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(19) **United States**(12) **Patent Application Publication**
YAMAGUCHI(10) **Pub. No.: US 2025/0266538 A1**(43) **Pub. Date: Aug. 21, 2025**(54) **SECONDARY BATTERY****H01M 50/107** (2021.01)**H01M 50/133** (2021.01)(71) Applicant: **MURATA MANUFACTURING CO., LTD.**, Kyoto (JP)(52) **U.S. Cl.****CPC** **H01M 50/124** (2021.01); **H01M 10/0431** (2013.01); **H01M 50/107** (2021.01); **H01M 50/133** (2021.01)(72) Inventor: **Soichi YAMAGUCHI**, Kyoto (JP)(21) Appl. No.: **19/199,721**(22) Filed: **May 6, 2025****Related U.S. Application Data**

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(57)

ABSTRACT

A secondary battery is provided and includes an electrode wound body, a battery can, and an outer package tube. The electrode wound body includes a positive electrode and a negative electrode that are stacked on each other with a separator interposed between the positive electrode and the negative electrode and are wound around a central axis. The battery can has a circular columnar outer shape in which a height direction corresponds to a direction along the central axis, and contains the electrode wound body. The outer package tube covers an outer peripheral surface of the battery can. Here, a first radial direction in which an outer diameter of the battery can is maximum and a second radial direction in which an outer diameter of the outer package tube is maximum differ from each other.

