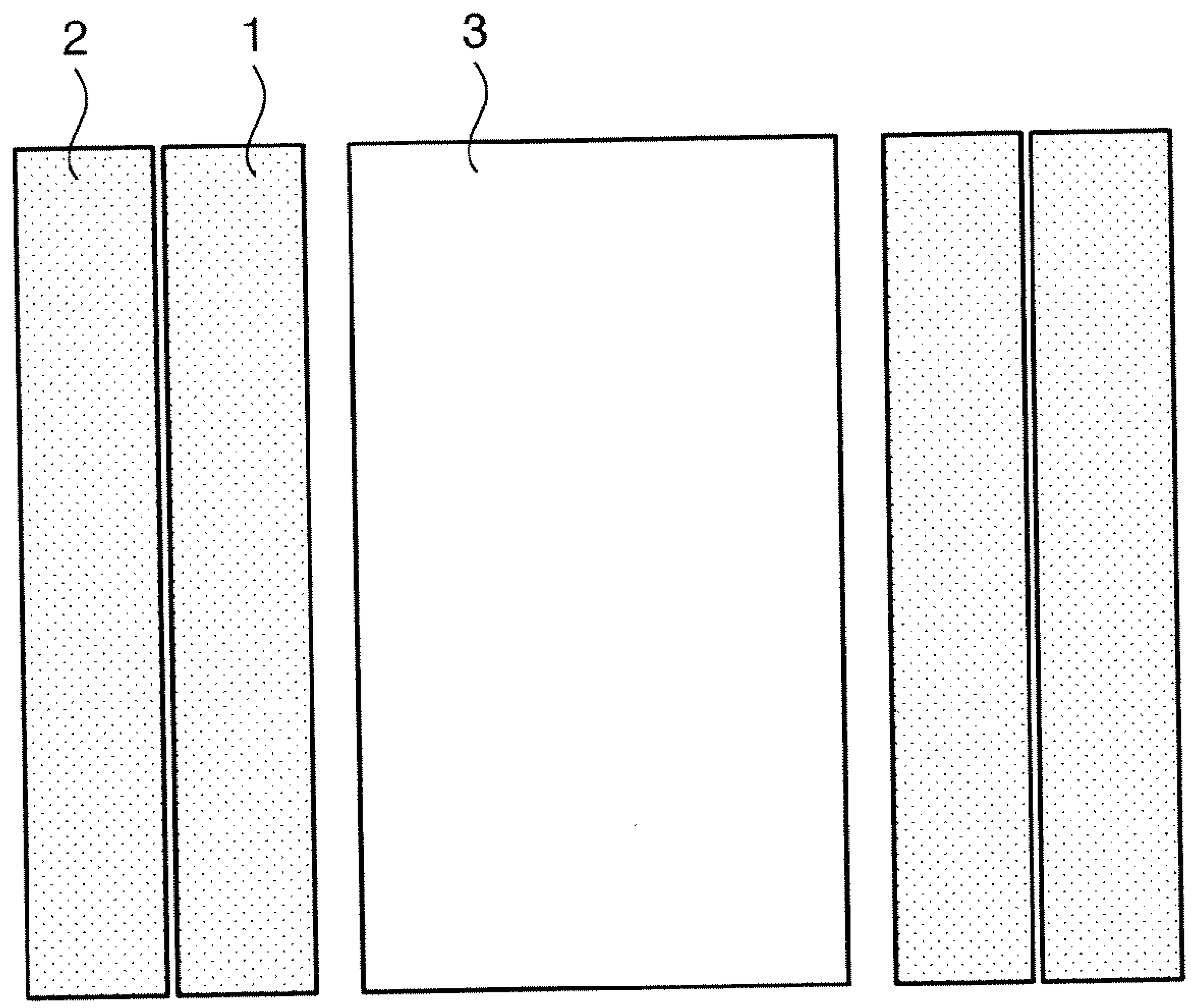
(a)



(b)

FIG. 1

(a)



(b)

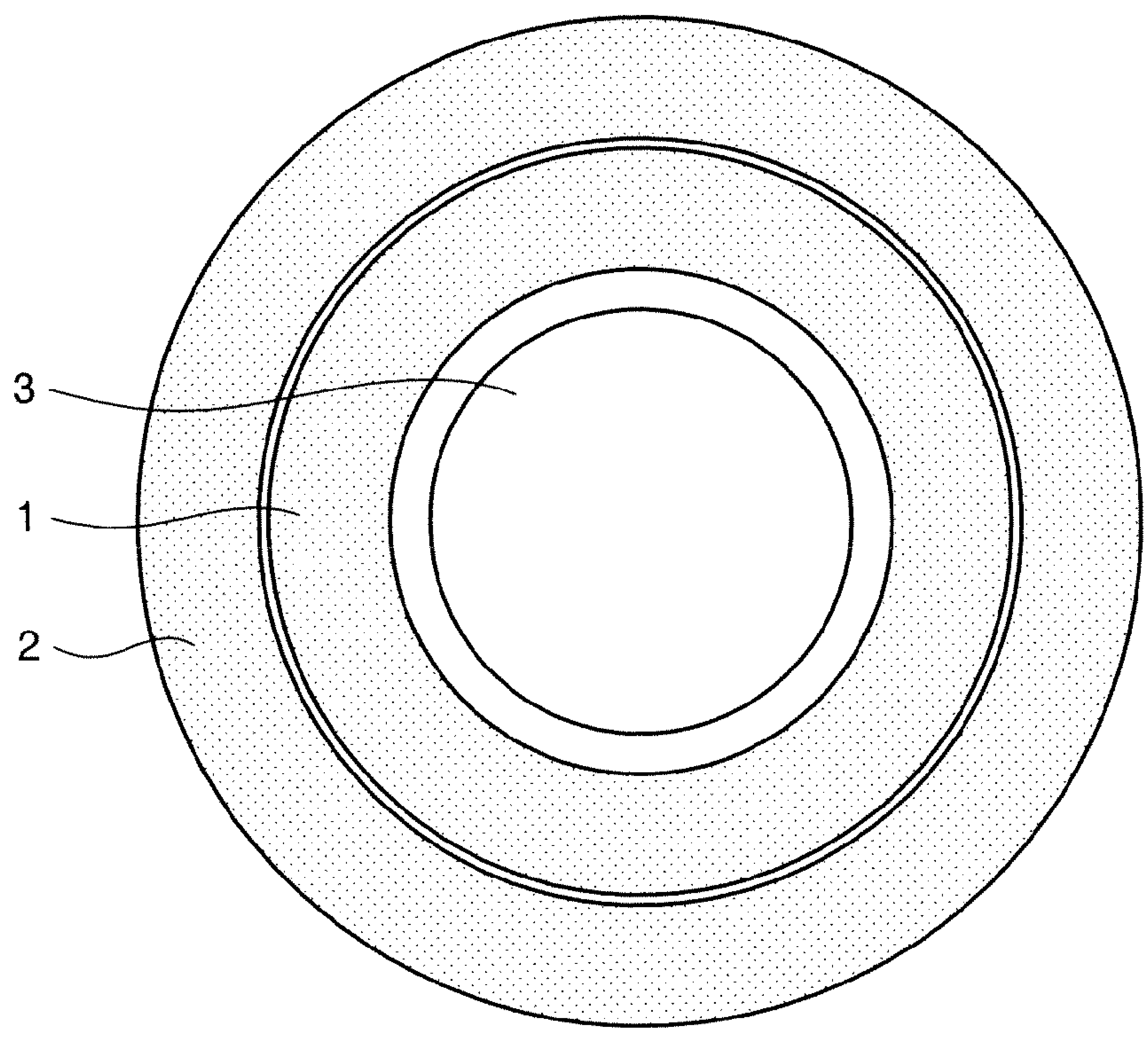
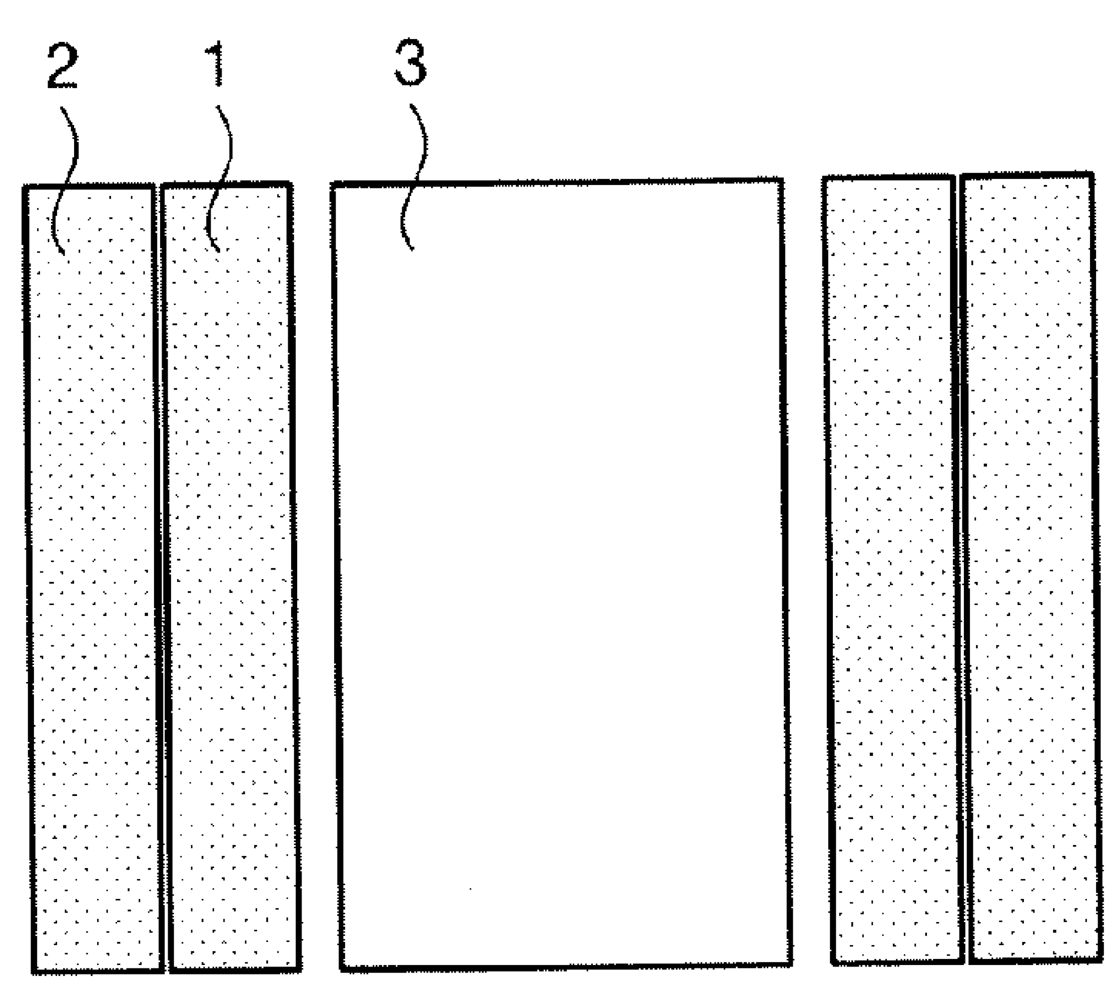
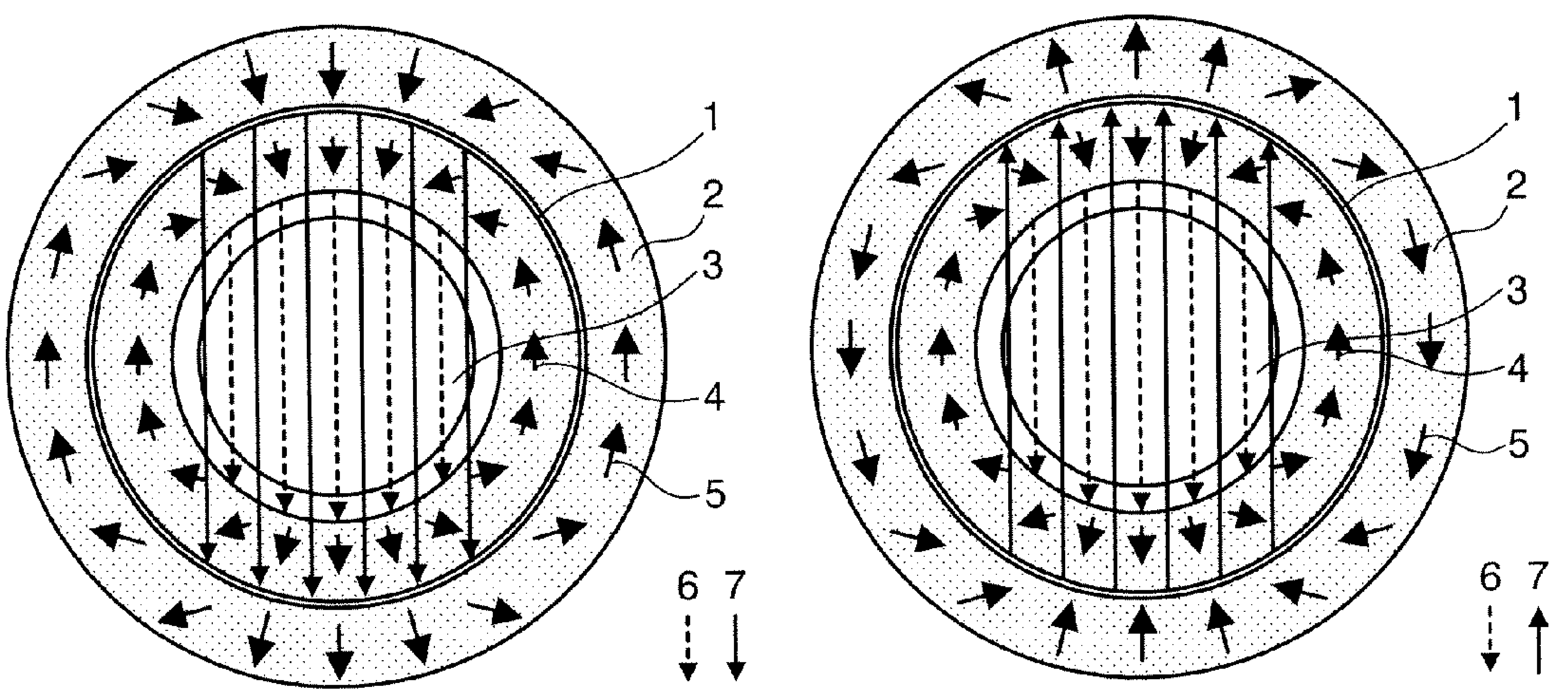


