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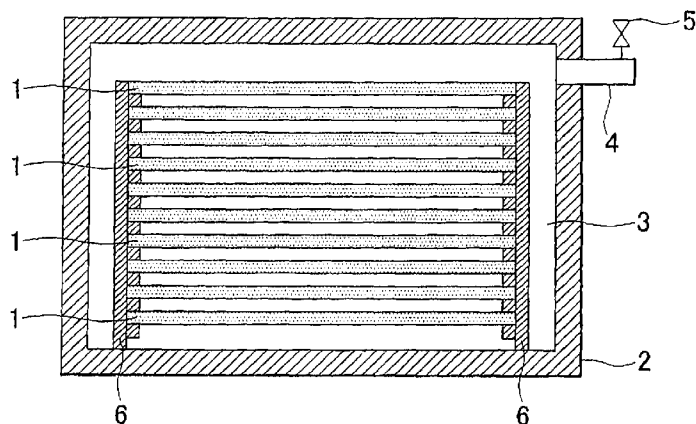
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FIG. 1

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(57) Abstract: A solid-state battery includes, plural unit cells that respectively include a positive electrode layer, a negative electrode layer, and a solid electrolyte layer which is disposed between the positive electrode layer and the negative electrode layer, and a vessel that houses the plural unit cells, in which a gas to apply pressure to a unit cell is filled in surroundings of the unit cell and an inside of the vessel, and a contact avoidance member is disposed between two adjacent unit cells and between the unit cell and the vessel, and contact between the two adjacent unit cells and contact between the unit cell and the vessel are avoided at least during operation of the unit cell by the contact avoidance member.

SOLID-STATE BATTERY

BACKGROUND OF THE INVENTION

5 1. Field of the Invention

[0001] The present invention relates to solid-state batteries and particularly to a solid-state battery with a structure that can easily apply pressure isotropically to a unit cell.

2. Description of Related Art

10 [0002] A lithium-ion secondary battery (hereinafter, referred to as "lithium secondary battery" sometimes) has higher energy density than other secondary batteries and can be operated at high voltages. Therefore, the lithium-ion secondary battery is used in an information technology device such as a cellular phone as the secondary battery that can easily achieve size and weight reductions. Recently, the demand for the
15 lithium-ion secondary battery grows as a large power source of an electric vehicle or a hybrid vehicle.

[0003] The lithium-ion secondary battery is provided with a positive electrode layer, a negative electrode layer, and an electrolyte layer that is arranged therebetween. As an electrolyte that is included in the electrolyte layer, a nonaqueous material in a
20 liquid or a solid form is used for example. In the case where the liquid electrolyte (hereinafter, referred to as an "electrolyte solution") is used, the electrolyte solution easily flows through the inside of the positive electrode layer or the negative electrode layer. Therefore, an interface between the electrolyte solution and an active material that is contained in the positive electrode layer or the negative electrode layer is easily
25 formed, and the performance of the battery can be easily improved. However, the electrolyte solution that is widely used is flammable, and therefore a system for assuring safety is required to be equipped with the battery. On the other hand, when the solid form electrolyte (hereinafter, referred to as a "solid electrolyte") that is nonflammable is

used, the aforementioned system can be simplified. Thus, the lithium-ion secondary battery that includes a layer which contains the nonflammable solid electrolyte (hereinafter, referred to as a "solid electrolyte layer") has been proposed.

[0004] As a technique regarding such the battery, for example, Japanese Patent Application Publication No. 10-214638 (JP 10-214638 A) discloses a lithium secondary battery that includes a battery pack which is constructed by assembling plural unit cells and housing the unit cells in a battery back casing. In the lithium secondary battery, at least one of gas, liquid, and solid powder or a blend material thereof is filled in a space between a unit cell casing and the battery pack casing, and the unit cells are pressurized by hydrostatic pressure that is generated within the battery pack casing. In addition, Japanese Patent Application Publication No. 2008-159570 (JP 2008-159570 A) discloses a bipolar battery that includes a pressing portion which is configured to press a battery element in a stacking direction and to apply pressing forces of different strengths to a plurality of positions along a surface direction of the battery element. Japanese Patent Application Publication No. 2006-261008 (JP 2006-261008 A) discloses an inorganic solid electrolyte battery that includes a positive electrode and a negative electrode which is disposed so as to be spaced apart from the positive electrode and meshed with each other. Japanese Patent Application Publication No. 2007-311264 (JP 2007-311264 A) discloses a battery structure that is formed by stacking a plurality of single cell layers in which a heat dissipating member which has a function to absorb a vibration transmitted from an outside is disposed between at least one single cell layer and another single cell layer of the plurality of single cell layers which forms the battery structure. As a technique regarding the battery that has a different form from the lithium-ion secondary battery, Japanese Patent Application Publication No. 2000-48857 (JP 2000-48857 A) discloses a sodium-sulfur battery (NAS battery) that includes a vacuum insulation vessel and a plurality of single cells which are housed in the vacuum insulation vessel with a space.

[0005] The technique that is disclosed in JP 10-214638 A applies pressure to the unit cell by using the hydrostatic pressure, and therefore it is considered that variations in

the performance of the unit cells that are caused by the application of nonuniform pressure can be prevented. However, if the plurality of unit cells are housed in the battery back casing while being in contact with each other, the difference between the pressure that is applied to a contacting part between the unit cells and the pressure that is applied to a non-contacting part with other unit cell is produced. Thus, the technique that is disclosed in JP 10-214638 A has been insufficient in terms of the effect of preventing performance degradation that is caused by the application of nonuniform pressure. Furthermore, when the secondary battery is disposed as disclosed in JP 2000-48857 A and the secondary battery is used in a vibrating device such as a vehicle, the vibration is easily transmitted to the secondary battery, and the performance of the secondary battery can be degraded. Those problems are hardly solved even if the techniques that are disclosed in JP 10-214638 A and JP 2000-48857 A are merely combined.

SUMMARY OF THE INVENTION

[0006] The object of the present invention is to provide a solid-state battery that can prevent the performance degradation thereof.

[0007] An aspect of the present invention relates to a solid-state battery including: plural unit cells that respectively include a positive electrode layer, a negative electrode layer, and a solid electrolyte layer which is disposed between the positive electrode layer and the negative electrode layer; and a vessel that houses the plural unit cells. A gas to apply pressure to a unit cell is filled in surroundings of the unit cell and an inside of the vessel, and a contact avoidance member is disposed between two adjacent unit cells and between the unit cell and the vessel, and contact between the two adjacent unit cells and contact between the unit cell and the vessel are avoided at least during operation of the unit cell by the contact avoidance member.

[0008] Here, the term of "during operation of the unit cell" means during charging and discharging when the unit cell is a secondary battery and during discharging when the unit cell is a primary battery.

[0009] In the solid-state battery according to the present invention, the contact between the two adjacent unit cells and the contact between the unit cell and the vessel are avoided at least during the operation of the unit cell by the contact avoidance member. When the solid-state battery is formed as described above, pressure can be applied uniformly to the surface of the unit cell by using gas in comparison with the case where two adjacent unit cells contact each other or the case where the unit cell and the vessel contact each other. When the pressure is applied uniformly, the performance degradation that is caused by the application of nonuniform pressure can be prevented, and therefore the performance of the battery can be increased. Thus, according to the present invention, the solid-state battery that can prevent the performance degradation thereof can be provided. In addition, in the solid-state battery according to the present invention, the unit cell and the vessel do not directly contact each other at least during the operation of the unit cell. Accordingly, even if the solid-state battery according to the present invention is used in a vibrating device such as a vehicle, vibration that is transmitted to the unit cell can be reduced, and as a result, the performance degradation of the unit cell can be prevented.

[0010] A blower may be housed in the vessel, and the plural unit cells may be stacked in a vertical direction, and the plural unit cells may be disposed so that pressure between the adjacent unit cells at a higher position in the vertical direction is lower when the gas that is filled in the vessel is circulated by the blower. The plural unit cells may be disposed so that pressure between a unit cell which is disposed at a highest position and the vessel is lower than the pressure between the adjacent unit cells when the gas that is filled in the vessel is circulated by the blower.