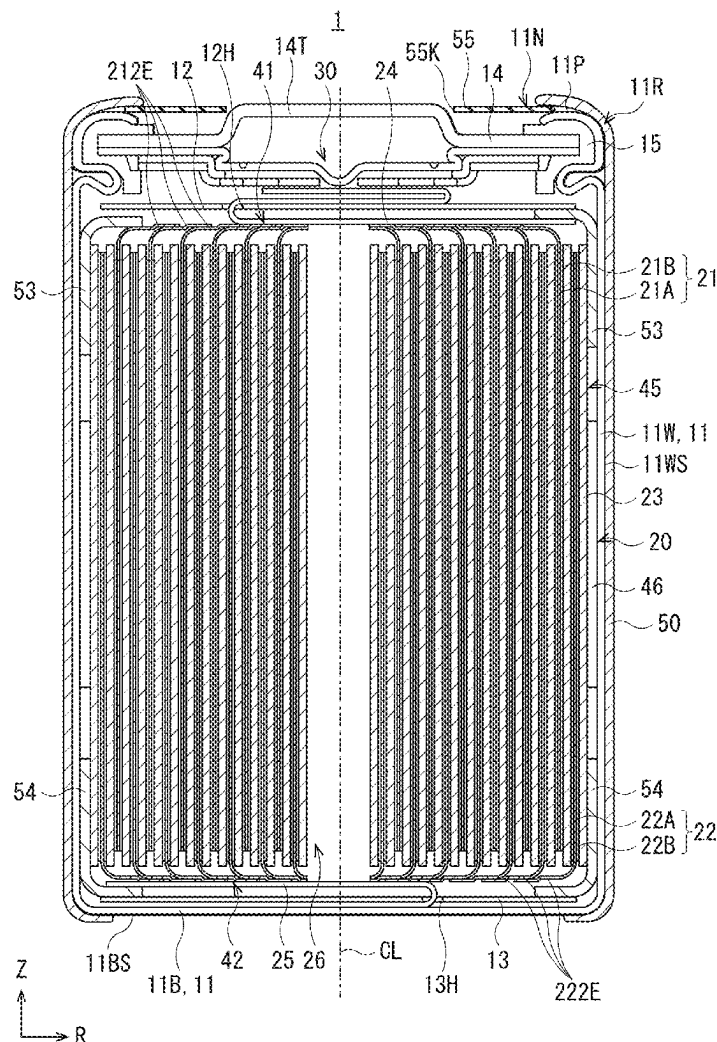


FIG. 2

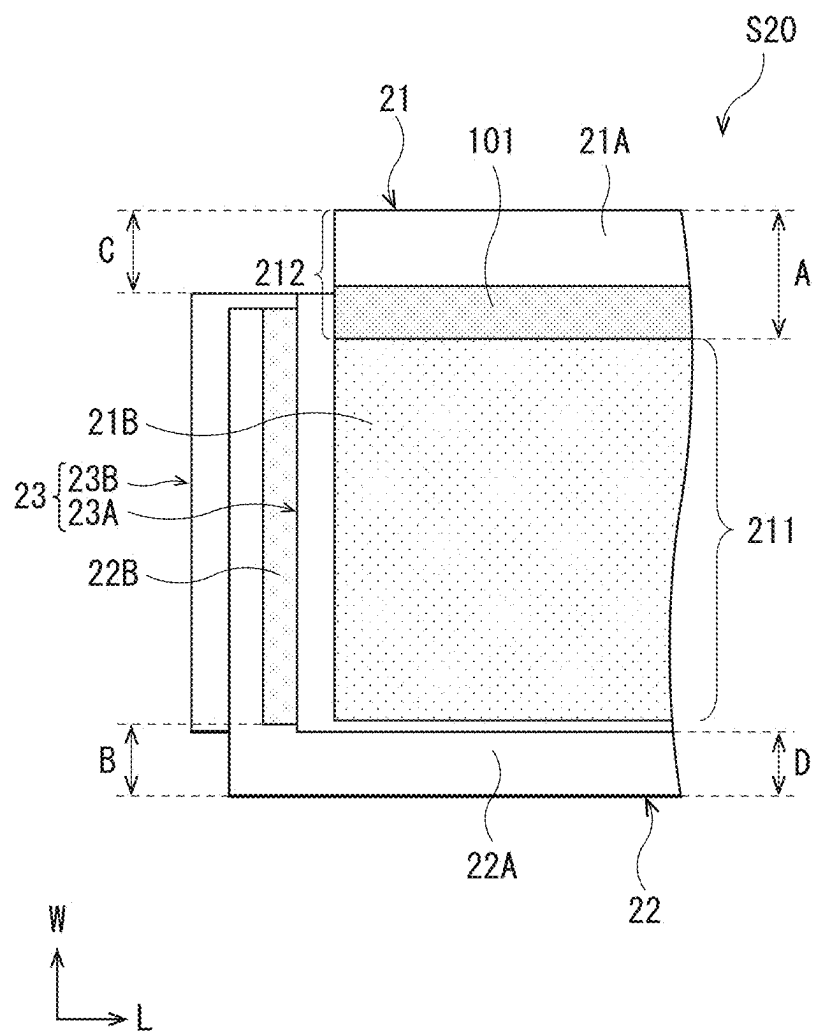


FIG. 3

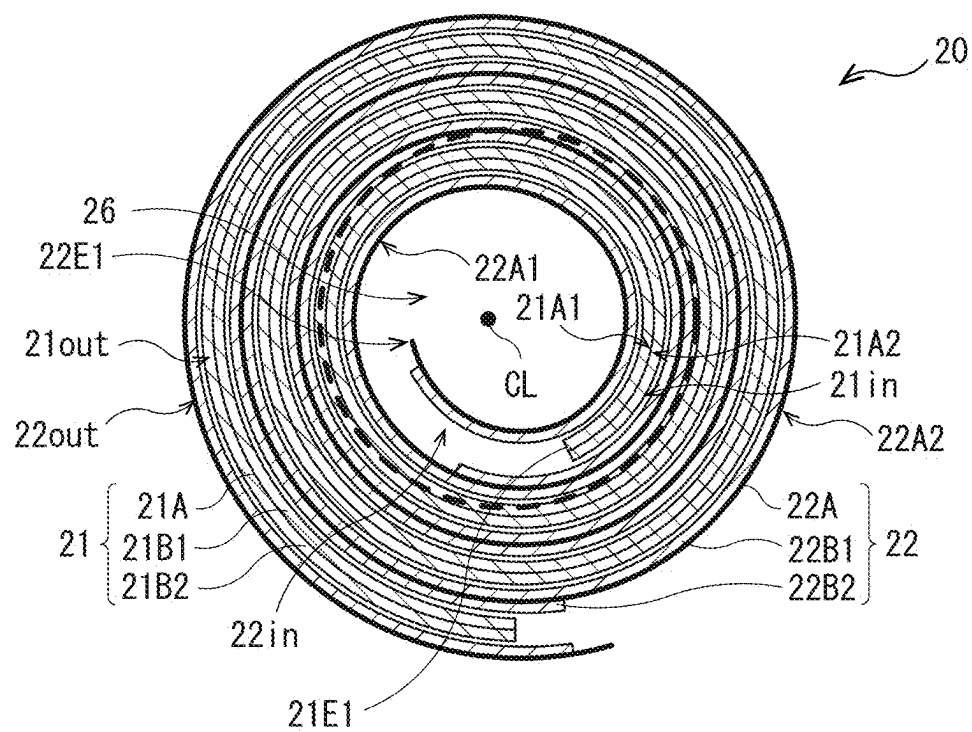


FIG. 4A

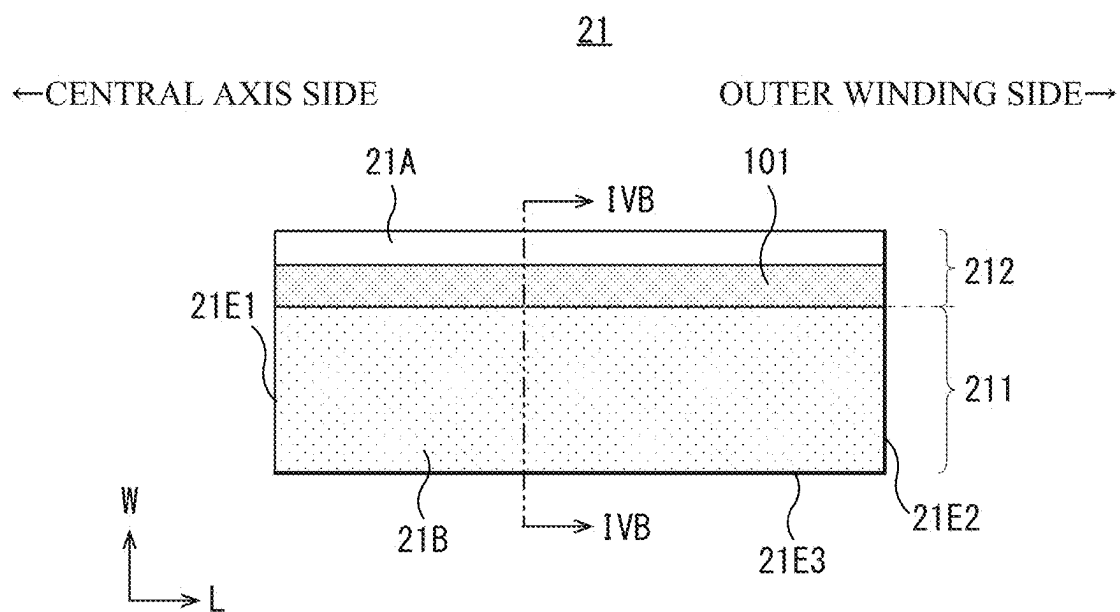


FIG. 4B

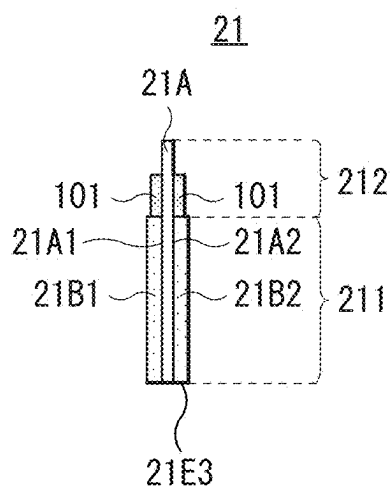


FIG. 5A

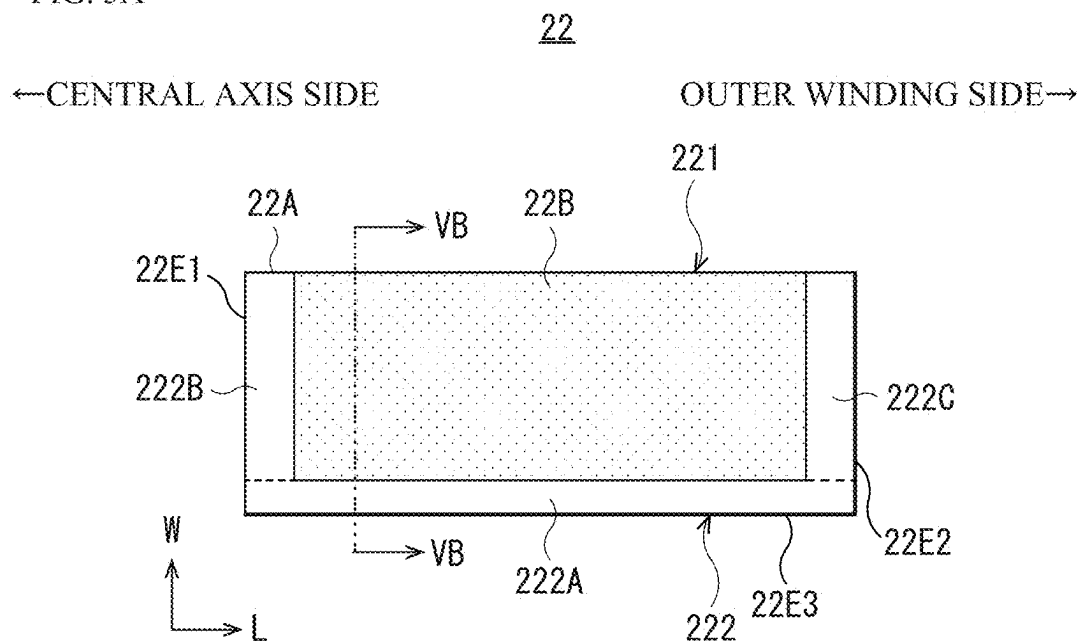


FIG. 5B

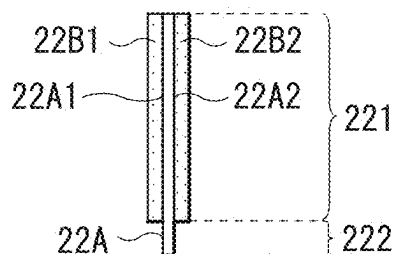


FIG. 6A

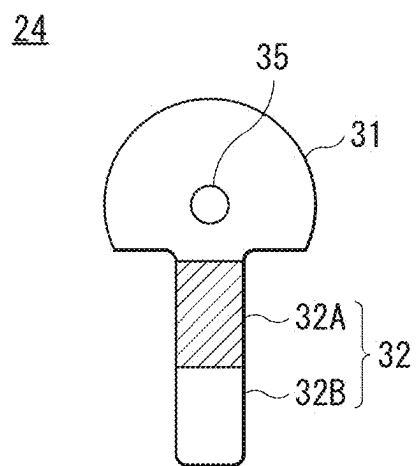


FIG. 6B

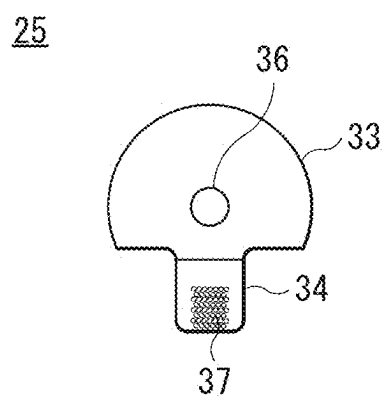


FIG. 7

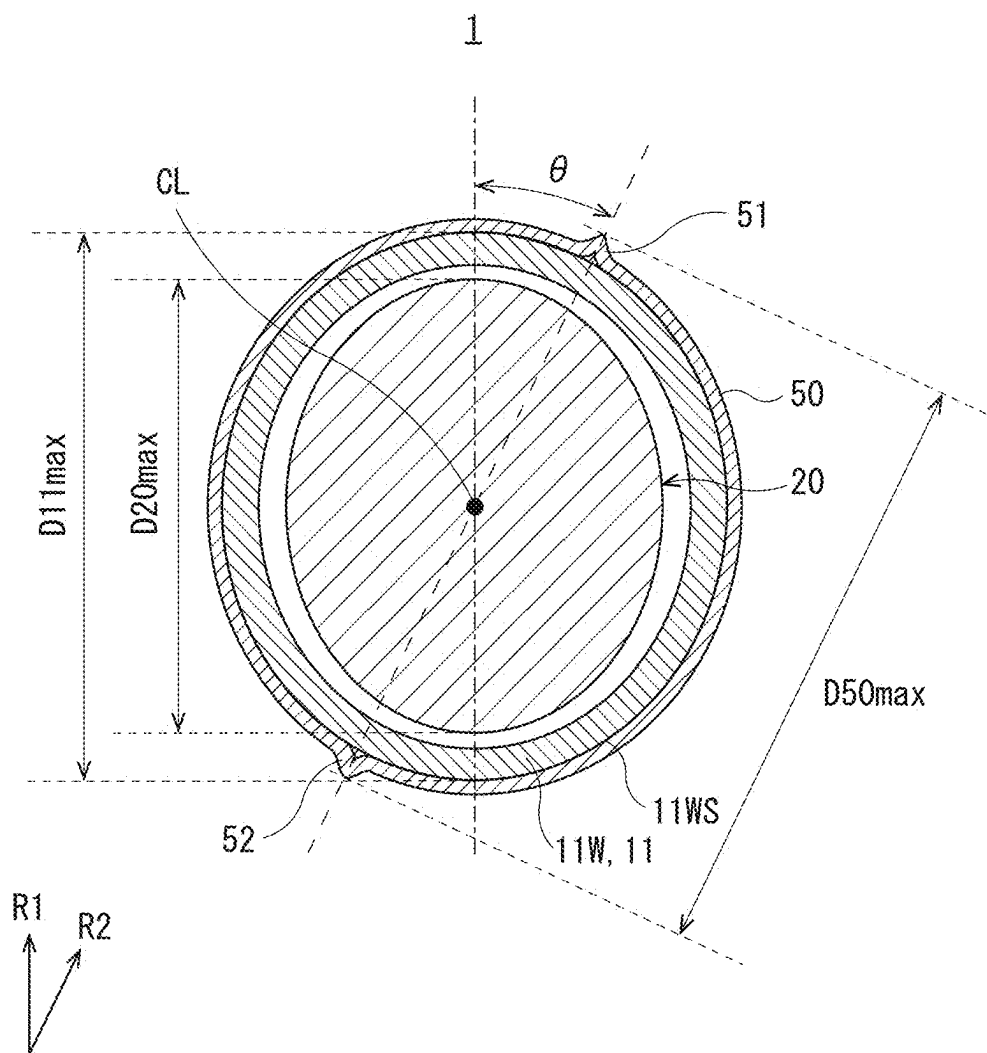


FIG. 8

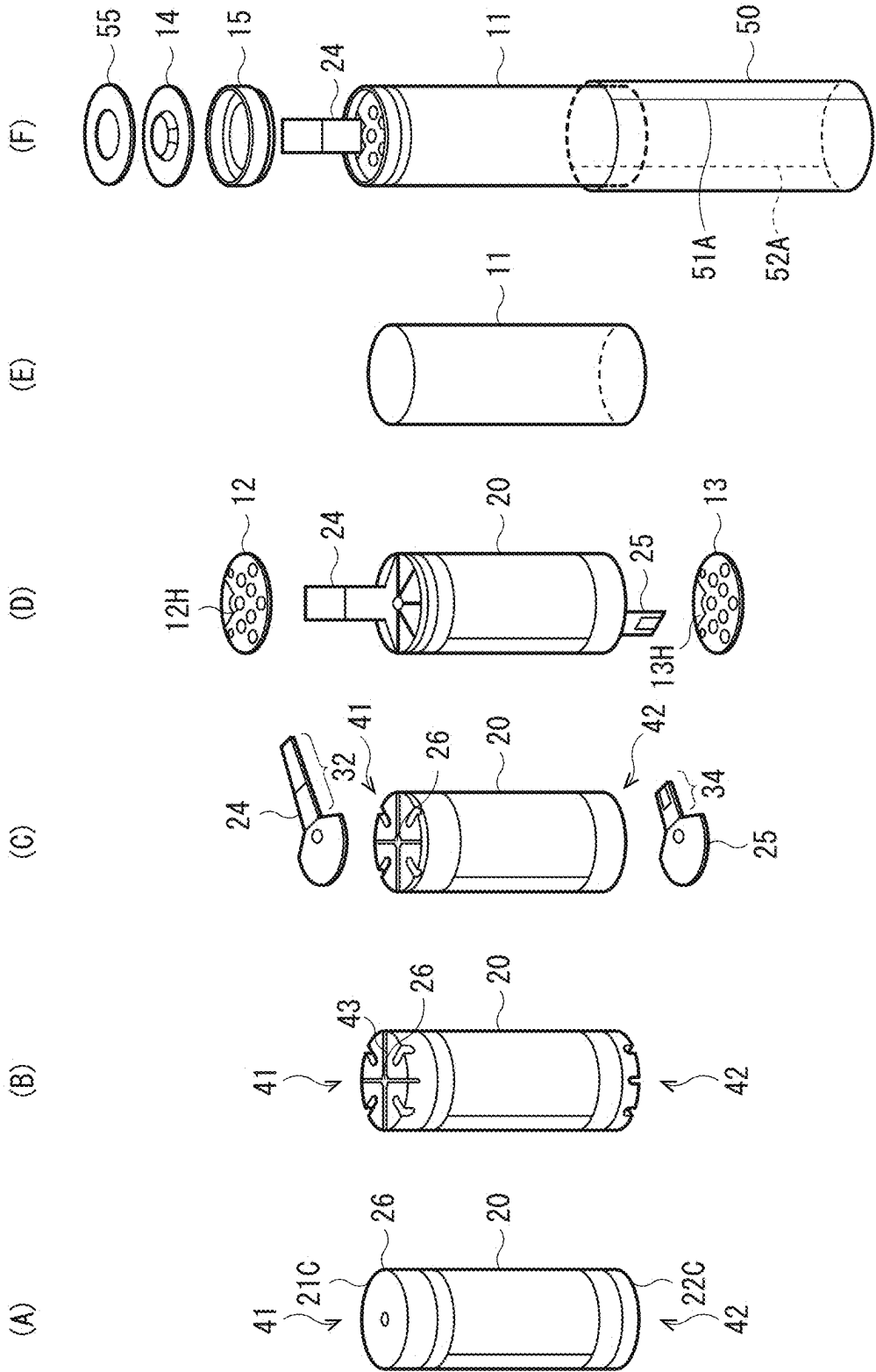


FIG. 9

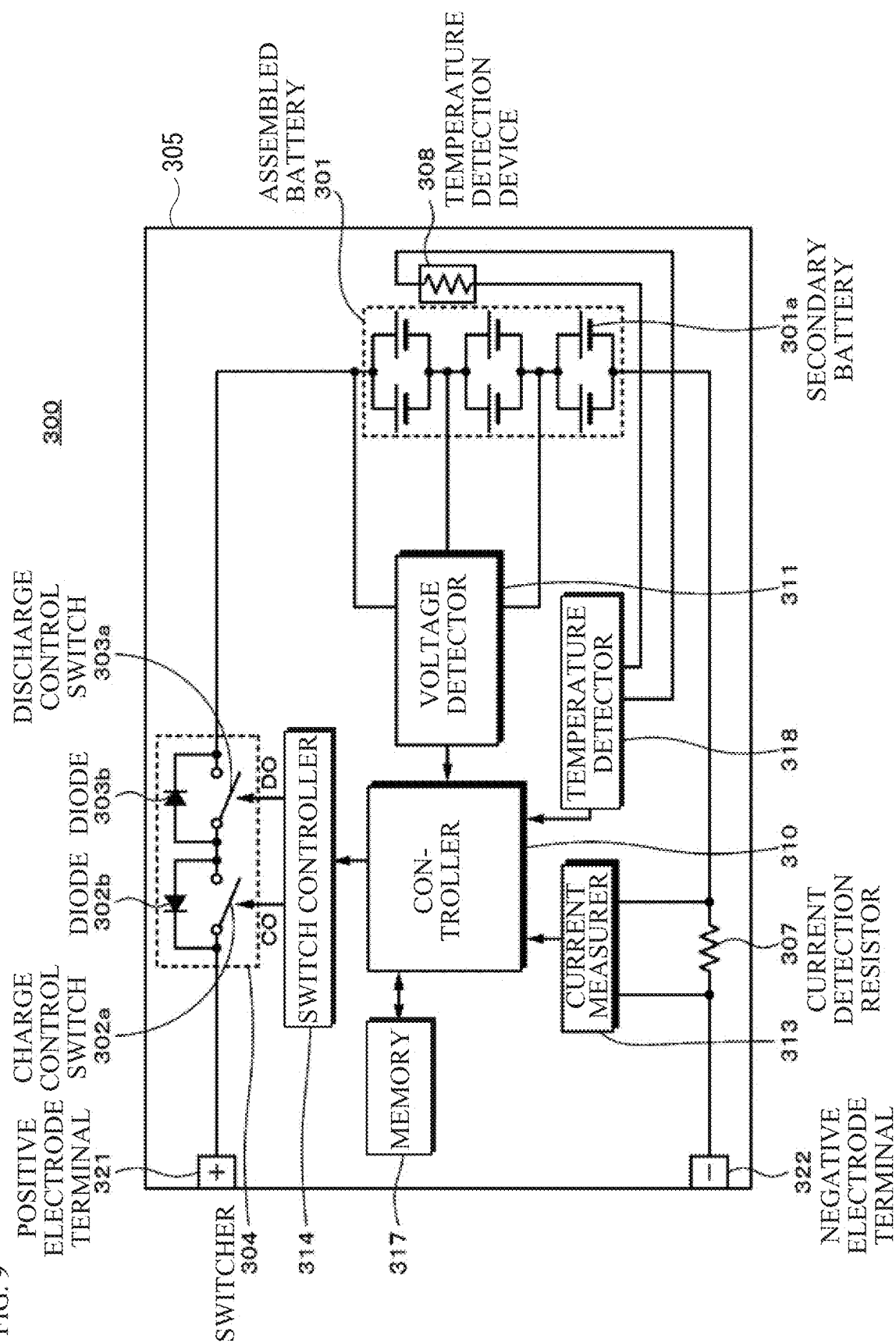


FIG. 10

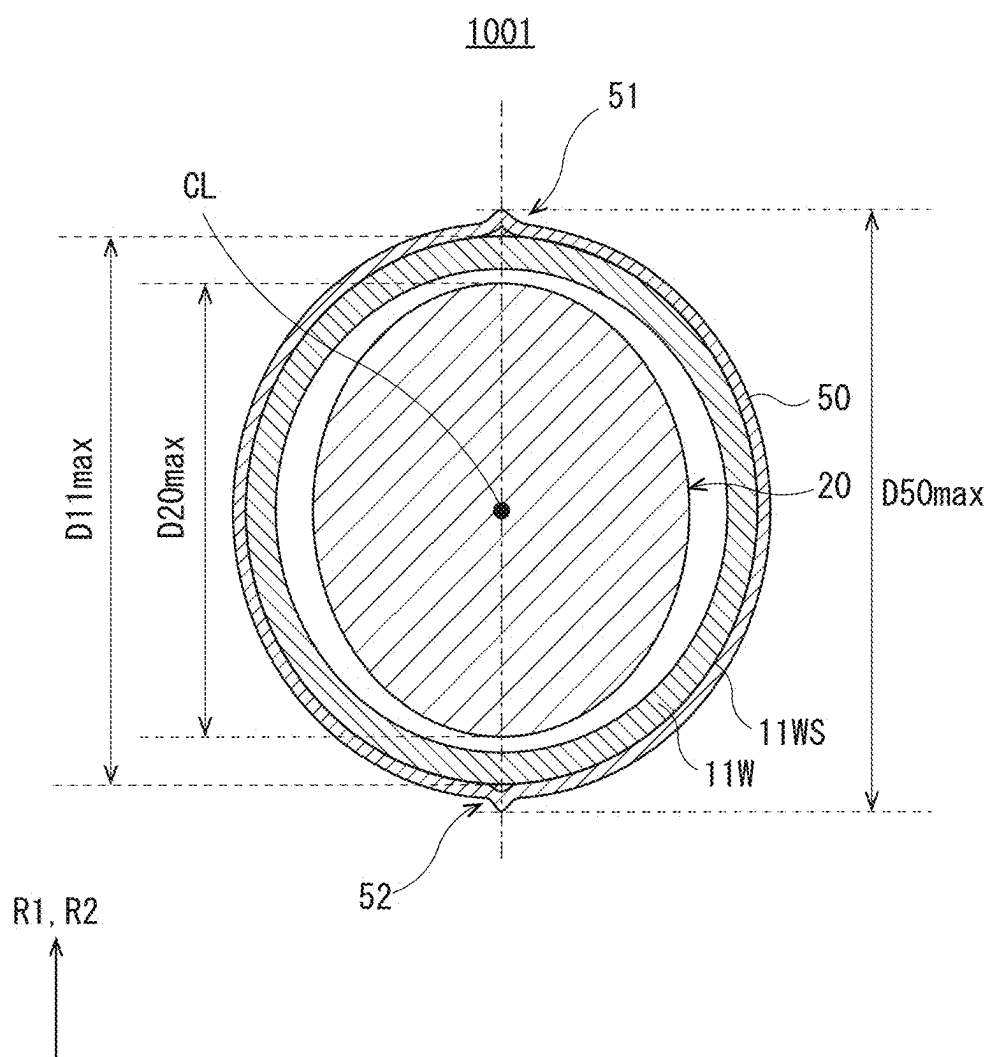
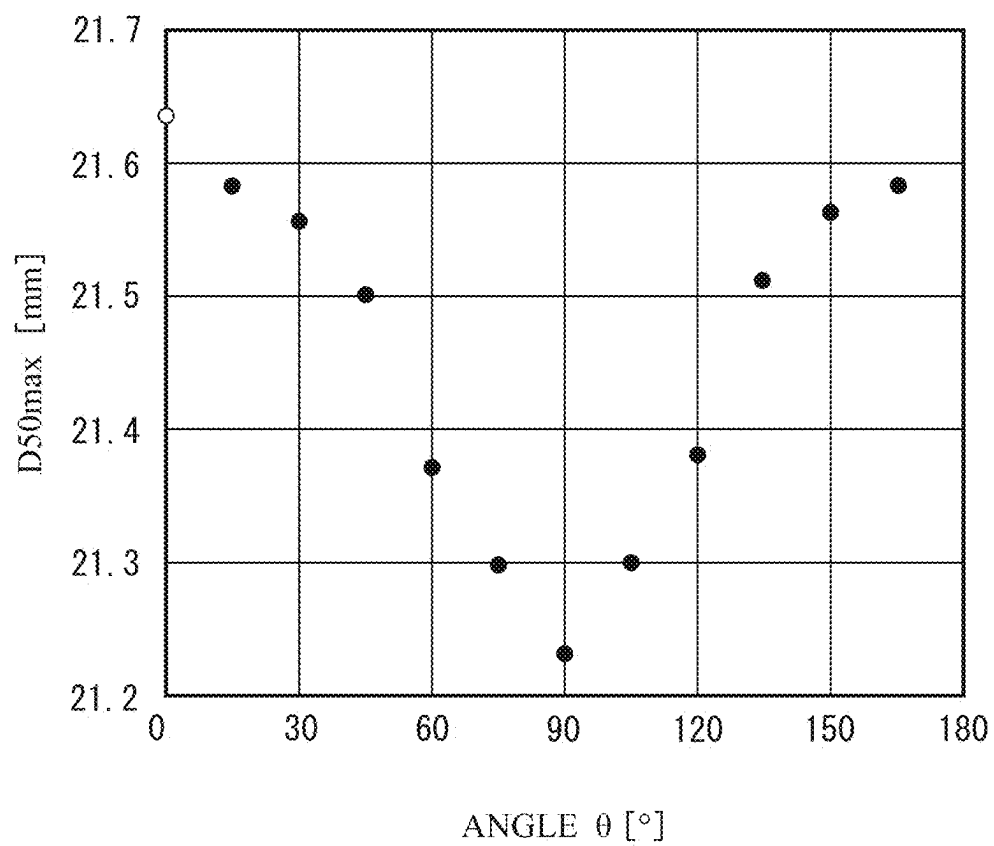


FIG. 11



SECONDARY BATTERY

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] The present application is a continuation of International Application No. PCT/JP2024/003380, filed on Feb. 2, 2024, which claims priority to Japanese Patent Application No. 2023-021782, filed on Feb. 15, 2023, the entire contents of which are incorporated herein by reference.

BACKGROUND

[0002] The present disclosure relates to a secondary battery.

[0003] Various kinds of electronic equipment, including mobile phones, have been widely used. Such widespread use has promoted development of a secondary battery as a power source that is smaller in size and lighter in weight and allows for a higher energy density. The secondary battery includes a battery device contained inside an outer package member. A configuration of the secondary battery has been considered in various ways.

[0004] In the secondary battery, charging and discharging causes expansion and contraction of the battery device. This can damage a separator interposed between a positive electrode and a negative electrode included in the battery device, resulting in a decrease in charging and discharging cyclability characteristic. To address this, a battery device employs a wound elliptical shape as an attempt to improve the charging and discharging cyclability characteristic.

SUMMARY

[0005] The present disclosure relates to a secondary battery.

[0006] Consideration has thus been given in various ways to improve operation performance of a secondary battery. However, it is required to reduce a maximum outer diameter of the secondary battery without reducing a capacity of the secondary battery.

[0007] It is therefore desirable to provide a secondary battery that has a smaller maximum outer diameter.

[0008] A secondary battery according to an embodiment of the present disclosure includes an electrode wound body, a battery can, and an outer package tube. The electrode wound body includes a positive electrode and a negative electrode that are stacked on each other with a separator interposed between the positive electrode and the negative electrode and are wound around a central axis. The battery can has a circular columnar outer shape in which a height direction corresponds to a direction along the central axis. The battery can contains the electrode wound body. The outer package tube covers an outer peripheral surface of the battery can. Here, a first radial direction and a second radial direction differ from each other. The first radial direction is a direction in which an outer diameter of the battery can is maximum. The second radial direction is a direction in which an outer diameter of the outer package tube is maximum.

[0009] According to the secondary battery of an embodiment of the present disclosure, the first radial direction in which the outer diameter of the battery can is maximum and the second radial direction in which the outer diameter of the outer package tube covering the battery can is maximum differ from each other. This decreases a flattening of the

secondary battery and thereby makes it possible to suppress an increase in maximum outer diameter of the secondary battery.

[0010] Note that effects of the present disclosure are not necessarily limited to those described above and may include any of a series of effects described below in relation to the present disclosure.

BRIEF DESCRIPTION OF THE FIGURES

[0011] FIG. 1 is a sectional diagram illustrating a configuration of a secondary battery according to an embodiment of the present disclosure.

[0012] FIG. 2 is a schematic diagram illustrating a configuration example of a stacked body including a positive electrode, a negative electrode, and a separator illustrated in FIG. 1.

[0013] FIG. 3 is a horizontal sectional diagram illustrating a configuration example of a horizontal sectional structure of the electrode wound body illustrated in FIG. 1.

[0014] FIG. 4A is a developed view of the positive electrode illustrated in FIG. 1.

[0015] FIG. 4B is a sectional view of the positive electrode illustrated in FIG. 1.

[0016] FIG. 5A is a developed view of the negative electrode illustrated in FIG. 1.

[0017] FIG. 5B is a sectional view of the negative electrode illustrated in FIG. 1.

[0018] FIG. 6A is a plan view of a positive electrode current collector plate illustrated in FIG. 1.

[0019] FIG. 6B is a plan view of a negative electrode current collector plate illustrated in FIG. 1.

[0020] FIG. 7 is a horizontal sectional diagram schematically illustrating a horizontal sectional structure of the secondary battery illustrated in FIG. 1.

[0021] FIG. 8 is a perspective diagram describing a process of manufacturing the secondary battery illustrated in FIG. 1.

[0022] FIG. 9 is a block diagram illustrating a circuit configuration of a battery pack to which the secondary battery according to an embodiment of the present disclosure is applied.

[0023] FIG. 10 is a horizontal sectional diagram schematically illustrating a horizontal sectional structure of a secondary battery according to Comparative example 1-1.

[0024] FIG. 11 is a characteristic diagram illustrating a relationship between an angle and a maximum diameter of an outer package tube in a secondary battery of each of Examples 1-1 to 1-11 and Comparative example 1-1.

DETAILED DESCRIPTION

[0025] The present disclosure is described below in further detail including with reference to the drawings according to an embodiment.

[0026] A description is given first of a secondary battery according to an embodiment of the present disclosure.

[0027] In the present embodiment, a cylindrical lithium-ion secondary battery having an outer appearance of a cylindrical shape will be described as an example. However, the secondary battery of the present disclosure is not limited to the cylindrical lithium-ion secondary battery, and may be a lithium-ion secondary battery having an outer appearance

of a shape other than the cylindrical shape, or may be a battery in which an electrode reactant other than lithium is used.

