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(54) Title of the Invention

High-Energy-Density Lithium-Ion Battery

(57) Abstract

The present invention relates to a high-energy-density lithium-ion battery and belongs to the technical field of lithium batteries. The lithium-ion battery of the present invention comprises a positive electrode sheet, a negative electrode sheet, and a separator, the positive electrode sheet is coated with a positive electrode active material, and the negative electrode sheet is coated with a negative electrode active material, characterized in that the compaction density of the positive electrode sheet is 2.4–2.55 g/cm³, which is its limiting compaction density, with an areal density of 360–380 g/m², and the compaction density of the negative electrode sheet is 1.4–1.50 g/cm³, with a thickness of 115–125 μm. The present invention achieves the limiting compaction density of the positive electrode sheet by the rational configuration of the positive and negative electrode materials of the lithium-ion battery, while effectively ensuring high-rate charge and discharge performance of the battery under such conditions, and at the same time, increases the battery capacity, thereby effectively improving the battery performance.

1. A high-energy-density lithium-ion battery, comprising a positive electrode sheet, a negative electrode sheet, and a separator, the positive electrode sheet being coated with a positive electrode active material, and the negative electrode sheet being coated with a negative electrode active material, characterized in that the compaction density of the positive electrode sheet is $2.4\text{--}2.55\text{ g/cm}^3$, which is its limiting compaction density, with an areal density of $360\text{--}380\text{ g/m}^2$, and the compaction density of the negative electrode sheet is $1.4\text{--}1.50\text{ g/cm}^3$, with a thickness of $115\text{--}125\text{ }\mu\text{m}$.

2. The lithium-ion battery according to claim 1, characterized in that the positive electrode active material comprises the following components in mass percentage: polyvinylidene fluoride 2.7-3.2%, conductive carbon black 0.8-1.3%, and lithium iron phosphate 95.5-96.5%.

3. The lithium-ion battery according to claim 2, characterized in that the particle size D_{50} of the lithium iron phosphate is $8\text{--}11\text{ }\mu\text{m}$.

4. The lithium-ion battery according to claim 1, characterized in that the negative electrode active material comprises the following components in mass percentage: sodium carboxymethyl cellulose 1.5-1.7%, conductive carbon black 1.4-1.6%, graphite 94.6-95.1%, and styrene-butadiene emulsion 1.9-2.1%.

5. The lithium-ion battery according to claim 1, characterized in that a plurality of positive electrode tabs are provided at equal intervals on the positive electrode sheet, and a plurality of negative electrode tabs are provided at equal intervals on the negative electrode sheet.

6. The lithium-ion battery according to claim 5, characterized in that the number of the positive electrode tabs is greater than the number of the negative electrode tabs.

7. The lithium-ion battery according to claim 5, characterized in that the number of the positive electrode tabs is m , the length of the positive electrode sheet is M , the number of the negative electrode tabs is n , the length of the negative electrode sheet is N , the distance between the positive electrode tab near the end of the positive electrode sheet and the end of the electrode sheet is less than or equal to $M/(m+1)$, and the distance between the negative electrode tab near the end of the negative electrode sheet and the end of the electrode sheet is less than or equal to $N/(n+1)$.

8. The lithium-ion battery according to claim 5, characterized in that the positive electrode tabs are welded to the positive electrode cap by ultrasonic welding.

9. The lithium-ion battery according to claim 1, characterized in that the separator is a wet-process ceramic separator.

High-Energy-Density Lithium-Ion Battery

Technical Field

[0001] The present invention belongs to the technical field of lithium batteries and relates to a high-energy-density lithium-ion battery.

Background Art

[0002] A lithium-ion battery is a type of secondary battery (rechargeable battery) that mainly operates through the movement of lithium ions between positive and negative electrodes. During the charging and discharging process, Li^+ is reversibly intercalated into and deintercalated from the two electrodes: during charging, Li^+ is deintercalated from the positive electrode, passes through an electrolyte, and is intercalated into the negative electrode, leaving the negative electrode in a lithium-rich state; during discharging, the process is reversed.

[0003] In the electrodes, the compaction density of an electrode sheet is related to the hardness of the material and the pressure. Generally speaking, the electrode coating is required to have a gap of tens of nanometers to allow electrolyte wetting and penetration, thereby facilitating the transport of ions. For a given volume of space, a higher compaction density corresponds to a higher capacity. Different batteries require the selection of materials and processing techniques according to performance requirements, and the compaction density must be controlled accordingly. If the compaction density is too high, ion transport becomes difficult, which affects a battery's charge and discharge performance, and the electrode sheets are prone to powder shedding and embrittlement.

[0004] The binder in an electrode is a polymer compound used to adhere an electrode active material to a current collector. Its main function is to bind and retain the active material, enhance the electronic contact between the electrode active material and a conductive agent, as well as between the active material and the current collector, and better stabilize the structure of the electrode sheet. Choosing a suitable lithium-ion battery binder requires low ohmic resistance and stable performance in an electrolyte, without swelling, loosening, or powder shedding. Generally speaking, the properties of the binder, such as adhesion, flexibility, alkali resistance, and hydrophilicity, directly affect the performance of the battery. By adding an optimal amount of the binder, a high capacity, long cycle life, and low internal resistance can be achieved, which helps improve the battery's cycling performance and fast charge-discharge capability, and reduce internal pressure of the battery. Therefore, choosing a suitable binder is very important.

[0005] In the existing cylindrical lithium-ion battery market, cylindrical lithium-ion batteries are not only an energy storage device, but also an important choice for more and more passenger cars and logistics vehicles. In this context, developing a high-energy-density battery is driven by market demand.

Summary of the Invention

[0006] The objective of the present invention is to address the above-mentioned problems existing in the prior art by proposing a high-energy-density lithium-ion battery.

[0007] The objective of the present invention can be achieved through the following technical solutions:

[0008] A high-energy-density lithium-ion battery, comprising a positive electrode sheet, a negative electrode sheet, and a separator, the positive electrode sheet is coated with a positive electrode active material, and the negative electrode sheet is coated with a negative electrode active material, characterized in that the compaction density of the positive electrode sheet is $2.4\text{--}2.55\text{ g/cm}^3$, which is its limiting compaction density, with an areal density of $360\text{--}380\text{ g/m}^2$, and the compaction density of the negative electrode sheet is $1.4\text{--}1.50\text{ g/cm}^3$, with a thickness of $115\text{--}125\text{ }\mu\text{m}$.

