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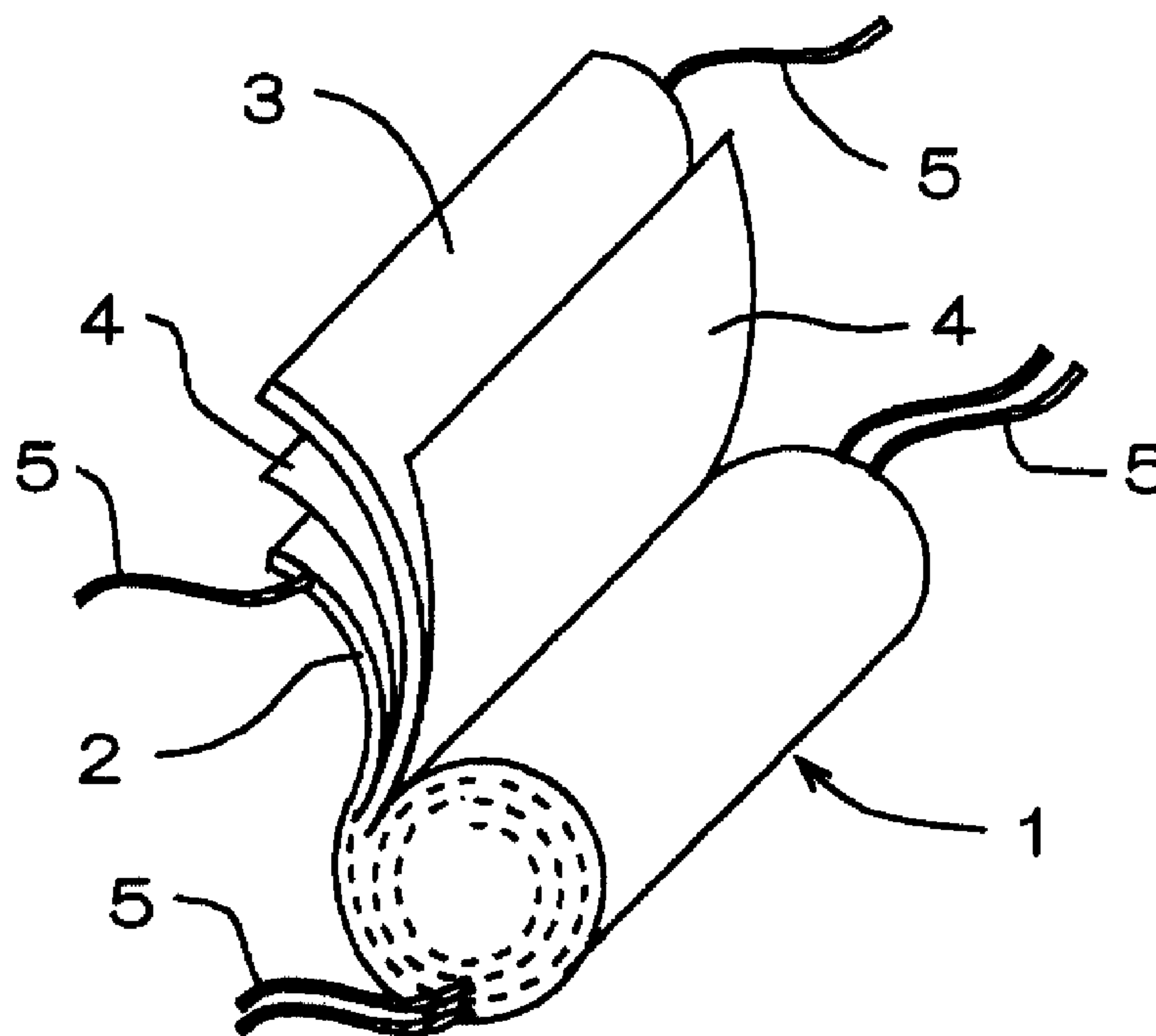
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(54) Titre : BATTERIE SECONDAIRE AU LITHIUM

(54) Title: LITHIUM SECONDARY BATTERY



(57) Abrégé/Abstract:

A lithium secondary battery includes a positive electrode, a negative electrode, a separator, an internal electrode body, and an organic electrolyte. The positive electrode and the negative electrode are wound through the separator so that the positive electrode and the negative electrode are not brought into direct contact with each other. A total thickness ( $\mu\text{m}$ ) of electrode substrates is divided by a total thickness ( $\mu\text{m}$ ) of electrode active material layers, and the resultant ratio is a total thickness ratio, which total thickness ratio has been set to be not less than 0.045 and not more than 0.31. The lithium secondary battery reduces internal resistance to attain good charging-discharging characteristics and to obtain an high output and a huge current.



## Abstract of the Disclosure

A lithium secondary battery includes a positive electrode, a negative electrode, a separator, an internal electrode body, and an organic electrolyte. The positive electrode and the negative electrode are wound through the separator so that the positive electrode and the negative electrode are not brought into direct contact with each other. A total thickness ( $\mu\text{m}$ ) of electrode substrates is divided by a total thickness ( $\mu\text{m}$ ) of electrode active material layers, and the resultant ratio is a total thickness ratio, which total thickness ratio has been set to be not less than 0.045 and not more than 0.31. The lithium secondary battery reduces internal resistance to attain good charging-discharging characteristics and to obtain an high output and a huge current.

## Title of the Invention

### LITHIUM SECONDARY BATTERY

#### 5 Background of the Invention and Related Art Statement

This invention relates to a lithium secondary battery to be suitably used in particular to drive a motor of an electric vehicle, etc., and in more particular to a lithium secondary battery which  
10 can reduce internal resistance, and attain good charging-discharging characteristics as well as an high output and a huge current by setting shape parameters of an internal electrode body under predetermined conditions.

In recent years, on the background with the height of  
15 movement to protect the earth environment, in midst that it is eagerly desired to regulate emission of exhaust gasses including carbon dioxide as well as other harmful matters, in the automobile industry, in replacement of automobiles using fossil fuels, such as a vehicle driven by gasoline, the movement to  
20 promote an introduction of an electric vehicle (EV), and a hybrid electric vehicle (HEV) has become active.

As a battery to drive motors of such EV as well as HEV, a lithium secondary battery with a large energy density is expected as a promising battery, but a lithium secondary battery  
25 is required to attain characteristics such as large capacity as well as a high output so as to attain predetermined acceleration performance, slope-climbing performance, and continuous

running performance, etc. For example, an HEV is in a mode to assist an output power at the time of acceleration, and therefore, a high output is required for a battery to drive a motor. Here, the voltage per battery depends on materials configuring the battery, and in the case of a lithium secondary battery, the voltage is approximately 4.2 V at highest, and a huge output means a huge current to flow.

On the other hand, a plurality of batteries are connected in series for use to secure required voltage for driving a motor, resulting in the same quantity of current will flow through each battery. Actually, in an HEV, etc., it can frequently occur that a current not less than 100 A flows. Accordingly, it is important to reduce the internal resistance of a battery as much as possible so that such high output characteristics as well as huge current characteristics are realized.

Here, the internal resistance of a battery is determined by the resistance value of a configuring members of a battery, and especially, it is extremely important that the resistance of an internal electrode body (charge-discharge unit) to be regarded as a central part of a battery should be reduced.