FIG. 2



(a)



(b)

FIG. 3

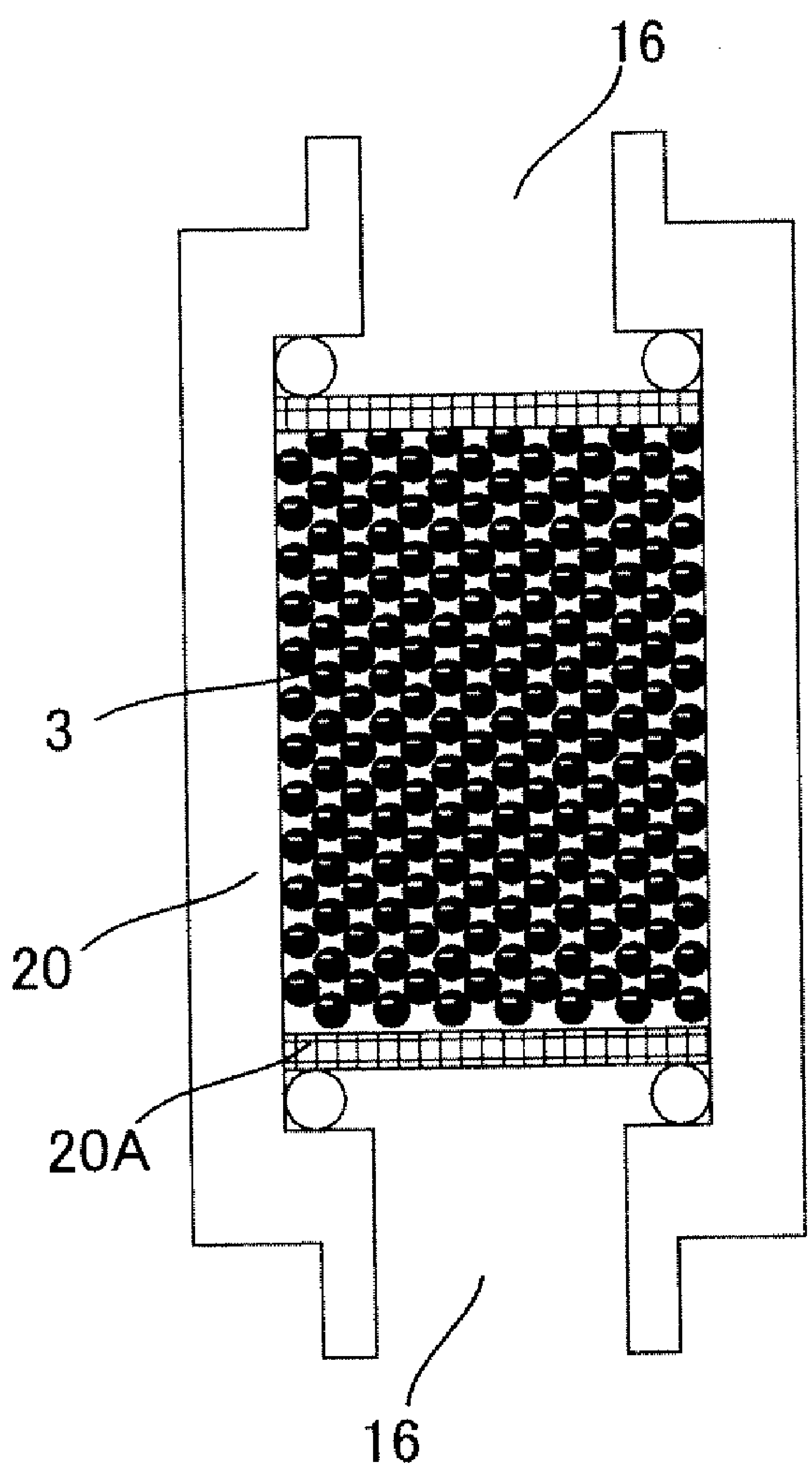


FIG. 4

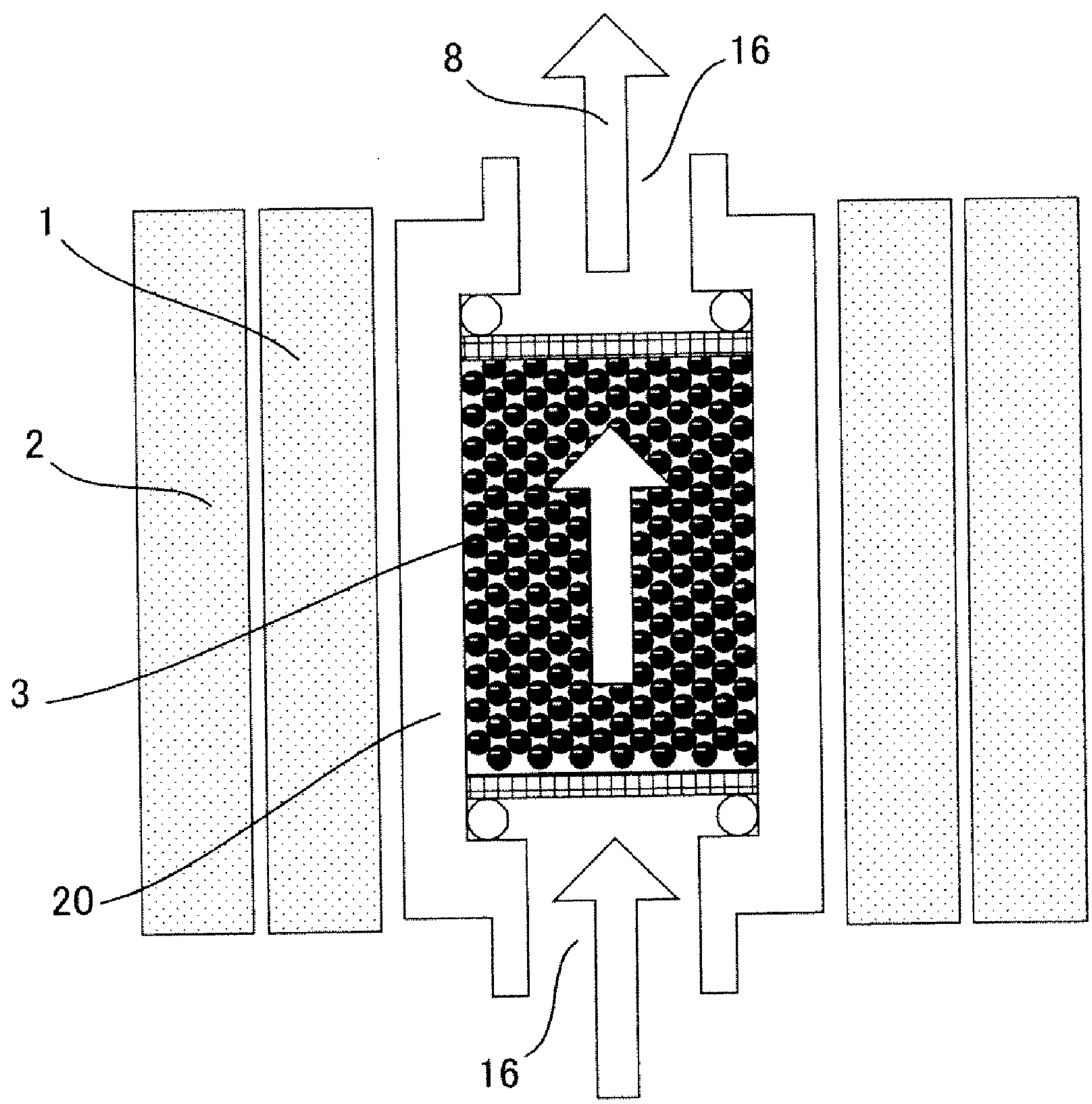
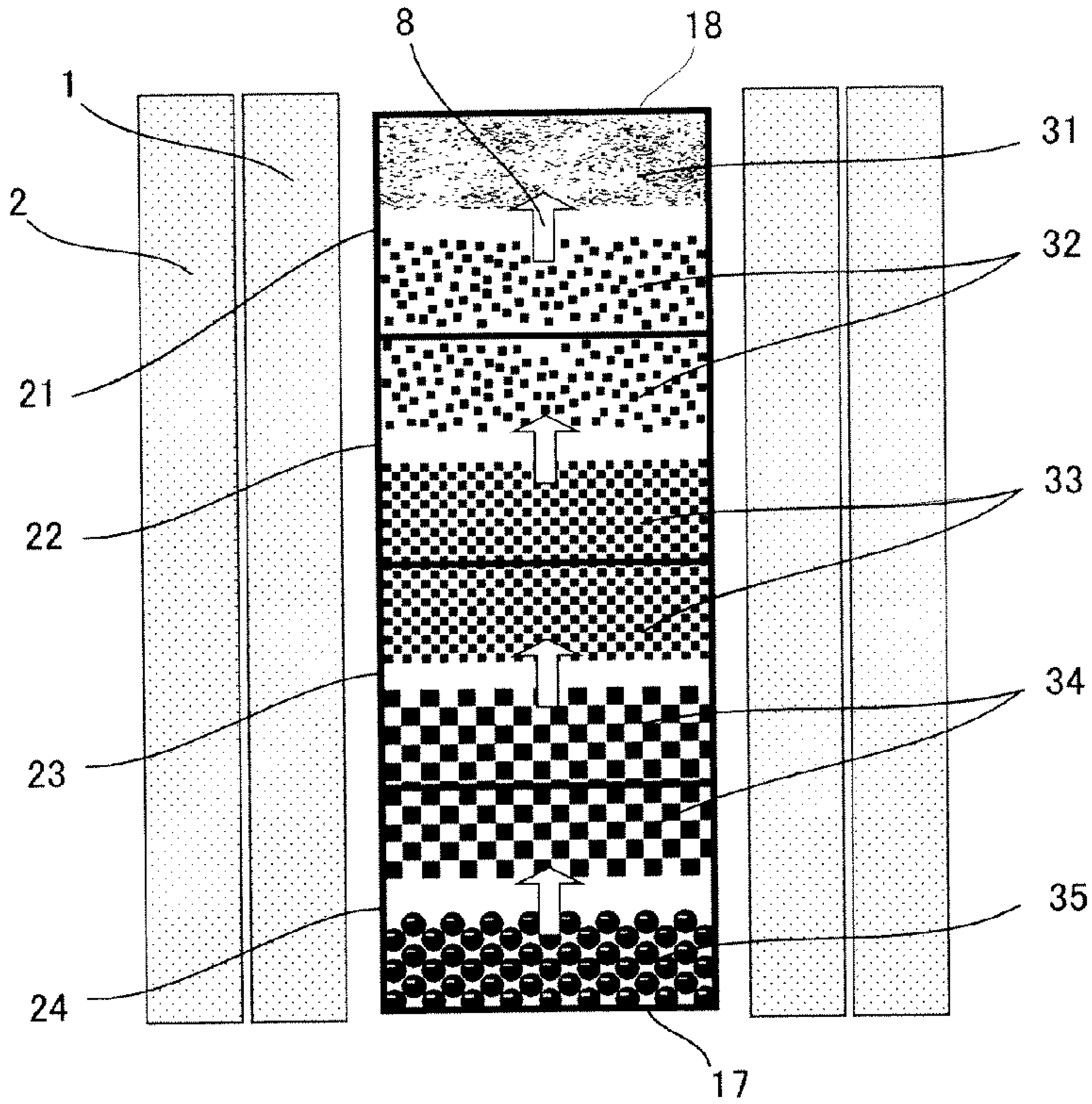
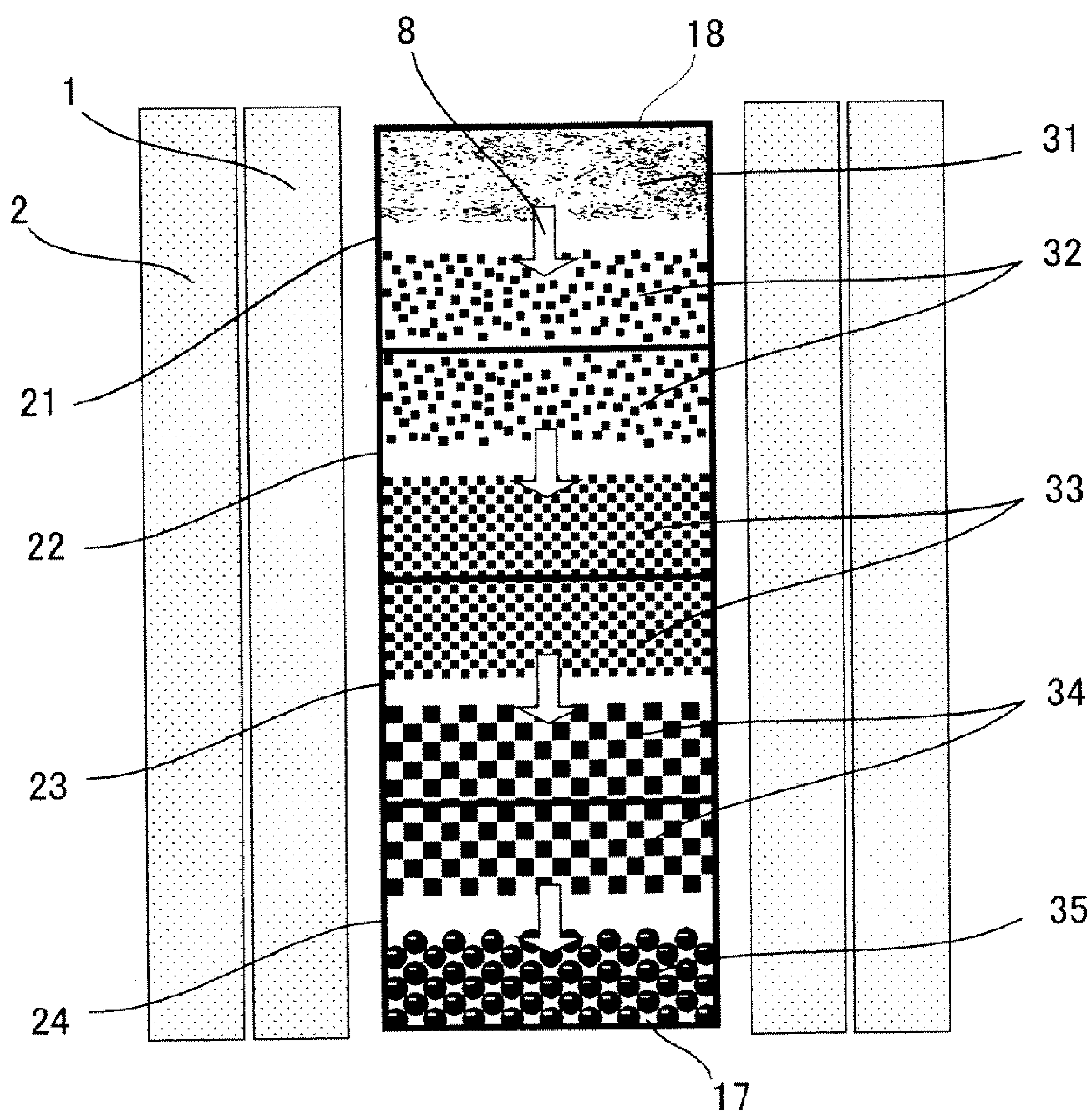


FIG. 5


8
18
1
31
2
32
21
22
33
23
34
35
24
17

(a)


8
18
1
31
2
32
21
22
33
23
34
35
24
17

(b)