[0028] Although a charge and discharge principle of the secondary battery is not particularly limited, the following description deals with a case where a battery capacity is obtained through insertion and extraction of the electrode reactant. The secondary battery includes a positive electrode, a negative electrode, and an electrolyte. In the secondary battery, to prevent precipitation of the electrode reactant on a surface of the negative electrode during charging, a charge capacity of the negative electrode is greater than a discharge capacity of the positive electrode. In other words, an electrochemical capacity per unit area of the negative electrode is set to be greater than an electrochemical capacity per unit area of the positive electrode.

[0029] Although not particularly limited in kind as described above, the electrode reactant is specifically a light metal such as an alkali metal or an alkaline earth metal. Examples of the alkali metal include lithium, sodium, and potassium. Examples of the alkaline earth metal include beryllium, magnesium, and calcium.

[0030] In the following, described as an example is a case where the electrode reactant is lithium. A secondary battery in which the battery capacity is obtained through insertion and extraction of lithium is what is called a lithium-ion secondary battery. In the lithium-ion secondary battery, lithium is inserted and extracted in an ionic state.

[0031] FIG. 1 illustrates a sectional configuration of a lithium-ion secondary battery 1 (hereinafter simply referred to as the secondary battery 1) according to the present embodiment along a height direction. The secondary battery 1 illustrated in FIG. 1 includes an outer package can 11 and an electrode wound body 20. The outer package can 11 serves as a battery can and has a circular columnar outer shape. The electrode wound body 20 serves as a battery device and is contained in the outer package can 11. The term “circular columnar” as used herein is not limited to a columnar shape in which a section orthogonal to the height direction has a circular shape, but also encompasses a columnar shape in which a section orthogonal to the height direction has an elliptical shape. The secondary battery 1 further includes an outer package tube 50 that covers an outer peripheral surface of the outer package can 11.

[0032] Specifically, the secondary battery 1 includes, inside the outer package can 11, a pair of insulating plates 12 and 13, the electrode wound body 20, a positive electrode current collector plate 24, and a negative electrode current collector plate 25, for example. The electrode wound body 20 is a structure in which a positive electrode 21 and a negative electrode 22 are stacked with a separator 23 interposed therebetween and are wound, for example. The electrode wound body 20 is impregnated with an electrolytic solution. The electrolytic solution is a liquid electrolyte. Note that the secondary battery 1 may further include a thermosensitive resistive (PTC) device, a reinforcing member, or both inside the outer package can 11.

[0033] The outer package can 11 has, for example, a hollow cylindrical structure with a lower end part and an upper end part in a Z-axis direction. The Z-axis direction is the height direction. The lower end part is closed, and the upper end part is open. Accordingly, the upper end part of the outer package can 11 is an open end part 11N, and the lower end part of the outer package can 11 is closed by a

bottom part 11B having a substantially circular plate shape. Provided between the open end part 11N and the bottom part 11B is a sidewall part 11W surrounding the electrode wound body 20. The outer package can 11 includes, for example, a metal material such as iron as a constituent material. Note that a surface of the outer package can 11 may be plated with, for example, a metal material such as nickel. The insulating plate 12 and the insulating plate 13 are so opposed to each other as to allow the electrode wound body 20 to be interposed therebetween in the Z-axis direction, for example. Note that in the present specification, the open end part 11N and the vicinity thereof may be referred to as an upper part of the secondary battery 1 in the Z-axis direction, and a region where the outer package can 11 is closed and the vicinity thereof may be referred to as a lower part of the secondary battery 1 in the Z-axis direction. The open end part 11N of the outer package can 11 is closed by a battery cover 14. The battery cover 14 will be described later.

[0034] The outer package tube 50 surrounds a side surface 11WS that is an outer surface of the sidewall part 11W of the outer package can 11. However, the outer package tube 50 may cover a bent part 11P provided at the upper end part of the outer package can 11, as illustrated in FIG. 1. The bent part 11P will be described later. Further, the outer package tube 50 may cover a portion of a bottom surface 11BS that is an outer surface of the bottom part 11B of the outer package can 11. The outer package tube 50 includes, for example, a thermally contractible insulating film that includes a material such as a polyester-based resin, a polyamide-based resin, or a thermoplastic elastomer resin.

[0035] A washer 55 is provided in a gap between the outer package tube 50 and the bent part 11P of the outer package can 11. The washer 55 is an insulating ring member that has an opening 55K in a middle region in a plane orthogonal to the height direction. Disposed in the opening 55K is a projecting part provided in a middle region of the battery cover 14. The washer 55 may include, for example, black modified polyphenylene ether as a constituent material.

[0036] Each of the insulating plates 12 and 13 is, for example, a dish-shaped plate having a surface perpendicular to a central axis CL of the electrode wound body 20, that is, a surface perpendicular to a Z-axis in FIG. 1. The insulating plates 12 and 13 are so disposed as to allow the electrode wound body 20 to be interposed therebetween.

[0037] For example, a structure in which the battery cover 14 and a safety valve mechanism 30 are crimped with a gasket 15 interposed therebetween, that is, a crimped structure 11R, is provided at the open end part 11N of the outer package can 11. The outer package can 11 is sealed by the battery cover 14, with the electrode wound body 20 and other components being contained inside the outer package can 11. The crimped structure 11R is what is called a crimp structure, and includes the bent part 11P serving as what is called a crimp part.

[0038] The battery cover 14 is a closing member that mainly closes the open end part 11N of the outer package can 11 in a state where the electrode wound body 20 and other components are contained inside the outer package can 11. The battery cover 14 includes a material similar to the material included in the outer package can 11, for example. In the middle region of the battery cover 14, provided is the projecting part that protrudes upward, i.e., in a +Z direction, for example. As a result, a peripheral region, i.e., a region

other than the middle region, of the battery cover **14** is in a state of being in contact with the safety valve mechanism **30**, for example.