[0009] The present invention effectively improves the capacity ($0.5\text{--}0.9\text{ Ah}$ higher than the prior art, and reaching $3.7\text{ Ah--}4.1\text{ Ah}$) and energy density (up to $142\text{--}148\text{ Wh/kg}$) of the lithium-ion battery by controlling the compaction density of the positive electrode sheet at its limiting compaction density and the areal density at $360\text{--}380\text{ g/m}^2$, while matching the compaction density and thickness of the negative electrode sheet. This reduces the internal resistance and polarization losses of the battery, while ensuring lithium-ion intercalation and deintercalation, which is beneficial to high-rate charge and discharge, extends the cycle life of the battery, and reduces battery-pack cost. In the electrode sheets of the present invention, the high compaction density may further enable the design of long cell electrode sheets and control the overall thickness of the cell. By increasing the compaction density, the length of the electrode sheets within the same volume can be increased, allowing the positive electrode sheet length to reach 1377 mm and the negative electrode sheet length to reach 1447 mm , whereas the positive electrode sheet length is 1233 mm and the negative electrode sheet length is 1317 mm under conventional conditions. As a result, a greater amount of the positive electrode material can be packed within the limited space of a 26650 steel casing, thereby increasing the capacity of the cell.

[0010] Preferably, the positive electrode active material comprises the following components in mass percentage: polyvinylidene fluoride 2.7-3.2%, conductive carbon black 0.8-1.3%, and lithium iron phosphate 95.5-96.5%.

[0011] By optimizing the formulation of the positive electrode active material, the present invention improves the adhesion of the electrode sheet and prevents the electrode sheet from easily shedding powder and becoming brittle under high areal density and high compaction density, which is beneficial to improving the cycle life of the battery.

[0012] Preferably, the lithium iron phosphate has a particle size D_{50} of 8-11 μm .

[0013] The present invention achieves control of areal density and compaction density by regulating the particle size of lithium iron phosphate, which is beneficial to lithium-ion transport. At the same time, in combination with other components in the active material, it improves the coating quality of the positive electrode sheet, thereby enhancing battery performance. By adopting different particle size distributions of lithium iron phosphate, the adjustment of high compaction density and areal density is realized, which further optimizes the performance of the lithium-ion battery.

[0014] Preferably, the negative electrode active material comprises the following components in mass percentage: sodium carboxymethyl cellulose (CMC) 1.5-1.7%, conductive carbon black 1.4-1.6%, graphite 94.6-95.1%, and styrene-butadiene emulsion 1.9-2.1%.

[0015] Preferably, the styrene content of the styrene-butadiene rubber in the styrene-butadiene emulsion is 35-43%.

[0016] Preferably, the styrene-butadiene rubber emulsion further contains 0.6-1.3% by mass of nano- SiO_2 and 0.2-0.8% by mass of silane coupling agent.

[0017] Preferably, the preparation process of the styrene-butadiene emulsion is as follows: first mixing nano- SiO_2 and silane coupling agent, and then adding them to the styrene-butadiene rubber emulsion.

[0018] Preferably, the particle size of the nano- SiO_2 is 20-70 nm.

[0019] The CMC and styrene-butadiene rubber emulsion composite has good performance as a binder for negative electrode materials. However, styrene-butadiene rubber emulsion is prone to demulsification at a high shear rate, so it cannot be mixed at a high stirring rate, which affects the preparation efficiency and bonding performance of the negative electrode binder. The present invention can significantly improve the shear stability of styrene-butadiene rubber emulsions by adding nano- SiO_2 and a silane coupling agent into the styrene-butadiene rubber emulsions, wherein these two agents undergo a grafting reaction with styrene-butadiene rubber macromolecules in the styrene-butadiene emulsion that grafts nano- SiO_2 onto the styrene-butadiene rubber macromolecular chains. Furthermore, by controlling the styrene content in the styrene-butadiene rubber, the grafting rate of nano- SiO_2 can be controlled. An excessively high grafting rate will affect a binder's bonding performance, while an excessively low grafting rate will affect the shear stability. At the same time, the particle size of nano- SiO_2 is controlled within the range of 20-70 nm. An excessively large nano- SiO_2 particle size will affect the flexibility of the grafted chains, leading to a significant decrease in the shear stability of the styrene-butadiene emulsion. Nano- SiO_2 with the aforementioned particle size also helps to prevent the negative electrode aqueous binder from becoming brittle after dehydration, while an excessively large particle size will significantly reduce the flexibility of the negative electrode binder, resulting in deteriorated electrode sheet performance.

[0020] Preferably, the positive electrode sheet is provided with a plurality of positive electrode tabs at equal intervals, and the negative electrode sheet is provided with a plurality of negative electrode tabs at equal intervals.

[0021] Preferably, the positive electrode tabs are made of aluminum, and the negative electrode tabs are made of nickel.

[0022] Preferably, the number of positive electrode tabs is 3-5, and the number of negative electrode tabs is 2-4.

[0023] The present invention achieves an effect similar to parallel connection through the arrangement of multiple tabs, thereby reducing the internal resistance of the battery. For example, a three-tab configuration for negative electrode tabs (with the negative electrode tabs respectively arranged at two ends and the middle of the negative electrode sheet) can reduce the internal resistance by approximately 5 m Ω compared with a two-tab configuration (with the negative electrode tabs respectively arranged at two ends of the negative electrode sheet).

[0024] Preferably, the number of positive electrode tabs is greater than the number of negative electrode tabs.

[0025] Preferably, the number of the positive electrode tabs is one more than that of the negative electrode tabs.

[0026] The present invention helps to reduce the output internal resistance of the battery by reasonably setting the number of positive and negative electrode tabs.

[0027] Preferably, the number of the positive electrode tabs is m , the length of the positive electrode sheet is M , the number of the negative electrode tabs is n , the length of the negative electrode sheet is N , the distance between the positive electrode tab near the end of the positive electrode sheet and the end of the electrode sheet is less than or equal to $M/(m+1)$, and the distance between the negative electrode tab near the end of the negative electrode sheet and the end of the electrode sheet is less than or equal to $N/(n+1)$.

[0028] By optimizing the positions of the tabs, the present invention moves the positions of the tabs at both ends of the electrode sheet simultaneously towards the middle, which helps to reduce the internal resistance of the battery. It can reduce the internal resistance of the battery by 0.5-1 m Ω based on the internal resistance of existing batteries, thereby achieving designs of different internal resistance.