However, lithium secondary batteries currently in practical use for electric appliances, are not with large battery capacities, and in few cases that large currents are required in their use, therefore no detailed studies on resistance of internal electrode body in a battery have been conducted to date.

For example, Japanese Patent Laid-Open No. 2701347 specification discloses a lithium secondary battery comprising a

band-shape positive electrode, and a band-shape negative electrode, the both electrodes being wound each other to configure a wound body, wherein the positive active material layer configuring the band-shape positive electrode and the negative active material layer configuring the band-shape negative electrode have predetermined thickness respectively, and the ratio of respective thickness falls in within a predetermined range.

The lithium secondary battery disclosed in this Japanese Patent Laid-Open No. 2701347 specification is the one having regulated the form of elements to configure the internal electrode body, nevertheless the resistance of the internal electrode body has not been studied. That is, in spite that thickness of an electrode active material layer is a factor to affect resistance of an internal electrode body, which point has not been discussed, and in addition, no consideration has been given to the influence of the resistance of electrode substrate (current collector (metal foil)) itself which is indispensable to configure a band-shape electrode as well as of band-shape electrode itself to the resistance of the internal electrode body.

In addition, a lithium secondary battery disclosed in Japanese Patent Laid-Open No. 2701347 specification has been made mainly to be used as a power source of an electronic appliance, aiming at fulfilling requirement for larger capacity, that is, mainly aiming at improvement in energy density, and in addition, aiming at prevention of occurrence of cracks in an electrode, and therefore, in Japanese Patent Laid-Open No.

2701347 specification no descriptions that higher output has been the purpose thereof are found.

Thus, since development of a compact battery has been proceeded mainly aiming at higher energy density, as concerns  
5 how to provide a lithium secondary battery to an output of which serious consideration has been given, how the relationship between thickness of electrode substrate of each positive and negative electrode and thickness of electrode active material layer would affect the resistance of an internal electric body was  
10 not so well understood. In addition, the density of winding, that is, the number of winding of the positive electrode or the negative electrode per unit length along the direction of diameter of the internal electrode body, was left similarly.

Moreover, Japanese Patent Laid-Open No. 2701347  
15 specification describes that it is preferable that lithium cobalt oxide ( $\text{LiCoO}_2$ ) with a large lithium capacity as the positive active material is used since the disclosed lithium secondary battery is attained with the main purpose having been set at improvement of energy density as described before.

20 However, in the case where the main purpose has been set at reduction in resistance of an internal electrode body as well as higher output, the quantity of lithium in a positive active material may be less to fall within a range which can secure the predetermined quantity, and instead the use of positive active  
25 material making resistance of the positive active material layer smaller is regarded as more important.

Incidentally, also as for a lithium secondary battery with a large capacity mainly aiming at above-described higher output such as to be used in EV, etc., it goes without saying that weight should be preferably lighter if the battery capacity is the same. In addition, if the volume of a battery is smaller, less mounting space is required in a vehicle, preferably resulting in larger freedom in space designing. Moreover, it is costly disadvantageous as well to use many materials without necessity.

#### Summary of the Invention

The present invention was attained, contemplating on the problems of the prior art mentioned above. According to the present invention, there is provided a lithium secondary battery, comprising a positive electrode, a negative electrode, a separator, and an internal electrode body, an organic electrolyte, the positive electrode and the negative electrode being wound through the separator so that the positive electrode and the negative electrode are not brought into direct contact with each other, wherein a total thickness ( $\mu\text{m}$ ) of electrode substrates is divided by a total thickness ( $\mu\text{m}$ ) of electrode active material layers, the resultant ratio being a total thickness ratio, which total thickness ratio is not less than 0.045 and not more than 0.31. Here, it is more preferable that the value of this ratio is not less than 0.05 and not more than 0.25.

In addition, according to the present invention, there is provided a lithium secondary battery, comprising a positive electrode, a negative electrode, a separator, and an internal electrode body, an organic electrolyte, the positive electrode and the negative electrode being wound through the separator so that the positive electrode and the negative electrode are not brought into direct contact with each other, wherein when the number of winding (round/cm) of the positive electrode or the negative electrode per unit length along the direction of diameter of the internal electrode body is multiplied by total thickness (cm) of the electrode active material layers, being designated as a correction winding density (round), the correction winding density is not less than 0.73 (round).

In the above-described lithium secondary battery of the present invention,  $\text{LiMn}_2\text{O}_4$  spinel is preferably used as a positive electrode active material to be used for the positive electrode, and at that time,  $\text{LiMn}_2\text{O}_4$  spinel having Li/Mn ratio of more than 0.5 is used more preferably. On the other hand, as a negative active material to be used in the negative electrode, highly graphitized carbon material is suitably used and the one in form of fiber quality is used more preferably. The lithium secondary battery according to the present invention is designed to go with reduction in battery's internal resistance and to attain higher output, and thus can be suitably used as the one for an electric vehicle (EV) or a hybrid electric vehicle (HEV). In addition, the battery hereof is suitably applied to a battery

having battery capacity of not less than 5 Ah which gives remarkable effects with higher output.

#### Brief Description of the Drawings

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Fig. 1 is a perspective view showing the structure of a wound-type internal electrode body.

Fig. 2 is an enlarged view showing a part of section view perpendicular to the winding axis of the internal electrode body.

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Figs. 3(a)(b) are graphs showing the relationship between the total thickness ratio and the battery's internal resistance as well as energy density.

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Figs. 4(a)(b) are graphs showing the relationship between the correction winding density and the battery's internal resistance as well as energy density.

#### Detailed Description of Preferred Embodiment

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An internal electrode body of a lithium secondary battery in the present invention (hereinafter to be referred to as a battery) is configured by comprising a positive electrode, a negative electrode, and a separator made of porous polymer film, the positive electrode and the negative electrode being wound through the separator so that the positive electrode and the negative electrode are not brought into direct contact with each other. In particular, as shown in Fig. 1, the internal electrode body 1 is formed by winding a positive electrode 2 and a negative

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electrode 3 through a separator 4, and the respective positive and negative electrode plates 2 and 3 (hereafter to be referred to as electrodes 2 and 3) are provided with tabs 5. These tabs 5 can be attached to the electrodes 2 and 3 by ultrasonic welding or the like at the time when the electrodes 2 and 3 are wound with the separator 4. Incidentally, the opposite end of each tab 5 which end has been connected to the electrodes 2 and 3 is attached to an output terminal (not shown) or a current extraction terminal (not shown) being conductive to the output terminal.

For the electrodes 2 and 3, the positive electrode 2 comprises metal foils and electrode active materials, the metal foil made of aluminum, and titanium, etc. for the positive electrode 2 and the metal foil made of copper and nickel, etc. for the negative electrode 3 being assigned as electrode substrates (electricity collection bodies), with electrode active materials being coated on the both sides of respective metal foils to form electrode active material layers to produce the electrodes 2 and 3. In addition, the tabs 5 are disposed along one side of such metal foils, and generally thin band type ones are used so that portions in the electrodes 2 and 3 where tabs 5 have been attached may not swell toward outer circumference at the time when the internal electrode body 1 has been formed. At that time, the tabs 5 are preferably disposed at an approximately equal distance so that one tab 5 may collect electricity from a fixed area in the electrodes 2 and 3, and in many cases the same

material as that of the metal foil where the tab 5 is attached is adopted as the material of the tab 5.