[0011] Because the plural unit cells are disposed so that pressure in a spacing on an upper side in the vertical direction becomes low when the gas that is filled in the vessel is circulated by the blower, the plural unit cells can float in the air with gas flow from the blower. When the plural unit cells can float in the air, application of uniform pressure to whole surface of the unit cell can be easily achieved, and therefore the performance of the solid-state battery can be increased easily.

[0012] Here, the phrase “pressure between the adjacent unit cells at a higher position in the vertical direction is lower” and “pressure between a unit cell which is disposed at a highest position and the vessel is lower than the pressure between the adjacent unit cells” means that, for example, in the case that two unit cells are housed within the vessel, when the pressure of a region that is interposed between the upper surface of the unit cell that is disposed on the upper side in the vertical direction and the vessel is designated as P1, the pressure of a region that is interposed between two unit cells is designated as P2, and the pressure of a region that is interposed between the lower surface of the unit cell that is disposed on the lower side in vertical direction and the vessel is designated as P3, a relation of $P1 < P2 < P3$ is achieved.

[0013] The contact avoidance member may have holes.

[0014] When the contact avoidance member has holes, the pressure can be applied also to parts of the unit cell that contacts the contact avoidance member by using the gas. Therefore, the application of uniform pressure to the unit cell that is housed in the vessel can be easily achieved, and therefore the performance of the solid-state battery can be increased easily.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] Features, advantages, and technical and industrial significance of exemplary embodiments of the invention will be described below with reference to the accompanying drawings, in which like numerals denote like elements, and wherein:

FIG. 1 is a cross-sectional view that illustrates a solid-state battery 10;

FIG. 2 is a cross-sectional view that illustrates a unit cell 1;

FIG. 3 is a cross-sectional view that illustrates a solid-state battery 20;

FIG. 4 is a cross-sectional view that illustrates a solid-state battery 30;

FIG. 5 is a cross-sectional view that illustrates a solid-state battery 40;

FIG. 6 is a cross-sectional view that illustrates a solid-state battery 50;

FIG. 7 is a cross-sectional view that illustrates a unit cell 51; and

FIG. 8 is a cross-sectional view that illustrates a solid-state battery 60.

DETAILED DESCRIPTION OF EMBODIMENTS

[0016] The following form exemplary describes the present invention, and the present invention is not limited to the form that is described below. In order to be easily understood, some reference numerals and symbols are omitted in the drawings.

[0017] FIG. 1 is a cross-sectional view that illustrates a solid-state battery 10 according to a first embodiment of the present invention. In FIG. 1, the solid-state battery 10 is shown in a simplified form. A direction from an upper side to a lower side on the sheet of FIG. 1 is a direction of gravitational force (vertical direction). As shown in FIG. 1, the solid-state battery 10 has plural unit cells 1 and a vessel 2 that houses the unit cells 1. An inert gas 3 to apply pressure to a unit cell 1 is filled in the surroundings of the unit cell 1 and the inside of the vessel 2. A gas passage 4 is provided in the vessel 2, and a valve 5 is connected to the gas passage 4. The position of the unit cells 1 in the vessel 2 is determined through an arrangement such that the end sections of the unit cells 1 are brought into contact with a contact avoidance member 6 in a comb teeth shape. Thereby, the contact with the adjacent unit cell 1 and the contact between the unit cell 1 and the vessel 2 are avoided by the contact avoidance member 6. The gas passage 4 is used during filling of the inert gas 3 in the vessel 2 that houses the unit cells which is disposed so as to contact the contact avoiding member 6, and the valve 5 is closed after the filling of the inert gas 3 is finished. When the valve 5 is closed, leakage of the inert gas 3 is prevented, and flow of atmosphere to the inside of the vessel 2 is also prevented. In addition, although not shown in the drawings, the vessel 2 is provided with a current terminal and an introducing part for a sensor such as a temperature sensor. As shown in FIG. 1, an upper surface of the unit cell 1 that is disposed at the highest position in the direction of gravitational force (vertical direction) does not contact the vessel 2.

[0018] FIG. 2 is a cross-sectional view that illustrates the unit cell 1. As shown in FIG. 2, the unit cell 1 has a stack 1x, and the stack 1x is covered with a laminate film 1y. The stack 1x includes a positive electrode current collector 1a, a positive electrode layer 1b that is connected to the positive electrode current collector 1a, a solid electrolyte

layer 1c that is disposed to contact the positive electrode layer 1b, a negative electrode layer 1d that is disposed on the opposite side to the positive electrode layer 1b with respect to the solid electrolyte layer 1c so as to contact the solid electrolyte layer 1c, and a negative electrode current collector 1e that is connected to the negative electrode layer 1d. The positive electrode current collector 1a is connected to a terminal 1f, and the negative electrode current collector 1e is connected to a terminal 1g. Respective ends of the terminal 1f and the terminal 1g are located outside the laminate film 1y. In the solid-state battery 10, plural terminals 1f are connected to a positive connecting terminal (not shown), and one end of the positive connecting terminal is connected to a positive terminal (not shown) that is located outside the vessel 2. Similarly, plural terminals 1g are connected to a negative connecting terminal (not shown), and one end of the negative connecting terminal is connected to a negative terminal (not shown) that is located outside the vessel 2.

[0019] As described above, in the solid-state battery 10, the contact with the adjacent unit cell 1 and the contact between the unit cell 1 and the vessel 2 are avoided by the contact avoidance member 6. Because the contact with the adjacent unit cell 1 and the contact between the unit cell 1 and the vessel 2 are avoided, pressure can be applied uniformly to the surface of the unit cell 1 with the use of the inert gas 3. In the solid-state battery 10, the terminal of the unit cell 1 and the contact avoidance member 6 contact each other. As described above, in the unit cell 1, the stack 1x is covered with the laminate film 1y, the laminate film 1y is sealed with heat seal of edges, for example. Therefore, by contacting between a sealed edge of the laminate film 1y and contact avoidance members 6, according to the solid-state battery 10, pressure can be applied uniformly to both end surfaces of the stack 1x in a stacking direction (upper surface and lower surface in FIG. 1). Thus, according to the present embodiment, uniform pressure can be applied to the stack 1x that is housed in the vessel 2, and therefore the performance degradation that is caused by the application of nonuniform pressure can be prevented.

[0020] Furthermore, in the solid-state battery 10, the vessel 2 and the unit cell 1

do not directly contact each other. Therefore, even if the solid-state battery 10 is used in a vibrating device, in comparison with the case where the unit cell and the vessel directly contact each other, the vibration that is transmitted to the unit cell 1 can be reduced. When the vibration that is transmitted to the unit cell 1 is reduced, the performance degradation that is caused by the vibration can be prevented, and therefore the performance can be increased according to the solid-state battery 10.

[0021] In the solid-state battery 10, the positive electrode current collector 1a and the negative electrode current collector 1e can be made of well-known conductive materials that can be used as the positive electrode current collector and the negative electrode current collector of the lithium-ion secondary battery. Examples of such the conductive materials are metal materials that include one or more elements which are selected from a group of Cu, Ni, Al, V, Au, Pt, Mg, Fe, Ti, Co, Cr, Zn, Ge, and In. In addition, the positive electrode current collector 1a and the negative electrode current collector 1e can be shaped into metal foil or metal mesh.

[0022] As a positive electrode active material that is contained in the positive electrode layer 1b, well-known active materials that can be contained in the positive electrode layer of the lithium-ion secondary battery can be used appropriately. An example of such the positive electrode active material includes lithium cobalt oxide (LiCoO_2). As the solid electrolyte that is contained in the positive electrode layer 1b, well-known solid electrolytes that can be contained in the positive electrode layer of the lithium-ion secondary battery can be used appropriately. Examples of such the solid electrolytes include oxide-based solid electrolytes such as Li_3PO_4 and sulfide-based solid electrolytes such as Li_3PS_4 and mixtures of Li_2S and P_2S_5 so as to be $\text{Li}_2\text{S}:\text{P}_2\text{S}_5 = 50:50$ through 100:0 (for example, sulfide solid electrolytes that is prepared by mixing Li_2S and P_2S_5 so as to be $\text{Li}_2\text{S}:\text{P}_2\text{S}_5 = 75:25$ in a mass ratio). In addition, the positive electrode layer 1b may contain a binder that binds the positive electrode active material and the solid electrolyte and a conductive material that improves electrical conductivity. An example of the binder that can be contained in the positive electrode layer 1b includes a butylene rubber, and an example of the conductive material that can be contained in the

positive electrode layer 1b includes a carbon black. As a solvent that is used in preparation of the positive electrode layer 1b, a well-known solvent that can be used in the preparation of slurry during the preparation of the positive electrode of the lithium-ion secondary battery can be used appropriately. An example of such the solvent includes heptane.