[0039] The gasket **15** is a sealing member interposed mainly between the bent part **11P** of the outer package can **11** and the battery cover **14**. The gasket **15** seals a gap between the bent part **11P** and the battery cover **14**. Note that a surface of the gasket **15** may be coated with, for example, asphalt. The gasket **15** includes any one or more of insulating materials, for example. The insulating material is not particularly limited in kind, and examples thereof include a polymer material such as polybutylene terephthalate (PBT) or polypropylene (PP). In particular, the insulating material is preferably polybutylene terephthalate. One reason for this is that this allows the gap between the bent part **11P** and the battery cover **14** to be sufficiently sealed, with the outer package can **11** and the battery cover **14** being electrically separated from each other.

[0040] The safety valve mechanism **30** is adapted to cancel the sealed state of the outer package can **11** to thereby release a pressure inside the outer package can **11**, i.e., an internal pressure of the outer package can **11**, on an as-needed basis, mainly upon an increase in the internal pressure. Examples of a cause of the increase in the internal pressure of the outer package can **11** include a gas generated due to a decomposition reaction of the electrolytic solution upon charging and discharging. The internal pressure of the outer package can **11** can also increase due to heating from outside.

[0041] The electrode wound body **20** is a power generation device that causes charging and discharging reactions to proceed, and is contained inside the outer package can **11**. The electrode wound body **20** includes the positive electrode **21**, the negative electrode **22**, the separator **23**, and the electrolytic solution as a liquid electrolyte.

[0042] FIG. 2 is a developed view of the electrode wound body **20**, and schematically illustrates a portion of a stacked body **S20** including the positive electrode **21**, the negative electrode **22**, and the separator **23**. In the stacked body **S20** that corresponds to the electrode wound body **20** in an unwound state, the positive electrode **21** and the negative electrode **22** are stacked on each other with the separator **23** interposed therebetween. The separator **23** includes, for example, two bases, that is, a first separator member **23A** and a second separator member **23B**. Accordingly, the electrode wound body **20** includes the stacked body **S20** that is four-layered. In the four-layered stacked body **S20**, the positive electrode **21**, the first separator member **23A**, the negative electrode **22**, and the second separator member **23B** are stacked in order. Each of the positive electrode **21**, the first separator member **23A**, the negative electrode **22**, and the second separator member **23B** is a substantially band-shaped member in which a W-axis direction corresponds to a transverse direction and an L-axis direction corresponds to a longitudinal direction.

[0043] As illustrated in FIG. 3, the electrode wound body **20** may be the stacked body **S20** so wound around the central axis **CL** extending in the Z-axis direction as to form a spiral shape in a horizontal section orthogonal to the Z-axis direction. Here, the stacked body **S20** is wound in an orientation in which the W-axis direction substantially coincides with the Z-axis direction. Note that FIG. 3 illustrates a configuration example of the electrode wound body **20** along the horizontal section orthogonal to the Z-axis direc-

tion. Note that, for higher visibility, FIG. 3 omits illustration of the separator **23**. The electrode wound body **20** has an outer appearance of a substantially circular columnar shape as a whole. The positive electrode **21** and the negative electrode **22** are wound, remaining in a state of being opposed to each other with the separator **23** interposed therebetween. The electrode wound body **20** has a through hole **26** as an internal space at a center thereof. The through hole **26** is a hole into which a winding core for assembling the electrode wound body **20** and an electrode rod for welding are each to be put.

[0044] The positive electrode **21**, the negative electrode **22**, and the separator **23** are so wound that the separator **23** is positioned in each of an outermost wind of the electrode wound body **20** and an innermost wind of the electrode wound body **20**. Further, in the outermost wind of the electrode wound body **20**, the negative electrode **22** is positioned on an outer side relative to the positive electrode **21**. In other words, as illustrated in FIG. 3, an outermost positive electrode wind part **21out** that is positioned in an outermost wind of the positive electrode **21** included in the electrode wound body **20** is positioned on an inner side relative to an outermost negative electrode wind part **22out** that is positioned in an outermost wind of the negative electrode **22** included in the electrode wound body **20**. Here, the outermost positive electrode wind part **21out** is a part corresponding to the outermost one wind of the positive electrode **21** in the electrode wound body **20**. The outermost negative electrode wind part **22out** is a part corresponding to the outermost one wind of the negative electrode **22** in the electrode wound body **20**. In contrast, in the innermost wind of the electrode wound body **20**, the negative electrode **22** is positioned on the inner side relative to the positive electrode **21**. In other words, as illustrated in FIG. 3, an innermost negative electrode wind part **22in** that is positioned in an innermost wind of the negative electrode **22** included in the electrode wound body **20** is positioned on the inner side relative to an innermost positive electrode wind part **21in** that is positioned in an innermost wind of the positive electrode **21** included in the electrode wound body **20**. Here, the innermost positive electrode wind part **21in** is a part corresponding to the innermost one wind of the positive electrode **21** in the electrode wound body **20**. The innermost negative electrode wind part **22in** is a part corresponding to the innermost one wind of the negative electrode **22** in the electrode wound body **20**. The number of winds of each of the positive electrode **21**, the negative electrode **22**, and the separator **23** is not particularly limited, and may be chosen as desired.

[0045] FIG. 4A is a developed view of the positive electrode **21**, and schematically illustrates a state before being wound. FIG. 4B illustrates a sectional configuration of the positive electrode **21**. Note that FIG. 4B illustrates a section of the positive electrode **21** as viewed in an arrowed direction along line IVB-IVB illustrated in FIG. 4A. The positive electrode **21** includes, for example, a positive electrode current collector **21A**, and a positive electrode active material layer **21B** provided on the positive electrode current collector **21A**. For example, the positive electrode active material layer **21B** may be provided only on one of two opposite surfaces of the positive electrode current collector **21A**, or may be provided on each of the two opposite surfaces of the positive electrode current collector **21A**. FIG. 4B illustrates a case where the positive electrode active

material layer 21B is provided on each of the two opposite surfaces of the positive electrode current collector 21A. More specifically, the positive electrode current collector 21A includes an inward positive electrode current collector surface 21A1 facing toward a winding center side of the electrode wound body 20, that is, facing toward the central axis CL, and an outward positive electrode current collector surface 21A2 facing toward a side opposite to the winding center side of the electrode wound body 20, that is, positioned on a side opposite to the inward positive electrode current collector surface 21A1. The positive electrode 21 includes, as the positive electrode active material layers 21B, an inner winding side positive electrode active material layer 21B1 covering all or a part of the inward positive electrode current collector surface 21A1, and an outer winding side positive electrode active material layer 21B2 covering all or a part of the outward positive electrode current collector surface 21A2. Note that in the present specification, the inner winding side positive electrode active material layer 21B1 and the outer winding side positive electrode active material layer 21B2 may each be generically referred to as the positive electrode active material layer 21B, without being distinguished from each other.

[0046] The positive electrode 21 includes a positive electrode covered region 211 in which the positive electrode current collector 21A is covered with the positive electrode active material layer 21B, and a positive electrode exposed region 212 in which the positive electrode current collector 21A is exposed without being covered with the positive electrode active material layer 21B. As illustrated in FIG. 4A, the positive electrode covered region 211 and the positive electrode exposed region 212 each extend from a central axis side edge 21E1 of the positive electrode 21 to an outer winding side edge 21E2 of the positive electrode 21 along the L-axis direction, i.e., the longitudinal direction of the positive electrode 21. Here, the L-axis direction corresponds to a winding direction of the electrode wound body 20. In other words, in the positive electrode 21, the positive electrode current collector 21A is covered with the positive electrode active material layer 21B from the central axis side edge 21E1 of the positive electrode 21 to the outer winding side edge 21E2 of the positive electrode 21 in the winding direction of the electrode wound body 20. The positive electrode covered region 211 and the positive electrode exposed region 212 are adjacent to each other in the W-axis direction, i.e., the transverse direction of the positive electrode 21. The W-axis direction substantially coincides with the central axis CL. Further, as illustrated in FIG. 3, in the electrode wound body 20, the central axis side edge 21E1 of the innermost positive electrode wind part 21in is positioned to be inwardly retracted relative to a central axis side edge 22E1 of the innermost negative electrode wind part 22in. The positive electrode 21 further has a lower edge 21E3 that extends in the L-axis direction on a lower side of the electrode wound body 20.

[0047] An insulating layer 101 is preferably provided in a region including a border between the positive electrode covered region 211 and the positive electrode exposed region 212 and the vicinity of the border. As with the positive electrode covered region 211 and the positive electrode exposed region 212, the insulating layer 101 also preferably extends from the central axis side edge 21E1 to the outer winding side edge 21E2 in the electrode wound body 20. Further, the insulating layer 101 is preferably

adhered to the first separator member 23A, the second separator member 23B, or both. One reason for this is that this makes it possible to prevent the positive electrode 21 and the separator 23 from becoming misaligned with each other. Further, the insulating layer 101 preferably includes a resin including polyvinylidene difluoride (PVDF). One reason for this is that when the insulating layer 101 includes PVDF, the insulating layer 101 is swollen by, for example, a solvent included in the electrolytic solution, which allows the insulating layer 101 to be favorably adhered to the separator 23. Note that a detailed configuration of the positive electrode 21 will be described later.

[0048] FIG. 5A is a developed view of the negative electrode 22, and schematically illustrates a state before being wound. FIG. 5B illustrates a sectional configuration of the negative electrode 22. Note that FIG. 5B illustrates a section of the negative electrode 22 as viewed in an arrowed direction along line VB-VB illustrated in FIG. 5A. The negative electrode 22 includes, for example, a negative electrode current collector 22A, and a negative electrode active material layer 22B provided on the negative electrode current collector 22A. For example, the negative electrode active material layer 22B may be provided only on one of two opposite surfaces of the negative electrode current collector 22A, or may be provided on each of the two opposite surfaces of the negative electrode current collector 22A. FIG. 5B illustrates a case where the negative electrode active material layer 22B is provided on each of the two opposite surfaces of the negative electrode current collector 22A. More specifically, the negative electrode current collector 22A includes an inward negative electrode current collector surface 22A1 facing toward the winding center side of the electrode wound body 20, that is, facing toward the central axis CL, and an outward negative electrode current collector surface 22A2 facing toward the side opposite to the winding center side of the electrode wound body 20, that is, positioned on a side opposite to the inward negative electrode current collector surface 22A1. The negative electrode 22 includes, as the negative electrode active material layers 22B, an inner winding side negative electrode active material layer 22B1 covering all or a part of the inward negative electrode current collector surface 22A1, and an outer winding side negative electrode active material layer 22B2 covering all or a part of the outward negative electrode current collector surface 22A2. Note that in the present specification, the inner winding side negative electrode active material layer 22B1 and the outer winding side negative electrode active material layer 22B2 may each be generically referred to as the negative electrode active material layer 22B, without being distinguished from each other.

[0049] The negative electrode 22 includes a negative electrode covered region 221 in which the negative electrode current collector 22A is covered with the negative electrode active material layer 22B, and a negative electrode exposed region 222 in which the negative electrode current collector 22A is exposed without being covered with the negative electrode active material layer 22B. As illustrated in FIG. 5A, the negative electrode covered region 221 and the negative electrode exposed region 222 each extend along the L-axis direction, i.e., the longitudinal direction of the negative electrode 22. The negative electrode exposed region 222 extends from the central axis side edge 22E1 of the negative electrode 22 to an outer winding side edge 22E2 of the

negative electrode 22 in the winding direction of the electrode wound body 20. In contrast, the negative electrode covered region 221 is provided at neither the central axis side edge 22E1 of the negative electrode 22 nor the outer winding side edge 22E2 of the negative electrode 22. As illustrated in FIG. 5A, portions of the negative electrode exposed region 222 are so provided as to allow the negative electrode covered region 221 to be interposed therebetween in the L-axis direction, i.e., the longitudinal direction of the negative electrode 22. Specifically, the negative electrode exposed region 222 includes a first part 222A, a second part 222B, and a third part 222C. The negative electrode 22 further has a lower edge 22E3 that extends in the L-axis direction on the lower side of the electrode wound body 20. The first part 222A is provided to be adjacent to the negative electrode covered region 221 in the W-axis direction, and extends from the central axis side edge 22E1 of the negative electrode 22 to the outer winding side edge 22E2 of the negative electrode 22 in the L-axis direction. The second part 222B and the third part 222C are so provided as to allow the negative electrode covered region 221 to be interposed therebetween in the L-axis direction. The first part 222A is positioned in a region including the lower edge 22E3 of the negative electrode 22 and the vicinity of the lower edge 22E3. The second part 222B is positioned in a region including the central axis side edge 22E1 of the negative electrode 22 and the vicinity of the central axis side edge 22E1, for example. The third part 222C is positioned in a region including the outer winding side edge 22E2 of the negative electrode 22 and the vicinity of the outer winding side edge 22E2. Note that FIGS. 5A and 5B each schematically illustrate the negative electrode current collector 22A in a state of being straightened along the W-axis direction. In actuality, however, as illustrated in FIG. 1, negative electrode edge parts 222E of the negative electrode exposed region 222 are bent toward the central axis CL and coupled to the negative electrode current collector plate 25. A detailed configuration of the negative electrode 22 will be described later.

[0050] In the stacked body S20 in the electrode wound body 20, the positive electrode 21 and the negative electrode 22 are so stacked with the separator 23 interposed therebetween that the positive electrode exposed region 212 and the first part 222A of the negative electrode exposed region 222 face toward mutually opposite directions along the W-axis direction, i.e., a width direction. In the electrode wound body 20, an end part of the separator 23 is fixed by attaching a fixing tape 46 to a side surface part 45 of the electrode wound body 20, which prevents loosening of winding.

[0051] In the secondary battery 1, as illustrated in FIG. 2, $A > B$ is preferably satisfied, where A is a width of the positive electrode exposed region 212, and B is a width of the first part 222A of the negative electrode exposed region 222. For example, when the width A is 7 (mm), the width B is 4 (mm). Further, $C > D$ is preferably satisfied, where C is a width of a portion of the positive electrode exposed region 212 protruding from an outer edge in the width direction of the separator 23, and D is a width of a portion of the first part 222A of the negative electrode exposed region 222 protruding from an opposite outer edge in the width direction of the separator 23. For example, when the width C is 4.5 (mm), the width D is 3 (mm).