As the positive active material to be used to form the positive electrode 2, in the present invention, lithium manganese oxide ( $\text{LiMn}_2\text{O}_4$ ) spinel is most suitably used. The  $\text{LiMn}_2\text{O}_4$  spinel belongs to the space group  $\text{Fd}\bar{3}\text{m}$ , and has characteristics that diffusion of Li ions takes place three-dimensionally, and therefore, is more suitable for the purpose of resistance reduction as well as higher output attainment for example with smaller diffusion resistance of Li ions in the battery reaction than in the case where such a material that causes diffusion of Li ions two-dimensionally as in lithium cobalt oxide ( $\text{LiCoO}_2$ ) which belongs to a space group  $\text{R}(-3)\text{m}$  ("-" indicates rotational inversion.) and has a layer-shape configuration. In addition,  $\text{LiMn}_2\text{O}_4$  spinel itself has excellent electron conductivity and serves to provide remarkable effects in terms of resistance reduction on the positive electrode 2.

Moreover, a battery utilizing  $\text{LiMn}_2\text{O}_4$  spinel has excellent characteristics that resistance remains low even under conditions that discharge has been proceeded to an extent, that is, discharge depth is deep, and thus is especially excellent as a battery material for usage which requires higher output discharge.

As for  $\text{LiMn}_2\text{O}_4$  spinel, more preferably, the one with composition of Li/Mn ratio exceeding 0.5 (Li/Mn ratio  $> 0.5$ ), that is, of more excessive Li than stoichiometry composition is to be used, preferably making it possible to plan reduction of

resistance remarkably. As such  $\text{LiMn}_2\text{O}_4$  spinel with composition of excess Li,  $\text{LiLi}_x\text{Mn}_{2-x}\text{O}_4$  spinel composition where a part of Mn has been replaced by Li ( $\text{Li/Mn}=(1+X)/(2-X)>0.5$ ) and  $\text{LiM}_x\text{Mn}_{2-x}\text{O}_4$  ( $\text{Li/Mn}=1/(2-X)>0.5$ ) where a part of Mn has been replaced by a metal element M can be nominated.

Incidentally, as a replacement element M, the symbols of chemical elements can be nominated in a list as follows: Fe, Ni, Mg, B, Al, Co, Si, Ti, Sn, P, V, Sb, Nb, Ta, Mo, and W. In addition, quantity of oxygen for the above-described respective  $\text{LiMn}_2\text{O}_4$  spinel, is 4 in terms of stoichiometry composition, however, may be changed as far as its crystal configuration is maintained due to valence of proton ions as well as existence of lattice defect, etc.

By the way, as a positive active material, other than  $\text{LiMn}_2\text{O}_4$  spinel a lithium transition metal compound oxides such as lithium cobalt oxide ( $\text{LiCoO}_2$ ), lithium nickel oxide ( $\text{LiNiO}_2$ ), etc. are possibly used, but there is a problem that, as described before, their ion diffusion is two dimensional and has bigger resistance. Incidentally, in all the cases where any of the above-mentioned positive active materials, for the purpose of further improving conductivity of the positive active materials as well as reducing resistance, it is also preferable to mix with an electrode active material the carbon powder such as acetylene black and graphite powder, etc.

On the other hand, for the negative electrode, an amorphous carbon material such as soft carbon or hard carbon, or carbon material such as artificial graphite and natural

graphite, etc. can be used, and in the present invention it is preferable in particular to use highly graphitized carbon material and more preferably those having form of fiber are suitably used.

5           The negative active materials are different each other in terms of Li capacity, and when a different negative active material is used for a same positive active material, changes are observed in the potential curve, thus it could occur that the desired battery characteristics are not obtainable. For example,  
10   in a lithium secondary battery having been disclosed in the above-described Japanese Patent Laid-Open No. 2701347 specification pitch coke (hard carbon) is suitably used, but in the case where pitch coke has been used, it is difficult to attain high output under deep discharge depth, thus pitch coke is not  
15   suitable for the purpose of the present invention.

          As described before, in the case where  $\text{LiMn}_2\text{O}_4$  spinel has been used as the positive active material, and especially in the case where highly graphitized carbon has been used as the negative active material, the internal resistance is maintained  
20   small to enable high output discharge without difficulty, even in the state where the depth of discharge is deep thus the one extremely preferable in terms of battery characteristics can be obtained.

          Now, each electrode active material of these kinds are in  
25   general respectively mixed with various solvents and binders to become a slurry, and thereafter is coated on the surface of the

predetermined electrode substrate and fixed, thus the electrodes 2 and 3 are formed.

As the separator 4, it is preferable to use one having a three-layer configuration in which a polyethylene film having lithium ion permeability and including micropores has been sandwiched between porous polypropylene films having lithium ion permeability. This serves also as a safety mechanism in which when the temperature of internal electrode body 1 is raised, the polyethylene film is softened at about 130 °C so that the micropores are collapsed to suppress the movement of lithium ions, that is, the battery reaction. And with this polyethylene film being sandwiched between the polypropylene films having a softening temperature higher than the said polyethylene film, it becomes possible to prevent the direct contact between the electrodes 2, 3 even in the case where the polyethylene has been softened, and thereby it becomes possible to steadily suppress the battery reaction.

Incidentally, a nonaqueous organic electrolyte in which one or more kinds of lithium fluoride complex compound such as  $\text{LiPF}_6$ , and  $\text{LiBF}_4$ , etc. or lithium halide such as  $\text{LiClO}_4$  as an electrolyte are dissolved in a single solvent or mixed solvent of organic solvents such as a carbonic acid ester family such as ethylene carbonate (EC), diethyl carbonate (DEC), dimethyl carbonate (DMC) and propylene carbonate (PC),  $\gamma$ -butyrolactone, tetrahydrofuran, and acetonitrile, etc., is preferably used. Such an electrolyte fills the internal space of the battery case and consequently permeates into the internal electrode body 1.

Now, in the internal electrode body 1 to be formed by using the above-described materials, etc., the relationship between thickness of an electrode substrate in the electrodes 2 and 3 and electrode active material layer to be coated on the electrode substrate of each electrode is thought to influence the battery's internal resistance to a large extent, to which point the present invention has paid attention. Fig. 2 is an enlarged view showing a part of section view perpendicular to the winding axis of the internal electrode body 1, and in the present invention, the total thickness ratio is defined by dividing total thickness ( $\mu\text{m}$ ) of electrode substrates with total thickness ( $\mu\text{m}$ ) of electrode active material layers, the total thickness of electrode substrates being the sum of thickness of positive electrode substrate 11 and thickness of negative electrode substrate 12, and total thickness of electrode active material layers being the sum of total thickness of positive electrode active material layer 13 formed on both surfaces of the positive electrode 2 and total thickness of negative electrode active material layer 14 formed on both surfaces of the negative electrode 3, and then this total thickness ratio should be not less than 0.045 and not more than 0.31. Incidentally, it goes without saying that the unit of thickness of total thickness of electrode substrates and total thickness of electrode active material layers is not limited to " $\mu\text{m}$ " if their units are the same.