[0029] Preferably, the positive electrode tabs are welded to the positive electrode cap by ultrasonic welding.

[0030] The present invention uses ultrasonic welding, which can effectively reduce the internal resistance of welding contact between the electrode tabs and the cap.

[0031] Preferably, the separator is a wet-process ceramic separator.

[0032] Preferably, the wet-process ceramic separator comprises a base film and a ceramic coating, wherein the thickness of the base film is 14 μm and the thickness of the ceramic coating is 2 μm .

[0033] By using a wet-process ceramic separator, the present invention can effectively avoid safety problems caused by micro-short circuits due to particle puncture of the separator. Furthermore, by controlling the thickness of the base film and ceramic coating of the wet-process ceramic separator, the overall mass of the battery is reduced, which is beneficial to improving the energy density of the battery.

[0034] Compared with the prior art, the present invention has the following beneficial effects: by the rational configuration of the positive and negative electrode materials of lithium-ion batteries, the positive electrode sheet reaches its limiting compaction density, and under this condition, the high rate of charge and discharge of the battery is effectively guaranteed, while the battery capacity is improved and the battery performance is effectively improved; by setting the position and number of electrode tabs, the internal resistance of the battery is effectively reduced; by the rational formulation of the battery negative electrode binder, the bonding performance of the negative electrode binder is improved, and the problem that aqueous styrene-butadiene rubber is prone to emulsification under high shear rates is solved.

Detailed Description of the Embodiments

[0035] The following are specific embodiments of the present invention, which further describe the technical solutions of the present invention, but the present invention is not limited to these embodiments.

[0036] Embodiment 1

[0037] The high-energy-density lithium-ion battery in this embodiment comprises a positive electrode sheet, a negative electrode sheet, and a separator.

[0038] The positive electrode sheet is coated with a positive electrode active material, which comprises the following components by mass percentage: 3% polyvinylidene fluoride, 1% conductive carbon black, and 96% lithium iron phosphate, the particle size D_{50} of lithium iron phosphate is 9-10 μm , the compaction density of the positive electrode sheet is its limiting compaction density of 2.45 g/cm³, and the areal density is 370 g/m².

[0039] The negative electrode sheet is coated with a negative electrode active material, which comprises the following components in mass percentage: CMC 1.6%, conductive carbon black 1.5%, graphite 94.9%, styrene-butadiene emulsion 2%, and the negative electrode sheet has a compaction density of 1.46 g/cm³ and a thickness of 120 μm .

[0040] Here, the styrene content of styrene-butadiene rubber in the styrene-butadiene emulsion is 39%. The styrene-butadiene rubber emulsion further contains 1.0% by mass of nano-SiO₂ and 0.6% by mass of silane coupling agent. The preparation process of the styrene-butadiene emulsion is as follows: first mixing nano-SiO₂ with a particle size between 20-70 nm and a silane coupling agent, and then adding them to the styrene-butadiene rubber emulsion. The negative electrode active material is first made into a slurry and then coated onto the metal foil of the negative electrode sheet. The slurry preparation process is as follows: first, CMC is dissolved to make a 1.5wt% CMC solution, then 70wt% CMC solution, conductive carbon black, and graphite are mixed and stirred at 400 rpm for 1.5 h, then the remaining 70wt% CMC solution is added and stirred at 2000 rpm for 1.5 h, and finally styrene-butadiene rubber emulsion is added and stirred at 2000 rpm for 15 min.

[0041] Three positive electrode tabs are arranged on the positive electrode sheet at equal intervals, and the positive electrode tabs are made of aluminum. Assuming the length of the positive electrode sheet is M, the distance between the positive electrode tab near the end of the positive electrode sheet and the end of the electrode sheet is less than or equal to M/4. The positive electrode tabs are ultrasonically welded to the positive electrode cap.

[0042] Two negative electrode tabs are arranged at equal intervals on the negative electrode sheet, and the negative electrode tabs are made of nickel.

[0043] Assuming the length of the negative electrode sheet is N, the distance between the negative electrode tab near the end of the negative electrode sheet and the end of the electrode sheet is less than or equal to N/3.

[0044] The separator is a wet-process ceramic separator, comprising a 14 μm thick base film and a 2 μm thick ceramic coating.

[0045] Embodiment 2

[0046] The high-energy-density lithium-ion battery in this embodiment comprises a positive electrode sheet, a negative electrode sheet, and a separator.

[0047] The positive electrode sheet is coated with a positive electrode active material, which comprises the following components by mass percentage: 2.7% polyvinylidene fluoride, 0.8% conductive carbon black, and 96.5% lithium iron phosphate, the particle size D_{50} of lithium iron phosphate is 8-9 μm , the compaction density of the positive electrode sheet is its limiting compaction density of 2.55 g/cm^3 , and the areal density is 380 g/m^2 .

[0048] The negative electrode sheet is coated with a negative electrode active material, which comprises the following components in mass percentage: CMC 1.5%, conductive carbon black 1.4%, graphite 95.2%, and styrene-butadiene emulsion 1.9%, and the negative electrode sheet has a compaction density of 1.5 g/cm^3 and a thickness of 115 μm .

[0049] Here, the styrene content of styrene-butadiene rubber in the styrene-butadiene emulsion is 35%. The styrene-butadiene rubber emulsion further contains 0.6% by mass of nano- SiO_2 and 0.2% by mass of silane coupling agent. The preparation process of the styrene-butadiene emulsion is as follows: first mixing nano- SiO_2 with a particle size between 20-70 nm and a silane coupling agent, and then adding them to the styrene-butadiene rubber emulsion. The negative electrode active material is first made into a slurry and then coated onto the metal foil of the negative electrode sheet. The slurry preparation process is as follows: first, CMC is dissolved to make a 1.5wt% CMC solution, then 70wt% CMC solution, conductive carbon black, and graphite are mixed and stirred at 400 rpm for 1.5 h, then the remaining 70wt% CMC solution is added and stirred at 2000 rpm for 1.5 h, and finally styrene-butadiene rubber emulsion is added and stirred at 2000 rpm for 15 min.

[0050] Three positive electrode tabs are arranged on the positive electrode sheet at equal intervals, and the positive electrode tabs are made of aluminum. Assuming the length of the positive electrode sheet is M, the distance between the positive electrode tab near the end of the positive electrode sheet and the end of the electrode sheet is less than or equal to M/4. The positive electrode tabs are ultrasonically welded to the positive electrode cap.