[0023] In addition, an example of the solid electrolyte that is contained in the solid electrolyte layer 1c includes the aforementioned solid electrolyte that can be contained in the positive electrode layer 1b. An example of the solvent that is used in the preparation of the solid electrolyte layer 1c includes the aforementioned solvent that can be used in the preparation of the positive electrode layer 1b.

[0024] As a negative electrode active material that is contained in the negative electrode layer 1d, well-known active materials that can be contained in the negative electrode layer of the lithium-ion secondary battery can be used appropriately. An example of such the active material includes graphite. As the solid electrolyte that is contained in the negative electrode layer 1d, well-known solid electrolytes that can be contained in the negative electrode layer of the lithium-ion secondary battery can be used appropriately. An example of such the solid electrolyte includes the aforementioned solid electrolyte that can be contained in the positive electrode layer 1b. In addition, the negative electrode layer 1d may contain a binder that binds the negative electrode active material and the solid electrolyte and a conductive material that improves electrical conductivity. An example of the binder or the conductive material that can be contained in the negative electrode layer 1d includes the aforementioned binder or conductive material that can be contained in the positive electrode layer 1b. An example of the solvent that is used in the preparation of the negative electrode layer 1d includes the aforementioned solvent that can be used in the preparation of the positive electrode layer 1b.

[0025] The laminate film 1y can use, without any limitation, a film that can withstand the environment during the use of the lithium-ion secondary battery, has a property which is impermeable to gases, and can be sealed. Examples of constituent

materials of such the films include resins as represented by polyethylene, polyvinyl fluoride, and polyvinylidene chloride, and metalized films in which metals such as aluminum are vapor-deposited on the surface of the aforementioned resins.

[0026] The terminals 1f and 1g can be made of the materials that have a good electron conductivity so as to withstand the environment during the use of the solid-state battery 10 and preferably made of the materials that have strength and flexibility which can withstand an external force that is exerted during the use of the solid-state battery 10. Examples of such the materials include carbon fibers as represented by carbon fiber reinforced plastics (CFRP).

[0027] In addition, the vessel 2, the gas passage 4, and the contact avoidance member 6 can be made of well-known materials that can withstand the environment during the use of the solid-state battery 10 and that has the strength which can withstand the pressure of the inert gas 3 which is applied to the unit cells 1 (for example, at about 1 atmospheric pressure or higher and 200 atmospheric pressure or lower). Examples of such the materials include metals such as aluminum and stainless steel and thermosetting resins as represented by polyether ether ketone (PEEK). In addition, the vessel 2, the gas passage 4, and the contact avoidance member 6 can also be made of similar materials to the aforementioned laminate film 1y.

[0028] For the inert gas 3, nitrogen gas and argon gas can be used, for example. In addition, for the gas to apply pressure to the unit cell 1, fluorine-containing gases that can be used as refrigerants (such as hydrofluorocarbon mixed refrigerants (R410A and R407C)), isobutane, carbon dioxide, and dry air can be used.

[0029] If the valve 5 has a function that can block the flow of fluid through the gas passage 4 and is made of the material that can withstand the environment during the use of the solid-state battery 10, the form of the valve 5 is not particularly limited. As the valve 5, a valve of which the operation is electronically controlled and a valve of which opening and closing are manually operated can be used.

[0030] FIG. 3 is a cross-sectional view that illustrates a solid-state battery 20 according to a second embodiment of the present invention. A direction from an upper

side to a lower side on the sheet of FIG. 3 is a direction of gravitational force (vertical direction). In FIG. 3, the same structures as the solid-state battery 10 are given with the same reference numerals and symbols as those used in FIG. 1, and the description thereof are not repeated appropriately. In FIG. 3, the solid-state battery 20 is shown in a simplified form.

[0031] As shown in FIG. 3, the solid-state battery 20 has plural unit cells 1 that are arranged in parallel in the vertical direction and a vessel 2 that houses the unit cells 1 and a blower 21. An inert gas 3 to apply pressure to a unit cell 1 is filled in the surroundings of the unit cell 1 and the inside of the vessel 2. A gas passage 4 is provided in the vessel 2, and a valve 5 is connected to the gas passage 4. The insides of the vessel 2 (on the sides that face the respective unit cells 1) have a positioning piece 22, a positioning piece 23, a positioning piece 24, a positioning piece 25, a positioning piece 26, and a positioning piece 27 (hereinafter, simply referred to as "positioning pieces" as a group) that can respectively determine the position of the unit cell 1 during the manufacture of the solid-state battery 20 and also prevent the contact between the unit cell 1 and the vessel 2 and the contact with the adjacent unit cells 1. In the manufacture of the solid-state battery 20, when a spacing between an upper surface of the unit cell 1 that is disposed to contact the positioning piece 23 and the vessel 2 is designated as L1, a spacing between an lower surface of the unit cell 1 and an upper surface of the unit cell 1 that is disposed to contact the positioning piece 24 is designated as L2, a spacing between an lower surface of the unit cell 1 and an upper surface of the unit cell 1 that is disposed to contact the positioning piece 25 is designated as L3, a spacing between an lower surface of the unit cell 1 and an upper surface of the unit cell 1 that is disposed to contact the positioning piece 26 is designated as L4, a spacing between an lower surface of the unit cell 1 and an upper surface of the unit cell 1 that is disposed to contact the positioning piece 27 is designated as L5, and a spacing between an lower surface of the unit cell 1 and the vessel 2 is designated as L6, the solid-state battery 20 has a relation of $L1 > L2 > L3 > L4 > L5 > L6$.

[0032] Here, the pressure of a region where the spacing is L1 is designated as

P1, the pressure of a region where the spacing is L2 is designated as P2, the pressure of a region where the spacing is L3 is designated as P3, and the pressure of a region where the spacing is L4 is designated as P4, the pressure of a region where the spacing is L5 is designated as P5, and the pressure of a region where the spacing is L6 is designated as P6.

5 Because the solid-state battery 20 has the relation of $L1 > L2 > L3 > L4 > L5 > L6$, when gas is blown from the blower 21 to the unit cell 1 during the operation of the unit cell 1, the relation of $P1 < P2 < P3 < P4 < P5 < P6$ can be made. In the solid-state battery 20, if the weight of the unit cell 1 is 3 g and an area of the surface that receives the gas flow is 50 cm^2 , when the blower 21 blows the gas of 0.5 m/s, the unit cells 1 can float in the air.

10 The floating unit cell 1 stays in a position where the force that is received from the upper surface balances with the force that is received from the lower surface. By achieving such the state, pressure can be applied uniformly to the surface of the unit cell 1. In addition, by floating the unit cell 1, if the solid-state battery 20 is used in the vibrating device, the vibration that is transmitted to the unit cell 1 can be made as zero. Therefore,

15 according to the solid-state battery 20, the performance can be improved.

[0033] The solid-state battery 20 can change the amount of floatation of the unit cell 1 by changing the strength of gas flow from the blower 21. When strong gas flow is blown from the blower 21, the unit cell 1 can float at an elevated position. As described above, the solid-state battery 20 is provided with the positioning pieces, and

20 therefore when the unit cell 1 float at the excessively elevated position, the contact between the adjacent unit cells 1 and the contact between the unit cell 1 and the vessel 2 can be prevented.

[0034] In the solid-state battery 20, the form of the blower 21 is not particularly limited as long as the blower 21 can blow gas flow to the unit cells 1. The blower 21

25 can use a well-known blower that is used for the purpose of cooling the lithium-ion secondary batteries, for example.

[0035] In addition, the form of the positioning piece is not particularly limited as long as the positioning piece can provide a function of determining a region where the unit cell 1 can move so that the adjacent unit cells 1 and the unit cell 1 and the vessel 2

do not contact each other, and the positioning piece is made of the material that can withstand the environment during the use of the solid-state battery 20. The positioning piece can be formed of the same material as the vessel 2, for example.