Table 1 shows characteristics which were obtained when batteries were assembled to have internal electrode bodies with variously different kinds of this total thickness ratio but to have

a constant diameter. Incidentally, every kind of common material having been used to form the batteries has been described in Table 2. As can be seen in Table 1, to form the batteries, only thickness of electrode substrates and thickness of electrode active material layers were changed. But, the ratio between thickness of the positive active material layers and thickness of the negative active material layers has been set as a constant. The purpose of this is to avoid making relationship between thickness of the electrode substrate and the internal resistance indistinct due to influence on battery capacity given by the ratio between thickness of the positive active material layer and the negative active material layer. In addition, the sizes of batteries is fixed at a constant. This serves necessarily to cause the number of windings to change if thickness of an electrode changes. Incidentally, the winding pressure at the time of electrodes being wound has been fixed at a constant in every battery to remove an influence to be given to the internal resistance.

[Table 1]

| Sample number | One side thickness of positive active material layer ( $\mu\text{m}$ ) | Total thickness of electrode active material layers ( $\mu\text{m}$ ) | Thickness of positive electrode substrate ( $\mu\text{m}$ ) | Thickness of negative electrode substrate ( $\mu\text{m}$ ) | Total thickness of electrode substrates ( $\mu\text{m}$ ) | Total thickness ratio | Number of winding (round) | Winding density (round/cm) | Correction winding density (round) | Energy density (Wh/kg) | Internal resistance ( $\text{m}\Omega$ ) |
|---------------|------------------------------------------------------------------------|-----------------------------------------------------------------------|-------------------------------------------------------------|-------------------------------------------------------------|-----------------------------------------------------------|-----------------------|---------------------------|----------------------------|------------------------------------|------------------------|------------------------------------------|
| 1             | 100                                                                    | 360                                                                   | 10                                                          | 5                                                           | 15                                                        | 0.042                 | 44                        | 23.8                       | 0.86                               | 90.7                   | 2.15                                     |
| 2             | 100                                                                    | 360                                                                   | 10                                                          | 8                                                           | 18                                                        | 0.050                 | 44                        | 23.8                       | 0.86                               | 88.2                   | 1.95                                     |
| 3             | 100                                                                    | 360                                                                   | 15                                                          | 8                                                           | 23                                                        | 0.064                 | 43                        | 23.2                       | 0.84                               | 87.1                   | 1.98                                     |
| 4             | 100                                                                    | 360                                                                   | 15                                                          | 10                                                          | 25                                                        | 0.069                 | 43                        | 23.2                       | 0.84                               | 85.8                   | 1.95                                     |
| 5             | 100                                                                    | 360                                                                   | 20                                                          | 10                                                          | 30                                                        | 0.083                 | 43                        | 23.2                       | 0.84                               | 84.9                   | 1.90                                     |
| 6             | 100                                                                    | 360                                                                   | 40                                                          | 20                                                          | 60                                                        | 0.167                 | 40                        | 21.6                       | 0.78                               | 74.7                   | 1.95                                     |
| 7             | 100                                                                    | 360                                                                   | 60                                                          | 30                                                          | 90                                                        | 0.250                 | 38                        | 20.5                       | 0.74                               | 67.0                   | 2.00                                     |
| 8             | 100                                                                    | 360                                                                   | 60                                                          | 40                                                          | 100                                                       | 0.278                 | 37                        | 20.0                       | 0.72                               | 62.8                   | 2.05                                     |
| 9             | 100                                                                    | 360                                                                   | 70                                                          | 40                                                          | 110                                                       | 0.306                 | 36                        | 19.5                       | 0.70                               | 61.5                   | 2.07                                     |
| 10            | 100                                                                    | 360                                                                   | 80                                                          | 40                                                          | 120                                                       | 0.333                 | 35                        | 18.9                       | 0.68                               | 60.2                   | 2.19                                     |
| 11            | 100                                                                    | 360                                                                   | 100                                                         | 50                                                          | 150                                                       | 0.417                 | 34                        | 18.4                       | 0.66                               | 55.3                   | 2.22                                     |
| 12            | 150                                                                    | 540                                                                   | 10                                                          | 5                                                           | 15                                                        | 0.028                 | 31                        | 16.8                       | 0.90                               | 95.5                   | 3.63                                     |
| 13            | 150                                                                    | 540                                                                   | 15                                                          | 10                                                          | 25                                                        | 0.046                 | 31                        | 16.6                       | 0.90                               | 93.2                   | 3.36                                     |
| 14            | 150                                                                    | 540                                                                   | 20                                                          | 10                                                          | 30                                                        | 0.056                 | 30                        | 16.2                       | 0.88                               | 90.7                   | 3.43                                     |
| 15            | 150                                                                    | 540                                                                   | 30                                                          | 20                                                          | 50                                                        | 0.093                 | 29                        | 15.7                       | 0.85                               | 84.1                   | 3.43                                     |
| 16            | 150                                                                    | 540                                                                   | 40                                                          | 20                                                          | 60                                                        | 0.111                 | 29                        | 15.7                       | 0.85                               | 83.0                   | 3.37                                     |
| 17            | 150                                                                    | 540                                                                   | 50                                                          | 30                                                          | 80                                                        | 0.148                 | 28                        | 15.1                       | 0.82                               | 77.5                   | 3.46                                     |
| 18            | 150                                                                    | 540                                                                   | 60                                                          | 40                                                          | 100                                                       | 0.185                 | 27                        | 14.6                       | 0.79                               | 72.5                   | 3.50                                     |
| 19            | 150                                                                    | 540                                                                   | 100                                                         | 50                                                          | 150                                                       | 0.278                 | 26                        | 1.41                       | 0.76                               | 66.1                   | 3.55                                     |
| 20            | 150                                                                    | 540                                                                   | 100                                                         | 80                                                          | 180                                                       | 0.333                 | 25                        | 13.5                       | 0.73                               | 62.3                   | 3.62                                     |
| 21            | 150                                                                    | 540                                                                   | 120                                                         | 80                                                          | 200                                                       | 0.370                 | 24                        | 13.0                       | 0.70                               | 57.0                   | 3.95                                     |

[Table 2]

|                                                                                 |             |                                                    |
|---------------------------------------------------------------------------------|-------------|----------------------------------------------------|
| Positive electrode substrate, tab for positive electrode electricity collection |             | Aluminum                                           |
| Negative electrode substrate, tab for negative electrode electricity collection |             | Copper                                             |
| Positive active material                                                        |             | (Excessive Li type) $\text{LiMn}_2\text{O}_4$      |
| Negative active material                                                        |             | Highly graphitized carbon material (fiber quality) |
| Electrolyte                                                                     | Electrolyte | $\text{LiPF}_6$                                    |
|                                                                                 | Solvent     | EC + DEC                                           |

Figs. 3(a) and 3(b) are graphs showing the relationship between the total thickness ratio and the battery's internal resistance as well as energy density in Table 1. Figs. 3(a) and 3(b) reveal that the energy density tends to get smaller as the total thickness ratio grow larger. The fact that the total thickness ratio is large means that the total thickness of electrode substrates is thick and/or the total thickness of electrode active material layers is thin, but this is an inevitable outcome if any of the cases means that quantity of electrode active materials per unit weight grows less. Accordingly, from the view point of energy density, smaller total thickness ratio is preferable, but in the case where the phenomenon of discharge of a great current has been taken into consideration, internal resistance characteristics are regarded as more important than this energy density.

And, taking a look at the relationship between the total thickness ratio and the internal resistance, any of Figs. 3(a) and 3(b) remarkably reveals that when the total thickness ratio falls within a particular range of values, the internal resistance gets smaller. For example, in the case where the total thickness is 0.042, the internal resistance has grown larger by approximately 10% than in the case with the total thickness being 0.05. This is thought to be caused by the fact that resistance of an electrode substrate grows larger when the electrode substrate is too thin.