FIG. 6

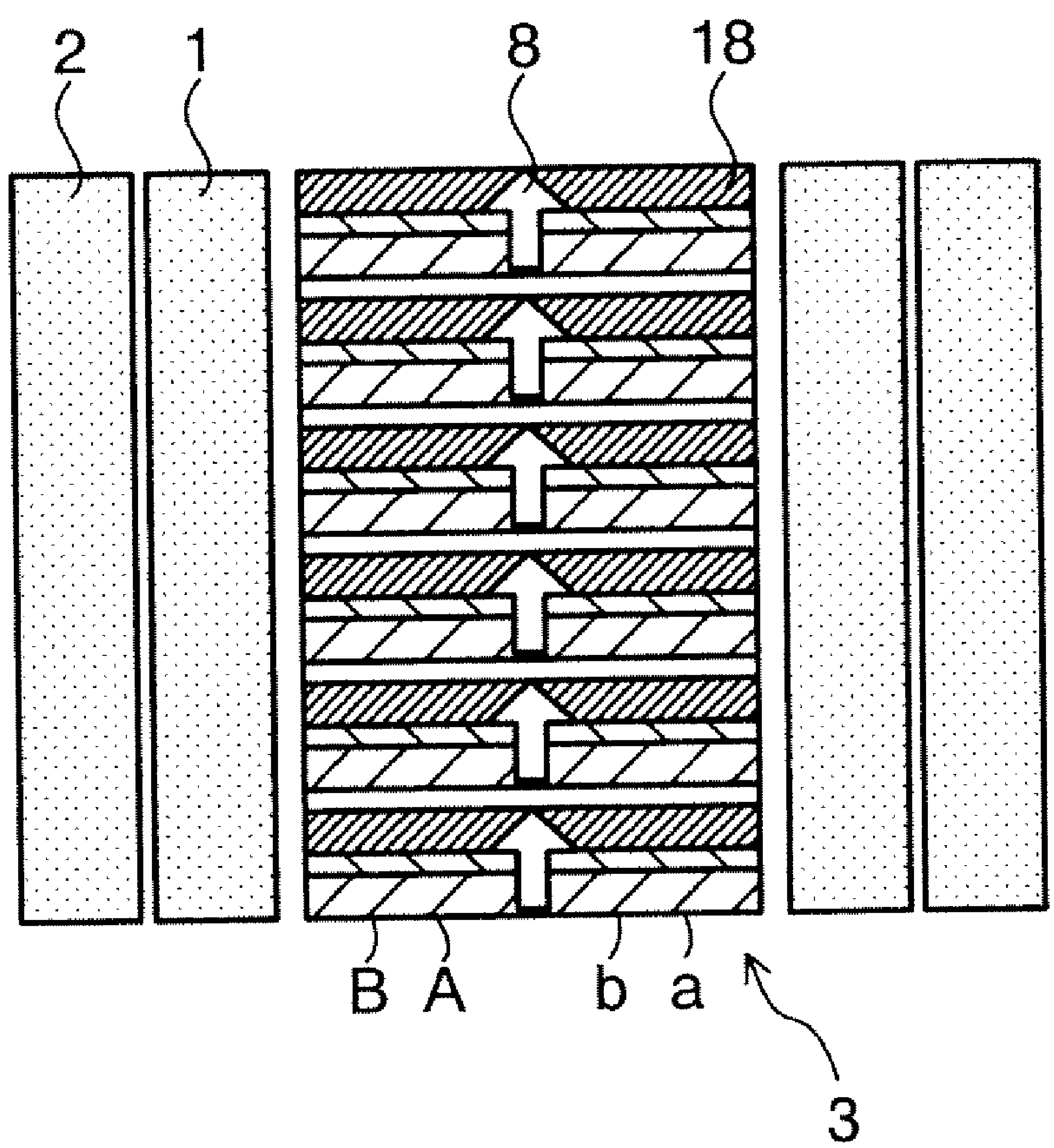
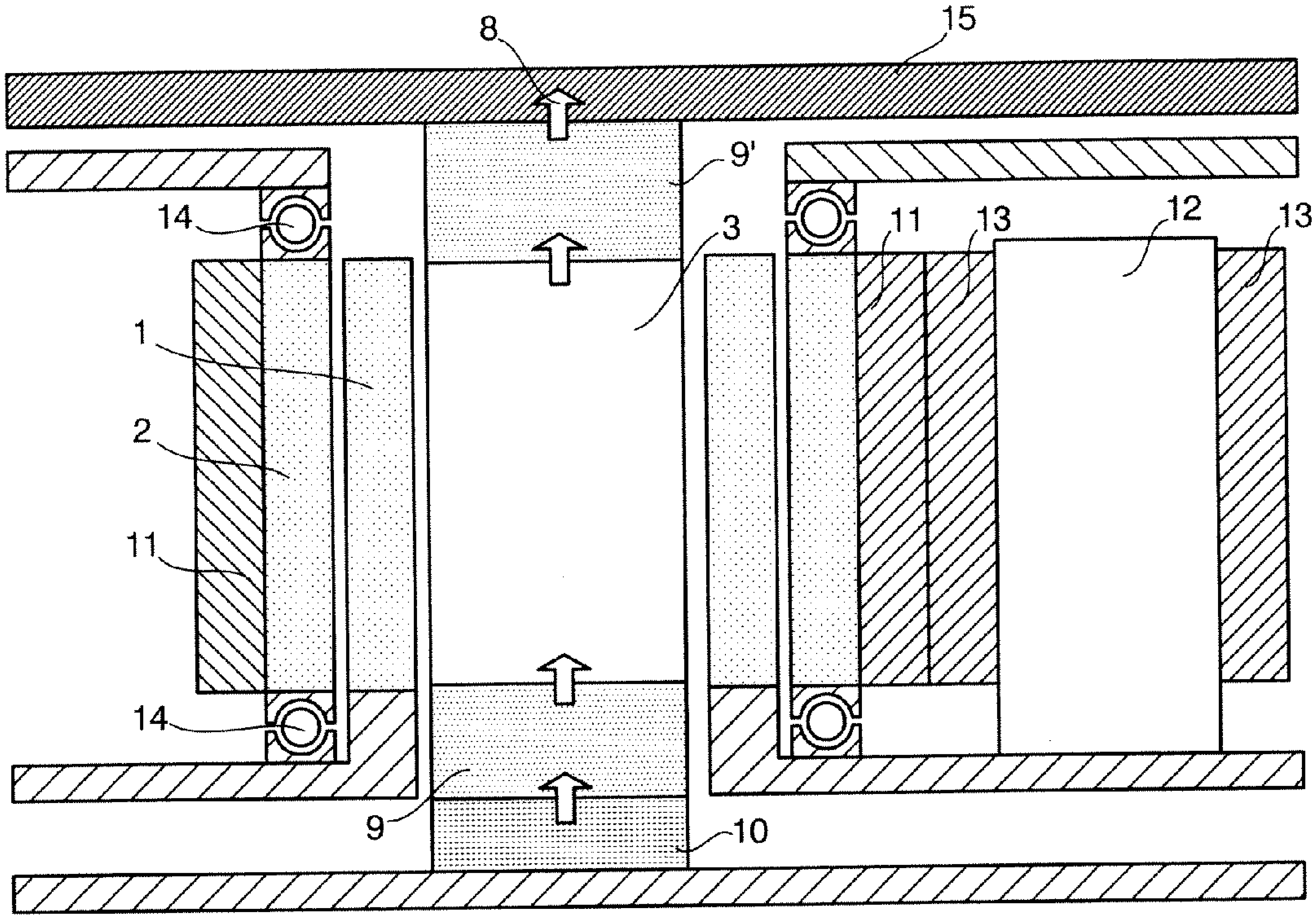
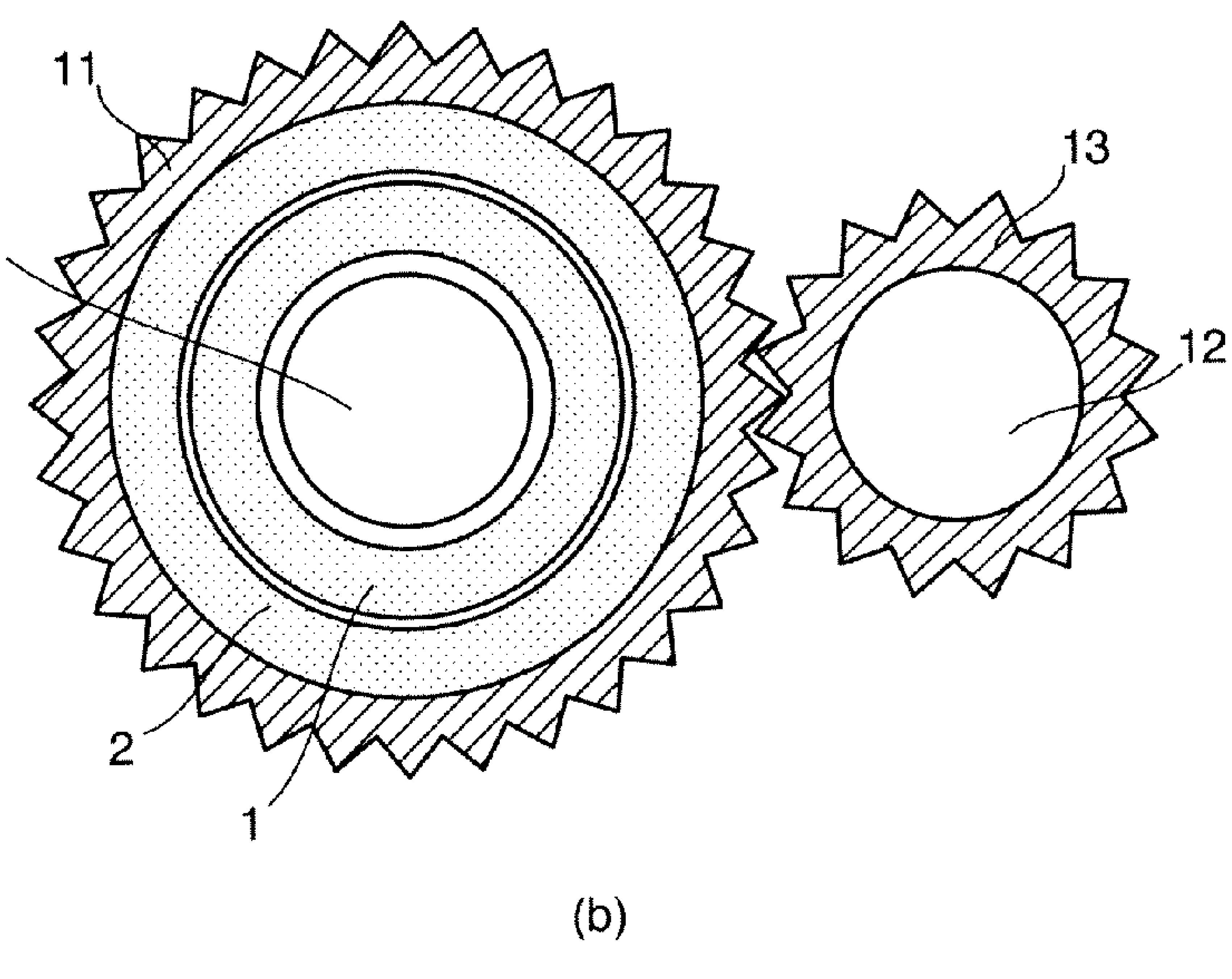