[0036] FIG. 4 is a cross-sectional view that illustrates a solid-state battery 30 according to a third embodiment of the present invention. A direction from an upper side to a lower side on the sheet of FIG. 4 is a direction of gravitational force (vertical direction). In FIG. 4, the same structures as the solid-state battery 20 are given with the same reference numerals and symbols as those used in FIG. 3, and the description thereof are not repeated appropriately. In FIG. 4, the solid-state battery 30 is shown in a simplified form.

[0037] As shown in FIG. 4, the solid-state battery 30 has plural unit cells 1 that are arranged in parallel in the vertical direction and a vessel 2 that houses the unit cells 1 and a blower 21. An inert gas 3 to apply pressure to a unit cell 1 is filled in the surroundings of the unit cell 1 and the inside of the vessel 2. A gas passage 4 is provided in the vessel 2, and a valve 5 is connected to the gas passage 4. The insides of the vessel 2 (on the sides that face the respective unit cells 1) have the positioning pieces that can respectively determine the position of the unit cell 1 during the manufacture of the solid-state battery 30 and also prevent the contact between the unit cell 1 and the vessel 2 and the contact with the adjacent unit cells 1. In the solid-state battery 30, a vane 31 is mounted on an end face of the unit cell 1 that is disposed so as to contact the positioning piece 23 during the manufacture of the solid-state battery 30, a vane 32 is mounted on an end face of the unit cell 1 that is disposed so as to contact the positioning piece 24 during the manufacture of the solid-state battery 30, a vane 33 is mounted on an end face of the unit cell 1 that is disposed so as to contact the positioning piece 25 during the manufacture of the solid-state battery 30, a vane 34 is mounted on an end face of the unit cell 1 that is disposed so as to contact the positioning piece 26 during the manufacture of the solid-state battery 30, and a vane 35 is mounted on an end face of the unit cell 1 that is disposed so as to contact the positioning piece 27 during the manufacture of the solid-state battery 30, respectively. When areas of surface 31z of the

vane 31, surface 32z of the vane 32, surface 33z of the vane 33, surface 34z of the vane 34, and surface 35z of the vane 35 are respectively designated as S1, S2, S3, S4, and S5, the solid-state battery 30 has a relation of $S1 > S2 > S3 > S4 > S5$.

[0038] Here, the pressure of a region that is interposed between the upper
5 surface of the unit cell 1 where the vane 31 is mounted and the vessel 2 is designated as P1, the pressure of a region that is interposed between the lower surface of the unit cell 1 where the vane 31 is mounted and the upper surface of the unit cell 1 where the vane 32 is mounted is designated as P2, the pressure of a region that is interposed between the lower surface of the unit cell 1 where the vane 32 is mounted and the upper surface of the
10 unit cell 1 where the vane 33 is mounted is designated as P3, the pressure of a region that is interposed between the lower surface of the unit cell 1 where the vane 33 is mounted and the upper surface of the unit cell 1 where the vane 34 is mounted is designated as P4, the pressure of a region that is interposed between the lower surface of the unit cell 1 where the vane 34 is mounted and the upper surface of the unit cell 1 where the vane 35
15 is mounted is designated as P5, and the pressure of a region that is interposed between the lower surface of the unit cell 1 where the vane 35 is mounted and the vessel 2 is designated as P6. Because the solid-state battery 30 has the relation of $S1 > S2 > S3 > S4 > S5$, when gas is blown from the blower 21 to the unit cell 1 during the operation of the unit cell 1, the relation of $P1 < P2 < P3 < P4 < P5 < P6$ can be made. In the
20 solid-state battery 30, if the weight of the unit cell 1 where the vane 31 is mounted is 3 g and an area of the surface that receives the gas flow is 50 cm^2 , when the blower 21 blows the gas of 0.3 m/s, the unit cells 1 can float in the air. According to the solid-state battery 30 as described above, the unit cells 1 can float in the air. Therefore, the performance can be increased according to the solid-state battery 30 in the similar
25 manner to the solid-state battery 20.

[0039] The solid-state battery 30 can also change the amount of floatation of the unit cell 1 by changing the strength of gas flow from the blower 21 in the similar manner to the solid-state battery 20. When strong gas flow is blown from the blower 21, the unit cell 1 can float at an elevated position. As described above, the solid-state battery

30 is provided with the positioning pieces, and therefore when the unit cell 1 float at the excessively elevated position, the contact between the adjacent unit cells 1 and the contact between the unit cell 1 and the vessel 2 can be prevented.

[0040] In the solid-state battery 30, the form of the vane 31, 32, 33, 34, or 35 is not particularly limited as long as the vane has a strength that can provide lift when receiving the gas flow from the blower 21, and the vane is made of the material that can withstand the environment during the use of the solid-state battery 30. In terms of easily lifting the unit cell 1, the vane is preferably made of lightweight materials. The vanes 31, 32, 33, 34, and 35 can be made of resins such as polyethylene terephthalate (PET).

[0041] FIG. 5 is a cross-sectional view that illustrates a solid-state battery 40 according to a fourth embodiment of the present invention. A direction from an upper side to a lower side on the sheet of FIG. 5 is a direction of gravitational force (vertical direction). In FIG. 5, the same structures as the solid-state battery 20 are given with the same reference numerals and symbols as those used in FIG. 3, and the description thereof are not repeated appropriately. In FIG. 5, the solid-state battery 40 is shown in a simplified form.

[0042] As shown in FIG. 5, the solid-state battery 40 has plural unit cells 1 that are arranged in parallel in the vertical direction and a vessel 2 that houses the unit cells 1 and a blower 21. An inert gas 3 to apply pressure to a unit cell 1 is filled in the surroundings of the unit cell 1 and the inside of the vessel 2. A gas passage 4 is provided in the vessel 2, and a valve 5 is connected to the gas passage 4. The insides of the vessel 2 (on the sides that face the respective unit cells 1) have the positioning pieces that can respectively determine the position of the unit cell 1 during the manufacture of the solid-state battery 40 and also prevent the contact between the unit cell 1 and the vessel 2 and the contact between the adjacent unit cells 1. In the solid-state battery 40, vanes 41 are mounted on the end faces of all unit cells 1. In the solid-state battery 40, when an angle between a surface where a vane 41 that is mounted on the unit cell 1 which is disposed so as to contact the positioning pieces 23 during the manufacture of the

solid-state battery 40 receives the gas flow from the blower 21 and a stacking direction of the unit cells 1 is designated as θ_1 , an angle between a surface where a vane 41 that is mounted on the unit cell 1 which is disposed so as to contact the positioning pieces 24 during the manufacture of the solid-state battery 40 receives the gas flow from the blower 21 and a stacking direction of the unit cells 1 is designated as θ_2 , an angle between a surface where a vane 41 that is mounted on the unit cell 1 which is disposed so as to contact the positioning pieces 25 during the manufacture of the solid-state battery 40 receives the gas flow from the blower 21 and a stacking direction of the unit cells 1 is designated as θ_3 , an angle between a surface where a vane 41 that is mounted on the unit cell 1 which is disposed so as to contact the positioning pieces 26 during the manufacture of the solid-state battery 40 receives the gas flow from the blower 21 and a stacking direction of the unit cells 1 is designated as θ_4 , and an angle between a surface where a vane 41 that is mounted on the unit cell 1 which is disposed so as to contact the positioning pieces 27 during the manufacture of the solid-state battery 40 receives the gas flow from the blower 21 and a stacking direction of the unit cells 1 is designated as θ_5 , the solid-state battery 40 has a relation of $\theta_1 > \theta_2 > \theta_3 > \theta_4 > \theta_5$.