[0051] Two negative electrode tabs are arranged at equal intervals on the negative electrode sheet, and the negative electrode tabs are made of nickel.

[0052] Assuming the length of the negative electrode sheet is N, the distance between the negative electrode tab near the end of the negative electrode sheet and the end of the electrode sheet is less than or equal to N/3.

[0053] The separator is a wet-process ceramic separator, comprising a 14 μm thick base film and a 2 μm thick ceramic coating.

[0054] Embodiment 3

[0055] The high-energy-density lithium-ion battery in this embodiment comprises a positive electrode sheet, a negative electrode sheet, and a separator.

[0056] The positive electrode sheet is coated with a positive electrode active material, which comprises the following components by mass percentage: 3.2% polyvinylidene fluoride, 1.3% conductive carbon black, and 96.5% lithium iron phosphate, the particle size D_{50} of lithium iron phosphate is 10-11 μm , the compaction density of the positive electrode sheet is its limiting compaction density of 2.4 g/cm^3 , and the areal density is 360 g/m^2 .

[0057] The negative electrode sheet is coated with a negative electrode active material, which comprises the following components in mass percentage: CMC 1.7%, conductive carbon black 1.6%, graphite 94.6%, and styrene-butadiene emulsion 2.1%, and the negative electrode sheet has a compaction density of 1.4 g/cm^3 and a thickness of 125 μm .

[0058] Here, the styrene content of styrene-butadiene rubber in the styrene-butadiene emulsion is 43%. The styrene-butadiene rubber emulsion further contains 1.3% by mass of nano- SiO_2 and 0.2-0.8% by mass of silane coupling agent. The preparation process of the styrene-butadiene emulsion is as follows: first mixing nano- SiO_2 with a particle size between 20-70 nm and a silane coupling agent, and then adding them to the styrene-butadiene rubber emulsion. The negative electrode active material is first made into a slurry and then coated onto the metal foil of the negative

electrode sheet. The slurry preparation process is as follows: first, CMC is dissolved to make a 1.5wt% CMC solution, then 70wt% CMC solution, conductive carbon black, and graphite are mixed and stirred at 400 rpm for 1.5 h, then the remaining 70wt% CMC solution is added and stirred at 2000 rpm for 1.5 h, and finally styrene-butadiene rubber emulsion is added and stirred at 2000 rpm for 15 min.

[0059] Three positive electrode tabs are arranged on the positive electrode sheet at equal intervals, and the positive electrode tabs are made of aluminum. Assuming the length of the positive electrode sheet is M, the distance between the positive electrode tab near the end of the positive electrode sheet and the end of the electrode sheet is less than or equal to $M/4$. The positive electrode tabs are ultrasonically welded to the positive electrode cap.

[0060] Two negative electrode tabs are arranged at equal intervals on the negative electrode sheet, and the negative electrode tabs are made of nickel.

[0061] Assuming the length of the negative electrode sheet is N, the distance between the negative electrode tab near the end of the negative electrode sheet and the end of the electrode sheet is less than or equal to $N/3$.

[0062] The separator is a wet-process ceramic separator, comprising a 14 μm thick base film and a 2 μm thick ceramic coating.

[0063] Comparative Example 1

[0064] The compaction density of the positive electrode sheet is 2.4 g/cm^3 (not its limiting compaction density), and the remainder is the same as in Embodiment 1.

[0065] Comparative Example 2

[0066] The particle size D_{50} of lithium iron phosphate is 12-13 μm , and its corresponding limiting compaction density is 2.33 g/cm^3 . The remainder is the same as in Embodiment 1.

[0067] Comparative Example 3

[0068] The particle size D_{50} of lithium iron phosphate is 7-8 μm , and its corresponding limiting compaction density is 2.67 g/cm^3 . The remainder is the same as in Embodiment 1.

[0069] Comparative Example 4

[0070] There are 2 positive electrode tabs and 3 negative electrode tabs, and the remainder is the same as in Embodiment 1.

[0071] Comparative Example 5

[0072] The distance between the positive electrode tab near the end of the positive electrode sheet and the end of the electrode sheet is 0.3M, and the remainder is the same as in Embodiment 1.

[0073] Comparative Example 6

[0074] The distance between the negative electrode tab near the end of the negative electrode sheet and the end of the electrode sheet is 0.35N, and the remainder is the same as in Embodiment 1.

[0075] Comparative Example 7

[0076] The styrene content of styrene-butadiene rubber in the styrene-butadiene emulsion is 45%, and the remainder is the same as in Embodiment 1.

[0077] Comparative Example 8

[0078] The styrene content of styrene-butadiene rubber in the styrene-butadiene emulsion is 33%, and the remainder is the same as in Embodiment 1.

[0079] Comparative Example 9

[0080] The styrene-butadiene emulsion does not contain nano- SiO_2 and silane coupling agent, and the remainder is the same as in Embodiment 1.

[0081] Comparative Example 10

[0082] The particle size of nano- SiO_2 in the styrene-butadiene emulsion is 70-100 nm, and the remainder is the same as in Embodiment 1.

[0083] The performance of the batteries prepared in Embodiments 1-3 and Comparative Examples 1-10 of the present invention was compared, and the comparison results are shown in Table 1.

[0084] Table 1: Comparison of battery performance in Embodiments 1-3 and Comparative Examples 1-10

[0085]

Performance Embodiment	Capacity (Ah)	Energy density (Wh/kg)	Internal resistance (mΩ)	Discharge capacity retention rate after 1000 cycles at 1C/1C /%
Embodiment 1	4.1	148	33	84.3
Embodiment 2	3.9	146	35	83.6
Embodiment 3	3.8	143	36	83.5
Comparative Example 1	3.3	131	38	80.2

[0086]

Comparative Example 2	3.2	128	37	83.3
Comparative Example 3	4.2	150	43	79.6
Comparative Example 4	4.0	148	35	82.2
Comparative Example 5	4.1	147	34	82.0
Comparative Example 6	4.0	148	35	81.9
Comparative Example 7	3.6	141	39	78.1
Comparative Example 8	3.7	145	38	78.5
Comparative Example 9	3.5	137	40	70.6
Comparative Example 10	3.6	141	38	73.7

[0087] The viscosities of the negative electrode active material slurries prepared in Embodiment 1 and Comparative Examples 7-10 were compared, and the results are shown in Table 2.