[0052] As illustrated in FIG. 1, in the upper part of the secondary battery 1, multiple positive electrode edge parts

212E, of the positive electrode exposed region 212 wound around the central axis CL, that are adjacent to each other in a radial direction (an R direction) of the electrode wound body 20 are so bent toward the central axis CL as to overlap each other to thereby form an upper end face 41 of the electrode wound body 20. Similarly, in the lower part of the secondary battery 1, the multiple negative electrode edge parts 222E, of the negative electrode exposed region 222 wound around the central axis CL, that are adjacent to each other in the radial direction (the R direction) are so bent toward the central axis CL as to overlap each other to thereby form a lower end face 42 of the electrode wound body 20. Accordingly, the multiple positive electrode edge parts 212E of the positive electrode exposed region 212 gather at the upper end face 41 of the electrode wound body 20, and the multiple negative electrode edge parts 222E of the negative electrode exposed region 222 gather at the lower end face 42 of the electrode wound body 20. To achieve better contact between the positive electrode current collector plate 24 that is provided for extracting a current and the multiple positive electrode edge parts 212E, the multiple positive electrode edge parts 212E are bent toward the central axis CL and form a flat surface. Similarly, to achieve better contact between the negative electrode current collector plate 25 that is provided for extracting a current and the multiple negative electrode edge parts 222E, the multiple negative electrode edge parts 222E are bent toward the central axis CL and form a flat surface. Note that as used herein, the term “flat surface” encompasses not only a completely flat surface but also a surface having some asperities or surface roughness to the extent that joining of the positive electrode exposed region 212 to the positive electrode current collector plate 24 and joining of the negative electrode exposed region 222 to the negative electrode current collector plate 25 are possible.

[0053] The positive electrode current collector 21A includes, for example, an aluminum foil, as will be described later. In contrast, the negative electrode current collector 22A includes, for example, a copper foil, as will be described later. In this case, the positive electrode current collector 21A is softer than the negative electrode current collector 22A. In other words, the positive electrode exposed region 212 has a Young's modulus lower than a Young's modulus of the negative electrode exposed region 222. Accordingly, in an embodiment, it is more preferable that the widths A to D satisfy a relationship of $A > B$ and $C > D$. In such a case, when the positive electrode exposed region 212 and the negative electrode exposed region 222 are simultaneously bent with equal pressures from respective electrode sides, the bent portion in the positive electrode 21 and the bent portion in the negative electrode 22 may sometimes have substantially equal heights measured from respective ends of the separator 23. In this case, the multiple positive electrode edge parts 212E (FIG. 1) of the positive electrode exposed region 212 appropriately overlap each other by being bent. This allows for easy joining of the positive electrode exposed region 212 and the positive electrode current collector plate 24 to each other. Similarly, the multiple negative electrode edge parts 222E (FIG. 1) of the negative electrode exposed region 222 appropriately overlap each other by being bent. This allows for easy joining of the negative electrode exposed region 222 and the negative electrode current collector plate 25 to each other. As used

herein, the term “joining” refers to coupling by, for example, laser welding; however, a method of joining is not limited to laser welding.

[0054] As illustrated in FIG. 2, a portion, of the positive electrode exposed region 212 of the positive electrode 21, that is opposed to the negative electrode 22 with the separator 23 interposed therebetween is covered with the insulating layer 101. The insulating layer 101 has a width of 3 mm in the W-axis direction, for example. The insulating layer 101 entirely covers the portion, of the positive electrode exposed region 212 of the positive electrode 21, that is opposed to the negative electrode covered region 221 of the negative electrode 22 with the separator 23 interposed therebetween. The insulating layer 101 makes it possible to effectively prevent an internal short circuit of the secondary battery 1 when foreign matter enters between the negative electrode covered region 221 and the positive electrode exposed region 212, for example. Further, when the secondary battery 1 undergoes an impact, the insulating layer 101 absorbs the impact and thereby makes it possible to effectively prevent bending of the positive electrode exposed region 212 and a short circuit between the positive electrode exposed region 212 and the negative electrode 22.

[0055] The secondary battery 1 may further include insulating tapes 53 and 54 in a gap between the outer package can 11 and the electrode wound body 20. The positive electrode exposed region 212 having the parts gathering at the upper end face 41 and the negative electrode exposed region 222 having the parts gathering at the lower end face 42 are electrical conductors, such as metal foils, that are exposed. Accordingly, if the positive electrode exposed region 212 and the negative electrode exposed region 222 are in proximity to the outer package can 11, a short circuit between the positive electrode 21 and the negative electrode 22 can occur via the outer package can 11. A short circuit can also occur when the positive electrode current collector plate 24 on the upper end face 41 and the outer package can 11 come into proximity to each other. Therefore, the insulating tapes 53 and 54 are preferably provided as insulating members. Each of the insulating tapes 53 and 54 is, for example, an adhesive tape including a base layer, and an adhesive layer provided on one surface of the base layer. The base layer includes, for example, any of polypropylene, polyethylene terephthalate, or polyimide. To prevent the provision of the insulating tapes 53 and 54 from resulting in a decreased capacity of the electrode wound body 20, the insulating tapes 53 and 54 are disposed not to overlap the fixing tape 46 attached to the side surface part 45, and a thickness of each of the insulating tapes 53 and 54 is set to be less than or equal to a thickness of the fixing tape 46.

[0056] In a typical lithium-ion secondary battery, for example, a lead for current extraction is welded to one location on each of the positive electrode and the negative electrode. However, such a structure increases the internal resistance of the lithium-ion secondary battery and causes the lithium-ion secondary battery to generate heat and become hot upon discharging; therefore, the structure is unsuitable for high-rate discharging. To address this, in the secondary battery 1 according to the present embodiment, the positive electrode current collector plate 24 is disposed to face the upper end face 41, and the negative electrode current collector plate 25 is disposed to face the lower end face 42. In addition, the parts of the positive electrode exposed region 212 present at the upper end face 41 and the

positive electrode current collector plate 24 are welded to each other at multiple points, and the parts of the negative electrode exposed region 222 present at the lower end face 42 and the negative electrode current collector plate 25 are welded to each other at multiple points. A reduced internal resistance of the secondary battery 1 is thereby achieved. Each of the upper end face 41 and the lower end face 42 is a flat surface, as described above, which also contributes to the reduced resistance. The positive electrode current collector plate 24 is electrically coupled to the battery cover 14 via the safety valve mechanism 30, for example. The negative electrode current collector plate 25 is electrically coupled to the outer package can 11, for example. FIG. 6A is a schematic diagram illustrating a configuration example of the positive electrode current collector plate 24. FIG. 6B is a schematic diagram illustrating a configuration example of the negative electrode current collector plate 25. The positive electrode current collector plate 24 is a metal plate including, for example, aluminum or an aluminum alloy as a single component, or a composite material of aluminum and the aluminum alloy. The negative electrode current collector plate 25 is a metal plate including, for example, nickel, a nickel alloy, copper, or a copper alloy as a single component, or a composite material of two or more thereof.

[0057] As illustrated in FIG. 6A, the positive electrode current collector plate 24 has a shape in which a band-shaped part 32 having a substantially rectangular shape is coupled to a fan-shaped part 31 having a substantially fan shape. The fan-shaped part 31 has a through hole 35 in the vicinity of a middle thereof. In the secondary battery 1, the positive electrode current collector plate 24 is provided to allow the through hole 35 to overlap the through hole 26 in the Z-axis direction. A hatched portion in FIG. 6A represents an insulating part 32A of the band-shaped part 32. The insulating part 32A is a portion of the band-shaped part 32 and has an insulating tape attached thereto or an insulating material applied thereto. Of the band-shaped part 32, a portion below the insulating part 32A is a coupling part 32B to be coupled to a sealing plate that also serves as an external terminal. Note that when the secondary battery 1 has a battery structure without a metallic center pin in the through hole 26 as illustrated in FIG. 1, there is a low possibility that the band-shaped part 32 will come into contact with a region of a negative electrode potential. In such a case, the positive electrode current collector plate 24 does not have to include the insulating part 32A. When the positive electrode current collector plate 24 does not include the insulating part 32A, it is possible to increase a width of each of the positive electrode 21 and the negative electrode 22 by an amount corresponding to a thickness of the insulating part 32A to thereby increase a charge and discharge capacity.

[0058] The negative electrode current collector plate 25 illustrated in FIG. 6B has a shape similar to the shape of the positive electrode current collector plate 24 illustrated in FIG. 6A. Note that the negative electrode current collector plate 25 has a band-shaped part 34 different from the band-shaped part 32 of the positive electrode current collector plate 24. The band-shaped part 34 of the negative electrode current collector plate 25 is shorter than the band-shaped part 32 of the positive electrode current collector plate 24, and includes no portion corresponding to the insulating part 32A of the positive electrode current collector plate 24. The band-shaped part 34 is provided with projections 37 that each have a round shape and that are depicted

as multiple circles. Upon resistance welding, a current concentrates on the projections 37, which causes the projections 37 to melt to cause the band-shaped part 34 to be welded to a bottom of the outer package can 11. As with the positive electrode current collector plate 24, the negative electrode current collector plate 25 has a through hole 36 in the vicinity of a middle of a fan-shaped part 33. In the secondary battery 1, the negative electrode current collector plate 25 is provided to allow the through hole 36 to overlap the through hole 26 in the Z-axis direction.

[0059] The fan-shaped part 31 of the positive electrode current collector plate 24 covers only a portion of the upper end face 41, owing to a plan shape of the fan-shaped part 31. Similarly, the fan-shaped part 33 of the negative electrode current collector plate 25 covers only a portion of the lower end face 42, owing to a plan shape of the fan-shaped part 33. Reasons why the fan-shaped part 31 does not entirely cover the upper end face 41 and why the fan-shaped part 33 does not entirely cover the lower end face 42 include the following two reasons, for example. A first reason is to allow the electrolytic solution to smoothly permeate the electrode wound body 20 in assembling the secondary battery 1, for example. A second reason is to allow a gas generated when the lithium-ion secondary battery comes into an abnormally hot state or an overcharged state to be easily released to the outside.

[0060] The positive electrode current collector 21A includes an electrically conductive material such as aluminum, for example. The positive electrode current collector 21A is a metal foil including aluminum or an aluminum alloy, for example.

[0061] The positive electrode active material layer 21B includes, as a positive electrode active material, any one or more of positive electrode materials into which lithium is insertable and from which lithium is extractable. Note that the positive electrode active material layer 21B may further include any one or more of other materials. Examples of the other materials include a positive electrode binder and a positive electrode conductor. It is preferable that the positive electrode material be a lithium-containing compound, and more specifically, a lithium-containing composite oxide or a lithium-containing phosphoric acid compound, for example. The lithium-containing composite oxide is an oxide including lithium and one or more of other elements, that is, one or more of elements other than lithium, as constituent elements. The lithium-containing composite oxide has any of crystal structures including, without limitation, a layered rock-salt crystal structure and a spinel crystal structure, for example. The lithium-containing phosphoric acid compound is a phosphoric acid compound including lithium and one or more of other elements as constituent elements, and has a crystal structure such as an olivine crystal structure, for example. The positive electrode active material layer 21B preferably includes, as the positive electrode active material, at least one of lithium cobalt oxide, lithium nickel cobalt manganese oxide, or lithium nickel cobalt aluminum oxide, in particular. The positive electrode binder includes, for example, any one or more of materials including, without limitation, a synthetic rubber and a polymer compound. Examples of the synthetic rubber include a styrene-butadiene-based rubber, a fluorine-based rubber, and ethylene propylene diene. Examples of the polymer compound include polyvinylidene difluoride and polyimide. The positive electrode conductor includes, for example, any one or

more of materials including, without limitation, a carbon material. Examples of the carbon material include graphite, carbon black, acetylene black, and Ketjen black. Note that the positive electrode conductor may be any of electrically conductive materials, and may be, for example, a metal material or an electrically conductive polymer.

[0062] The negative electrode current collector 22A includes an electrically conductive material such as copper, for example. The negative electrode current collector 22A is a metal foil including, for example, nickel, a nickel alloy, copper, or a copper alloy. A surface of the negative electrode current collector 22A is preferably roughened. One reason for this is that this improves adherence of the negative electrode active material layer 22B to the negative electrode current collector 22A owing to what is called an anchor effect. In this case, the surface of the negative electrode current collector 22A is to be roughened at least in a region facing the negative electrode active material layer 22B. Examples of a roughening method include a method in which microparticles are formed through an electrolytic treatment. In the electrolytic treatment, the microparticles are formed on the surface of the negative electrode current collector 22A by an electrolytic method in an electrolyzer. This provides the surface of the negative electrode current collector 22A with asperities. A copper foil produced by the electrolytic method is generally called an electrolytic copper foil.

[0063] The negative electrode active material layer 22B includes, as a negative electrode active material, any one or more of negative electrode materials into which lithium is insertable and from which lithium is extractable. Note that the negative electrode active material layer 22B may further include any one or more of other materials. Examples of the other materials include a negative electrode binder and a negative electrode conductor. For example, the negative electrode material is a carbon material. One reason for this is that the carbon material exhibits very little change in crystal structure at the time of insertion and extraction of lithium, and a high energy density is thus obtainable stably. Another reason is that the carbon material also serves as a negative electrode conductor, which allows the negative electrode active material layer 22B to be improved in electrically conductive property. Examples of the carbon material include graphitizable carbon, non-graphitizable carbon, and graphite. Note that spacing of a (002) plane of the non-graphitizable carbon is preferably 0.37 nm or greater. Spacing of a (002) plane of the graphite is preferably 0.34 nm or less. More specific examples of the carbon material include pyrolytic carbons, cokes, glassy carbon fibers, an organic polymer compound fired body, activated carbon, and carbon blacks. Examples of the cokes include pitch coke, needle coke, and petroleum coke. The organic polymer compound fired body is a resultant of firing or carbonizing a polymer compound such as a phenol resin or a furan resin at a suitable temperature. Other than the above, the carbon material may be low-crystalline carbon heat-treated at a temperature of about 1000° C. or lower, or may be amorphous carbon. Note that the carbon material may have any of a fibrous shape, a spherical shape, a granular shape, and a flaky shape. In the secondary battery 1, when an open circuit voltage in a fully charged state, that is, a battery voltage is 4.25 V or higher, the amount of extracted lithium per unit mass increases as compared with when the open circuit voltage in the fully charged state is 4.20 V, even with

the same positive electrode active material. The amount of the positive electrode active material and the amount of the negative electrode active material are therefore adjusted accordingly. This makes it possible to obtain a high energy density.