On the other hand, in the case where the total thickness ratio is 0.33, the internal resistance has increased by approximately 5%, as compared with the case of the total

thickness ratio being 0.306. In this case, it is thought to be caused by the fact that number of winding decreased due to the electrode substrate having become thicker, and consequently charging/discharging area contributing to the battery reaction decreased and resistance of electrode reaction portion increased. On the other hand, with the total thickness ratio within the range not less than 0.045 and not more than 0.31, any big change in internal resistance can be seen.

With such a result, a range where no sudden changes in internal resistance take place, that is, the range where the total thickness ratio is not less than 0.045 and not more than 0.31, more preferably the range of not less than 0.05 and not more than 0.25, is at the same time the range to be able to control the internal resistance to a small amount, and preferable.

Reduction in internal resistance not only enables a stable discharge of a huge current but also makes energy loss at the time of charging/discharging smaller, and thus improves the charging/discharging cycle characteristics.

Next, Figs. 4(a) and 4(b) are graphs showing the relationship between the correction winding density and the battery's internal resistance as well as energy density at the time when the correction winding density (round) has been defined by multiplying the number of winding (round/cm) of the positive electrode 2 or the negative electrode 3 per unit length along the direction of diameter of the internal electrode body 1 with the total thickness (cm) of the electrode active material layers. As the correction winding density gets larger, the

energy density tends to gets larger. This is caused by the fact that larger number of winding of the electrodes 2 and 3 per unit length along the direction of diameter of the internal electrode body 1 and/or thicker total thickness of the electrode active materials results in larger amount of electrode active materials contributing to the battery reaction.

However, as remarkably shown in Fig. 4(b), in the case with the correction winding density being 0.70 (round), the internal resistance has increased by approximately 9% compared with the case with the correction winding density being 0.73 (round). In addition, with the correction winding density being not less than 0.73 (round), there are no big changes in the internal resistance, which, moreover, has been suppressed to small values. This takes place because the smaller correction winding density means the case with the thicker electrode substrate where the correction winding density is a parameter which does not depend on the thickness of the electrode active material layer but depends on the thickness of the electrode substrate, and therefore, as concerns the relationship between the correction winding density and the internal resistance, an argument similar to that on the relationship between the total thickness ratio and the internal resistance described before is applicable.

The internal resistance gets larger under the condition that the correction winding density decreases to reach not more than 0.69 (round), which is shown in Fig. 4(a) not more remarkably than in Fig. 4(b). On the other hand, with the correction winding density being not less than 0.69 (round), there are no big

changes in the internal resistance, however, in the case where the internal resistance values themselves have been taken into consideration, it is judged that the correction winding density of not less than 0.73 (round) is preferable. Accordingly, as the  
5 result of the above, in the present invention, it is judged that the correction winding density of not less than 0.73 (round) can reduce the internal resistance of batteries and preferable.

Incidentally, at the time when winding pressure has been changed while a battery is being formed, the correction winding  
10 density is to change as per this winding pressure. However, as concerns the upper limit of the correction winding density, it goes without saying that due to a predetermined thickness of electrodes there is naturally a limit in spite of higher winding pressure. In addition when the winding pressure is heightened  
15 too much, it is worried to result in an incident that the electrodes could break, or at a later time the electrolyte could become impermeable to inside the internal electrode body, and as a consequent the battery reaction might not go on well and the internal resistance could increase. On the contrary, when the  
20 winding pressure is insufficient, such a problem that the internal electrode body might not be maintained in a fixed shape could occur. Accordingly, to form a battery, the winding pressure is consequently to be set under predetermined conditions.

25 The configuration of the above-described lithium secondary battery of the present invention is suitably applied to huge capacity batteries with the battery capacity of not less than 5 Ah,

and in that case, reduction effect of internal resistance remarkably appears. But, it goes without saying that the configuration may be applied to batteries with the capacity of not more than 5 Ah as well. Thus due to small internal resistance,  
5 discharge of huge currents becomes feasible without any obstacles, thus the lithium secondary battery of the present invention is suitably used for an electric vehicle (EV) or a hybrid electric vehicle (HEV).

Up until now, the lithium secondary battery of the present  
10 invention has been described in detail, and when the present invention is compared with the invention disclosed in the above-described Japanese Patent Laid-Open No. 2701347 specification, it is obvious that their configuration, effects, and functions are respectively different each other.

15 As described above, in the lithium secondary battery of the present invention, the thickness ratio of thickness of electrode substrates and electrode active material layers in electrodes is set at a suitable ratio so that the resistance of the internal electrode body of a battery is reduced, and therefore, the battery  
20 can be used without any obstacles for usage such as batteries for an EV as well as an HEV or the like where discharging of huge currents takes place frequently. In addition, according to the present invention, charging/discharging loss is reduced to suppress Jules' heat to be generated, and consequently an  
25 excellent effect can be obtained that deterioration of batteries can be controlled and charging/discharging cycle characteristics can be made to get improved. Moreover, by using materials

having lower resistance as electrode active materials, the configuration has characteristics that high output characteristics are maintained under conditions of deeper discharging depths. In addition, it becomes possible to make the shape of the internal electrode body of a battery compact within a range so as to secure necessary battery capacity, and space utility for disposition of a battery is improved, which serves to attain an effect that reduction of production costs can be planned.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A lithium secondary battery, comprising:  
an internal electrode body including a positive electrode, a negative electrode and a separator, the positive electrode and the negative electrode being wound through the separator so that the positive electrode and the negative electrode are not brought into direct contact with each other; and  
an organic electrolyte;  
wherein, when the number of turns of the positive electrode or the negative electrode per unit length (turns/cm) along a diameter of the internal electrode body is multiplied by total thickness (cm) of active material layers, of the electrodes, being designated as a correction winding density (turns), the correction winding density is not less than 0.73 turns.
2. The lithium secondary battery according to claim 1, wherein the positive electrode comprises  $\text{LiMn}_2\text{O}_4$  spinel.
3. The lithium secondary battery according to claim 2, wherein the Li/Mn ration in the  $\text{LiMn}_2\text{O}_4$  spinel exceeds 0.5.

4. The lithium secondary battery according to claim 1, 2 or 3, wherein the negative electrode comprises graphitized carbon material.
5. The lithium secondary battery according to claim 4, wherein the highly graphitized carbon material is in form of fibers.
6. The lithium secondary battery according to any one of claims 1 to 5, wherein the battery capacity is not less than 5 Ah.
7. The lithium secondary battery according to any one of claims 1 to 6, wherein the battery is adapted for use in an electric vehicle or a hybrid electric vehicle.