[0088] Table 2: Comparison of viscosity of negative electrode active material slurries in Embodiment 1 and Comparative Examples 7-10

[0089]

	Embodiment 1	Comparative Example 7	Comparative Example 8	Comparative Example 9	Comparative Example 10
Viscosity (mpa·s)	722.3	601.8	587.6	379.5	598.2

[0090] As can be seen from Table 2 and the observation of the prepared slurries, the slurry in Comparative Example 8 showed slight demulsification after high-speed stirring, while the slurry in Comparative Example 9 showed obvious demulsification. The slurry prepared in Comparative Example 7 showed a small amount of agglomeration and poor shear stability. The slurry in Comparative Example 10 did not show obvious demulsification, but its shear stability was significantly reduced.

[0091] The negative electrode sheets prepared in Embodiment 1 and Comparative Examples 7-10 were subjected to a 90° right-angle bending test. The results showed that the negative electrode sheet in Embodiment 1 had active material detachment only after 50 bends, while the active materials in Comparative Examples 7-10 detached after 30, 26, 13 and 29 bends, respectively.

[0092] In summary, the present invention effectively improves the performance of lithium-ion batteries by the rational configuration of the positive and negative electrode materials and the separator, as well as the settings of the electrode sheets.

[0093] The specific embodiments described herein are merely illustrative of the spirit of the present invention. Those skilled in the art to which the present invention pertains may make various modifications or additions to the specific embodiments described, or use similar methods to replace them, without departing from the spirit of the present invention or exceeding the scope defined by the appended claims.



DECLARATION OF TRANSLATOR

I, Jian Zhang, hereby declare as follows:

1. I personally performed the attached translation from Chinese into English of the patent that is entitled “CN108899475A (Hu)” in Chinese and “CN108899475A (Hu)” in English (also attached).

2. The attached translation is, to the best of my knowledge, a true, full and accurate translation of the attached Chinese document.

3. I am competent to perform this translation, because I have more than 30 years of experience in patent translation between English and Chinese.

4. I declare under the penalty of perjury under the laws of the United States that the foregoing is true and correct; and further declare that I am aware that willful false statements and the like so made are punishable by fine or imprisonment, or both, under 1001 of Title 18 of the United States Code.

Dated: 05/12/2026

A handwritten signature in black ink, appearing to be "Jian Zhang", written in a cursive style.

(Bibliographic information, abstract, specifications)

(Claims, drawings)



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一种高能量密度锂离子电池

(57)摘要

本发明涉及一种高能量密度锂离子电池,属于锂电技术领域。本发明的锂离子电池包括正极极片、负极极片、隔膜,所述正极极片上涂覆有正极活性材料,所述负极极片上涂覆有负极活性材料,其特征在于,所述正极极片的压实密度为其极限压实密度 $2.4-2.55\text{g}/\text{cm}^3$,面密度为 $360-380\text{g}/\text{m}^2$,所述负极极片的压实密度为 $1.4-1.50\text{g}/\text{cm}^3$,厚度为 $115-125\mu\text{m}$ 。本发明通过对锂离子电池正负极材料的合理配置,使正极极片达到其在极限压实密度,并在该条件下有效保证了电池的高倍率充放电,同时提高了电池容量,有效提高了电池性能。

1. 一种高能量密度锂离子电池,包括正极极片、负极极片、隔膜,所述正极极片上涂覆有正极活性材料,所述负极极片上涂覆有负极活性材料,其特征在于,所述正极极片的压实密度为其极限压实密度 $2.4-2.55\text{g}/\text{cm}^3$,面密度为 $360-380\text{g}/\text{m}^2$,所述负极极片的压实密度为 $1.4-1.50\text{g}/\text{cm}^3$,厚度为 $115-125\mu\text{m}$ 。

2. 根据权利要求1所述的锂离子电池,其特征在于,所述正极活性材料包括以下质量百分比的组分:聚偏二氟乙烯 $2.7-3.2\%$,导电炭黑 $0.8-1.3\%$,磷酸铁锂 $95.5-96.5\%$ 。

3. 根据权利要求2所述的锂离子电池,其特征在于,所述磷酸铁锂的粒径 D_{50} 为 $8-11\mu\text{m}$ 。

4. 根据权利要求1所述的锂离子电池,其特征在于,所述负极活性材料包括以下质量百分比的组分:羧甲基纤维素钠 $1.5-1.7\%$,导电炭黑 $1.4-1.6\%$,石墨 $94.6-95.1\%$,丁苯乳液 $1.9-2.1\%$ 。

5. 根据权利要求1所述的锂离子电池,其特征在于,所述正极极片上等间距设置有多个正极极耳,所述负极极片上等间距设有多个负极极耳。

6. 根据权利要求5所述的锂离子电池,其特征在于,所述正极极耳的数量多于负极极耳的数量。

7. 根据权利要求5所述的锂离子电池,其特征在于,所述正极极耳的数量为 m ,所述正极极片的长度为 M ,所述负极极耳的数量为 n ,所述负极极片的长度为 N ,正极极片上靠近极片端部的正极极耳距离极片端部的长度小于等于 $M/(m+1)$,负极极片上靠近极片端部的负极极耳距离极片端部的长度小于等于 $N/(n+1)$ 。

8. 根据权利要求5所述的锂离子电池,其特征在于,所述正极极耳采用超声波焊接方式与正极盖帽焊接。

9. 根据权利要求1所述的锂离子电池,其特征在于,所述隔膜为湿法陶瓷隔膜。

一种高能量密度锂离子电池

技术领域

[0001] 本发明属于锂电技术领域,涉及一种高能量密度锂离子电池。

背景技术

[0002] 锂离子电池在是一种二次电池(充电电池),它主要依靠锂离子在正极和负极之间移动来工作。在充放电过程中, Li^+ 在两个电极之间往返嵌入和脱嵌:充电时, Li^+ 从正极脱嵌,经过电解质嵌入负极,负极处于富锂状态;放电时则相反。

[0003] 在电极中,极片的压实密度与材料的软硬、压力有关,一般来说,对于极片涂层要求有几十纳米的空隙,以便电解液的湿润和进入,方便离子的传输,而对于一定容积的空间,压实越大,容量越高。不同的电池需要根据性能要求选择材料和加工工艺,控制不同的压实密度,压实密度过大,离子很难传输,影响到电池的充放电,并且极片容易掉粉和变脆。