FIG. 7



(a)



(b)

FIG. 8

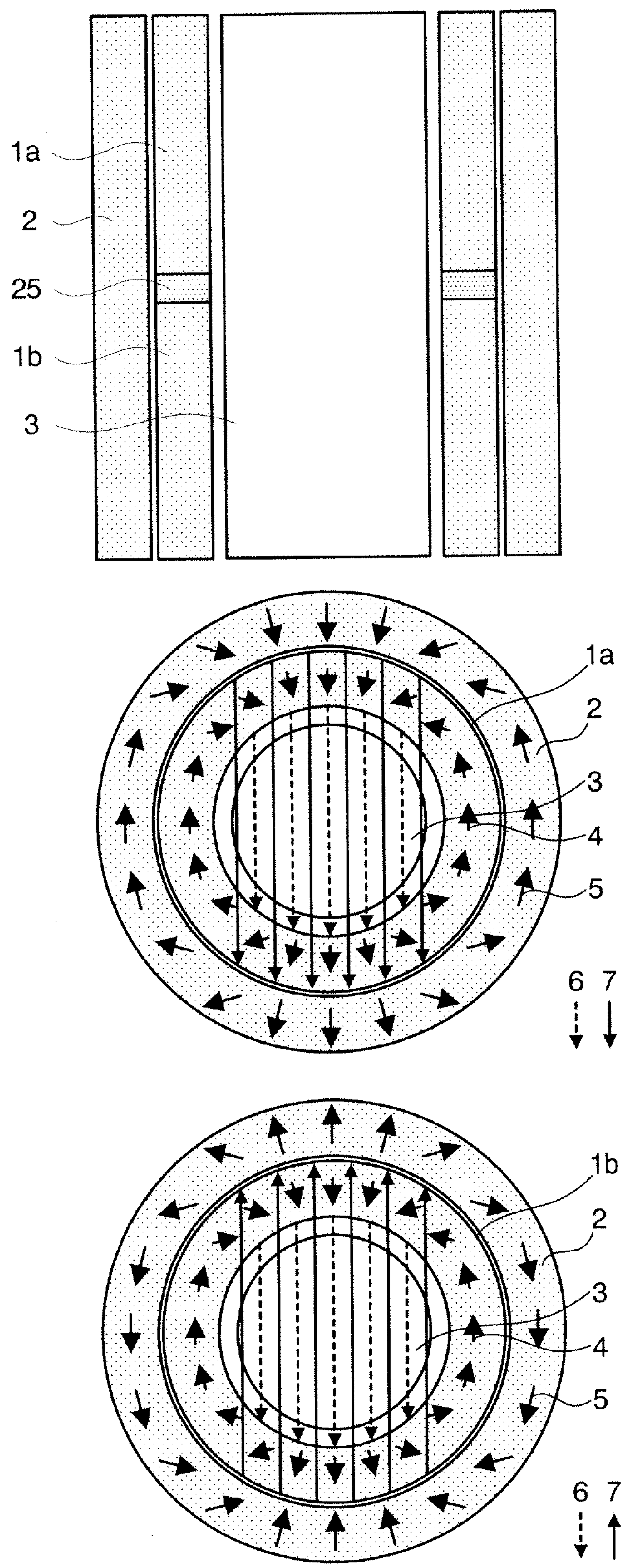
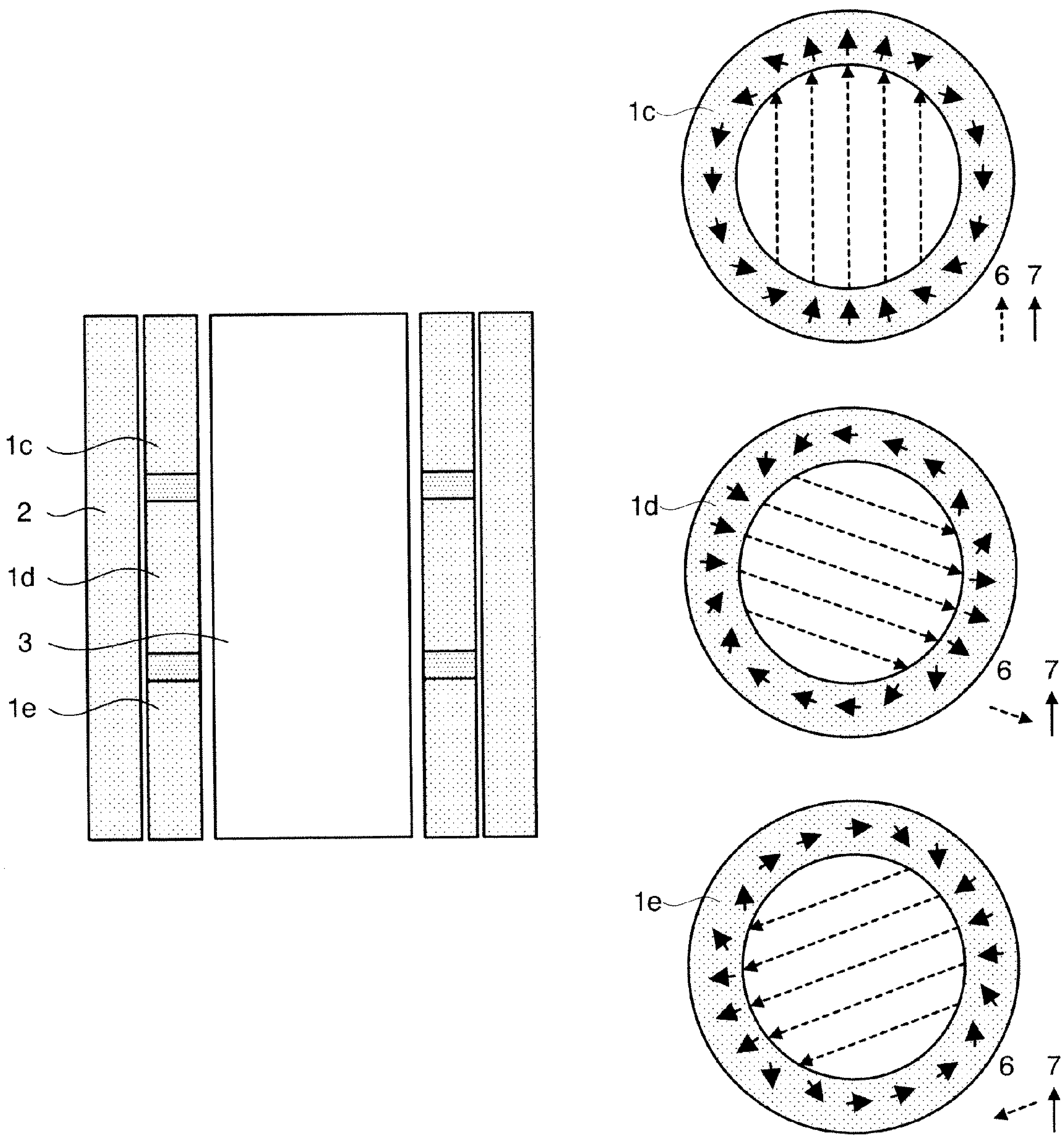