FIG. 1

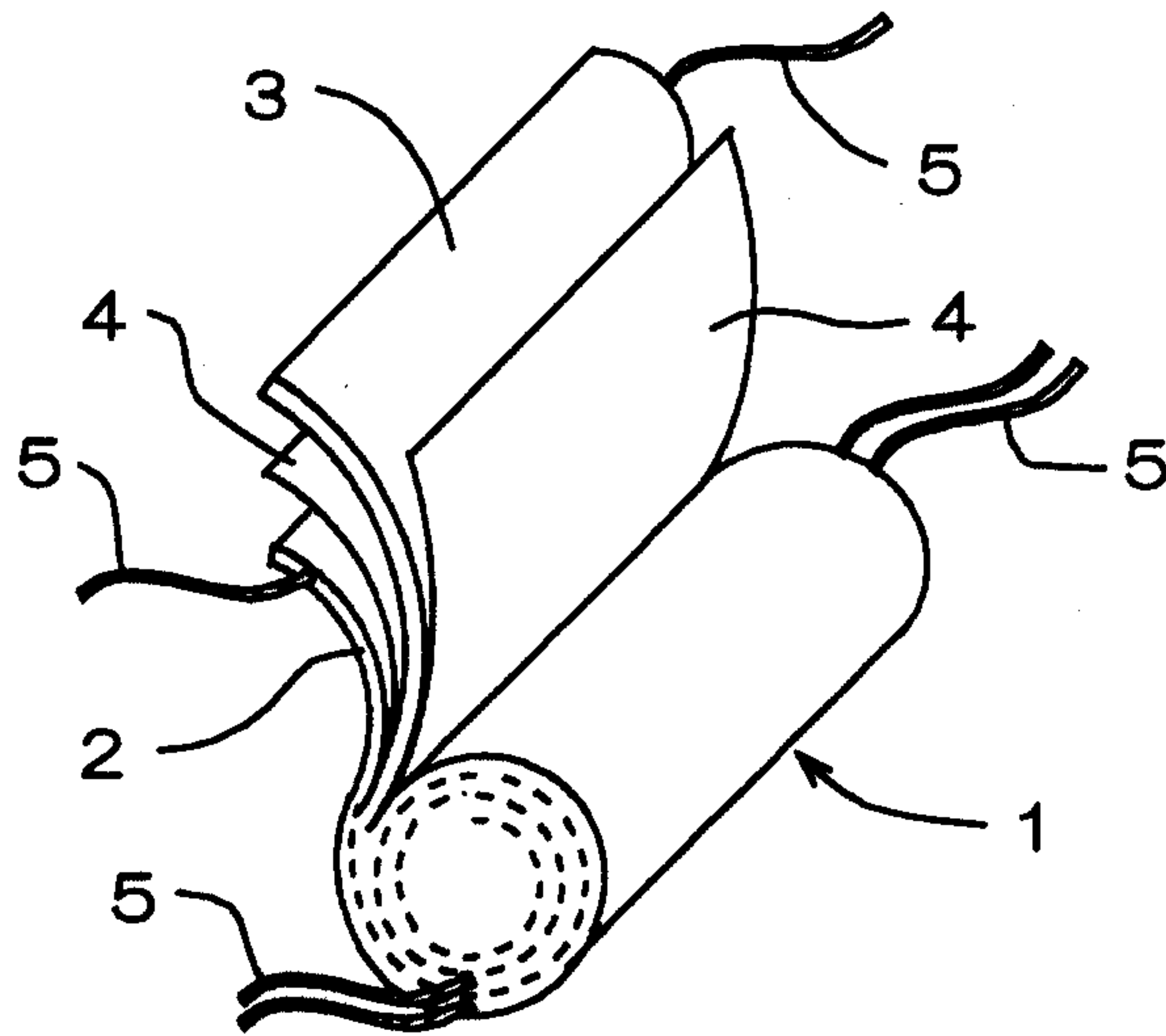
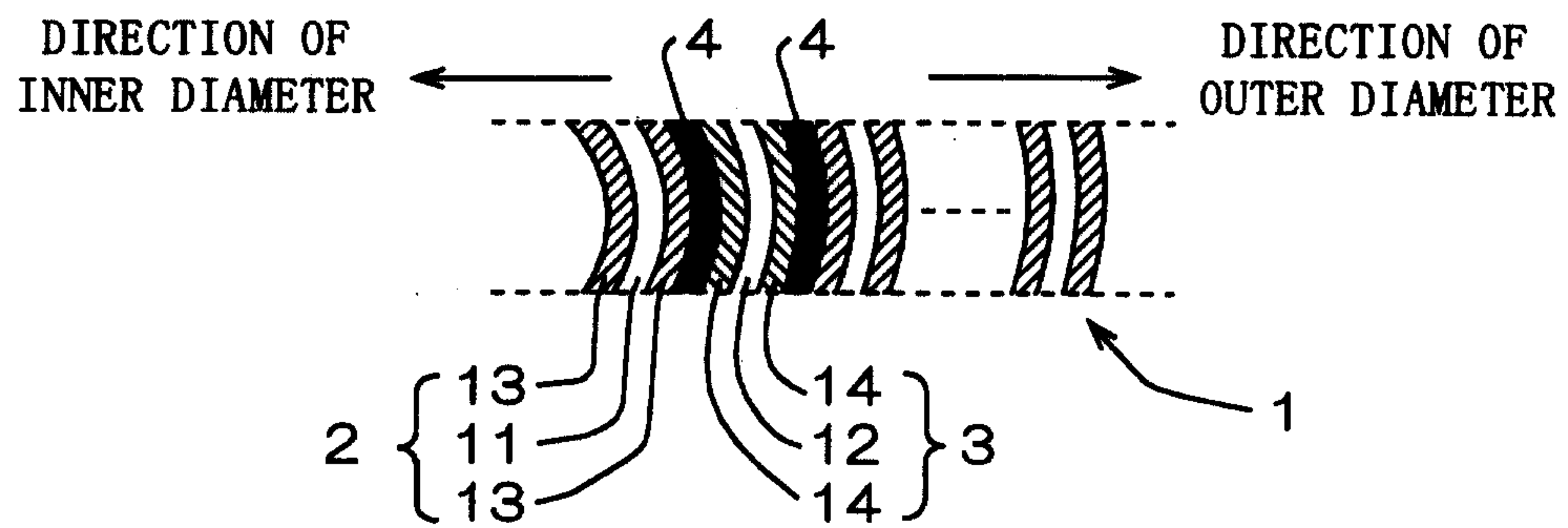