[0064] The negative electrode active material layer **22B** may include, as the negative electrode active material, a silicon-containing material including at least one of silicon, silicon oxide, a carbon-silicon compound, or a silicon alloy. The term “silicon-containing material” is a generic term for a material that includes silicon as a constituent element. Note that the silicon-containing material may include only silicon as the constituent element. One silicon-containing material may be used, or two or more silicon-containing materials may be used. The silicon-containing material is able to form an alloy with lithium, and may be a simple substance of silicon, a silicon alloy, a silicon compound, a mixture of two or more thereof, or a material including one or more phases thereof. Further, the silicon-containing material may be crystalline or amorphous, or may include both a crystalline part and an amorphous part. Note that the simple substance described here refers to a simple substance merely in a general sense. The simple substance may thus include a small amount of impurity. In other words, purity of the simple substance is not limited to 100%. The silicon alloy includes, as one or more constituent elements other than silicon, any one or more of elements including, without limitation, tin, nickel, copper, iron, cobalt, manganese, zinc, indium, silver, titanium, germanium, bismuth, antimony, and chromium, for example. The silicon compound includes, as one or more constituent elements other than silicon, any one or more of elements including, without limitation, carbon and oxygen, for example. Note that the silicon compound may include, as one or more constituent elements other than silicon, any one or more of the series of constituent elements described above in relation to the silicon alloy, for example. Specific examples of the silicon alloy and the silicon compound include SiB_4 , SiB_6 , Mg_2Si , Ni_2Si , TiSi_2 , MoSi_2 , CoSi_2 , NiSi_2 , CaSi_2 , CrSi_2 , CuSi , FeSi_2 , MnSi_2 , NbSi_2 , TaSi_2 , VSi_2 , WSi_2 , ZnSi_2 , SiC , Si_3N_4 , $\text{Si}_2\text{N}_2\text{O}$, and SiO_v (where $0 < v \leq 2$). Note that v may be set within any desired range, and may, for example, fall within the following range: $0.2 < v < 1.4$.

[0065] The separator **23** is interposed between the positive electrode **21** and the negative electrode **22**. The separator **23** allows lithium ions to pass through and prevents a short circuit of a current caused by contact between the positive electrode **21** and the negative electrode **22**. The separator **23** includes, for example, any one or more kinds of porous films each including, for example, a synthetic resin or a ceramic, and may include a stacked film of two or more kinds of porous films. Examples of the synthetic resin include polytetrafluoroethylene, polypropylene, and polyethylene. Note that the separator **23** preferably includes the bases that each include a single-layer polyolefin porous film including polyethylene. One reason for this is that a favorable high output characteristic is obtainable as compared with a stacked film. When the first separator member **23A** and the second separator member **23B** included in the separator **23** each include a single-layer porous film including polyolefin, the porous film preferably has a thickness of greater than or equal to $10\text{ }\mu\text{m}$ and less than or equal to $15\text{ }\mu\text{m}$, for example. An internal short circuit is sufficiently avoidable if the single-layer porous film including polyolefin has a thickness

of greater than or equal to $10\text{ }\mu\text{m}$. A more favorable discharge capacity characteristic is achievable if the thickness of the single-layer porous film including polyolefin is less than or equal to $15\text{ }\mu\text{m}$. Further, the porous film preferably has a surface density of greater than or equal to 6.3 g/m^2 and less than or equal to 8.3 g/m^2 , for example. An internal short circuit is sufficiently avoidable if the surface density of the single-layer porous film including polyolefin is greater than or equal to 6.3 g/m^2 . A more favorable discharge capacity characteristic is achievable if the surface density of the single-layer porous film including polyolefin is less than or equal to 8.3 g/m^2 .

[0066] In particular, the separator **23** may include, for example, the porous film as each of the above-described bases, and a polymer compound layer provided on one of or each of two opposite surfaces of each of the bases. One reason for this is that adherence of the separator **23** to each of the positive electrode **21** and the negative electrode **22** improves, which suppresses distortion of the electrode wound body **20**. As a result, a decomposition reaction of the electrolytic solution is suppressed, and leakage of the electrolytic solution with which the bases are impregnated is also suppressed. This prevents an easy increase in resistance even upon repeated charging and discharging, and also suppresses swelling of the battery. The polymer compound layer includes a polymer compound such as polyvinylidene difluoride, for example. One reason for this is that the polymer compound such as polyvinylidene difluoride has superior physical strength and is electrochemically stable. Note that the polymer compound may be other than polyvinylidene difluoride. To form the polymer compound layer, for example, a solution in which the polymer compound is dissolved in a solvent such as an organic solvent is applied on the base layer, following which the base is dried. Alternatively, the base may be immersed in the solution and thereafter dried. The polymer compound layer may include any one or more kinds of insulating particles such as inorganic particles, for example. Examples of the kind of the inorganic particles include aluminum oxide and aluminum nitride.

[0067] The electrolytic solution includes a solvent and an electrolyte salt. Note that the electrolytic solution may further include any one or more of other materials. Examples of the other materials include an additive. The solvent includes any one or more of nonaqueous solvents including, without limitation, an organic solvent. An electrolytic solution including a nonaqueous solvent is what is called a nonaqueous electrolytic solution. The nonaqueous solvent includes a fluorine compound and a dinitrile compound, for example. The fluorine compound includes, for example, at least one of fluorinated ethylene carbonate, trifluorocarbonate, trifluoroethyl methyl carbonate, a fluorinated carboxylic acid ester, or a fluorine ether. The nonaqueous solvent may further include at least one of nitrile compounds other than the dinitrile compound. Examples of the nitrile compounds other than the dinitrile compound include a mononitrile compound and a trinitrile compound. For example, succinonitrile (SN) is preferable as the dinitrile compound. Note that the dinitrile compound is not limited to succinonitrile, and may be another dinitrile compound such as adiponitrile.

[0068] The electrolyte salt includes, for example, any one or more of salts including, without limitation, a lithium salt. Note that the electrolyte salt may include a salt other than the lithium salt, for example. Examples of the salt other than the

lithium salt include a salt of a light metal other than lithium. Examples of the lithium salt include lithium hexafluorophosphate (LiPF_6), lithium tetrafluoroborate (LiBF_4), lithium perchlorate (LiClO_4), lithium hexafluoroarsenate (LiAsF_6), lithium tetraphenylborate ($\text{LiB}(\text{C}_6\text{H}_5)_4$), lithium methanesulfonate (LiCH_3SO_3), lithium trifluoromethanesulfonate (LiCF_3SO_3), lithium tetrachloroaluminate (LiAlCl_4), dilithium hexafluorosilicate (Li_2SiF_6), lithium chloride (LiCl), and lithium bromide (LiBr). In particular, the lithium salt is preferably any one or more of lithium hexafluorophosphate, lithium tetrafluoroborate, lithium perchlorate, or lithium hexafluoroarsenate, and more preferably, lithium hexafluorophosphate. Although not particularly limited, a content of the electrolyte salt is preferably within a range from 0.3 mol/kg to 3 mol/kg both inclusive with respect to the solvent, in particular. When the electrolytic solution includes LiPF_6 as the electrolyte salt, a concentration of LiPF_6 in the electrolytic solution is preferably higher than or equal to 1.25 mol/kg and lower than or equal to 1.45 mol/kg. One reason for this is that this makes it possible to prevent cycle deterioration caused by consumption, or decomposition, of the salt at the time of high load rate charging, and thus allows for improvement in high-load cyclability characteristic. When the electrolytic solution further includes LiBF_4 in addition to LiPF_6 as the electrolyte salt, a concentration of LiBF_4 in the electrolytic solution is preferably higher than or equal to 0.001 (wt %) and lower than or equal to 0.1 (wt %). One reason for this is that this makes it possible to more effectively prevent the cycle deterioration caused by consumption, or decomposition, of the salt at the time of high load rate charging, and thus allows for further improvement in high-load cyclability characteristic.

[0069] FIG. 7 schematically illustrates a structure at a horizontal section orthogonal to the central axis CL of the secondary battery 1. FIG. 7 illustrates only the electrode wound body 20, the outer package can 11, and the outer package tube 50, and omits illustration of other components. Further, FIG. 7 illustrates the electrode wound body 20 not with a detailed configuration, but to a degree that allows for understanding of an outer shape of the electrode wound body 20.

[0070] In the secondary battery 1, the outer package can 11 has a horizontal sectional shape that is substantially elliptical, as illustrated in FIG. 7. Here, a first radial direction in which an outer diameter of the outer package can 11 becomes maximum in the horizontal section is referred to as a radial direction R1. In FIG. 7, the radial direction R1 corresponds to an up-down direction of a sheet plane. The outer package can 11 has a maximum diameter D11max along the radial direction R1. In addition, the electrode wound body 20 contained inside the outer package can 11 also has a horizontal sectional shape that is substantially elliptical. As illustrated in FIG. 7, a third radial direction in which an outer diameter of the electrode wound body 20 becomes maximum in the horizontal section substantially coincides with the radial direction R1 (the first radial direction) in which the outer diameter of the outer package can 11 becomes maximum. In the example illustrated in FIG. 7, the electrode wound body 20 has a maximum diameter D20max along the radial direction R1. One reason for this is that the horizontal sectional shape of the outer package can 11 tends to be similar to the horizontal sectional shape of the electrode wound body 20. The horizontal sectional shape of the

outer package can 11, however, has a flattening smaller than a flattening of the horizontal sectional shape of the electrode wound body 20. Note that in FIG. 7, although there is a space between the outer package can 11 and the electrode wound body 20, in actuality, the space is filled with components including, without limitation, the separator 23 and the fixing tape 46. Accordingly, in the secondary battery 1, expansion and contraction of the electrode wound body 20 caused by repetitive charging and discharging causes the horizontal sectional shape of the outer package can 11 to become similar to the horizontal sectional shape of the electrode wound body 20.

[0071] In contrast, in the secondary battery 1, a second radial direction in which an outer diameter of the outer package tube 50 becomes maximum in the horizontal section orthogonal to the central axis CL differs from the radial direction R1. Hereinafter, the second radial direction is referred to as a radial direction R2. It suffices that an angle θ formed by the radial direction R1 and the radial direction R2 is greater than 0° and less than 180° . However, the angle θ is preferably greater than or equal to 30° and less than or equal to 150° . As illustrated in FIG. 7, the outer package tube 50 has a maximum diameter D50max along the radial direction R2. The outer package tube 50 includes one or two projecting parts protruding in the radial direction R2. In the example illustrated in FIG. 7, the outer package tube 50 includes two projecting parts 51 and 52. Note that the projecting parts 51 and 52 are provided at respective positions that are opposite to each other on a virtual straight line passing through the central axis CL and extending along the radial direction R2. Each of the projecting parts 51 and 52 is, for example, a part in which portions of the thermally contractible insulating film lie over each other and is, for example, a wrinkled part resulting from thermal contraction of the thermally contractible insulating film. A location where such a wrinkled part is formed upon the thermal contraction is controllable by making a fold in advance in the insulating film before the thermal contraction. The projecting parts 51 and 52 each extend continuously from an upper part to a lower part of the outer package can 11 substantially along the height direction Z. The outer package tube 50 has a maximum thickness in a part in which the outer diameter of the outer package tube 50 becomes maximum, i.e., in which the outer package tube 50 has the maximum diameter D50max.

[0072] In the secondary battery 1 according to the present embodiment, for example, upon charging, lithium ions are extracted from the positive electrode 21, and the extracted lithium ions are inserted into the negative electrode 22 via the electrolytic solution. In the secondary battery 1, for example, upon discharging, lithium ions are extracted from the negative electrode 22, and the extracted lithium ions are inserted into the positive electrode 21 via the electrolytic solution.

[0073] A method of manufacturing the secondary battery 1 will be described with reference to FIG. 8 as well as FIGS. 1 to 7. FIG. 8 is a perspective diagram describing a process of manufacturing the secondary battery illustrated in FIG. 1.

[0074] First, the positive electrode current collector 21A is prepared, and the positive electrode active material layer 21B is selectively formed on the surface of the positive electrode current collector 21A to thereby form the positive electrode 21 including the positive electrode covered region 211 and the positive electrode exposed region 212. There-

after, the negative electrode current collector **22A** is prepared, and the negative electrode active material layer **22B** is selectively formed on the surface of the negative electrode current collector **22A** to thereby form the negative electrode **22** including the negative electrode covered region **221** and the negative electrode exposed region **222**. The positive electrode **21** and the negative electrode **22** may be subjected to a drying process. Thereafter, the positive electrode **21** and the negative electrode **22** are stacked, with the first separator member **23A** and the second separator member **23B** on the positive electrode **21** and the negative electrode **22**, respectively, to cause the positive electrode exposed region **212** and the first part **222A** of the negative electrode exposed region **222** to be on opposite sides to each other in the W-axis direction. The stacked body **S20** is thereby fabricated. Thereafter, the stacked body **S20** is so wound in a spiral shape as to form the through hole **26**. In addition, the fixing tape **46** is attached to an outermost wind of the stacked body **S20** wound in the spiral shape. The electrode wound body **20** is thus obtained as illustrated in part (A) of FIG. 8.

[0075] Thereafter, as illustrated in part (B) of FIG. 8, a portion of the upper end face **41** and a portion of the lower end face **42** of the electrode wound body **20** are each locally bent by pressing an end of, for example, a 0.5-millimeter-thick flat plate against each of the upper end face **41** and the lower end face **42** perpendicularly, that is, in the Z-axis direction. As a result, grooves **43** are formed to extend radiately in radial directions (the R directions) from the through hole **26**. Note that the number and arrangement of the grooves **43** illustrated in part (B) of FIG. 8 are merely an example, and the present disclosure is not limited thereto.