FIG. 9



MAGNETIC REFRIGERATING DEVICE AND MAGNETIC REFRIGERATING METHOD

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is based upon and claims the benefit of priority from the prior Japanese Patent Application No. 2006-265833, filed on Sep. 28, 2006; the entire contents of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The present invention relates to a magnetic refrigeration device and a magnetic refrigeration method which utilize a permanent magnet as a magnetic field-generating means and particularly, to a magnetic refrigeration device and a magnetic refrigeration method which can reduce heat flow into the magnetic refrigeration working chamber when the magnetic refrigeration material is magnetizing and demagnetizing.

[0004] 2. Description of the Related Art

[0005] When the intensity of magnetic field to be applied is changed for a certain magnetic material, the temperature of the magnetic material also changes, which is called as a "magneto-caloric effect". Physically, the degree of freedom of magnetic spins (electrons bearing the magnetic property) in the magnetic material is changed with the change of the external magnetic field so that the entropy of the magnetic spins is changed. In this case, the rapid energy exchange between the electrons and the lattice in the magnetic material occurs so as to change the temperature of the magnetic material which is concerned with the lattice vibration. The refrigerating operation based on the magneto-caloric effect as mentioned above is called as a "magnetic refrigeration".

[0006] At present, a gas compressing and expanding cycle refrigeration technique is widely used for practical application in daily life such as a refrigerator, a freezer and an air conditioning. However, in the refrigeration technique using the gas compressing and expanding cycle such as a chlorofluorocarbon (CFC) or hydrochlorofluorocarbon (HCFC) or hydrofluorocarbon (HFC) gas, there are some problems relating to the ozone layer destruction or the global warming caused by the environmental exhaust of those gasses. In this point of view, some alternatives for the specific Freon gas are considered, but concerned in view of the environmental influence such as global warming.

[0007] Therefore, it is desired that a clean refrigeration technique with no harm gas medium and high efficiency without the environmental destruction caused by the exhaust of working gas is realized. Recently, the magnetic refrigeration technique near room temperature region is intensely researched and developed which is expected as an environment-friendly refrigeration technique.

[0008] As the magnetic refrigeration technique, the AMR (Active Magnetic Regenerative Refrigeration) system is proposed by "Barclay" in US (refer to U.S. Pat. No. 4,332,135). Zimm, Gschneidner and Pecharsky made the prototype of the AMR system and realized the continuous steady operation of the magnetic refrigeration cycle near room temperature range (1997). In this case, gadolinium (Gd) metal is employed as the magnetic refrigerant and a magnetic field with a high intensity of 5 T is applied to the magnetic refrigerant by means of superconducting magnet.

[0009] The magnetic refrigerant is shaped into spherical particles with the size of about 0.3 mm in diameter and packed into the container. The container was put into place the inside of coil of superconducting solenoid magnet (SM; superconducting solenoid magnet). The container can be displaced with reciprocating motion upward and downward along the axis of the SM coil, and inside and outside of the bore of SM coil so that the intensity of the magnetic field to be applied to the magnetic refrigerant in the container can be changed by displacing the location of the container. The inlet and the outlet of the heat transfer medium are provided at both ends of the container so that the heat transfer medium can be introduced into and discharged from the container. As the heat transfer medium, a water or a mixture of water and ethanol was employed.

[0010] Since the container includes the magnetic refrigerant and conducts the heat transfer by the applying and the removing of the magnetic field and flowing the heat transfer medium so as to realize the magnetic refrigerating operation, the container is called as a "magnetic refrigeration working chamber".

[0011] The AMR cycle of refrigeration can be conducted as follows: (1) The magnetic refrigeration working chamber (AMR bed) is put into the bore of the SM coil, and the magnetic field is applied to the magnetic refrigerant thereby the magnetic refrigerant heat up. (2) The heat transfer medium is flowed through the magnetic refrigerant in the AMR bed from the one end to the other end of the AMR bed and transfers the thus generated hotness. (3) The AMR bed is removed from the bore of the SM coil to remove the magnetic field applied to the magnetic refrigerant, thereby the magnetic refrigerant cool down. (4) The heat transfer medium is flowed from the other end to the one end of the AMR bed (the direction opposite to the direction in the Step (2)) and transfers the coldness. By repeating the heat cycle of Steps (1) to (4), a temperature gradient can be generated in the magnetic refrigerant packed into the AMR bed. To begin with the magnetic refrigerant heat up by applying a magnetic field to the refrigerant in the AMR bed, and the hotness is transferred from the magnetic refrigerant to the heat transfer medium. Then, the hotness transports with transfer medium by flowing forward direction and then, the hotness is transferred from the heat transfer medium to the magnetic refrigerant.

[0012] Likewise, the magnetic refrigerant is cooled down by removing the magnetic field from the refrigerant, and the coldness is transferred from the heat transfer medium to the magnetic refrigerant. In this case, the coldness transports with the heat transfer medium by flowing backward direction and then, the coldness is transferred from the heat transfer medium to the magnetic refrigerant. Namely, when the thermal cycle is repeated, the thus generated heat in the magnetic refrigerant, originated from the magneto-caloric effect, is transferred in one direction via the heat transfer medium so that the temperature gradient can be generated in the heat transfer direction from the regenerative effect of the solid magnetic refrigerant. In the steady state, therefore, a large difference in temperature can be generated between both ends of the AMR bed.

[0013] According to Zimm et al., the thermal difference is generated at both ends of the magnetic refrigeration working chamber of AMR bed by ΔT=about 30° C. by changing the intensity of the magnetic field from zero to 5 T with the superconducting magnet near room temperature range. Then, a high refrigerating efficiency of COP=15 (this value is not containing the input power of current supplier of the superconducting magnet for the SM) can be realized under the condition of ΔT=about 13° C. With the conventional technique using gas compression and expansion cycle of Freon gas, e.g., in a refrigerator of household use, the refrigerating efficiency of only COP=1-3 can be realized.

[0014] In this way, according to the magnetic refrigeration, high refrigerating efficiency may be realized without the operating gas medium such as Freon gas.

[0015] In the above-described embodiment, however, the SM is employed in order to apply the high magnetic field, e.g., 5 T to the magnetic refrigerating working material. Since operating the SM requires the extreme low temperature of about 10K (cryogenic condition), which needs a liquid helium or refrigerator for generating extreme low temperature. However, the magnetic refrigeration system is grown in size.

[0016] The intended magnetic refrigeration requires the cryogenic condition of extreme lower temperature environment than the intended refrigerating environment, which is paradox in engineering application. In this point of view, the magnetic refrigeration system using the SM is distant. As the magnetic field-generating means, an electromagnet may be employed instead of the superconducting magnet. With the electromagnet, in order to generate a magnetic field with the intensity of 1 T or over, it requires a large current in the electromagnet so as to require the water cooling system for removing the Joule heat generated in the electromagnet. Therefore, the magnetic refrigeration system becomes complicated, grows in size and requires high operation cost. In order to mitigate the growth in size of the magnetic refrigerating system, it is preferable to employ a permanent magnet.

[0017] Recently, a magnetic refrigeration system using the permanent magnet as a compact and simple system is examined. In the magnetic refrigeration system and the magnetic refrigeration device, a magnetic field is applied to and removed from the magnetic refrigerant by changing the relative position between the permanent magnet and the magnetic refrigerant or the magnetic refrigeration working chamber containing the magnetic refrigerant.

[0018] For example, two permanent magnets made of Nd—Fe—B based material are disposed opposite to one another, and joined one another with a magnetic yoke made of magnetic material with high permeability, thereby forming a U-shaped face-type magnet (with the yoke). Then, the magnetic refrigerant or the magnetic refrigeration container containing the magnetic refrigerant is disposed in the space in the magnetic flux formed in the gap of the U-shaped face-type magnet so that the intended magnetic field is applied to the magnetic refrigerant. Then, the magnetic refrigerant or the magnetic refrigeration container containing the magnetic refrigerant is removed from the magnetic field formed in the gap of the U-shaped face-type magnet so that the intended magnetic field is removed from the magnetic refrigerant. The relative position between the permanent magnet and the magnetic refrigerant or the AMR bed containing the magnetic refrigerant can be changed by moving at least one of the permanent magnet and the magnetic refrigerant.

[Reference No. 1]	USP 4,332,135
[Reference No. 2]	USP 5,743,095
[Reference No. 3]	C. Zimm, et al., Advances in Cryogeneric Engineering, Vol. 43 (1998), p. 1759

-continued

[0019] As described above, in the magnetic refrigeration device using the permanent magnet as a magnetic field-generating means, by changing the relative position between the permanent magnet and the magnetic refrigerant or the magnetic refrigeration working chamber containing the magnetic refrigerant, the intensity of the magnetic field to be applied to the magnetic refrigerant is changed.

[0020] However, since it is difficult to generate the high magnetic field in the intensity of 5 T by using the permanent magnet, the intensity of the magnetic field in a practical adaptation becomes smaller than the intensity of the magnetic field by using the SM. In this point of view, it is desired to use the magnetic field generated from the permanent magnet as effectively as possible in the magnetic refrigerating device using the permanent magnet as a magnetic field-generating means. In order to use the magnetic flux generated by the permanent magnet as effectively as possible, it is better to be narrow the gap in the above-described face-type magnet (with the yoke).

[0021] In contrast, in order to utilize the space in the magnetic flux effectively, it is preferable to enlarge the magnetic refrigeration working chamber containing the magnetic refrigerant as large as possible in relation to the gap space in the magnetic flux. In this point of view, in order to utilize the magnetic field effectively in the magnetic refrigeration device using the permanent magnet, therefore, the proximal relative position between the permanent magnet and the magnetic refrigeration working chamber is forced to narrow when the magnetic refrigeration working chamber is disposed in the gap of the permanent magnet.

[0022] In the case that the magnetic refrigeration working chamber is disposed proximate to the permanent magnet, the magnetic refrigeration working chamber is likely to be influenced by the heat radiation from the permanent magnet. Then, when the relative position between the permanent magnet and the magnetic refrigeration working chamber is shifted, the permanent magnet may be contacted and fractioned with the magnetic refrigeration working chamber to generate the frictional heat. The bulk of permanent magnet is also a large heat bath so that when the heat is flowed, which means heat loss, into the magnetic refrigerant or the magnetic refrigeration working chamber containing the magnetic refrigerant, the refrigeration efficiency of the magnetic refrigerating operation is deteriorated, which means a significant disincentive for the refrigeration.