[0004] 电极中的粘结剂是用来将电极活性物质粘附在集流体上的高分子化合物,其主要作用是粘结和保持活性物质,增强电极活性材料与导电剂以及活性材料与集流体之间的电子接触,更好地稳定极片的结构。选择一种合适的锂离子电池粘结剂,要求其欧姆电阻要小,在电解液中性能稳定,不膨胀、不松散、不脱粉,一般而言,粘结剂的性能如粘结力、柔韧性、耐碱性、亲水性等,直接影响电池的性能。加入最佳量的粘结剂,可以获得较大的容量、较长的循环寿命和较低的内阻,对提高电池的循环性能、快速充放电能力以及降低电池的内压等具有促进作用。因此选择一种合适的粘结剂非常重要。

[0005] 在现有的圆柱锂离子电池市场下,圆柱锂离子电池不仅仅是一种储能更是成为越来越多乘用车和物流车的重要选择。在此大环境下,开发一款高能量密度的电池是市场所需。

发明内容

[0006] 本发明的目的是针对现有技术存在的上述问题,提出了一种能量密度高的锂离子电池。

[0007] 本发明的目的可通过下列技术方案来实现:

[0008] 一种高能量密度锂离子电池,包括正极极片、负极极片、隔膜,所述正极极片上涂覆有正极活性材料,所述负极极片上涂覆有负极活性材料,其特征在于,所述正极极片的压实密度为其极限压实密度 $2.4\text{--}2.55\text{g}/\text{cm}^3$,面密度为 $360\text{--}380\text{g}/\text{m}^2$,所述负极极片的压实密度为 $1.4\text{--}1.50\text{g}/\text{cm}^3$,厚度为 $115\text{--}125\mu\text{m}$ 。

[0009] 本发明通过将正极极片的压实密度控制在其极限压实密度,面密度控制在 $360\text{--}380\text{g}/\text{m}^2$,同时匹配负极极片的压实和厚度,有效提高了锂离子电池的容量(比现有技术高 $0.5\text{--}0.9\text{Ah}$,可提高至到 $3.7\text{Ah--}4.1\text{Ah}$)和能量密度(可达到 $142\text{--}148\text{Wh}/\text{kg}$),减小了电池内阻和极化损失,同时保证了锂离子的嵌入和脱出,有利于高倍率充放电,延长了电池的循环寿命,并降低了PACK成本。本发明极片中高压实密度还可实现长电芯极片的设计,控制电芯整体的厚度,采用增加压实密度的方法,在同样的体积内增加放置极片的长度,使正极片长度

可以达到1377mm,负极片长度可以达到1447mm,而常规条件下正极极片长度为1233mm,负极极片1317mm,从而可以在26650钢壳有限的空间内装入更多的正极材料,进而提高了电芯的容量。

[0010] 作为优选,所述正极活性材料包括以下质量百分比的组分:聚偏二氟乙烯2.7-3.2%,导电炭黑0.8-1.3%,磷酸铁锂95.5-96.5%。

[0011] 本发明通过优化正极活性材料的配方,提高了极片的粘结性,防止极片在高面密度和高压实密度下易掉粉和变脆的问题,有利于提高电池的循环寿命。

[0012] 作为优选,所述磷酸铁锂的粒径 D_{50} 为8-11 μm 。

[0013] 本发明通过控制磷酸铁锂的粒径实现面密度和压实密度的控制,有利于锂离子的传输,同时与活性材料中其他物质配合,提高正极极片涂布质量,从而提高电池性能,并通过采用不同磷酸铁锂粒径分布来实现高压实密度和面密度的调整,进一步优化锂离子电池的性能。

[0014] 作为优选,所述负极活性材料包括以下质量百分比的组分:羧甲基纤维素钠(CMC)1.5-1.7%,导电炭黑1.4-1.6%,石墨94.6-95.1%,丁苯乳液1.9-2.1%。

[0015] 作为优选,所述丁苯乳液中丁苯橡胶的苯乙烯含量为35-43%。

[0016] 作为优选,所述丁苯胶乳液中还含有质量百分比为0.6-1.3%的纳米 SiO_2 和质量百分比为0.2-0.8%的硅烷偶联剂。

[0017] 作为优选,所述丁苯乳液的制备过程为,先将纳米 SiO_2 和硅烷偶联剂混合处理后再加入到丁苯橡胶乳液中。

[0018] 作为优选,所述纳米 SiO_2 的粒径为20-70nm。

[0019] CMC和丁苯橡胶乳液复合作为负极材料的粘结剂具有良好的使用性能,但是丁苯橡胶乳液在较大的剪切速率下容易破乳,因此不能在较大搅拌速率下进行混合,影响负极粘结剂的制备效率和粘结性能。本发明通过在丁苯橡胶乳液中添加纳米 SiO_2 和硅烷偶联剂,二者与丁苯乳液中丁苯橡胶大分子发生接枝反应,将纳米 SiO_2 接枝到丁苯橡胶大分子链上,能够大幅提高丁苯橡胶乳液的抗剪切能力;并通过控制丁苯橡胶中苯乙烯含量,控制纳米 SiO_2 的接枝率,而接枝率过高会影响粘结剂的粘结性能,接枝率过低则会影响抗剪切能力;同时控制纳米 SiO_2 的粒径在20-70nm内,纳米 SiO_2 的粒径过大,接枝链的柔性会受到影响,导致丁苯乳液的抗剪切能力大幅下降,上述粒径的纳米 SiO_2 还有利于避免负极水系粘结剂在脱水后变脆的问题,而粒径过大则会使负极粘结剂的柔韧性大幅下降,导致极片性能变差。

[0020] 作为优选,所述正极极片上等间距设置有多个正极极耳,所述负极极片上等间距设置多个负极极耳。

[0021] 作为优选,所述正极极耳的材质为铝,所述负极极耳的材质为镍。

[0022] 作为优选,所述正极极耳的数量为3-5个,所述负极极耳的数量为2-4个。

[0023] 本发明通过多极耳的设置,实现类似于并联的效果,从而降低电池内阻,比如负极极耳为三极耳设置(负极极耳分别设置于负极极片两端和中部)比双极耳设置(负极极耳分别设置于负极极片两端)内阻可降低5m Ω 左右。