FIG. 2



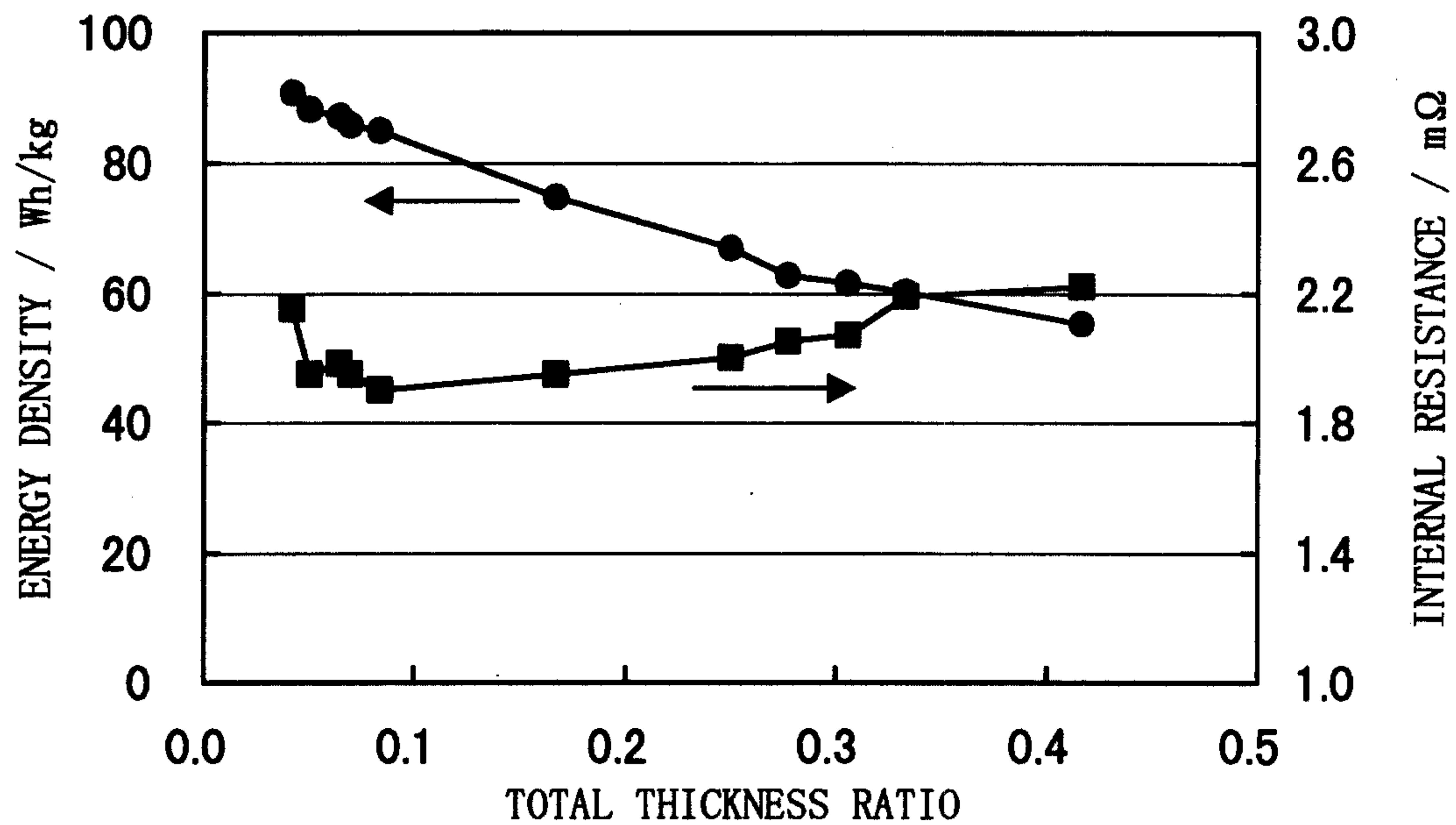


FIG. 3 (a) ONE SIDE THICKNESS OF POSITIVE ACTIVE MATERIAL LAYER :  
WITH 100  $\mu$  m

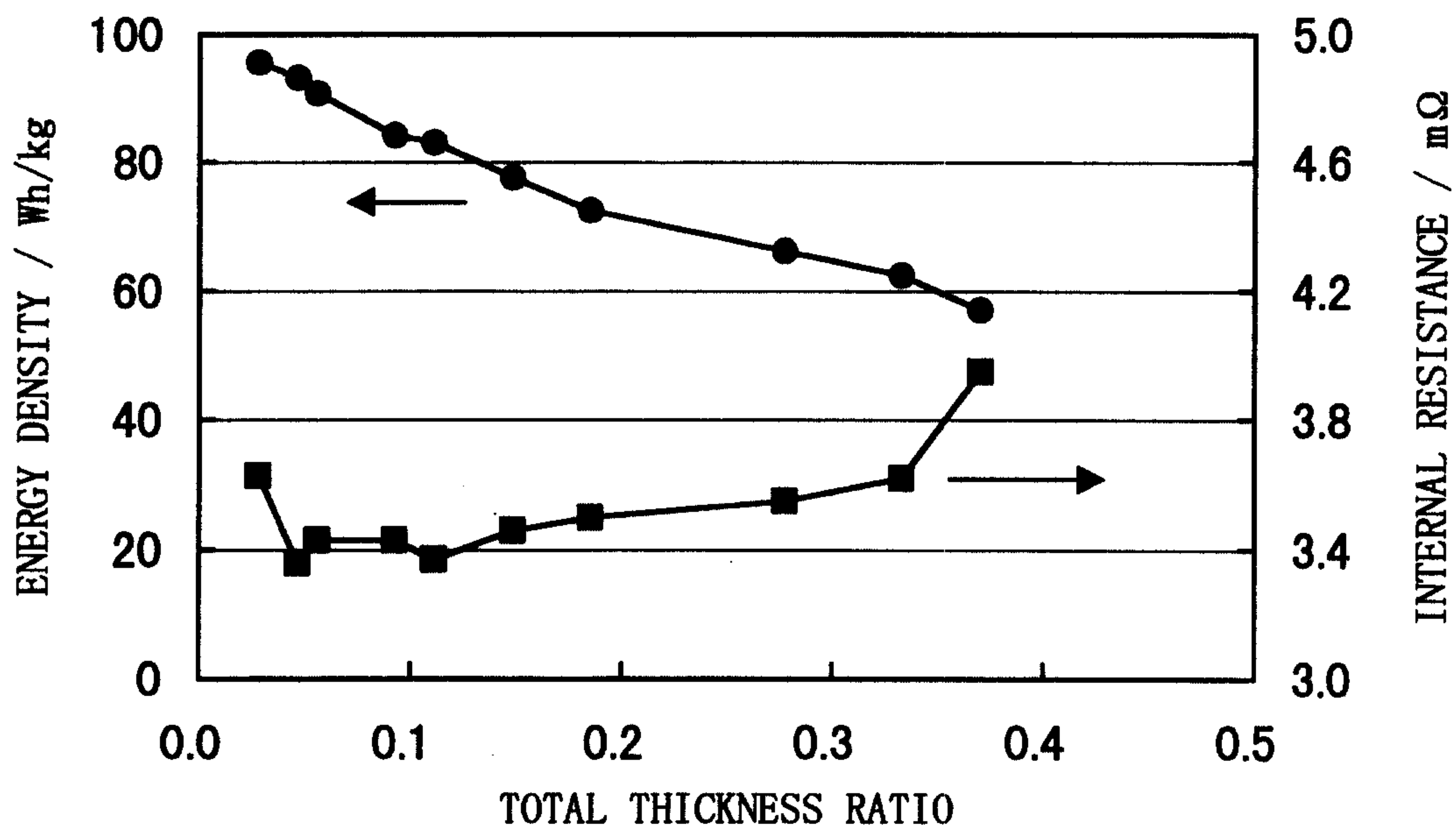


FIG. 3 (b) ONE SIDE THICKNESS OF POSITIVE ACTIVE MATERIAL LAYER :  
WITH 150  $\mu$  m