[0043] Here, the pressure of a region that is interposed between the upper surface of the unit cell 1 that is disposed at the highest position in the vertical direction and the vessel 2 is designated as P1, the pressure of a region that is interposed between the lower surface of the unit cell 1 that is disposed at the highest position in the vertical direction (the top of the vertical direction) and the upper surface of the unit cell 1 that is disposed in the second from the top of the vertical direction is designated as P2, the pressure of a region that is interposed between the lower surface of the unit cell 1 that is disposed in the second from the top of the vertical direction and the upper surface of the unit cell 1 that is disposed in the third from the top of the vertical direction is designated as P3, the pressure of a region that is interposed between the lower surface of the unit cell 1 that is disposed in the third from the top of the vertical direction and the upper surface of the unit cell 1 that is disposed in the second from the bottom of the vertical direction is designated as P4, the pressure of a region that is interposed between the lower surface of

the unit cell 1 that is disposed in the second from the bottom of the vertical direction and the upper surface of the unit cell 1 that is disposed in the bottom of the vertical direction is designated as P5, and the pressure of a region that is interposed between the lower surface of the unit cell 1 that is disposed in the bottom of the vertical direction (at the lowest position) and the vessel 2 is designated as P6. Because the solid-state battery 40 has the relation of $\theta_1 > \theta_2 > \theta_3 > \theta_4 > \theta_5$, when gas is blown from the blower 21 to the unit cell 1 during the operation of the unit cell 1, the relation of $P_1 < P_2 < P_3 < P_4 < P_5 < P_6$ can be made. In the solid-state battery 40, if the weight of the unit cell 1 where the vane 41 is mounted is 3 g and an area of the surface that receives the gas flow is 50 cm², when the blower 21 blows the gas of 0.3 m/s, the unit cells 1 can float in the air. According to the solid-state battery 40 as described above, the unit cells 1 can float in the air. Therefore, the performance can be increased according to the solid-state battery 40 in the similar manner to the solid-state battery 20 or the solid-state battery 30.

[0044] The solid-state battery 40 can also change the amount of floatation of the unit cell 1 by changing the strength of gas flow from the blower 21 in the similar manner to the solid-state battery 20 or the solid-state battery 30. When strong gas flow is blown from the blower 21, the unit cell 1 can float at an elevated position. As described above, the solid-state battery 40 is provided with the positioning pieces, and therefore when the unit cell 1 float at the excessively elevated position, the contact between the adjacent unit cells 1 and the contact between the unit cell 1 and the vessel 2 can be prevented.

[0045] In the solid-state battery 40, the vanes 41 can be formed similarly to the vanes 31, 32, 33, 34, and 35.

[0046] The description of the solid-state batteries 20, 30, and 40 that use the blower 21 refer to the solid-state battery 20 in which the spacing between the vessel 2 and the unit cell 1 and the spacing between the adjacent unit cells 1 are changed, the solid-state battery 30 in which the surfaces that receive the gas flow are changed, and the solid-state battery 40 in which the angles where the vanes are mounted are changed; however, the form of the solid-state battery that uses the blower is not limited to the above. When the solid-state battery is provided with the blower, the combination of two

or three forms that are selected from a group of the forms in which (1) the spacings are changed, (2) the areas of the vanes are changed, and (3) the angles of the vanes are changed, can be made.

5 [0047] FIG. 6 is a cross-sectional view that illustrates a solid-state battery 50 according to a fifth embodiment of the present invention. A direction from an upper side to a lower side on the sheet of FIG. 6 is a direction of gravitational force (vertical direction). In FIG. 6, the same structures as the solid-state battery 10 are given with the same reference numerals and symbols as those used in FIG. 1, and the description thereof are not repeated appropriately. In FIG. 6, the solid-state battery 50 is shown in a
10 simplified form.

[0048] As shown in FIG. 6, the solid-state battery 50 has plural unit cells 51 that are stacked in the vertical direction and a vessel 2 that houses the unit cells 51. An inert gas 3 to apply pressure to a unit cell 51 is filled in the surroundings of the unit cell 51 and the inside of the vessel 2. A gas passage 4 is provided in the vessel 2, and a valve 5
15 connected to the gas passage 4. As shown in FIG. 6, an upper surface of the unit cell 51 that is disposed at the highest position in the direction of gravitational force (vertical direction) does not contact the vessel 2.

[0049] FIG. 7 is a cross-sectional view that illustrates the unit cell 51. In FIG. 7, the same structures as the unit cell 1 are given with the same reference numerals and
20 symbols as those used in FIG. 2, and the description thereof are not repeated appropriately.

[0050] As shown in FIG. 7, the unit cell 51 has a stack 1x and a protruding piece 52 that is mounted on an edge (end) of the stack 1x, and the stack 1x and the protruding piece 52 are covered with a laminate film 1y. By achieving such the form, protrusions
25 and indentations can be created at parts of the stack 1x where the protruding piece 52 is mounted and where the protruding piece 52 is not mounted on end faces in the stacking direction of the unit cell 51 (surfaces on the upper side and the lower side in FIG. 6). For example, when the positive electrode layer 1b is formed at the part other than the edge of the positive electrode current collector 1a and the negative electrode layer 1d is

formed at the part other than the edge of the negative electrode current collector 1e, according to the solid-state battery 50, pressure can be applied uniformly to the parts where the positive electrode layer 1b and the negative electrode layer 1d are formed. Thus, according to the present embodiment, uniform pressure can be applied to the positive electrode layer 1b and the negative electrode layer 1d, and as a result, the performance degradation that is caused by the application of nonuniform pressure can be prevented.

[0051] In the solid-state battery 50, the protruding pieces 52 (and the laminate film 1y) are interposed between the vessel 2 and the stack 1x. Therefore, even if the solid-state battery 50 is used in a vibrating device, in comparison with the case where only the laminate film is interposed between the stack and the vessel, the vibration that is transmitted to the stack 1x can be reduced. When the vibration that is transmitted to the stack 1x is reduced, the performance degradation that is caused by the vibration can be prevented, and therefore the performance can be increased according to the solid-state battery 50.

[0052] In the solid-state battery 50, the protruding piece 52 can be made of the materials that have a high electron conductivity and can withstand the environment during the use of the solid-state battery 50 and preferably made of the materials that can absorb the vibration. The protruding piece 52 can be made of carbon fibers as represented by carbon fiber reinforced plastics (CFRP). In addition, when the unit cells 51 can be disposed in parallel, the protruding piece 52 may be provided to at least one of the positive electrode current collector 1a and the negative electrode current collector 1e.

[0053] FIG. 8 is a cross-sectional view that illustrates a solid-state battery 60 according to a sixth embodiment of the present invention. A direction from an upper side to a lower side on the sheet of FIG. 8 is a direction of gravitational force (vertical direction). In FIG. 8, the same structures as the solid-state battery 10 are given with the same reference numerals and symbols as those used in FIG. 1, and the description thereof are not repeated appropriately. In FIG. 8, the solid-state battery 60 is shown in a simplified form.

[0054] As shown in FIG. 8, the solid-state battery 60 includes a cell stack 62 that is formed with a porous member 61 and the unit cell 1 which are alternately stacked in the vertical direction, and the vessel 2 that houses the cell stack 62. The porous member 61 is disposed at the lowest position of the cell stack 62 in the stacking direction, and the unit cell 1 is disposed at the highest position of the cell stack 62 in the vertical direction. An inert gas 3 to apply pressure to a unit cell 1 is filled in the surroundings of the unit cell 1 and the inside of the vessel 2. A gas passage 4 is provided in the vessel 2, and a valve 5 is connected to the gas passage 4. As shown in FIG. 8, an upper surface of the unit cell 1 that is disposed at the highest position in the direction of gravitational force (vertical direction) does not contact the vessel 2.

[0055] In the solid-state battery 60, approximately whole end faces of the unit cell 1 in the stacking direction (surface on the upper side and/or the lower side on the sheet of FIG. 8) and the porous member 61 are contacted each other, and the contact between the adjacent unit cells 1 and the contact between the unit cell 1 and the vessel 2 are avoided by the porous member 61. The inert gas 3 can pass through the inside of the porous member 61. When the contact between the adjacent unit cells 1 and the contact between the unit cell 1 and the vessel 2 are avoided by the porous member 61 of which the inert gas 3 can pass through the inside, pressure can be applied uniformly to the surface of the unit cell 1 with the use of the inert gas 3. The uniform pressure is applied to the surface of the unit cell 1, and therefore the performance degradation that is caused by the application of nonuniform pressure can be prevented.