[0024] 作为优选,所述正极极耳的数量多于负极极耳的数量。

[0025] 作为优选,所述正极极耳比负极极耳多一个。

[0026] 本发明通过合理设置正极极耳和负极极耳的数量,有利于减少电池的输出内阻。

[0027] 作为优选,所述正极极耳的数量为 m ,所述正极极片的长度为 M ,所述负极极耳的数量为 n ,所述负极极片的长度为 N ,正极极片上靠近极片端部的正极极耳距离极片端部的长度小于等于 $M/(m+1)$,负极极片上靠近极片端部的负极极耳距离极片端部的长度小于等于 $N/(n+1)$ 。

[0028] 本发明通过优化极耳位置,将极片两端的极耳位置同时往中间移,有利于降低电池内阻,可在现有电池内阻的基础上降低 $0.5-1m\Omega$,从而达到不同内阻大小设计。

[0029] 作为优选,所述正极极耳采用超声波焊接方式与正极盖帽焊接。

[0030] 本发明采用超声波焊接方式,能有效降低极耳和盖帽焊接接触内阻。

[0031] 作为优选,所述隔膜为湿法陶瓷隔膜。

[0032] 作为优选,所述湿法陶瓷隔膜包括基膜和陶瓷涂层,所述基膜的厚度为 $14\mu m$,所述陶瓷涂层的厚度为 $2\mu m$ 。

[0033] 本发明通过使用湿法陶瓷隔膜,能够有效避免颗粒刺穿隔膜造成微短路而引发的安全问题,并通过控制湿法陶瓷隔膜基膜和陶瓷涂层的厚度,减小了电池整体的质量,有利于提升电池的能量密度

[0034] 与现有技术相比,本发明具有以下有益效果:通过对锂离子电池正负极材料的合理配置,使正极极片达到其在极限压实密度,并在该条件下有效保证了电池的高倍率充放电,同时提高了电池容量,有效提高了电池性能;通过对极耳位置和数量的设置,有效降低了电池内阻;通过对电池负极粘结剂的合理配伍,提高了负极年积极的粘结性能,解决了水性丁苯橡胶高剪切速率下易乳化的问题。

具体实施方式

[0035] 以下是本发明的具体实施例,对本发明的技术方案作进一步的描述,但本发明并不限于这些实施例。

[0036] 实施例1

[0037] 本实施例中的高能量密度锂离子电池,包括正极极片、负极极片、隔膜。

[0038] 正极极片上涂覆有正极活性材料,正极活性材料包括以下质量百分比的组分:聚偏二氟乙烯3%,导电炭黑1%,磷酸铁锂96%,磷酸铁锂的粒径 D_{50} 为 $9-10\mu m$,正极极片的压实密度为其极限压实密度 $2.45g/cm^3$,面密度为 $370g/m^2$ 。

[0039] 负极极片上涂覆有负极活性材料,负极活性材料包括以下质量百分比的组分:CMC1.6%,导电炭黑1.5%,石墨94.9%,丁苯乳液2%,负极极片的压实密度为 $1.46g/cm^3$,厚度为 $120\mu m$ 。

[0040] 其中,丁苯乳液中丁苯橡胶的苯乙烯含量为39%。丁苯胶乳液中还含有质量百分比为1.0%的纳米 SiO_2 和质量百分比为0.6%的硅烷偶联剂。丁苯乳液的制备过程为,先将粒径为 $20-70nm$ 纳米 SiO_2 和硅烷偶联剂混合处理后再加入到丁苯橡胶乳液中。负极活性材料先制成浆料再涂覆在负极极片的金属箔上,浆料的制备过程为,先将CMC溶解,制成1.5wt%CMC溶液,然后将70wt%CMC溶液、导电炭黑、石墨混合,以400rpm的速度搅拌1.5h,再加入余下的70wt%CMC溶液,以2000rpm的速度搅拌1.5h,最后加入丁苯橡胶乳液,继续以2000rpm的速度搅拌15min。

[0041] 正极极片上等间距设置有3个正极极耳,正极极耳的材质为铝,假设正极极片的长度为M,正极极片上靠近极片端部的正极极耳距离极片端部的长度小于等于M/4,正极极耳采用超声波焊接方式与正极盖帽焊接。

[0042] 负极极片上等间距设有2个负极极耳,负极极耳的材质为镍,

[0043] 假设负极极片的长度为N,负极极片上靠近极片端部的负极极耳距离极片端部的长度小于等于N/3。

[0044] 隔膜为湿法陶瓷隔膜,包括14 μm 厚的基膜和2 μm 厚的陶瓷涂层。

[0045] 实施例2

[0046] 本实施例中的高能量密度锂离子电池,包括正极极片、负极极片、隔膜。

[0047] 正极极片上涂覆有正极活性材料,正极活性材料包括以下质量百分比的组分:聚偏二氟乙烯2.7%,导电炭黑0.8%,磷酸铁锂96.5%,磷酸铁锂的粒径 D_{50} 为8-9 μm ,正极极片的压实密度为其极限压实密度2.55g/cm³,面密度为380g/m²。

[0048] 负极极片上涂覆有负极活性材料,负极活性材料包括以下质量百分比的组分:CMC1.5%,导电炭黑1.4%,石墨95.2%,丁苯乳液1.9%,负极极片的压实密度为1.5g/cm³,厚度为115 μm 。

[0049] 其中,丁苯乳液中丁苯橡胶的苯乙烯含量为35%。丁苯胶乳液中还含有质量百分比为0.6%的纳米SiO₂和质量百分比为0.2%的硅烷偶联剂。丁苯乳液的制备过程为,先将粒径为20-70nm纳米SiO₂和硅烷偶联剂混合处理后再加入到丁苯橡胶乳液中。负极活性材料先制成浆料再涂覆在负极极片的金属箔上,浆料的制备过程为,先将CMC溶解,制成1.5wt%CMC溶液,然后将70wt%CMC溶液、导电炭黑、石墨混合,以400rpm的速度搅拌1.5h,再加入余下的70wt%CMC溶液,以2000rpm的速度搅拌1.5h,最后加入丁苯橡胶乳液,继续以2000rpm的速度搅拌15min。

[0050] 正极极片上等间距设置有3个正极极耳,正极极耳的材质为铝,假设正极极片的长度为M,正极极片上靠近极片端部的正极极耳距离极片端部的长度小于等于M/4,正极极耳采用超声波焊接方式与正极盖帽焊接。