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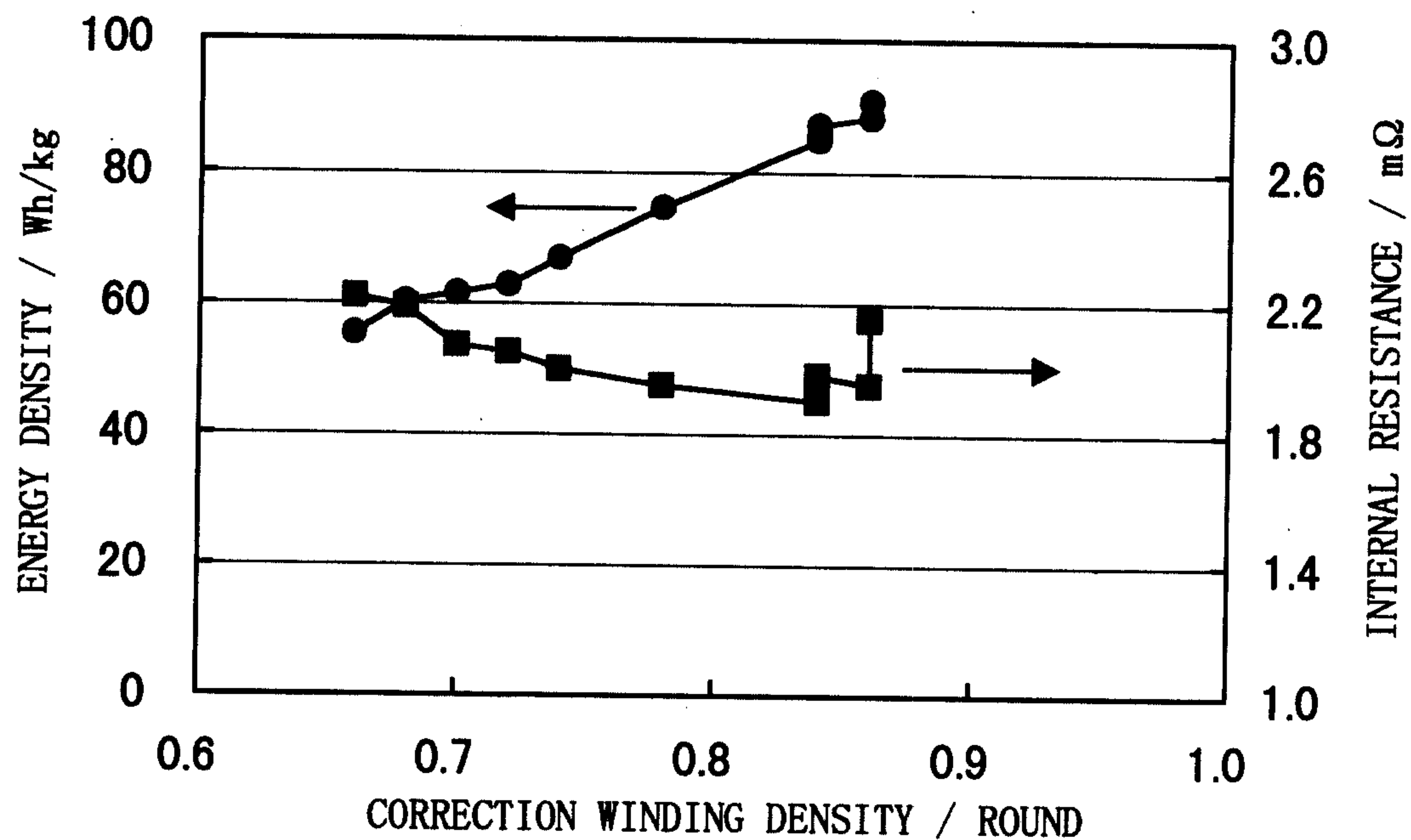


FIG. 4 (a) ONE SIDE THICKNESS OF POSITIVE ACTIVE MATERIAL LAYER :  
WITH  $100 \mu m$

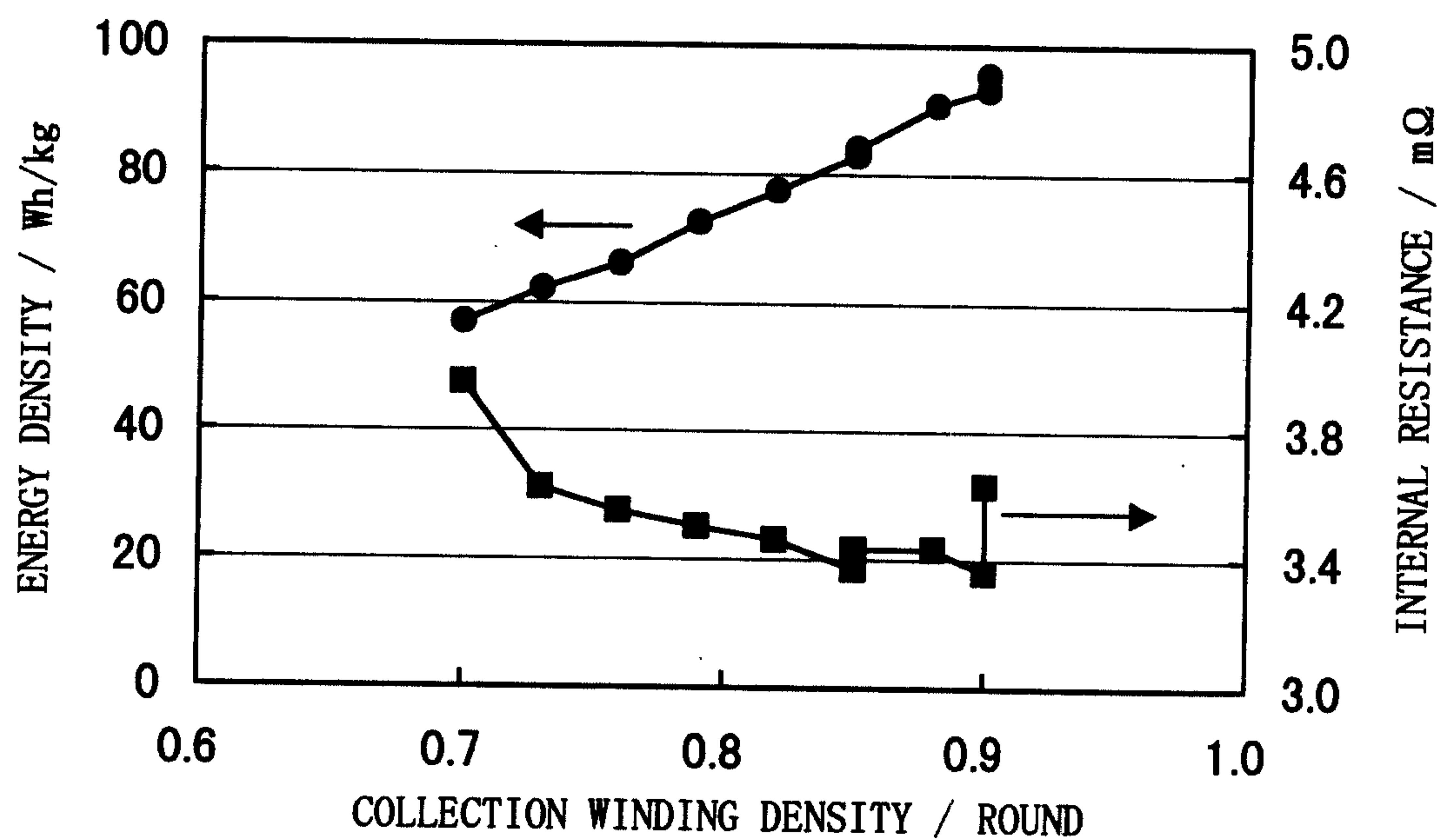


FIG. 4 (b) ONE SIDE THICKNESS OF POSITIVE ACTIVE MATERIAL LAYER :  
WITH  $150 \mu m$

Mark & Clerk