BRIEF SUMMARY OF THE INVENTION

[0023] It is an object of the present invention, in view of the above-described problems relating to the magnetic refrigeration device using the permanent magnet as a magnetic field-generating means, to provide a small and simple magnetic refrigeration device and a magnetic refrigerating method which can reduce heat loss when a magnetic field is applied to and removed from the magnetic refrigerant or the magnetic refrigeration working chamber containing the magnetic refrigerant.

[0024] In order to achieve the above object, an aspect of the present invention relates to a magnetic refrigerating device, including: at least one set of double-structured Halbach magnet including a ring-shaped inner Halbach type magnet and a ring-shaped outer Halbach type magnet which are coaxially arranged one another so that a magnetic field generated by the inner Halbach type magnet is superimposed with a magnetic field generated by the outer Halbach type magnet; a magnetic refrigerant or a magnetic refrigeration working chamber including the magnetic refrigerant therein disposed in a bore space of the inner Halbach type magnet; and a rotating mechanism to rotate the outer Halbach type magnet while the inner Halbach type magnet is stationed.

[0025] Another aspect of the present invention relates to a magnetic refrigerating method, comprising: disposing a magnetic refrigerant or a magnetic refrigeration working chamber including the magnetic refrigerant therein in a bore space of at least one set of double-structured Halbach type magnet including a ring-shaped inner Halbach type magnet and a ring-shaped outer Halbach type magnet which are coaxially arranged one another so that a magnetic field generated by the inner Halbach type magnet is superimposed with a magnetic field generated by the outer Halbach type magnet; and rotating the outer Halbach type magnet while the inner Halbach type magnet is stationed so that a first magnetic field with a first intensity is applied to the magnetic refrigerant and a second magnetic field with a second intensity smaller than the first intensity is applied to the magnetic refrigerant, thereby generating a magneto-caloric effect in the magnetic refrigerant and thus, conduct a heat transfer.

[0026] According to the aspects of the present invention, at least one set of double-structured Halbach type magnet including a ring-shaped inner Halbach type magnet and a ring-shaped outer Halbach type magnet which are coaxially arranged one another so that a magnetic field generated by the inner Halbach type magnet is superimposed with a magnetic field generated by the outer Halbach type magnet is prepared, and a magnetic refrigerant or a magnetic refrigerating working chamber including the magnetic refrigerant therein is disposed in a bore space of the inner Halbach type magnet. Then, a first magnetic field and a second magnetic field with the respective different intensities, which are changed by rotating the outer Halbach type magnet while the relative position between the inner Halbach type magnet and the magnetic refrigerant or the magnetic refrigeration working chamber containing the magnetic refrigerant therein is not changed, is applied to the magnetic refrigerant so as to generate the magneto-caloric effect in the magnetic refrigerant and thus, conduct the intended heat transfer.

[0027] As a result, the heat generated from the friction against the permanent magnet is not flowed into the magnetic refrigerating device so that the refrigerating efficiency can be enhanced.

[0028] In an embodiment, the heat transfer is conducted through a heat transfer medium which can realize a direct heat exchange between the magnetic refrigerant and the heat transfer medium. According to the heat transfer medium, the heat transfer can be easily conducted.

[0029] In another embodiment, the magnetic refrigerant is rendered particulate. In this case, when the heat transfer is conducted with the heat transfer medium, the heat exchange area between the magnetic refrigerant and the heat transfer medium can be increased so as to enhance the heat transfer efficiency, that is, the refrigerating efficiency.

[0030] In still another embodiment, the body of magnetic refrigerant includes a magnetic material "A" exhibiting a magneto-caloric effect that the temperature of the material "A" is increased by applying a magnetic field and the temperature of the material "A" is decreased by removing a magnetic field, a magnetic material "B" exhibiting a magneto-caloric effect that the temperature of the material "B" is decreased by applying a magnetic field and the temperature of the material "B" is increased by removing a magnetic field, a heat conductive material "a" exhibiting higher heat conductivity under the application of a magnetic field and lower heat conductivity without a magnetic field, and a heat conductive material "b" exhibiting lower heat conductivity under the application of a magnetic field and higher heat conductivity without a magnetic field. In this case, the magnetic refrigerating material is configured so as to include at least one layered structure denoted by "AaBb" which is formed by subsequently stacking the materials "A", "a", "B", "b" or at least one layered structure denoted by "AbBa" which is formed by subsequently stacking the materials "A", "b", "B", "a".

[0031] In the above embodiment, the layered structure denoted by "AaBb" or the layered structure denoted by "AbBa" constitutes a magnetic refrigerating unit. In this embodiment, the heat is transferred from one end of the magnetic refrigerating unit to the other end of the magnetic refrigerating unit by utilizing the alternately repeated heat generation and heat insulation under the application of the first magnetic field and the second magnetic field for the magnetic refrigerating unit. According to this embodiment, therefore, the intended heat transfer can be conducted using the constituent materials of the magnetic refrigerating unit without the heat transfer medium. As a result, various problems due to the use of the heat transfer medium such as the destruction of the particulate magnetic refrigerating material originated from the collision can be suppressed.

[0032] The material "a" or "b" may include a substance which is shifted from a metallic state phase to an insulating state phase by changing an intensity of a magnetic field to be applied thereto. Moreover, the material "a" or "b" may include a substance which is shifted from a ferromagnetic metallic state phase to a non-magnetic insulating state phase by changing an intensity of a magnetic field to be applied thereto.

[0033] According to the aspect of the present invention can be provided a small and simple magnetic refrigerating device and a magnetic refrigerating method without environment risk which can reduce heat loss when a magnetic field is applied to and removed from the magnetic r refrigerant or the magnetic refrigeration working chamber containing the magnetic refrigerant.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0034] FIG. **1** is a schematic view illustrating a portion of the magnetic refrigerating device according to an embodiment of the present invention.

[0035] FIG. **2** is an explanatory view for the magnetic refrigeration heat cycle in the magnetic refrigerating device in FIG. **1**.

[0036] FIG. **3** is a structural view illustrating a concrete embodiment relating to the magnetic refrigerating device in FIG. **1**.

[0037] FIG. **4** is an explanatory view for the magnetic refrigeration heat cycle in the magnetic refrigerating device in FIG. **1**.

[0038] FIG. **5** is a structural view illustrating a magnetic refrigerating device modified from the magnetic refrigerating device in FIGS. **3** and **4**.

[0039] FIG. **6** is a schematic view illustrating the magnetic refrigerating device according to another embodiment of the present invention.

[0040] FIG. **7** is a structural view illustrating a magnetic refrigerating device varied from the magnetic refrigerating device in FIG. **6** which contains a driving mechanism for rotating one of the double-structured Halbach type magnet.

[0041] FIG. **8** is a schematic view illustrating the magnetic refrigerating device according to still another embodiment of the present invention.

[0042] FIG. **9** is a schematic view illustrating the magnetic refrigerating device according to a further embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0043] Hereinafter, the present invention will be described in detail with reference to the drawings.

[0044] FIG. **1** is a schematic view illustrating a portion of the magnetic refrigerating device according to an embodiment of the present invention. FIG. **1**(*a*) is directed at the cross section of the magnetic refrigerating device, and FIG. **1**(*b*) is directed at the top plan view of the magnetic refrigerating device. In the present specification, like or corresponding components are designated by the same reference numerals.

[0045] In FIG. **1**, the reference numeral "**1**" designates an inner Halbach type magnet and the reference numeral "**2**" designates an outer Halbach type magnet. The inner Halbach type magnet is coaxially disposed in the outer Halbach type magnet so as to form the double-structured Halbach type magnet. The reference numeral "**3**" designates a magnetic refrigerant which may be accommodated into a container (not shown).

[0046] In this embodiment, since the intended heat transfer is carried out for the magnetic refrigerant accommodated into the container by applying and removing a magnetic field as will described below, the magnetic refrigerant **3** and the container constitute the magnetic refrigeration working chamber.

[0047] The magnetic refrigerant **3** is disposed in the bore space of the inner Halbach type magnet **1**. The outer Halbach type magnet **2** is joined with a (not shown) rotating mechanism to be rotated coaxially around the center axis of the inner and the outer Halbach type magnets. The rotating mechanism may be configured as an outer motor or a gear type rotating mechanism. With the gear type rotating mechanism, some gears are formed at the outer side of the outer Halbach type magnet **2**.

[0048] With the double-structured Halbach type magnet, a gap is formed between the inner Halbach type magnet **1** and the outer Halbach type magnet **2** so as not to make friction there between when the outer Halbach type magnet **2** is rotated. The magnetic refrigerant **3** or the magnetic refrigeration working chamber containing the magnetic refrigerant is thermally insulated from the inner Halbach type magnet **1** so as not to generate the heat transfer between the inner Halbach type magnet **1** and the magnetic refrigerant. The gap may be rendered a simple space or infiltrated with a thermal insulating material.

[0049] FIG. **2** is an explanatory view for the magnetic refrigeration heat cycle in the magnetic refrigerating device in FIG. **1**.

[0050] FIG. **2**(*a*) is directed at the cross section of the magnetic refrigerating device corresponding to FIG. **1**(*a*), and FIG. **2**(*b*) is directed at the top plan view of the magnetic refrigerating device corresponding to FIG. **1**(*b*). In these drawings, the reference numerals "**4**" and "**5**" designate the directions of magnetic anisotropy of the inner Halbach type magnet **1** and the outer Halbach type magnet **2**. As is apparent from FIG. **2**, the directions of magnetic anisotropy depends on the positions of the magnets **1** and **2**.

[0051] In the left view of FIG. **2**(*b*), the direction of the magnetic field **6** generated by the inner Halbach type magnet **1** via the bore space thereof becomes parallel to the direction of the magnetic field **7** generated by the outer Halbach type magnet **2** via the bore space thereof so as to generate a magnetic field with high intensity in the bore space. In the right view of FIG. **2**(*b*), the direction of the magnetic field **6** generated by the inner Halbach type magnet **1** via the bore space thereof becomes antiparallel to the direction of the magnetic field **7** generated by the outer Halbach type magnet **2** via the bore space thereof so as to generate a magnetic field with low intensity in the bore space because the magnetic field generated from the inner Halbach type magnet **1** is at least partially cancelled by the magnetic field generated from the outer Halbach type magnet **2**. In the latter case, if the intensity of the magnetic field from the inner Halbach type magnet **1** is set almost equal to the intensity of the magnetic field from the outer Halbach type magnet **2**, the magnetic field generated in the bore space can be set almost zero.

[0052] Namely, in the left view of FIG. **2**(*b*), since the direction of the magnetic field generated from the inner Halbach type magnet **1** becomes parallel to the direction of the magnetic field generated from the outer Halbach type magnet **2**, the magnetic field with high intensity is applied to the magnetic refrigerating material **3**. In the right view of FIG. **2**(*b*), since the direction of the magnetic field generated from the inner Halbach type magnet **1** becomes antiparallel to the direction of the magnetic field generated from the outer Halbach type magnet **2** and thus, cancelled, no magnetic field is applied to the magnetic refrigerant **3**.

[0053] When the outer Halbach type magnet **2** is rotated while the inner Halbach type magnet **1** is stationed, the relative direction between the magnetic field of the inner Halbach type magnet **1** and the magnetic field of the outer Halbach type magnet **2** is changed in accordance with the rotation of the outer Halbach type magnet **2**. Therefore, the intensity of the magnetic field to be applied to the magnetic refrigerating material **3** is changed within a range of zero to a given several magnitudes (Tesla). Namely, the intensity of the magnetic field to be applied to the magnetic refrigerant **3** can be controlled in accordance with the rotation of the outer Halbach type magnet **2**.