[0051] 负极极片上等间距设有2个负极极耳,负极极耳的材质为镍,

[0052] 假设负极极片的长度为N,负极极片上靠近极片端部的负极极耳距离极片端部的长度小于等于N/3。

[0053] 隔膜为湿法陶瓷隔膜,包括14 μm 厚的基膜和2 μm 厚的陶瓷涂层。

[0054] 实施例3

[0055] 本实施例中的高能量密度锂离子电池,包括正极极片、负极极片、隔膜。

[0056] 正极极片上涂覆有正极活性材料,正极活性材料包括以下质量百分比的组分:聚偏二氟乙烯3.2%,导电炭黑1.3%,磷酸铁锂96.5%,磷酸铁锂的粒径 D_{50} 为10-11 μm ,正极极片的压实密度为其极限压实密度2.4g/cm³,面密度为360g/m²。

[0057] 负极极片上涂覆有负极活性材料,负极活性材料包括以下质量百分比的组分:CMC1.7%,导电炭黑1.6%,石墨94.6%,丁苯乳液2.1%,负极极片的压实密度为1.4g/cm³,厚度为125 μm 。

[0058] 其中,丁苯乳液中丁苯橡胶的苯乙烯含量为43%。丁苯胶乳液中还含有质量百分比为1.3%的纳米SiO₂和质量百分比为0.2-0.8%的硅烷偶联剂。丁苯乳液的制备过程为,

先将粒径为20-70nm纳米SiO₂和硅烷偶联剂混合处理后再加入到丁苯橡胶乳液中。负极活性材料先制成浆料再涂覆在负极极片的金属箔上,浆料的制备过程为,先将CMC溶解,制成1.5wt% CMC溶液,然后将70wt% CMC溶液、导电炭黑、石墨混合,以400rpm的速度搅拌1.5h,再加入余下的70wt% CMC溶液,以2000rpm的速度搅拌1.5h,最后加入丁苯橡胶乳液,继续以2000rpm的速度搅拌15min。

[0059] 正极极片上等间距设置有3个正极极耳,正极极耳的材质为铝,假设正极极片的长度为M,正极极片上靠近极片端部的正极极耳距离极片端部的长度小于等于M/4,正极极耳采用超声波焊接方式与正极盖帽焊接。

[0060] 负极极片上等间距设有2个负极极耳,负极极耳的材质为镍,

[0061] 假设负极极片的长度为N,负极极片上靠近极片端部的负极极耳距离极片端部的长度小于等于N/3。

[0062] 隔膜为湿法陶瓷隔膜,包括14μm厚的基膜和2μm厚的陶瓷涂层。

[0063] 对比例1

[0064] 正极极片的压实密度为2.4g/cm³(非其极限压实密度),其他与实施例1相同。

[0065] 对比例2

[0066] 磷酸铁锂的粒径D₅₀为12-13μm,其对应极限压实密度为2.33g/cm³,其他与实施例1相同。

[0067] 对比例3

[0068] 磷酸铁锂的粒径D₅₀为7-8μm,其对应极限压实密度为2.67g/cm³,其他与实施例1相同。

[0069] 对比例4

[0070] 正极极耳设有2个,负极极耳设有3个,其他与实施例1相同。

[0071] 对比例5

[0072] 正极极片上靠近极片端部的正极极耳距离极片端部的长度为0.3M,其他与实施例1相同。

[0073] 对比例6

[0074] 负极极片上靠近极片端部的负极极耳距离极片端部的长度为0.35N,其他与实施例1相同。

[0075] 对比例7

[0076] 丁苯乳液中丁苯橡胶的苯乙烯含量为45%,其他与实施例1相同。

[0077] 对比例8

[0078] 丁苯乳液中丁苯橡胶的苯乙烯含量为33%,其他与实施例1相同。

[0079] 对比例9

[0080] 丁苯乳液中不含纳米SiO₂和硅烷偶联剂,其他与实施例1相同。

[0081] 对比例10

[0082] 丁苯乳液中纳米SiO₂的粒径为70-100nm,其他与实施例1相同。

[0083] 将本发明实施例1-3、对比例1-10中制得的电池的性能进行比较,比较结果如表1所示。

[0084] 表1:实施例1-3、对比例1-10中电池性能的比较

[0085]

性能 实施例	容量 (Ah)	能量密度 (Wh/kg)	内阻 (mΩ)	1C/1C 循环 1000 次后放 电容量保持率/%
实施例 1	4.1	148	33	84.3
实施例 2	3.9	146	35	83.6
实施例 3	3.8	143	36	83.5
对比例 1	3.3	131	38	80.2

[0086]

对比例 2	3.2	128	37	83.3
对比例 3	4.2	150	43	79.6
对比例 4	4.0	148	35	82.2
对比例 5	4.1	147	34	82.0
对比例 6	4.0	148	35	81.9
对比例 7	3.6	141	39	78.1
对比例 8	3.7	145	38	78.5
对比例 9	3.5	137	40	70.6
对比例 10	3.6	141	38	73.7

[0087] 将实施例1、对比例7-10中制备的负极活性物质浆料的粘度进行对比,结果如表2所示,

[0088] 表2:实施例1、对比例7-10中:负极活性物质浆料的粘度比较

[0089]

	实施例1	对比例7	对比例8	对比例9	对比例10
粘度 (mpa • s)	722.3	601.8	587.6	379.5	598.2

[0090] 由表2和对制备所得的浆液的观察可知,对比例8中的浆液在高速搅拌后有轻微破乳,而对比例9中的浆液则有明显破乳现象,对比例7中制得的浆液有少量团聚现象,抗剪切能力差,对比例10中的浆液观察并无明显破乳现象,但抗剪切能力有明显下降。

[0091] 将实施例1、对比例7-10中制备的负极极片进行90°直角弯折试验,结果表明,实施例1中的负极极片在弯折50次后才有活性物质脱落,而对比例7-10则分别在弯折30次、26次、13次和29次后就有活性物质脱落。

[0092] 综上所述,本发明通过对锂离子电池的正负极材料、隔膜的合理配置,以及对极片的设置,有效提高了锂离子电池的性能。

[0093] 本文中所描述的具体实施例仅仅是对本发明精神作举例说明。本发明所属技术领域的技术人员可以对所描述的具体实施例做各种各样的修改或补充或采用类似的方式替代,但并不会偏离本发明的精神或者超越所附权利要求书所定义的范围。