[0056] Furthermore, in the solid-state battery 60, the vessel 2 and the unit cell 1 do not directly contact each other. Therefore, even if the solid-state battery 60 is used in a vibrating device, in comparison with the case where the unit cell and the vessel directly contact each other, the vibration that is transmitted to the unit cell 1 can be reduced. When the vibration that is transmitted to the unit cell 1 is reduced, the performance degradation that is caused by the vibration can be prevented, and therefore the performance can be increased according to the solid-state battery 60.

[0057] In the solid-state battery 60, the porous member 61 can withstand the

environment during the use of the solid-state battery 60 and can be made of the porous materials that are permeable to the inert gas 3, and the porous member 61 is preferably made of the materials that can absorb the vibration. The porous member 61 can be formed of porous metals as represented by metal meshes and foam metals. In addition, the porous member 61 can be formed of well-known porous plastics.

[0058] Although the above description about the solid-state battery 60 refers to the cell stack 62 where the unit cell 1 is disposed at the highest position in the vertical direction, the present invention is not limited to this form. When the porous member is used in the solid-state battery according to the present invention, additional porous members can be disposed on the upper surface of the unit cell at the highest position in the vertical direction.

[0059] Although the above descriptions about the present embodiments refer to the unit cells 1 and 51 in which the stacks 1x and 51x are respectively housed in the laminate film 1y, the present invention is not limited to this form. The unit cell that is provided in the solid-state battery of the present invention may include one or more battery cell. When two or more battery cells are provided in the unit cell, these battery cells can be connected in series and/or parallel.

[0060] In addition, although the above descriptions about the present embodiment exemplify the unit cells 1 and 51 in an approximately square pole shape, the present invention is not limited to this form. The unit cell that is provided in the solid-state battery of the present invention may be formed in other forms such as a column shape.

[0061] In addition, although the above descriptions about the present embodiment exemplify the unit cells 1 and 51 that are covered with the laminate film 1y, the present invention is not limited to this form. The unit cell that is provided in the solid-state battery of the present invention may be formed to be covered with the member which the fluid does not permeate, can withstand the environment during the use of the solid-state battery and can transmit the pressure that is applied from the outside to the inside. Examples of such the materials can include metal foil such as aluminum foil.

[0062] In addition, although the above descriptions about the present embodiment mainly exemplify the form in which the unit cells 1 and 51 as the lithium-ion secondary battery are provided, the battery to which the present invention is applicable is not limited to this form. The unit cell according to the present invention
5 can be formed such that ions other than the lithium ion can move between the positive electrode layer and the negative electrode layer. Examples of such ions can include a sodium ion and a potassium ion. When the ion other than the lithium ion moves, the positive electrode active material, the solid electrolyte, and the negative electrode active material may be selected appropriately in accordance with the moving ion. In addition,
10 the unit cell that is provided in the solid-state battery of the present invention may be a primary battery.

[0063] The contact avoidance member 6 and the positioning pieces 22 through 27 according to the first through fourth embodiments may be made of the porous materials.

CLAIMS

1. A solid-state battery comprising:

plural unit cells that respectively include a positive electrode layer, a negative electrode layer, and a solid electrolyte layer which is disposed between the positive electrode layer and the negative electrode layer; and

a vessel that houses the plural unit cells, wherein

a gas to apply pressure to a unit cell is filled in surroundings of the unit cell and an inside of the vessel, and a contact avoidance member is disposed between two adjacent unit cells and between the unit cell and the vessel; and

contact between the two adjacent unit cells and contact between the unit cell and the vessel are avoided at least during operation of the unit cell by the contact avoidance member.

2. The solid-state battery according to claim 1, wherein

a blower is housed in the vessel, and the plural unit cells are stacked in a vertical direction, and

the plural unit cells are disposed so that pressure between the adjacent unit cells at a higher position in the vertical direction is lower when the gas that is filled in the vessel is circulated by the blower.

3. The solid-state battery according to claim 1, wherein

a blower is housed in the vessel, and the plural unit cells are stacked in a vertical direction, and

the plural unit cells are disposed so that pressure between a unit cell which is disposed at a highest position and the vessel is lower than pressure between the adjacent unit cells when the gas that is filled in the vessel is circulated by the blower.

4. The solid-state battery according to any one of claims 1 to 3, wherein the contact avoidance member has holes.
5. The solid-state battery according to claim 2 or 3, wherein a spacing between the adjacent unit cells at a higher position is larger than a spacing between the adjacent unit cells at a lower position.
6. The solid-state battery according to claim 2 or 3, wherein the plural unit cells have vanes at respective ends, and the ends are opposite ends to ends on sides where the blower is disposed within the vessel.
7. The solid-state battery according to claim 6, wherein area of each vane at a higher position is larger than area of each at a lower position.
8. The solid-state battery according to claim 6 or 7, wherein an angle between the vane and a stacking direction of the plural unit cells at a higher position is larger than an angle between the vane and a stacking direction of the plural unit cells at a lower position.
9. The solid-state battery according to any one of claims 1 to 3 and 5 to 8, wherein the contact avoidance member includes a first member that is disposed between the plural unit cells.
10. The solid-state battery according to claim 9, wherein the contact avoidance member includes a second member that is connected to the first member and is disposed on a side of the plural unit cells.

11. The solid-state battery according to claim 9 or 10, wherein
the contact avoidance member includes a third member that is disposed between a unit cell which is disposed at a lowest position and the vessel.

12. The solid-state battery according to any one of claims 9 to 11, wherein
the contact avoidance member includes a fourth member that is disposed between a unit cell which is disposed at a highest position and the vessel.

13. The solid-state battery according to claim 1, wherein
the plural unit cells respectively include a positive electrode current collector and a negative electrode current collector, and
the contact avoidance member includes a fifth member that is disposed to at least one of the positive electrode current collector and the negative electrode current collector.

14. The solid-state battery according to claim 9, wherein
the first member is a porous material.

15. The solid-state battery according to any one of claims 1 to 14, wherein
the solid-state battery is a lithium secondary battery.