[0054] FIG. **3** is a structural view illustrating a concrete embodiment relating to the magnetic refrigerating device in FIG. **1**. In this embodiment, the container **20** is prepared and the magnetic refrigerant **3** processed in minute particle is packed into the container **20**. The inlet-outlet **16** for a heat transfer medium is formed at both ends of the container **20** so that the heat transfer medium can be introduced into and discharged from the container **20**. Then, the mesh-like members **20**A are provided at both ends of the container **20**. According to the mesh-like members **20**A, the particulate magnetic refrigerant **3** is held in the container **20** under the condition that the heat transfer medium can be passed through the packed refrigerants in the container **20** via the mesh-like member **20**A and the inlet-outlet **16**. In this case, the magnetic refrigerant **3** and the container **20** constitute the magnetic refrigeration working chamber.

[0055] The heat transfer medium is made of gas or liquid. In this case, the heat transfer medium can be passed through the clearance gaps of the particulate magnetic refrigerant **3** packed into the container **20** so as to be introduced into and discharged from the container **20**. At the same time, the heat transfer medium can obtain the heat generated by the magnetic refrigerating operation through the thermal exchange. The kind of gas or liquid is appropriately determined in view of the heat quantity generated by the magnetic refrigerant **3** and the heat capacity of the magnetic refrigerant **3**.

[0056] Then, the magnetic refrigeration method using the magnetic refrigerating device in this embodiment will be described with reference to FIGS. **2** and **4**. In this embodiment, the magnetic refrigeration will be carried out as follows: (1) In the double-structured Halbach type magnet, the outer Halbach type magnet **2** is rotated so that the direction of the magnetic field generated by the generated inner Halbach type magnet **1** becomes parallel to the direction of that generated by the outer Halbach type magnet **2** (refer to the left side view in FIG. **2**(*b*), thereby applying a magnetic field with high intensity to the magnetic refrigerant **3**. (2) The heat transfer medium is flowed from the one end to the other end of the magnetic refrigeration working chamber via the inlet-outlet **16** so as to transfer the thus generated heat. (3) The outer Halbach type magnet **2** is rotated so that the direction of the magnetic field generated by the inner Halbach type magnet **1** becomes antiparallel to the direction of that generated by the outer Halbach type magnet **2** (refer to the right side view in FIG. **2**(*b*), thereby removing the magnetic field with high intensity strength from the magnetic refrigerant **3**. (4) The heat transfer medium is flowed from the other end to the one end of the magnetic refrigeration working chamber (the direction opposite to the direction in the Step (2)) via the inlet-outlet **16** to transfer the heat. When the heat cycle of Steps (1) to (4) is repeated, the magnetic refrigeration can be realized.

[0057] Namely, in Steps (1) and (2), the temperature of the magnetic refrigerant **3** in the container **20** (magnetic refrigeration working chamber) is increased by applying the magnetic field and then, the temperature of the heat transfer medium is also increased through the thermal exchange with the magnetic refrigerant **3**. Then, in Steps (3) and (4), the temperature of the magnetic refrigerant **3** in the container **20** (magnetic refrigeration working chamber) is decreased by removing the magnetic field and then, the temperature of the heat transfer medium is also decreased through the thermal exchange with the magnetic refrigerant **3**. If the heat cycle is repeated, the temperature gradient is generated in the magnetic refrigerant **3** and the heat transfer medium as designated by the arrow in FIG. **4**.

[0058] Therefore, the thus generated heat is exhausted along the direction designated by the arrow so that the top of the container **20** (magnetic refrigeration working chamber) is increased in temperature and the bottom of the container **20** is decreased in temperature. In this case, if a material to be refrigerated is attached to the bottom of the container **20**, the material can be refrigerated.

[0059] FIG. **5** is a structural view illustrating a magnetic refrigerating device modified from the magnetic refrigerating device in FIGS. **3** and **4**. In this embodiment, a plurality of containers **21** to **24** are prepared and several kind of magnetic refrigerants **31** to **35** are charged into the corresponding containers. Then, a not shown heat transfer medium is passed through the magnetic refrigerating materials **31** to **35**. In this embodiment, the containers **21** to **24** and the corresponding magnetic refrigerants **31** to **35** constitute the corresponding magnetic refrigeration working chambers. Then, the containers **21** to **24** and the magnetic refrigerants **31** to **35** constitute one magnetic refrigeration working chamber entirely.

[0060] With this embodiment, in the double-structured Halbach type magnet, the outer Halbach type magnet **2** is rotated so that the direction of the magnetic field generated by the inner Halbach type magnet **1** becomes parallel to the direction of that generated by the outer Halbach type magnet **2** (refer to the left side view in FIG. **2**(*b*), thereby applying a magnetic field with high intensity to the magnetic refrigerants **31** to **35**. In this case, the magnetic refrigerants **31** to **35** are increased in temperature so that the heat transfer medium filled in the containers **21** to **24** is heated up by the heat exchange with the corresponding magnetic refrigerants located at the bottoms of the corresponding containers, partially-gasified and thus, moved toward the top sides of the corresponding containers **21** to **24** (designated by the arrow "**8**", in FIG. **5**(*a*)). The partially-gasified heat transfer medium transfers the hotness to the corresponding magnetic refrigerants located at the tops of the containers. Then, the outer Halbach type magnet **2** is rotated so that the direction of the magnetic field generated by the inner Halbach type magnet **1** becomes antiparallel to the direction of that generated by the outer Halbach type magnet **2** (refer to the right side view in FIG. **2**(*b*), thereby removing the magnetic field with high intensity from the magnetic refrigerants **31** to **35**. In this case, each magnetic refrigerants **31** to **35** are decreased in temperature so that the heat transfer medium filled in the containers **21** to **24** is cooled down by heat exchange with the corresponding magnetic refrigerant located at the top of each containers, partially-liquefied and thus, moved toward the bottom sides of the corresponding containers **21** to **24** (designated by the arrow "**8**" in FIG. **5**(*b*)). The partially-liquefied heat transfer medium transfers the coldness to the corresponding magnetic refrigerants located at the bottoms of the containers.

[0061] Namely, the containers **21** to **24** function as a given active heat pipe, respectively. In the embodiment relating to FIG. **5**, a plurality of active heat pipes are connected in series with one another. By transferring the thus generated heat to a given heat exhaust (not shown) provided outside from the high temperature stage **18** in FIG. **5**, the generated heat is exhausted. By connecting a material (not shown) to be refrigerated thermally with the low temperature stage **17**, the material can be refrigerated.

[0062] FIG. **6** is a schematic view illustrating the magnetic refrigerating device according to another embodiment of the present invention. In this embodiment, the magnetic refrigerant **3** is composed of the magnetic materials "A" and "B" and the heat conductive materials "a" and "b". The magnetic material "A" exhibits the magneto-caloric effect that the temperature of the material "A" is increased by applying the magnetic field and the temperature of the material "A" is decreased by removing the magnetic field. The magnetic material "B" exhibits the magneto-caloric effect that the temperature of the material "B" is decreased by applying the magnetic field and the temperature of the material "B" is increased by removing the magnetic field. The heat conductive material "a" exhibits higher heat conductivity under the application of the magnetic field and lower heat conductivity without the magnetic field. The heat conductive material "b" exhibits lower heat conductivity under the application of the magnetic field and higher heat conductivity without the magnetic field. In this embodiment, the materials A, a, B, b are subsequently stacked to form the layered structure denoted by "AaBb". The layered structure "AaBb" constitutes one magnetic refrigerating unit.

[0063] In this embodiment, when the magnetic field is applied to the magnetic refrigerant **3**, the magnetic material "A" is increased in temperature and the magnetic material "B" is decreased in temperature. Since the material "a" exhibits higher heat conductivity and the material "b" exhibits lower heat conductivity, the thus generated heat is flowed from the magnetic material "A" to the magnetic material "B" in the magnetic refrigerant **3**. When the magnetic field is removed from the magnetic refrigerant **3**, the magnetic material "A" is decreased in temperature and the magnetic material "B" is increased in temperature. Since the material "a" exhibits lower heat conductivity and the material "b" exhibits higher heat conductivity, the thus generated heat is flowed from the magnetic material "B" to the magnetic material "A" in the magnetic refrigerant **3**. As a result, by repeating the operation of applying and removing the magnetic field as mentioned above, the heat gradient is generated in the magnetic refrigerant **3** as designated by the arrow in FIG. **6**.

[0064] By transferring the thus generated heat to a given heat exhaust (not shown) provided outside from the high temperature stage **18** in FIG. **6**, the generated heat is exhausted. By connecting a substance (not shown) to be refrigerated thermally with the low temperature stage **17**, the substance can be refrigerated.

[0065] FIG. **7** is a structural view illustrating a magnetic refrigerating device varied from the magnetic refrigerating device in FIG. **6** which contains a driving mechanism for rotating outer Halbach type magnet. FIG. **7**(*a*) is directed at the cross section of the magnetic refrigerating device, and FIG. **7**(*b*) is directed at the top plan view showing the essential components.

[0066] In FIG. **7**, the reference numeral "**1**" designates an inner Halbach type magnet, and the reference numeral "**2**" designates an outer Halbach type magnet, and the reference numeral "**3**" designates a magnetic refrigerating material unit. The inner Halbach type magnet **1** is fixed onto a plate and the outer Halbach type magnet **2** is placed onto a plate via a movable mechanism (e.g., the bearing **14**). A gear **11** is provided on the outer side of the outer Halbach type magnet **2**. A gear **13** is provided so as to be engaged with the gear **11**, and connected with a rotating mechanism **12** (e.g., motor). The reference numeral "**15**" designates a substance to be refrigerated, and the reference numeral "**15**" designates a heat exhaust portion. The substance **10** and the heat exhaust portion **15** are connected with the magnetic refrigerating unit **3** via the heat conductive members **9** and **9'**.

[0067] When the gear **13** is rotated by the rotating mechanism **12**, the outer Halbach type magnet **2** is rotated via the gear **11**. As explained with reference to FIG. **6**, when the outer Halbach type magnet **2** is continuously rotated, the thus generated heat is transferred in the magnetic refrigerating unit **3** by the heat cycle operation of magnetic refrigeration so that heat is absorbed from the substance **10** to be refrigerated via the heat conductive member **9** (as designated by the arrow **8** in FIG. **7**), and transferred to the heat exhaust portion **15** via the heat conductive member **9'**, thereby refrigerate the substance **10**.

[0068] The heat conductive members **9** and **9'** may be made of non-magnetic material with higher heat conductivity. Concretely, the heat conductive members **9** and **9'** can be made of non-magnetic metal, ceramics or resin improved in heat conductivity. The heat exhaust portion **15** is made of material with higher heat conductivity and configured so as to be enlarged in specific surface. Preferably, the heat exhaust portion **15** is made of non-magnetic material in view of the influence of the magnetic field. Concretely, the heat exhaust portion **15** is made of Cu, Al or higher heat conductivity material containing Cu and/or Al. Then, the heat exhaust portion **15** is configured in plate-shape, fin-shape or honeycomb-shape so as to increase the specific surface thereof.

[0069] The magnetic material "A" is required to exhibit the magneto-caloric effect that the temperature of the material "A" is increased by the application of the magnetic field and the temperature of the material "A" is decreased by the removal of the magnetic field. Preferably, therefore, the magnetic material "A" is a magnetic material exhibiting the magnetic phase transition (ordering) from paramagnetism to ferromagnetism or ferrimagnetism utilizing the inherent magnetic phase transition temperature. Concretely, the magnetic material "A" can be made of rare-earth metal, rare-earth metal alloy or intermetallic compound of rare-earth metal and transition metal such as Gd, Gd alloy, R_2Fe_{17}, RCo_2, RNi_2, RAl_2. The "R" means a rare-earth element.

[0070] The magnetic material "B" is required to exhibit the magneto-caloric effect that the temperature of the material "B" is decreased by the application of the magnetic field and the temperature of the material "B" is increased by the removal of the magnetic field. Preferably, therefore, the magnetic material "B" is a magnetic material exhibiting the magnetic phase transition (ordering) from antiferromagnetism to ferromagnetism. Concretely, the magnetic material "B" can be made of GdRh or $MnGa_3C$.