[0076] Thereafter, as illustrated in part (C) of FIG. 8, substantially equal pressures are applied to the upper end face **41** and the lower end face **42** in substantially perpendicular directions from above and below the electrode wound body **20** at substantially the same time. At this time, for example, a rod-shaped jig is placed in the through hole **26** in advance. By this operation, the positive electrode exposed region **212** and the first part **222A** of the negative electrode exposed region **222** are bent to thereby make each of the upper end face **41** and the lower end face **42** into a flat surface. At this time, the positive electrode edge parts **212E** of the positive electrode exposed region **212** positioned at the upper end face **41** are caused to bend toward the through hole **26** while overlapping each other, and the negative electrode edge parts **222E** of the negative electrode exposed region **222** positioned at the lower end face **42** are caused to bend toward the through hole **26** while overlapping each other. Thereafter, the fan-shaped part **31** of the positive electrode current collector plate **24** is joined to the upper end face **41** by a method such as laser welding, and the fan-shaped part **33** of the negative electrode current collector plate **25** is joined to the lower end face **42** by a method such as laser welding.

[0077] Thereafter, the insulating tapes **53** and **54** are attached to respective predetermined locations on the electrode wound body **20**. Thereafter, as illustrated in part (D) of FIG. 8, the band-shaped part **32** of the positive electrode current collector plate **24** is bent and inserted through a hole **12H** of the insulating plate **12**. Further, the band-shaped part **34** of the negative electrode current collector plate **25** is bent and inserted through a hole **13H** of the insulating plate **13**.

[0078] Thereafter, the electrode wound body **20** having been assembled in the above-described manner is placed

into the outer package can **11** illustrated in part (E) of FIG. 8, following which a bottom part of the outer package can **11** and the negative electrode current collector plate **25** are welded to each other. Thereafter, a narrow part is formed in the vicinity of the open end part **11N** of the outer package can **11**. Further, the electrolytic solution is injected into the outer package can **11**, following which the band-shaped part **32** of the positive electrode current collector plate **24** and the safety valve mechanism **30** are welded to each other.

[0079] Thereafter, as illustrated in part (F) of FIG. 8, sealing is performed with the gasket **15**, the safety valve mechanism **30**, and the battery cover **14**, through the use of the narrow part. Lastly, the outer package can **11** with the washer **55** attached on the battery cover **14** is covered with the outer package tube **50**, following which the outer package tube **50** is heated by, for example, applying hot air to the outer package tube **50**. The outer package tube **50** is thus contracted and closely attached to the outer surface of the outer package can **11**. In covering the outer package can **11** with the outer package tube **50**, adjustment is made to cause each of folds **51A** and **52A**, which are to become the projecting parts **51** and **52** of the outer package tube **50**, to be positioned at the angle θ with respect to the radial direction **R1**.

[0080] The secondary battery **1** according to the present embodiment is completed in the above-described manner.

[0081] As described above, in the secondary battery **1** of the present embodiment, the radial direction **R1** in which the outer diameter of the outer package can **11** becomes maximum and the radial direction **R2** in which the outer diameter of the outer package tube **50** covering the outer peripheral surface of the outer package can **11** becomes maximum differ from each other ($0 < \theta < 180^\circ$). This decreases the flattening of the secondary battery **1** and thereby makes it possible to suppress an increase in the maximum outer diameter of the secondary battery **1**, as compared with when the radial direction **R1** in which the outer package can **11** has the maximum diameter **D11max** and the radial direction **R2** in which the outer package tube **50** has the maximum diameter **D50max** coincide with each other.

[0082] In particular, the angle θ may be greater than or equal to 30° and less than or equal to 150° . This decreases the flattening of the secondary battery **1**.

[0083] Examples of applications of the secondary battery **1** according to the foregoing embodiment of the present disclosure are as described below.

[0084] FIG. 9 is a block diagram illustrating a circuit configuration example in which a battery according to an embodiment of the invention is applied to a battery pack **300**. Hereinafter, the battery according to the embodiment will be referred to as a “secondary battery” as appropriate. The battery pack **300** includes an assembled battery **301**, an outer package body **305**, a switcher **304**, a current detection resistor **307**, a temperature detection device **308**, and a controller **310**. The outer package body **305** contains the assembled battery **301**. The switcher **304** includes a charge control switch **302a** and a discharge control switch **303a**.

[0085] The battery pack **300** includes a positive electrode terminal **321** and a negative electrode terminal **322**. Upon charging, the positive electrode terminal **321** and the negative electrode terminal **322** are respectively coupled to a positive electrode terminal and a negative electrode terminal of a charger to thereby perform charging. Upon use of electronic equipment, the positive electrode terminal **321**

and the negative electrode terminal **322** are respectively coupled to a positive electrode terminal and a negative electrode terminal of the electronic equipment to thereby perform discharging.

[0086] The assembled battery **301** includes multiple secondary batteries **301a** coupled in series or in parallel. The secondary battery **1** described above is applicable to each of the secondary batteries **301a**. Note that FIG. **9** illustrates an example case in which six secondary batteries **301a** are coupled in a two parallel coupling and three series coupling (2P3S) configuration; however, the secondary batteries **301a** may be coupled in any other manner such as in any n parallel coupling and m series coupling configuration (where n and m are each an integer).

[0087] The switcher **304** includes the charge control switch **302a**, a diode **302b**, the discharge control switch **303a**, and a diode **303b**, and is controlled by the controller **310**. The diode **302b** has a polarity that is in a reverse direction with respect to a charge current flowing in a direction from the positive electrode terminal **321** to the assembled battery **301** and that is in a forward direction with respect to a discharge current flowing in a direction from the negative electrode terminal **322** to the assembled battery **301**. The diode **303b** has a polarity that is in the forward direction with respect to the charge current and in the reverse direction with respect to the discharge current. In FIG. **9**, the switcher **304** may be provided on a positive side; however, in some embodiments, the switcher **304** may be provided on a negative side.

[0088] The charge control switch **302a** is so controlled by a charge and discharge controller that when the battery voltage reaches an overcharge detection voltage, the charge control switch **302a** is turned off to thereby prevent the charge current from flowing through a current path of the assembled battery **301**. After the charge control switch **302a** is turned off, only discharging is enabled through the diode **302b**. Further, the charge control switch **302a** is so controlled by the controller **310** that when a large current flows upon charging, the charge control switch **302a** is turned off to thereby block the charge current flowing through the current path of the assembled battery **301**. The discharge control switch **303a** is so controlled by the controller **310** that when the battery voltage reaches an overdischarge detection voltage, the discharge control switch **303a** is turned off to thereby prevent the discharge current from flowing through the current path of the assembled battery **301**. After the discharge control switch **303a** is turned off, only charging is enabled through the diode **303b**. Further, the discharge control switch **303a** is so controlled by the controller **310** that when a large current flows upon discharging, the discharge control switch **303a** is turned off to thereby block the discharge current flowing through the current path of the assembled battery **301**.

[0089] The temperature detection device **308** is, for example, a thermistor. The temperature detection device **308** is provided in the vicinity of the assembled battery **301**, measures a temperature of the assembled battery **301**, and supplies the measured temperature to the controller **310**. A voltage detector **311** measures a voltage of the assembled battery **301** and a voltage of each of the secondary batteries **301a** included in the assembled battery **301**, performs A/D conversion on the measured voltages, and supplies the converted voltages to the controller **310**. A current measurer **313** measures a current by means of the current detection

resistor **307**, and supplies the measured current to the controller **310**. A switch controller **314** controls the charge control switch **302a** and the discharge control switch **303a** of the switcher **304**, based on the voltages inputted from the voltage detector **311** and the current inputted from the current measurer **313**.

[0090] When a voltage of any of the multiple secondary batteries **301a** reaches the overcharge detection voltage or below, or reaches the overdischarge detection voltage or below, or when a large current flows suddenly, the switch controller **314** transmits a control signal to the switcher **304** to thereby prevent overcharging and overdischarging, and overcurrent charging and discharging. For example, when the secondary battery is a lithium-ion secondary battery, the overcharge detection voltage is determined to be, for example, $4.20\text{ V} \pm 0.05\text{ V}$, and the overdischarge detection voltage is determined to be, for example, $2.4\text{ V} \pm 0.1\text{ V}$.

[0091] As the charge and discharge control switches, for example, semiconductor switches such as MOSFETs are usable. In this case, parasitic diodes of the MOSFETs serve as the diodes **302b** and **303b**. When P-channel FETs are used as the charge and discharge control switches, the switch controller **314** supplies control signals CO and DO to a gate of the charge control switch **302a** and a gate of the discharge control switch **303a**, respectively. When the charge control switch **302a** and the discharge control switch **303a** are of P-channel type, the charge control switch **302a** and the discharge control switch **303a** are turned on by a gate potential that is lower than a source potential by a predetermined value or more. That is, in normal charging and discharging operations, the control signals CO and DO are set to a low level to turn on the charge control switch **302a** and the discharge control switch **303a**.

[0092] For example, upon overcharging or overdischarging, the control signals CO and DO are set to a high level to turn off the charge control switch **302a** and the discharge control switch **303a**.

[0093] A memory **317** includes a RAM and a ROM. For example, the memory **317** includes an erasable programmable read only memory (EPROM) as a nonvolatile memory. In the memory **317**, values including, without limitation, numerical values calculated by the controller **310** and a battery's internal resistance value of each of the secondary batteries **301a** in an initial state measured in the manufacturing process stage, are stored in advance and are rewritable on an as-needed basis. Further, by storing a full charge capacity of the secondary battery **301a**, it is possible to calculate, for example, a remaining capacity with the controller **310**.

[0094] A temperature detector **318** measures a temperature with use of the temperature detection device **308**, performs charge and discharge control upon abnormal heat generation, and performs correction in calculating the remaining capacity.

[0095] The secondary battery according to the foregoing embodiment of the present disclosure is mountable on, or usable to supply electric power to, for example, any of equipment including, without limitation, electronic equipment, an electric vehicle, an electric aircraft, and an electric power storage apparatus.

[0096] Examples of the electronic equipment include laptop personal computers, smartphones, tablet terminals, PDAs (i.e., mobile information terminals), mobile phones, wearable terminals, cordless phone handsets, hand-held

video recording and playback devices, digital still cameras, electronic books, electronic dictionaries, music players, radios, headphones, game machines, navigation systems, memory cards, pacemakers, hearing aids, electric tools, electric shavers, refrigerators, air conditioners, televisions, stereos, water heaters, microwave ovens, dishwashers, washing machines, dryers, lighting equipment, toys, medical equipment, robots, road conditioners, and traffic lights.

[0097] Examples of the electric vehicle include railway vehicles, golf carts, electric carts, and electric automobiles including hybrid electric automobiles. The secondary battery is usable as a driving power source or an auxiliary power source for any of these electric vehicles. Examples of the electric power storage apparatuses include an electric power storage power source for architectural structures including residential houses, or for power generation facilities.

EXAMPLES

[0098] Examples of the present disclosure will be described according to an embodiment.

Examples 1-1 to 1-11

[0099] As described below, cylindrical secondary batteries illustrated in FIG. 1, etc. were each fabricated, following which dimensions of each of the fabricated secondary batteries were measured. Here, the fabricated secondary batteries were each a lithium-ion secondary battery with nominal-value dimensions of 21 mm in diameter and 70 mm in length. Note that in each of Examples, 10 secondary batteries (n=10) were fabricated and evaluated.

[Fabrication Method]

[0100] First, an aluminum foil having a thickness of 12 μm was prepared as the positive electrode current collector 21A. Thereafter, a positive electrode mixture was obtained by mixing a layered lithium oxide as the positive electrode active material with a positive electrode binder and a conductive additive. The layered lithium oxide included lithium nickel cobalt aluminum oxide (NCA) having a Ni ratio of 85% or greater. The positive electrode binder included polyvinylidene difluoride. The conductive additive included a mixture of carbon black, acetylene black, and Ketjen black. A mixture ratio between the positive electrode active material, the positive electrode binder, and the conductive additive was set to 96.4:2:1.6. Thereafter, the positive electrode mixture was put into an organic solvent (N-methyl-2-pyrrolidone), following which the organic solvent was stirred to thereby prepare a positive electrode mixture slurry in paste form. Thereafter, the positive electrode mixture slurry was applied on respective predetermined regions of the two opposite surfaces of the positive electrode current collector 21A by means of a coating apparatus, following which the applied positive electrode mixture slurry was dried to thereby form the positive electrode active material layers 21B. Further, a coating material including polyvinylidene difluoride (PVDF) was applied on surfaces of the positive electrode exposed region 212, at respective locations adjacent to the positive electrode covered region 211. The applied coating material was dried to thereby form the

insulating layers 101 each having a width of 3 mm and a thickness of 8 μm . Thereafter, the positive electrode active material layers 21B were compression-molded by means of a roll pressing machine. The positive electrode 21 including the positive electrode covered region 211 and the positive electrode exposed region 212 was thus obtained. Thereafter, the positive electrode 21 was sheared to make the positive electrode covered region 211 have a width of 60 mm in the W-axis direction, and to make the positive electrode exposed region 212 have a width of 7 mm in the W-axis direction. A length of the positive electrode 21 in the L-axis direction was set to 1700 mm.

[0101] Further, a copper foil having a thickness of 8 μm was prepared as the negative electrode current collector 22A. Thereafter, a negative electrode mixture was obtained by mixing the negative electrode active material with a negative electrode binder and a conductive additive. The negative electrode active material included a mixture of a carbon material and SiO. The carbon material included graphite. The negative electrode binder included polyvinylidene difluoride. The conductive additive included a mixture of carbon black, acetylene black, and Ketjen black. A mixture ratio between the negative electrode active material, the negative electrode binder, and the conductive additive was set to 96.1:2.9:1.0. Further, a mixture ratio between graphite and SiO in the negative electrode active material was set to 95:5. Thereafter, the negative electrode mixture was put into an organic solvent (N-methyl-2-pyrrolidone), following which the organic solvent was stirred to thereby prepare a negative electrode mixture slurry in paste form. Thereafter, the negative electrode mixture slurry was applied on respective predetermined regions of the two opposite surfaces of the negative electrode current collector 22A by means of a coating apparatus, following which the applied negative electrode mixture slurry was dried to thereby form the negative electrode active material layers 22B. Thereafter, the negative electrode active material layers 22B were compression-molded by means of a roll pressing machine. The negative electrode 22 including the negative electrode covered region 221 and the negative electrode exposed region 222 was thus obtained. Thereafter, the negative electrode 22 was sheared to make the negative electrode covered region 221 have a width of 62 mm in the W-axis direction, and to make the first part 222A of the negative electrode exposed region 222 have a width of 4 mm in the W-axis direction. A length of the negative electrode 22 in the L-axis direction was set to 1760 mm.