FIG. 1

10

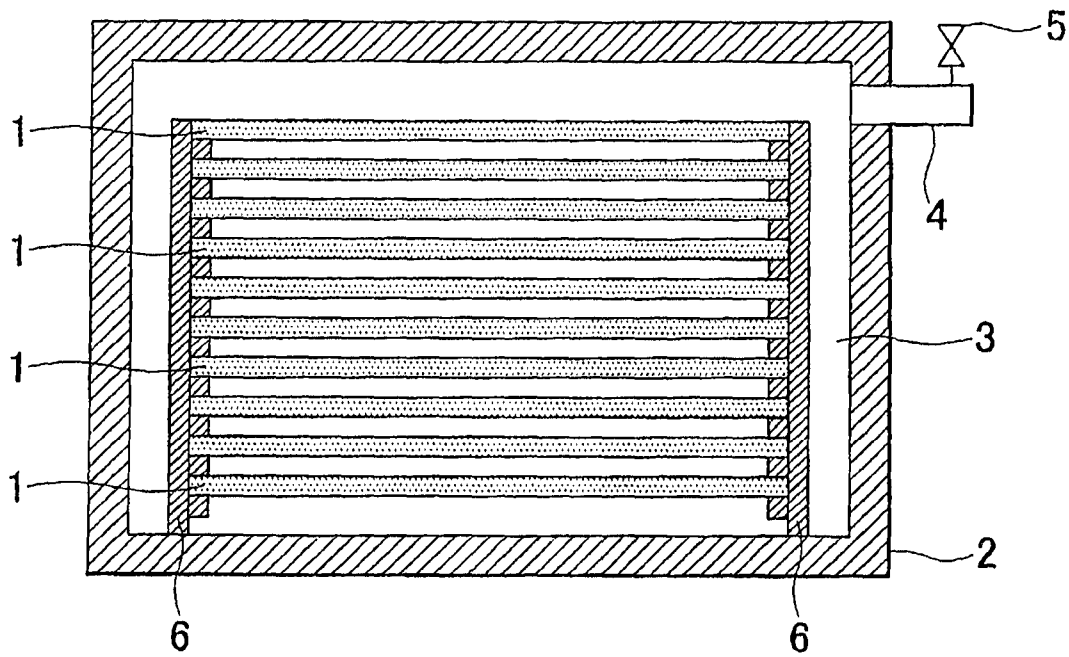


FIG. 2

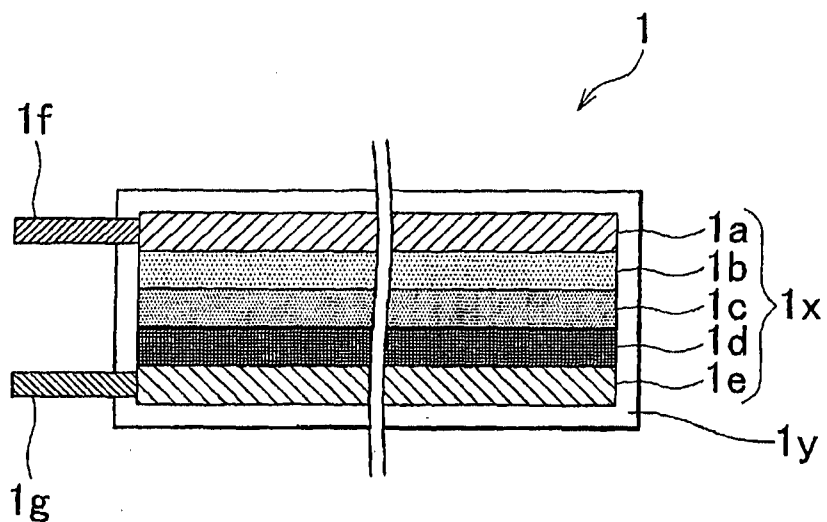


FIG. 3

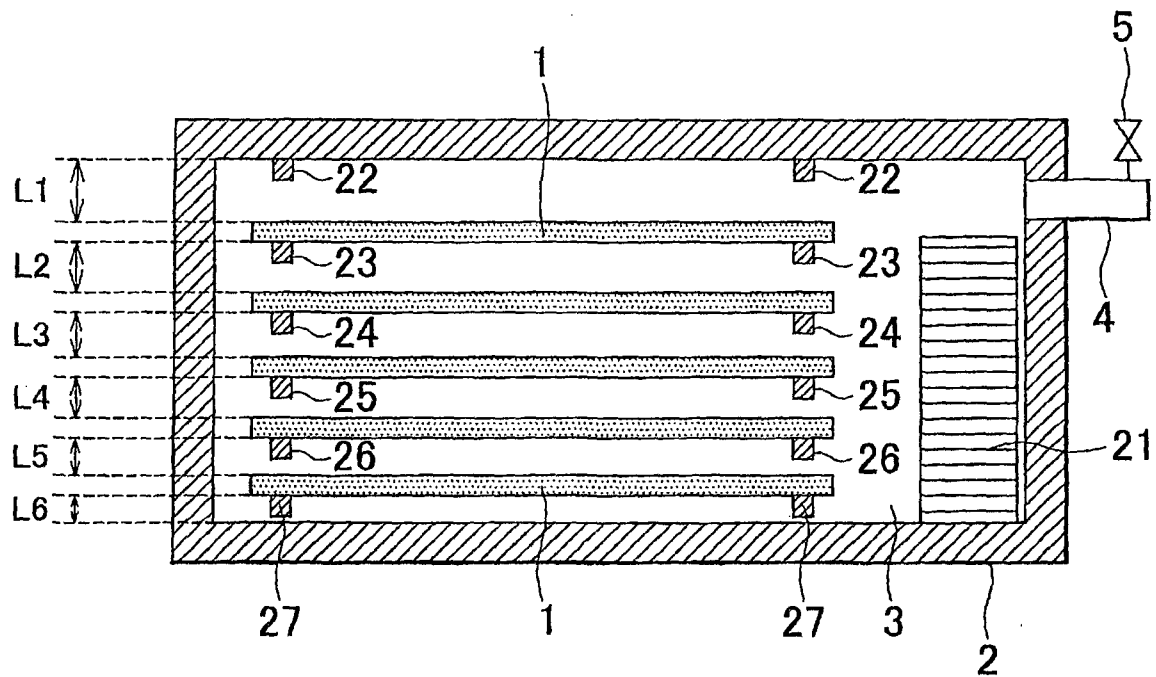
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FIG. 4

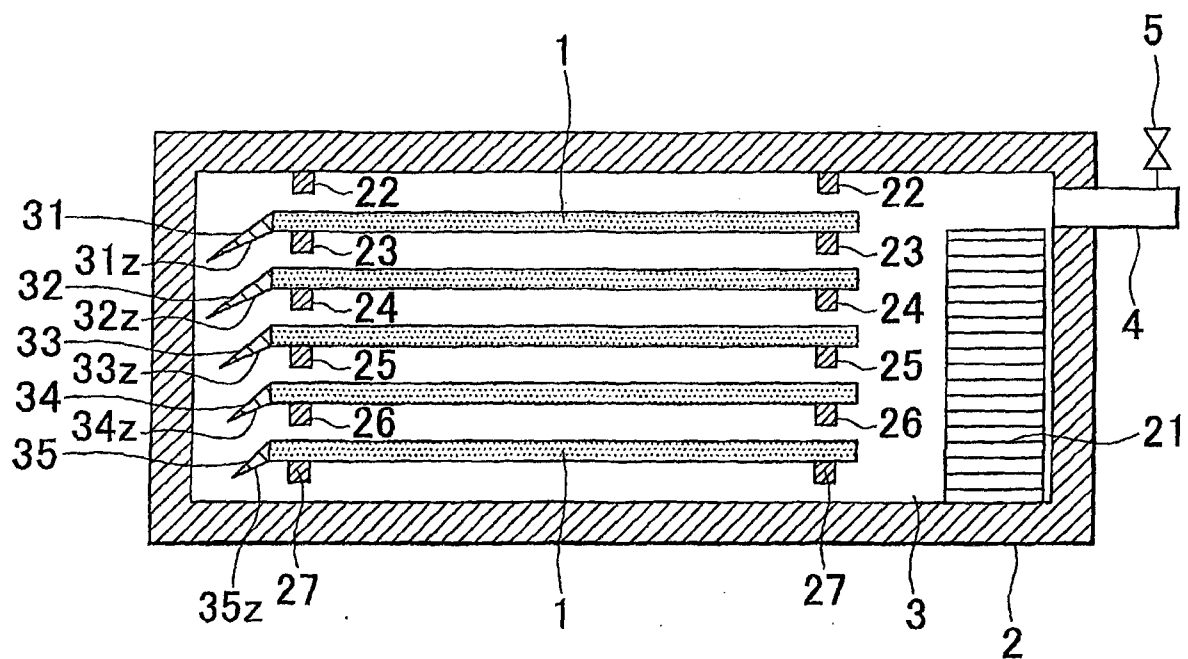
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FIG. 5

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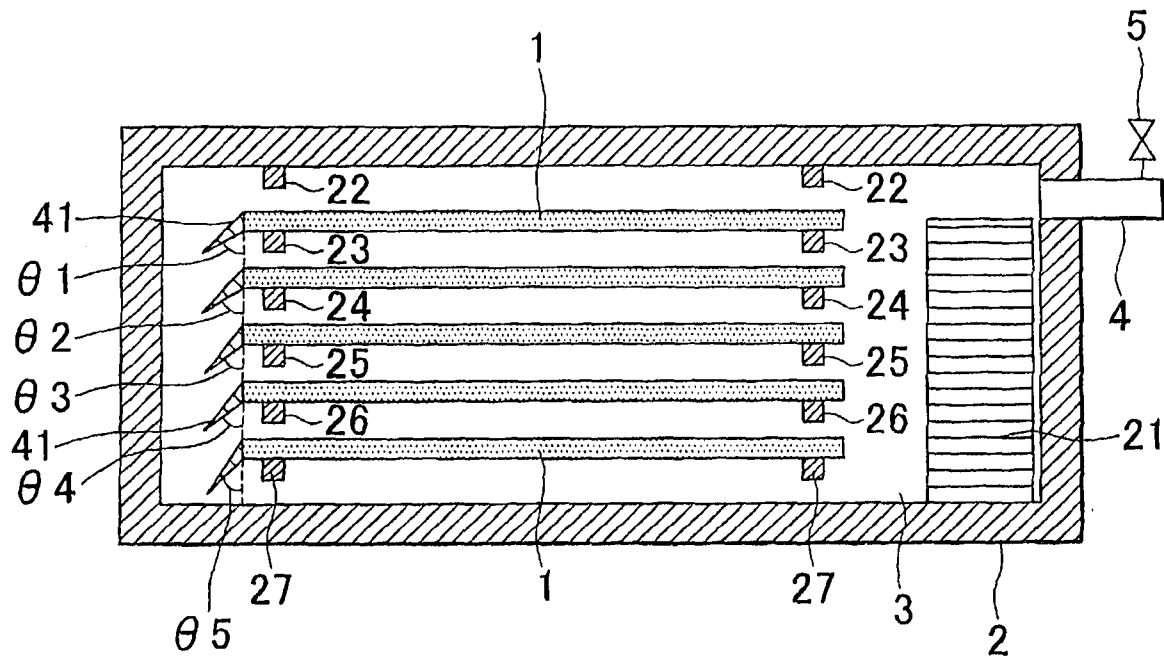