[0071] The heat conductive material "a" is required to exhibit higher heat conductivity under the application of the magnetic field and lower heat conductivity without the magnetic field. In this point of view, the heat conductive material "a" can be made of a material exhibiting the phase transition to the ferromagnetic and metallic phase from the non-magnetic and insulating phase.

[0072] The heat conductive material "b" is required to exhibit lower heat conductivity under the application of the magnetic field and higher heat conductivity without the magnetic field. In this point of view, the heat conductive material "b" can be made of a material exhibiting the heat conductivity reduction caused by large electron scattering from the destruction of ordering by applying the magnetic field or exhibiting the heat conductivity reduction of phonons contribution caused by change of the lattice structure by applying the magnetic field.

[0073] FIG. **8** is a schematic view illustrating the magnetic refrigerating device according to still another embodiment of the present invention. FIG. **9** is a schematic view illustrating the magnetic refrigerating device according to a further embodiment of the present invention. In the embodiment relating to FIGS. **4** to **6**, the magnetic field is cyclically applied to and removed from the magnetic refrigerating unit by rotating the outer Halbach type magnet. It is noticed that the magnetic material (including magnet) is subject to forces of the magnetic torque when varying the magnetic flux therein. That is, in the magnetic refrigerating device according to the present invention, the outer Halbach type magnet is subject to forces in rotating motion.

[0074] In order to mitigate such a problem as described above, a plurality sets of magnetic refrigerating units and Halbach type magnets are prepared so that the magnetic torque generated from one set of magnetic refrigerating unit and Halbach type magnet can be cancelled by the magnetic torque generated from another set of magnetic refrigerating unit and Halbach type magnet through the phase shift of the heat cycle. In this case, the motive energy load for realizing the heat cycle of magnetic refrigeration using the above-described magnetic refrigerating system can be reduced.

[0075] In the embodiments relating to FIGS. **8** and **9**, the outer Halbach type magnet **2** generates a magnetic field in one direction via the bore space. On the other hand, the inner Halbach type magnet **1** is composed of a plurality of Halbach type magnets **1***a* to **1***e* via the fixing member **25** so that the magnetic fields can be generated from the Halbach type magnets **1***a* to **1***e* in various directions in accordance with the Halbach type magnets **1***a* to **1***e*. Namely, the direction **7** of the magnetic field generated from the outer Halbach type magnet **2** is relatively different from the direction **6** of the magnetic field generated from the inner Halbach type magnet **1**. In the cyclic operation to change the magnetic field to be applied to the magnetic refrigerating unit **3** by rotating the outer Halbach type magnet **2**, the relative directions in magnetic field of the sets of inner Halbach type magnets and the outer Halbach type magnet are different from one another (e.g., "**1***a*" and "**2**"; "**1***b*" and "**2**" in FIG. **8**, "**1***c*" and "**2**"; "**1***d*" and "**2**"; "**1***e*" and "**2**" in FIG. **9**).

[0076] In this way, in the embodiments relating to FIGS. **8** and **9**, the inner Halbach type magnet or the outer Halbach type magnet is composed of a plurality Halbach type magnets so that the direction of the magnetic field generated from the inner Halbach type magnet is different from the direction of the magnetic field generated from the outer Halbach type magnet by shifting the plurality of the Halbach type magnets. As a result, in the illustrated double-structured Halbach type magnet, if the outer Halbach type magnet is rotated under the condition that the inner Halbach type magnet and the magnetic refrigerating unit are fixed, the thus generated magnetic torque can be cancelled only by the rotation of the outer Halbach type magnet and thus, the motive energy load to rotate the outer Halbach type magnet can be reduced.

[0077] Although the present invention was described in detail with reference to the above examples, this invention is not limited to the above disclosure and every kind of variation and modification may be made without departing from the scope of the present invention.

[0078] For example, although the magnetic refrigerating materials "A", "a", "B", "b" are subsequently stacked and unified to form the multilayered structure denoted by "AaBb", the magnetic refrigerating materials "A", "b", "B", "a" are subsequently stacked and unified to form the multilayered structure denoted by "AbBa". In the latter case, the heat transfer can be carried out by the application and the removal of the magnetic field. However, the magnetic material "A" is increased in temperature and the magnetic material "B" is decreased in temperature under the application of the magnetic field. Since the material "a" exhibits high heat conductivity and the material "b" exhibits low heat conductivity, the magnetic materials "A" and "B" are thermally insulated by the material "b" in the magnetic refrigerating unit **3** so that no heat is flowed.

[0079] On the other hand, the magnetic material "A" is decreased in temperature and the magnetic material "B" is increased in temperature under the removal of the magnetic field. Since the material "a" exhibits low heat conductivity and the material "b" exhibits high heat conductivity, the thus generated heat is flowed from the magnetic material "B" to the magnetic material "A".

[0080] As a result, when the magnetic refrigerating unit **3** is constituted of the multilayered structure of "AbBa", the heat transfer is carried out in the direction opposite to the direction designated by the arrow **8**.

What is claimed is:

1. A magnetic refrigerating device, comprising:

at least one set of double-structured Halbach type magnet including a ring-shaped inner Halbach type magnet and a ring-shaped outer Halbach type magnet which are coaxially arranged one another so that a magnetic field generated from said inner Halbach type magnet is superimposed with a magnetic field generated from said outer Halbach type magnet;

a magnetic refrigerant or a magnetic refrigeration working chamber including said magnetic refrigerant therein disposed in a bore space of said inner Halbach type magnet; and

a rotating mechanism to rotate said outer Halbach type magnet while said inner Halbach type magnet is stationed.

2. The magnetic refrigerating device as set forth in claim **1**, further comprising a heat transfer medium which can realize a heat exchange with said magnetic refrigerant through a contact of said heat transfer medium with said magnetic refrigerant.

3. The magnetic refrigerating device as set forth in claim **1**, wherein said magnetic refrigerant is rendered particulate.

4. The magnetic refrigerating device as set forth in claim **1**, wherein said outer Halbach type magnet includes a gear and is configured so as to be rotated around said inner Halbach type magnet by said rotating mechanism through the engagement of said gear of said outer Halbach type magnet with said rotating mechanism.

5. The magnetic refrigerating device as set forth in claim **4**, wherein said outer Halbach type magnet is thermally insulated from said inner Halbach type magnet.

6. The magnetic refrigerating device as set forth in claim **1**, wherein said magnetic refrigerant is composed of a plurality of magnetic refrigerants or said magnetic refrigeration working chamber is composed of a plurality of magnetic refrigeration working chambers.

7. The magnetic refrigerating device as set forth in claim **1**, wherein said magnetic refrigerant includes a magnetic material "A" exhibiting a magneto-caloric effect that the temperature of said material "A" is increased by applying a magnetic field and the temperature of said material "A" is decreased by removing a magnetic field, a magnetic material "B" exhibiting a magneto-caloric effect that the temperature of said material "B" is decreased by applying a magnetic field and the temperature of said material "B" is increased by removing a magnetic field, a heat conductive material "a" exhibiting higher heat conductivity under the application of a magnetic field and lower heat conductivity without a magnetic field, and a heat conductive material "b" exhibiting lower heat conductivity under the application of a magnetic field and higher heat conductivity without a magnetic field, wherein said magnetic refrigerant is configured so as to include at least one layered structure denoted by "AaBb" which is formed by subsequently stacking said materials "A", "a", "B", "b" or at least one layered structure denoted by "AbBa" which is formed by subsequently stacking said materials "A", "b", "B", "a".

8. The magnetic refrigerating device as set forth in claim **7**,

wherein said material "a" or "b" include a substance which is shifted from a metallic phase state to an insulating phase state by changing an intensity of a magnetic field to be applied thereto.

9. The magnetic refrigerating device as set forth in claim **7**,

wherein said material "a" or "b" include a substance which is shifted from a ferromagnetic metallic phase state to a non-magnetic insulating phase state by changing an intensity of a magnetic field to be applied thereto.

10. The magnetic refrigerating device as set forth in claim **1**,

wherein at least one of said inner Halbach type magnet and said outer Halbach type magnet is composed of a plurality of Halbach type magnets so that the direction of a magnetic field generated by said inner Halbach type magnet is different from the direction of a magnetic field generated by said outer Halbach type magnet by shifting said plurality of Halbach type magnets.

11. A magnetic refrigerating method, comprising:

disposing a magnetic refrigerant or a magnetic refrigerating working chamber including said magnetic refrigerant therein in a bore space of at least one set of double-structured Halbach type magnet including a ring-shaped inner Halbach type magnet and a ring-shaped outer Halbach type magnet which are coaxially arranged one another so that a magnetic field generated from said inner Halbach type magnet is superimposed with a magnetic field generated from said outer Halbach type magnet; and

rotating said outer Halbach type magnet while said inner Halbach type magnet is stationed so that a first magnetic field with a first intensity is applied to said magnetic refrigerating material and a second magnetic field with a second intensity smaller than said first intensity is applied to said magnetic refrigerant, thereby generating a magneto-caloric effect in said magnetic refrigerant and thus, conduct a heat transfer.

12. The magnetic refrigerating method as set forth in claim **11**,

wherein said heat transfer is conducted through a heat transfer medium which can realize a heat exchange with said magnetic refrigerant through a contact of said heat transfer medium with said magnetic refrigerant.

13. The magnetic refrigerating method as set forth in claim **11**,

wherein said magnetic refrigerant is rendered particulate.

14. The magnetic refrigerating method as set forth in claim **11**,

wherein said outer Halbach type magnet includes a gear and is configured so as to be rotated around said inner Halbach type magnet by said rotating mechanism through the engagement of said gear of said outer Halbach type magnet with said rotating mechanism.

15. The magnetic refrigerating method as set forth in claim **14**,

wherein said outer Halbach type magnet is thermally insulated from said inner Halbach type magnet.

16. The magnetic refrigerating method as set forth in claim **11**,

wherein said magnetic refrigerant is composed of a plurality of magnetic refrigerant or said magnetic refrigeration working chamber is composed of a plurality of magnetic refrigeration working chambers.

17. The magnetic refrigerating method as set forth in claim **11**,

wherein said magnetic refrigerant includes a magnetic material "A" exhibiting a magneto-caloric effect that the temperature of said material "A" is increased by applying a magnetic field and the temperature of said material "A" is decreased by removing a magnetic field, a magnetic material "B" exhibiting a magneto-caloric effect that the temperature of said material "B" is decreased by applying a magnetic field and the temperature of said material "B" is increased by removing a magnetic field, a heat conductive material "a" exhibiting higher heat conductivity under the application of a magnetic field and lower heat conductivity without a magnetic field, and a heat conductive material "b" exhibiting lower heat conductivity under the application of a magnetic field and higher heat conductivity without a magnetic field,

wherein said magnetic refrigerant is configured so as to include at least one layered structure denoted by "AaBb" which is formed by subsequently stacking said materials "A", "a", "B", "b" or at least one layered structure denoted by "AbBa" which is formed by subsequently stacking said materials "A", "b", "B", "a".

18. The magnetic refrigerating method as set forth in claim **17**,

wherein said material "a" or "b" include a substance which is shifted from a metallic phase state to an insulating phase state by changing an intensity of a magnetic field to be applied thereto.

19. The magnetic refrigerating method as set forth in claim **17**,

wherein said material "a" or "b" include a substance which is shifted from a ferromagnetic metallic phase state to a non-magnetic insulating phase state by changing an intensity of a magnetic field to be applied thereto.

20. The magnetic refrigerating method as set forth in claim **11**,

wherein at least one of said inner Halbach type magnet and said outer Halbach type magnet is composed of a plurality of Halbach type magnets so that the direction of a magnetic field generated by said inner Halbach type magnet is different from the direction of a magnetic field generated by said outer Halbach type magnet by shifting said plurality of Halbach type magnets.

* * * * *