[0102] Thereafter, the positive electrode 21 and the negative electrode 22 were stacked, with the first separator member 23A and the second separator member 23B on the positive electrode 21 and the negative electrode 22, respectively, to cause the positive electrode exposed region 212 and the first part 222A of the negative electrode exposed region 222 to be on opposite sides to each other in the W-axis direction. The stacked body S20 was thereby fabricated. At this time, the stacked body S20 was fabricated not to allow the positive electrode active material layers 21B to protrude from the negative electrode active material layers

22B in the W-axis direction. As each of the first separator member 23A and the second separator member 23B, used was a polyethylene sheet having a width of 65 mm and a thickness of 14 μm . Thereafter, the stacked body S20 was so wound in a spiral shape as to form the through hole 26 and as to allow a cutout to be disposed near the central axis CL, and the fixing tape 46 was attached to the outermost wind of the stacked body S20 thus wound. The electrode wound body 20 was thereby obtained.

[0103] Thereafter, the upper end face 41 and the lower end face 42 of the electrode wound body 20 were each locally bent by pressing an end of a 0.5-millimeter-thick flat plate against each of the upper end face 41 and the lower end face 42 in the Z-axis direction. The grooves 43 extending radially in the radial directions (the R directions) from the through hole 26 were thereby formed.

[0104] Thereafter, substantially equal pressures were applied to the upper end face 41 and the lower end face 42 in substantially perpendicular directions from above and below the electrode wound body 20 at substantially the same time. The positive electrode exposed region 212 and the first part 222A of the negative electrode exposed region 222 were thereby bent to make each of the upper end face 41 and the lower end face 42 into a flat surface. At this time, the positive electrode edge parts 212E of the positive electrode exposed region 212 positioned at the upper end face 41 were caused to bend toward the through hole 26 while overlapping each other, and the negative electrode edge parts 222E of the negative electrode exposed region 222 positioned at the lower end face 42 were caused to bend toward the through hole 26 while overlapping each other. Thereafter, the fan-shaped part 31 of the positive electrode current collector plate 24 was joined to the upper end face 41 by laser welding, and the fan-shaped part 33 of the negative electrode current collector plate 25 was joined to the lower end face 42 by the laser welding.

[0105] Thereafter, the insulating tapes 53 and 54 were attached to the respective predetermined locations on the electrode wound body 20, following which the band-shaped part 32 of the positive electrode current collector plate 24 was bent and inserted through the hole 12H of the insulating plate 12, and the band-shaped part 34 of the negative electrode current collector plate 25 was bent and inserted through the hole 13H of the insulating plate 13.

[0106] Thereafter, the electrode wound body 20 having been assembled in the above-described manner was placed into the outer package can 11, following which the bottom part of the outer package can 11 and the negative electrode current collector plate 25 were welded to each other. Thereafter, the narrow part was formed in the vicinity of the open end part 11N of the outer package can 11. Further, the electrolytic solution was injected into the outer package can 11, following which the band-shaped part 32 of the positive electrode current collector plate 24 and the safety valve mechanism 30 were welded to each other.

[0107] As the electrolytic solution, used was a solution including a solvent prepared by adding fluoroethylene carbonate (FEC) and succinonitrile (SN) to a major solvent, i.e., ethylene carbonate (EC) and dimethyl carbonate (DMC), and including LiBF_4 and LiPF_6 as the electrolyte salt. In the lithium-ion secondary battery of the present Example, a

content ratio (wt %) between EC, DMC, FEC, SN, LiBF_4 , and LiPF_6 in the electrolytic solution was set to 12.7:56.2:12.0:1.0:1.0:17.1.

[0108] Lastly, sealing was performed with the gasket 15, the safety valve mechanism 30, and the battery cover 14 through use of the narrow part, following which the outer package can 11 was covered with the outer package tube 50, and the outer package tube 50 was heated. The outer package tube 50 was thus contracted and closely attached to the outer surface of the outer package can 11. At this time, the outer package can 11 was so covered with the outer package tube 50 that, in the horizontal section orthogonal to the central axis CL, the folds 51A and 52A of the outer package tube 50 were each disposed at the angle θ indicated in Table 1 to be described later, with respect to the radial direction R1 in which the outer package can 11 had the maximum diameter D11max. The folds 51A and 52A were to become the projecting parts 51 and 52 of the outer package tube 50, respectively.

[0109] The secondary batteries of Examples 1-1 to 1-11 were thus obtained.

Comparative Example 1-1

[0110] A secondary battery of Comparative example 1-1 was fabricated in a manner similar to that in Examples 1-1 to 1-11, except that the radial direction R1 and the radial direction R2 were caused to substantially coincide with each other as in a secondary battery 1001 illustrated in FIG. 10. FIG. 10 schematically illustrates a horizontal sectional structure of the secondary battery according to Comparative example 1-1.

[Evaluation of Battery Characteristic]

[0111] The secondary batteries of Examples 1-1 to 1-11 and Comparative example 1-1 obtained as described above were each subjected to a charging and discharging operation for once under the following charging and discharging conditions, and were thereafter each subjected to measurement of dimensions. The charging and discharging operation was performed in an ambient temperature environment at 23° C. First, the secondary battery was charged with a constant current of 1 C until a voltage reached 4.2 V, and was thereafter charged with a constant voltage of 4.2 V, until a current reached 0.05 C. Thereafter, the secondary battery was discharged with a constant current of 1 C until the voltage reached 3.0 V. Note that “1 C” was a value of a current that caused a battery capacity (a theoretical capacity) to be completely discharged in one hour, and “0.05 C” was a value of a current that caused the battery capacity to be completely discharged in 20 hours. As the dimensions of the secondary battery, measured were: the maximum diameter D50max, a minimum diameter D50 min, and an average diameter D50ave of the outer package tube 50; the maximum diameter D11max, a minimum diameter D11 min, and an average diameter D11ave of the outer package can 11 in a state where the outer package tube 50 was removed; and the maximum diameter D20max, a minimum diameter D20 min, and an average diameter D20ave of the electrode wound body 20 taken out of the outer package can 11. The results are presented in Table 1. In addition, a relationship between the angle θ and the maximum diameter D50max is presented in FIG. 11.

TABLE 1

	Angle θ [°]	Outer diameter D50 [mm] of outer package tube			Outer diameter D11 [mm] of outer package can			Outer diameter D20 [mm] of electrode wound body		
		D50max	D50min	D50ave	D11max	D11min	D11ave	D20max	D20min	D20ave
Comparative example 1-1	0	21.636	21.592	21.619	21.476	21.432	21.454	21.076	21.032	21.054
Example 1-1	15	21.582	21.544	21.566	21.442	21.404	21.423	20.942	20.904	20.923
Example 1-2	30	21.556	21.518	21.537	21.436	21.392	21.414	20.936	20.892	20.914
Example 1-3	45	21.501	21.434	21.459	21.378	21.307	21.342	20.878	20.808	20.843
Example 1-4	60	21.371	21.316	21.340	21.251	21.190	21.221	20.751	20.690	20.721
Example 1-5	75	21.298	21.240	21.271	21.188	21.100	21.144	20.688	20.600	20.644
Example 1-6	90	21.232	21.164	21.203	21.117	21.054	21.086	20.617	20.554	20.586
Example 1-7	105	21.300	21.241	21.272	21.160	21.101	21.131	20.560	20.502	20.530
Example 1-8	120	21.381	21.319	21.341	21.262	21.187	21.224	20.712	20.687	20.699
Example 1-9	135	21.512	21.440	21.459	21.392	21.314	21.353	20.892	20.764	20.828
Example 1-10	150	21.563	21.515	21.537	21.443	21.389	21.416	20.943	20.889	20.916
Example 1-11	165	21.583	21.543	21.566	21.443	21.403	21.423	20.943	20.903	20.923

[0112] As indicated in Table 1 and FIG. 11, it was confirmed that in each of Examples 1-1 to 1-11 in which the angle θ was within a range from 15° to 165° both inclusive, it was possible to reduce the maximum diameter D50max as compared with Comparative example 1-1.

[0113] Although the present disclosure has been described hereinabove with reference to some embodiments and Examples, the configuration of the present disclosure is not limited to the configurations described in relation to the embodiments and Examples above, and is therefore modifiable in a variety of ways.

[0114] For example, in the embodiments and Examples above, the description has been given of the case where the electrode reactant is lithium; however, the electrode reactant is not particularly limited. Accordingly, the electrode reactant may be another alkali metal such as sodium or potassium, or may be an alkaline earth metal such as beryllium, magnesium, or calcium, as described above. In addition, the electrode reactant may be another light metal such as aluminum.

[0115] The effects described herein are merely examples, and the effects of the present disclosure are not limited to those described herein. Accordingly, the present disclosure may achieve other effects.

[0116] The present disclosure may encompass the following embodiments.

<1>

[0117] A secondary battery including:

[0118] an electrode wound body including a positive electrode and a negative electrode that are stacked on each other with a separator interposed between the positive electrode and the negative electrode and are wound around a central axis;

[0119] a battery can having a circular columnar outer shape in which a height direction corresponds to a direction along the central axis, the battery can containing the electrode wound body; and

[0120] an outer package tube covering an outer peripheral surface of the battery can, in which

[0121] a first radial direction and a second radial direction differ from each other in a section orthogonal to the central axis, the first radial direction being a direction in which an outer diameter of the battery can is maximum, the second radial direction being a direction in which an outer diameter of the outer package tube is maximum.

<2>

[0122] The secondary battery according to <1>, in which a third radial direction differs from the second radial direction in the section orthogonal to the central axis, the third radial direction being a direction in which an outer diameter of the electrode wound body is maximum.

<3>

[0123] The secondary battery according to <2>, in which the first radial direction and the third radial direction substantially coincide with each other.

<4>

[0124] The secondary battery according to any one of <1> to <3>, in which the outer package tube has a maximum thickness in a part in which the outer diameter of the outer package tube is maximum.

<5>

[0125] The secondary battery according to any one of <1> to <4>, in which the outer package tube includes one or two projecting parts that protrude in the second radial direction.

<6>

[0126] The secondary battery according to <5>, in which [0127] the outer package tube includes a thermally contractible insulating film, and

[0128] the one or two projecting parts are each a part in which portions of the thermally contractible insulating film lie over each other.

<7>

[0129] The secondary battery according to any one of <1> to <6>, in which an angle formed by the first radial direction and the second radial direction is greater than or equal to 30 degrees and less than or equal to 150 degrees.

<8>

[0130] The secondary battery according to any one of <1> to <7>, further including:

[0131] a positive electrode current collector plate disposed to face a first end face of the electrode wound body in the height direction; and

[0132] a negative electrode current collector plate disposed to face a second end face of the electrode wound body in the height direction, the second end face being on a side opposite to the first end face in the height direction, in which

[0133] the positive electrode includes a positive electrode covered region in which a positive electrode current collector is covered with a positive electrode active material layer, and a positive electrode exposed

region in which the positive electrode current collector is exposed without being covered with the positive electrode active material layer and is joined to the positive electrode current collector plate,

[0134] the negative electrode includes a negative electrode covered region in which a negative electrode current collector is covered with a negative electrode active material layer, and a negative electrode exposed region in which the negative electrode current collector is exposed without being covered with the negative electrode active material layer and is joined to the negative electrode current collector plate, and

[0135] the positive electrode exposed region wound around the central axis includes multiple first edge parts that are adjacent to each other in a radial direction of the electrode wound body, and the negative electrode exposed region wound around the central axis includes multiple second edge parts that are adjacent to each other in the radial direction, the multiple first edge parts, the multiple second edge parts, or both being bent toward the central axis and overlapping each other.

[0136] It should be understood that various changes and modifications to the embodiments described herein will be apparent to those skilled in the art. Such changes and modifications can be made without departing from the spirit and scope of the present subject matter and without diminishing its intended advantages. It is therefore intended that such changes and modifications be covered by the appended claims.

1. A secondary battery comprising:
 - an electrode wound body including a positive electrode and a negative electrode that are stacked on each other with a separator interposed between the positive electrode and the negative electrode and are wound around a central axis;
 - a battery can having a circular columnar outer shape in which a height direction corresponds to a direction along the central axis, the battery can containing the electrode wound body; and
 - an outer package tube covering an outer peripheral surface of the battery can, wherein
 - a first radial direction and a second radial direction differ from each other in a section orthogonal to the central axis, the first radial direction being a direction in which an outer diameter of the battery can is maximum, the second radial direction being a direction in which an outer diameter of the outer package tube is maximum.
2. The secondary battery according to claim 1, wherein a third radial direction differs from the second radial direction in the section orthogonal to the central axis, the third radial direction being a direction in which an outer diameter of the electrode wound body is maximum.
3. The secondary battery according to claim 2, wherein the first radial direction and the third radial direction substantially coincide with each other.

4. The secondary battery according to claim 1, wherein the outer package tube has a maximum thickness in a part in which the outer diameter of the outer package tube is maximum.

5. The secondary battery according to claim 1, wherein the outer package tube includes one or two projecting parts that protrude in the second radial direction.

6. The secondary battery according to claim 5, wherein the outer package tube includes a thermally contractible insulating film, and

the one or two projecting parts are each a part in which portions of the thermally contractible insulating film lie over each other.

7. The secondary battery according to claim 1, wherein an angle formed by the first radial direction and the second radial direction is greater than or equal to 30 degrees and less than or equal to 150 degrees.

8. The secondary battery according to claim 1, further comprising:

a positive electrode current collector plate disposed to face a first end face of the electrode wound body in the height direction; and

a negative electrode current collector plate disposed to face a second end face of the electrode wound body in the height direction, the second end face being on a side opposite to the first end face in the height direction, wherein

the positive electrode includes a positive electrode covered region in which a positive electrode current collector is covered with a positive electrode active material layer, and a positive electrode exposed region in which the positive electrode current collector is exposed without being covered with the positive electrode active material layer and is joined to the positive electrode current collector plate,

the negative electrode includes a negative electrode covered region in which a negative electrode current collector is covered with a negative electrode active material layer, and a negative electrode exposed region in which the negative electrode current collector is exposed without being covered with the negative electrode active material layer and is joined to the negative electrode current collector plate, and

the positive electrode exposed region wound around the central axis includes multiple first edge parts that are adjacent to each other in a radial direction of the electrode wound body, and the negative electrode exposed region wound around the central axis includes multiple second edge parts that are adjacent to each other in the radial direction, the multiple first edge parts, the multiple second edge parts, or both being bent toward the central axis and overlapping each other.

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