FIG. 6

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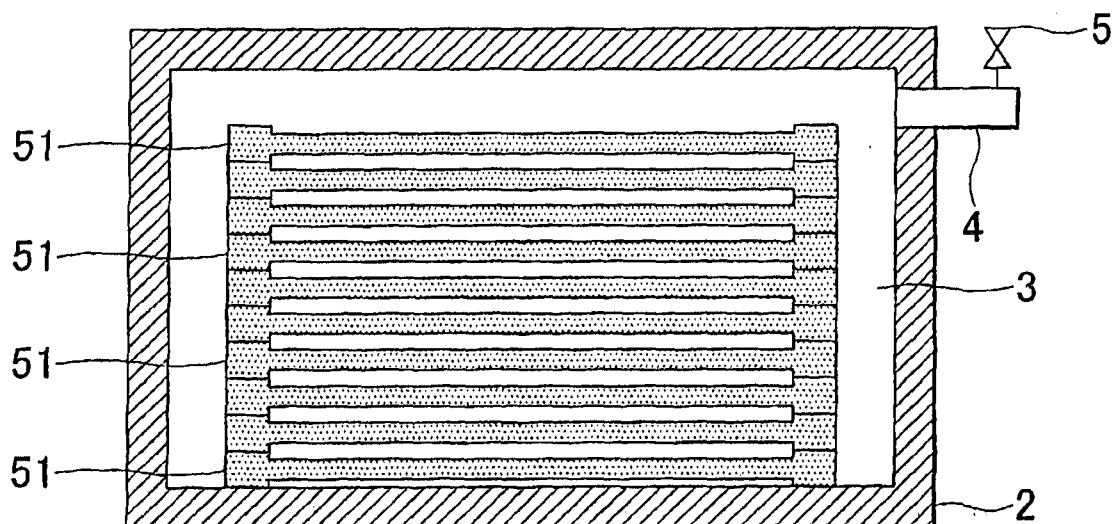


FIG. 7

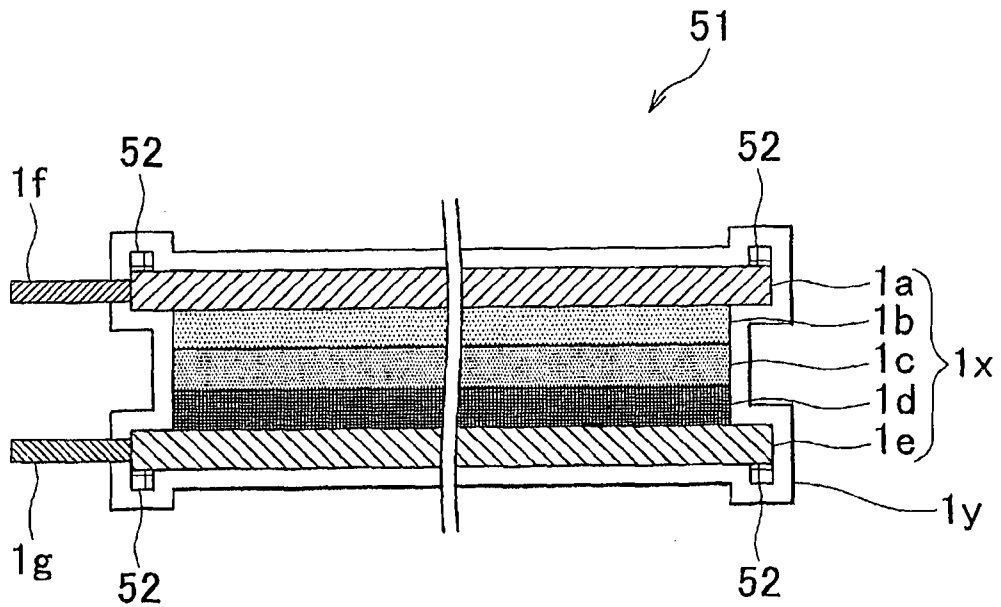
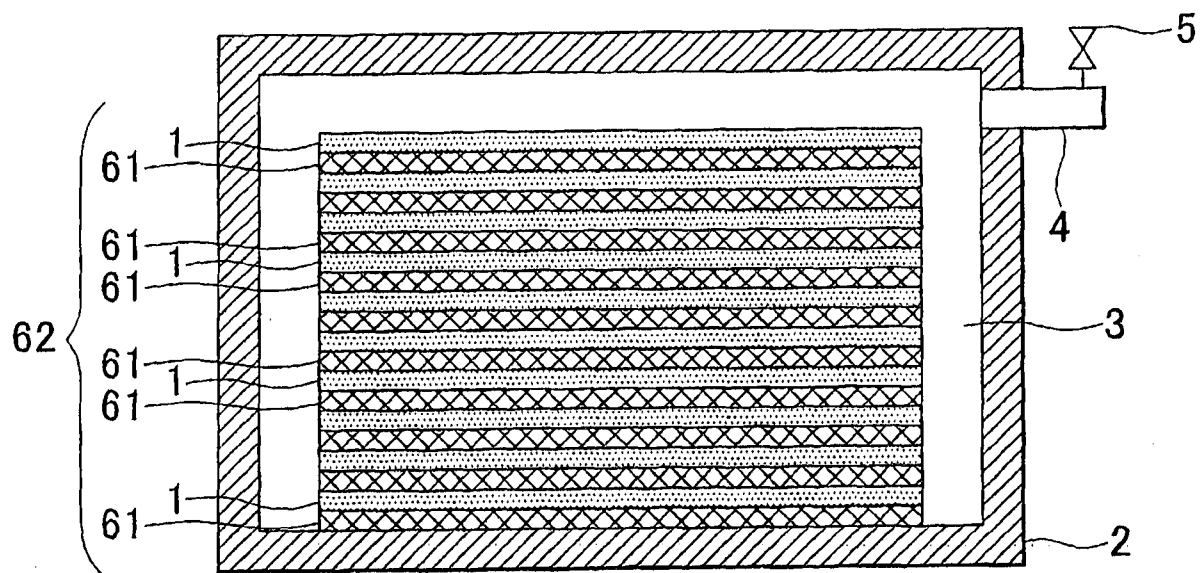


FIG. 8

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INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2012/000656

A. CLASSIFICATION OF SUBJECT MATTER

INV. H01M2/14 H01M10/04 H01M10/0562 H01M10/0525 H01M10/0585
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H01M

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EP0-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	paragraphs [0025], [0041], [0053], [0056]; figures 3,4B	2,3,5-8
X	EP 0 114 233 A1 (BBC BROWN BOVERI & CIE [DE]) 1 August 1984 (1984-08-01)	1,4,9-12,15
A	page 1, line 21 - page 2, line 6 page 5, line 29 - page 9, line 7 figures 1,3	2,3,5-8,14
A	EP 0 269 038 A1 (BBC BROWN BOVERI & CIE [DE]) 1 June 1988 (1988-06-01) the whole document	1-15
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Further documents are listed in the continuation of Box C.



See patent family annex.

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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Date of the actual completion of the international search

2 July 2012

Date of mailing of the international search report

11/07/2012

Name and mailing address of the ISA/

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Schwake, Andree

INTERNATIONAL SEARCH REPORT

International application No
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